Annex to the Implementation Plan of the Global Framework for Climate Services – Research, Modelling, and Prediction Component

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GFCS
GLOBAL FRAMEWORK FOR CLIMATE SERVICES

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ANNEX

TO

THE IMPLEMENTATION PLAN OF THE GLOBAL FRAMEWORK FOR CLIMATE SERVICES -

RESEARCH, MODELLING, AND PREDICTION COMPONENT

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EXECUTIVE SUMMARY

During the past few decades, national and international investments in climate observations, research, and modelling have resulted in significant progress in experimental and practical climate prediction and projection. They have also led to significant improvement in scientific understanding of the climate, its change and variability. These efforts provide a sound scientific foundation for developing the Global Framework for Climate Services (GFCS). However, implementation of the GFCS will require further expansion of climate research aimed at developing applications of climate knowledge over a wide range of socio-economic sectors important to all regions of the world. Systematic conversion of existing climate knowledge into practical solutions in turn requires a change in how climate research is conducted. In order to meet the diverse needs for climate services, professional networks should be developed to unite climate researchers and practitioners in the field.

The GFCS Research, Modelling, and Prediction (RMP) pillar of GFCS will:

- Target research towards developing and improving practical applications and information products to satisfy the identified needs of climate information users, subject to the current state of science and the current level of technology, especially in the four near-term GFCS priority areas;
- Enhance communication, interaction, and cooperation among the corresponding research communities, climate information providers and users with help of the GFCS User Interface Platform (UIP);
- Enhance the science readiness level for producing improved climate projections, predictions, and user-tailored climate information products;
- Continue to improve our understanding of the Earth's climate aspects to enhance our ability to provide useful climate information services.

The GFCS RMP activities will be coordinated and integrated with activities in other pillars of the Framework to ensure scientific support for developing GFCS overall and to build capacity for timely and effective delivery of science-based climate information needed by communities of users and decision-makers. These activities will include:

- Developing research and contributing to user-interactive communication and cooperation in the GFCS priority areas, diversifying and expanding research focused on practical applications, and strengthening validation and verification of resulting products in partnership with user communities;
- Systematically shortening the transition time from research to operations, expanding the scope of research products available to climate services users in partnership with the GFCS Climate Services Information System (CSIS) and UIP, and developing means for effective scientific support for climate risk management as well as for effective adaptation to climate change and variability;
- Enhancing research on observations, design and development of observing networks; producing fundamental climate data records along with their summaries and analyses of climate quality datasets; improving modelling and prediction/projection capabilities; and building required infrastructure and capacity in both developed and developing regions.

To provide sound science support to GFCS development it is imperative to involve key stakeholders in corresponding activities and to ensure continuation of effective coordination of practically-oriented climate and climate prediction research. The World Climate Research Programme (WCRP) has made a commitment to contribute effectively to GFCS development, while leading professional organizations in the sectors of human health, food and agriculture, water resources and disaster risk management, and will direct and support research in the main climate services application areas. Strategic partnerships among communities of climate scientists,

practitioners, and users of climate information will be fostered to guide the development and use of specialized climate products in support of GFCS priorities.

This Annex to the GFCS Implementation Plan has been developed based on the High Level Taskforce (HLT) Report recommendations, considerations, and principles governing the GFCS, taking into account existing and emerging climate information needs identified by the UIP and CSIS pillars. It has been prepared in close consultation with the Earth system science community, which will play a critically important role in conducting research required to address these needs.

To benefit from climate services, users and decision-makers need to know the limits of current scientific understanding of climate, know how to take into account the inherent uncertainty of provided information, and know how to communicate their identified needs effectively and accurately to scientists. The research communities must assess the current and future ability of climate science to satisfy these identified requirements and to accommodate corresponding needs within their observations, research, development, and communication priorities.

This Annex is also intended for the national and international research funding agencies as well as for environmental agencies sponsoring/conducting basic and applied climate research. The research priorities suggested here are essential for developing and implementing GFCS, and it is hoped that they will be supported by research funding agencies and in the corresponding research and development plans of operational agencies. Without targeted investments in research, modelling and prediction activities, progress in fulfilling decision-makers' needs for science-based climate information will be limited at best.

Focusing climate research on delivery of climate information for decision-making support will involve, *inter alia,* experimental and theoretical work aimed at improving the quality of datasets and guidance material; extending the lead time and/or range of sub-seasonal to seasonal climate predictions; exploring the potential for practical decadal predictions while improving longer-term projections; further substantiating climate models; developing techniques for observations and data assimilation, attribution and prediction of extreme events and assessment of their statistics; assessments of climate impacts on human health and its protection; food security, disaster risk reduction, and water management.

The main objective of research under the GFCS will be to expand its practical dimension to make research outcomes valuable for decision-making that is dependent on the efficient use of climate information, for example in early warning systems (EWSs) and monitoring. The overall approach to implementing the GFCS RMP pillar will be to facilitate the transformation of existing independent research activities into a more coherent, better supported, and more focused research process culminating in systematic development, assessment, verification, while improving timely climate-dependent information products tailored to the needs of decision makers and users. The ultimate success of the GFCS RMP activities will therefore be measured by improvements in the timely delivery and usefulness of science-based products and services offered to different socio-economic sectors and regions.

1 INTRODUCTION

The HLT identified research, modelling, and prediction as one of the GFCS pillars and stated "… the research element encompasses the work of expert institutions to improve our understanding of climate and to develop core prediction tools, applications, and products that are essential for the ongoing development and continuous improvement of climate services."

1.1 Objective, scope, and functions

The objectives of the RMP pillar of GFCS are to:

- Target research towards developing and improving practical applications and information products to satisfy the identified needs of climate information users, subject to the current state of science and the current level of technology, especially in the four near-term GFCS priority areas;
- Enhance communication, interaction, and cooperation among the corresponding research communities, climate information providers and users with help of the UIP;
- Enhance the science readiness level for producing improved climate projections, predictions, and user-tailored climate information products;
- Continue to improve our understanding of the Earth's climate aspects to enhance our ability to provide useful climate information services.

The scope of the GFCS RMP can be defined as:

- Encompassing a combination of fundamental and applied climate research;
- Embracing atmospheric sciences, oceanography, hydrology, cryospheric sciences, terrestrial and marine biogeochemistry, research on socio-economic and human systems, and research on climate–dependent applications in key areas of human activity;
- Considering the Earth as a *system*, i.e. focusing on the significant interactions of all its components including human and natural subsystems;
- Including information on the past climate largely based on paleoclimate research and observations, and prognostic information on the future climate up to the end of this century and possibly beyond based on exploiting our understanding of predictable processes and phenomena;
- Covering a continuum of time scales (i.e. beyond the typical two-week limit of deterministic weather prediction) and relevant space scales (i.e. national, regional and global);
- Combining deterministic and probabilistic sources of climate information to evaluate climate information uncertainty, limits, and value for decision-making;
- Including all types and methods of research such as observations, field and model experiments, process studies, pilot predictions and projections, assessment, production and validation of relevant datasets and derived information, etc.;
- Including policy-relevant, but not policy-prescriptive, information;
- Facilitating both cutting edge research and capacity development (CD) at the global, regional, and national levels.

GFCS implementation requires resources and expertise to develop science-based information along with the technologies and innovative solutions to enable effective adaptation, mitigation and risk management activities associated with climate variability and change. The main function of the RMP is to facilitate, in close coordination with service providers and users, improvements in relevant scientific knowledge so that it can be transformed into valuable science-based climate information.

1.2 Requirement for the Research, Modelling, and Prediction pillar

The World Climate Conference-3 stated that "major new and strengthened research efforts are required to increase the time-range and skill of climate prediction through new research and modelling initiatives; and to improve the observational basis for climate prediction and services, and the availability and quality control of climate data." To achieve these objectives, it called for strengthening the essential elements of GFCS such as the Global Climate Observing System (GCOS) and WCRP. These two international programmes are indeed central for climate observations and research. However, there needs to be a dedicated GFCS research pillar in order to foster expanded and systematic delivery of tailored climate information to the end-users and facilitate helpful feedback on these products that creates incentives to improve them. RMP will unite communities conducting climate research and will provide corresponding services while bringing together professionals from the health, water, food, agriculture, energy, disaster risk management and other sectors along with the users of resulting information products. GFCS implementation activities will add value by integrating the outcomes of individual research programmes into a set of common deliverables that respond to identified user needs.

1.3 Inter-linkages with other pillars

Representing GFCS as a composition of five pillars helps with designing and organizing implementation of the overall system. The GFCS pillars are expected to interact strongly with each other.

Scientific research is a fundamental means of CD. In turn, education and training, as essential parts of traditional CD, help provide the human resource base for scientific research. The links between the RMP and the CD pillar will therefore be twofold. First, contributions of the RMP pillar such as enhancing the availability and rigor of climate information and improving the usefulness and availability of practical applications will facilitate CD programmes in human health, food security and agriculture, water management and disaster risk reduction, especially for developing regions and nations. Second, national and regional networks and resources available through the CD pillar will help the RMP pillar fulfil its scientific mandate.

Developing capacity should be an integral part of every RMP activity. The WCRP Coordinated Regional Downscaling Experiment (CORDEX) project, for instance, develops the capacity to downscale global climate predictions and projections to the regional and sub-regional scales. Regional experts evaluate and validate the products before they are used to assess the regional impacts of climate variability and change or in any other practical application (Giorgi et al., 2009). CORDEX is using both dynamic and statistical means of downscaling climate projections from the global to regional and sub-regional level and makes the resulting information accessible openly to all scientists around the world through the Earth System Grid Framework. Activities like CORDEX offer a very promising platform for educational and CD activities in regions. Several CORDEX-based regional CD activities have already been organized under the GFCS umbrella in Africa, Asia and Latin America, and many more are planned.

The availability of relevant climate observations is essential for climate research, so the Observations and Monitoring (OBS) pillar of GFCS is fundamentally important to the RMP pillar. Research on observing techniques as well as their development and deployment are vital for closing gaps in observational coverage and for expanding the range of observed climate variables.

The HLT report emphasizes that decision-making at all levels is highly dependent on the availability of sound climate information. Currently, the demand for information based on reliable observations and solid science greatly exceeds supply. One of the RMP pillar's key objectives will be to improve availability and access to science-based climate products, primarily through the CSIS. The growing demand for products responding to identified user requirements will facilitate research generating user-oriented and user-friendly information for decision-making in targeted sectors. This will stimulate institutional support for providing timely observations, model simulations,

as well as analysis and synthesis of the resulting climate information, forming the scientific basis of enhanced or completely new types of climate services.

The UIP will direct the research towards developing practical applications of climate science that will provide the required information products. At present the discussion among the climate research community, climate service providers, and climate information users is just beginning. The UIP will help to facilitate interactions between providers and users of climate information on various regional scales, from global to regional, national, and local. The role of research communities in this interaction will be to inform both the supply and demand sides about what is possible or what may become possible if targeted research is conducted, indicating the limits of the resulting information products that stem from insufficient knowledge or from inherent scientific uncertainty. User feedback will inform the research focus and may result in improving the quality of climate information. This interaction will signify a cardinal change in the practice of defining user requirements for climate science and services. It will facilitate translating available climate information into customized sector-specific and region-specific products and will inform users of the latest developments in fundamental climate science as well as of the current ability of that science to provide new information in their areas of interest.

1.4 Relevant existing activities and identification of gaps

The HLT emphasized the need for active engagement in GFCS development of climate scientists from academic institutions, hydrometeorological services, and other research organizations. These communities conduct research to understand how the Earth's climate system functions, design observing systems, develop climate models for projecting and predicting future climate conditions, and are engaged in applied research with respect of climate impacts on various aspects of human activity and on natural ecosystems. A description of existing activities and key partners and programmes of relevance to GFCS is given in Appendix 1. At present these communities operate independently of each other. As a rule they are not required, nor do they have an incentive, to contribute the results of their research to an integrated system.

This is unlike what is obtained in meteorological services, where observations, data transmission and processing, modelling and prediction form a chain. In the case of meteorological services, experience shows that any failure to deliver in one of its parts is immediately flagged both by the end-user and by other parts of the chain. Such integrated systems can detect flaws and improve all their various parts synergistically. Meteorological research and services benefit also from regular feedback from their users. GFCS must adopt a similar approach to research, development, application and feedback processes in order to succeed.

Analysis of existing research and development activities in climate services reveals two main kinds of gap affecting GFCS implementation. First, there are gaps in knowledge and understanding of certain climate aspects that limit our ability to develop plausible climate information. Second, there are communication gaps between climate scientists per se, research communities active in the GFCS initial priority sectors (water, food and agriculture, disaster reduction, and human health), and providers of climate information to users. At present, relations between these communities are ad hoc at best, and institutional arrangements for their effective cooperation are very limited. Such arrangements will have to be developed in the course of RMP pillar design and implementation. Many of the stakeholders identified in the four GFCS Exemplars will be important contributors to such efforts.

The communication gaps are common among the four GFCS near-term priority sectors. For example, the Health Exemplar identified the following foci for existing climate and health activities: early warnings for various diseases; response systems to health emergencies; and assessments of the health impacts of air quality problems, climate change, and climate variability. Noting the multitude of existing activities, the Exemplar listed only those having particularly strong research dimensions. They are as follows:

- The Meningitis Environmental Risk Information Technologies (MERIT);

- The IRI Training Programme on Climate Information for Public Health;
- The Climate and Health Working Groups (international and national);
- Regional Health Policy for Climate Change;
- Health Alert systems for Extreme Weather events in the UK.

Having analysed these activities in detail while noting the conclusions of the WMO Working Group on Climate and Health, the Exemplar identified the following main research-related gaps:

- Inadequate understanding of user needs;
- Lack of user-awareness about available and potential services;
- Inadequate communication between National Meteorological and Hydrological Services (NMHSs) and the users of such information.

Similar gaps can be noted in the other sectors. For example, the Water Exemplar states that even in technologically advanced countries there are significant constraints on funding support for research in water and climate applications. This is especially true for modelling and prediction. Insufficient support for this area of research is explained in part by the inability of this sector to demonstrate convincingly its potential future value to integrated water management. This is due to a combination of the relative inaccuracy of current climate predictions over a useful range of time scales and limited ability to provide accurate water resource guidance even if available climate information were perfect. The Food Security Exemplar lists several collaborative research activities between meteorological and agriculture communities. However, similar to the water sector, a significant divide can be detected between food and agriculture practitioners and the respective research communities. The Disaster Risk Reduction Exemplar states that the requirements for associated research and the means of directing and supporting it await consolidation. The climate-oriented component of the disaster risk research still needs to be shaped on a variety of spatial scales.

2 IMPLEMENTATION OF THE PILLAR

A significant volume of research is currently taking place on analysis of observations, data assimilation, climate models improvement, evaluation and uncertainty analysis of models and their results, understanding predictable elements of global and regional climate at a range of time scales, and development of information products necessary for climate services. GFCS implementation offers as major opportunity for enhancing these efforts, but most importantly for coordinating them to provide operational climate services to a wide range of decision makers. It is envisioned that the RMP will facilitate the integration of research activities that are presently independent in order to satisfy the needs of climate information users. This will occur through more efficient planning, development, implementation and evaluation in partnership with stakeholders. Such efforts will go far beyond simply expanding existing climate research and will do so by including the specific research needs identified by the GFCS CSIS and UIP pillars.

2.1 Necessary and sufficient conditions for successful implementation of the pillar

The RMP will be successful in contributing to the development of GFCS to the extent that it improves the quality and scope of useful climate information for past, current and future climate conditions, estimating their uncertainty in a manner useful and understandable to users of such information. It will also add value by providing guidance on how to make the information 'actionable', i.e. how to make specific optimized decisions in various sectors while taking into account the uncertainty of the available information and of the limits to its use. In time the quality of climate predictions will improve, but the need to consider a range of future probabilities will always be a challenge for decision-making. In this regard, the core value of climate research is that it not only develops observations and prediction tools but that it also provides a framework for identifying and answering questions that are not yet obvious to decision-makers.

The necessary conditions for the RMP pillar contribution successfully to the GFCS development include:

- Active engagement of the climate science and corresponding applied science communities in:
    - Coordinating and targeting research on, and development of, all GFCS elements;
    - Improving our understanding of the Earth's climate and its impacts on people, ecosystems, and infrastructure;
    - Identifying predictable climate elements;
    - Attributing the causes of individual events;
    - Developing and using technologies for climate observation, prediction and projection as well as developing datasets and their interpretation, etc.;
- Commitment of climate information developers and climate service providers to work together with users to identify information products necessary for practical applications in various socio-economic sectors;
- Involvement of funding agencies and university scientists, along with support from leading agencies at the global, regional, national, and local levels;
- Efficient planning of RMP activities, particularly in the initial stages of GFCS implementation; involvement of GFCS priority sectors stakeholders in this process; and early identification of relevant partners and of their potential contributions and interests;
- Adequate funding, human resources, and computing/data transmission and information technology (IT) support;
- Resourceful and targeted CD and related education in core and applied climate research;
- Availability and sustainability of adequate observations for the Earth System, including variables used in predictive models for setting initial conditions as well as describing forcing functions of known predictable processes and phenomena, and for validating model-based data and information;

- Creating an environment in which all communities involved in the RMP activities can work together on design, development and delivery of climate information to produce helpful guidance on how to use efficiently the available observations, data, model-based results, and fundamental scientific understanding.

None of these conditions are easy to fulfil. For example, active engagement of the climate science community in improving the practical aspects of climate services and in transferring research to services contradicts the very nature of academic research, which is always moving on to new horizons and, in principle, lacks the incentive to see innovations transferred to decision-making processes. A possible remedy for this may be to offer opportunities for successful research by working across disciplines and together with operational service providers. Turning climate research into a more user-oriented and responsive domain of work offering greater possibility of verifying its practical outcomes, along with more incentives for improving techniques and models, may itself require novel approaches. The US National Oceanic and Atmospheric Administration (NOAA) Climate Test Bed (CTB) is one model worth considering in this regard because it helps to increase the availability of research-based climate information for a variety of uses.

The sufficient condition for RMP's successful contribution to the GFCS may be that it fulfils all the conditions outlined above and creates a framework or platform whereby guided scientific developments result in improving climate information products that could be used effectively in climate-reliant decision-making. If such synergistic arrangements are in place, they will increase support over time to both core and applied climate research. Any possibility for creating this "positive climate science-services feedback" should not be missed, and the initial task for the RMP will be to create a platform for dialogue among communities involved in climate science and services. These communities include those interested in developing practical applications of climate knowledge in a variety of socio-economic sectors.

Computing power remains a serious limiting factor for progress in developing climate models and for the corresponding data processing and visualisation. It has set the pace for improvement of climate/weather models' horizontal, vertical and time resolutions. In some cases it has inhibited the development and use of comprehensive parameterization packages for unresolved physical, biological or chemical processes such as clouds, aerosols, radiation, and their interactions. It also blocks the use of extended prediction ensembles, thus reducing the reliability and comprehensiveness of prediction statistics and adversely affects the way *in situ* and satellite observations are processed and used in conjunction with models. Access to adequate computing resources, sustained and comprehensive observations, broad bandwidth for data/information sharing and transmission, fast data processing and massive storage possibilities are necessary technical requirements for the specific success of the RMP pillar and for GFCS generally. Efficient sharing of resources and the use of distributed information technology solutions should therefore be maximized, for example through partnership arrangements.

2.2 Criteria for identification of projects/activities at global, regional and national levels

GFCS development will be based on continuing, strengthening, and to some extent refocusing existing research activities, as well as on a series of new research and development projects specifically addressing the main science requirements of GFCS. GFCS activities should adhere to the eight fundamental GFCS governance principles. The approach taken in identifying the corresponding research activities to be continued or initiated under the umbrella of GFCS should involve reviewing decision-makers' *main* requirements in these areas and consolidating and translating them into guidance with regards of the need for essential research products supporting these requirements. Then opportunities to generate and deliver such products or to improve existing products through research should be sought and implementation activities that involve active and early user engagement should be proposed. This process requires the participation not only of scientists but also of users and climate information service providers. The implementation plan for the RMP pillar was developed based on these principles, and its proposed activities are expected to:

- Build major new partnerships or strengthen existing ones among the basic and applied scientific research communities, service developers, and users by actively engaging them in co-developing and co-producing climate information and services while providing required guidance;
- Develop and deliver important outcomes during the initial stage of GFCS implementation;
- Create a solid basis for continuing GFCS development during succeeding stages of its implementation.

For sector-specific and regional activities, the necessary development projects and programmes, along with demonstration projects, still need to be identified. The main criterion for proposing any RMP activity will therefore be its role and value for implementing RMP objectives and for addressing the research needs and priorities of this pillar.

A very significant fraction of these scientific activities will be resourced by research funding agencies that are independent of the main GFCS stakeholders. Promoting identified GFCS needs to research funders, along with active two-way communication with them, are therefore vital tasks that need to be accomplished to initiate research that is highly relevant to the GFCS. Criteria of project selection in force in the agencies will be used to identify successful proposals and teams. Timely and open access to the funded project's data and information is a very important criterion that funding agencies promote strongly, while respecting existing sensitivities and national interests. Other important selection criteria are:

- Anticipated value and impact of the successful proposal for RMP objectives at the global, regional, and national levels;
- The likelihood of achieving project objectives and of delivering an operational product or a result facilitating faster transfer of activities from research to operations;
- A focus on achieving a public good, benefitting the most vulnerable members of the population and assisting governments in providing climate services for public safety and well-being;
- Cost effectiveness and avoidance of duplication.

One example of these funding possibilities is the "Seasonal-to-decadal climate predictions towards climate services" call opened by the Seventh Framework Programme of the European Commission. The activities chosen will contribute to developing European climate services based on seasonal-to-decadal forecast systems. Similar research themes and projects should be considered as contributing to GFCS implementation.

2.3 Implementation activities at the global, regional, and national levels

The major foci for research activities under the RMP pillar will be:

- Developing new, or improving existing, climate products based on sound science in close coordination with the user community;
- Creating a platform, opportunities and incentives for scientific groups to progress from simply investigating scientific problems to creating pilot products, technologies, methods and models for existing and envisioned climate services;
- Making such products available and evaluating how they can be used effectively in the domain of climate services, whether experimentally or routinely;
- Developing applied research in climate-dependent sectors of human activities, creating possibilities for effectively using climate information and services.

Such research may take place in several phases. In its initial phase, considerable efforts should be dedicated not only to the research and development activities per se, but also to detailed planning of subsequent phases, establishing connections and partnerships with potential partners and working closely with them to achieve timely and effective transfer of research outcomes to routine

decision-making and management practices. Implementation actions will in principle be crosscutting for GFCS and will involve more than one GFCS pillar.

The main types of activity to be undertaken under the RMP pillar will include:

- Detailed planning of activities, building relevant partnerships, working towards commitment to support the identified research activities, and creating linkages that facilitate broader access to research outcomes while aiming the research towards achieving GFCS objectives;
- Bridging climate research and services, communication and cooperation between involved communities;
- Creating and improving practical applications for the GFCS priority areas;
- Developing and improving climate information products or technologies such as key EWSs that would be of major significance for climate services in multiple sectors.

2.3.1 Detailed RMP planning, building partnerships, linkages and commitments

Although a great deal of relevant research information, as well as some capacity, exists in the priority domains of GFCS implementation, it is highly dispersed across disciplines, individuals and institutions. Commitments from leading organizations and programmes such as WCRP to support GFCS research activities have been secured for the initial GFCS priorities. However, even for these it is necessary to elaborate further the scope of RMP activities and to establish planning, monitoring, and coordination mechanisms. For other sectors and for the RMP as a whole, creating a solid framework is therefore required for implementation as well as for significant planning, consolidation, and resource mobilization activities.

The most needed GFCS activities in the human health and climate arena include building national capacities of both climate and health partners to conduct local research and to develop climate data products for the sector. These include assessments of climate change and variability impacts on health and on the effectiveness of health protection. These two streams of research should be coordinated and should strengthen each other, e.g. through a forum to enhance application research and to support the transfer of climate science to operations. For example, the forum might help develop a standard research terminology to be used by collaborating climate and health sectors. The GFCS should also help climate service providers such as NMHSs participate in health research forums and partnerships, and, similarly, facilitate engagement of health sector specialists in the activities of climate forums. Such exchange would help focus climate and health research on building evidence for health policy-making. Simple measures aimed at improving communication and interpretation of climate information in the health sector, including recognizing its uncertainty, might be a starting point. Further actions should include establishing verification and quality assurance standards and mechanisms as well as evaluating the effectiveness of climate services in the sector.

A virtual forum on climate and health would help bring together the existing body of relevant research methods, tools, data sets and research results. It would review periodically the state-of-the-art, identify major gaps in responding to the requests of decision-makers, and highlight opportunities for research funding and training opportunities. It would also facilitate collaboration between researchers working in this field, including researchers from both developing and developed countries.

Activities in climate and health research require a broad agenda with clearly identified goals, systematic analysis of capacity and approaches to developing it, and should involve a set of specific case studies on the benefits of climate services in the health sector. Engaging social sciences can help in evaluating readiness, perceptions, and the usefulness of climate services for end-users. Discussions with resource managers and economists may provide a useful cost-benefit analysis of activities as well as required evidence of efficiency for policy making. The resulting GFCS climate and health research strategy may also identify targets and priorities that support research at the regional and national levels.

For the water management, food and agriculture, and disaster risk reduction sectors, the motivation for establishing planning and coordinating research activities is similar to that of the health sector, but these sectors involve a large number of activities and initiatives that are still loosely associated, and the volume of necessary preparatory work that needs to be done is even greater than in the health and climate sector.

Initiative groups will be formed to identify stakeholders and partners for GFCS-relevant research, to develop the scope of required activities in more detail, to seek commitments, to establish oversight and monitoring mechanisms, and to mobilize the resources required for implementation. Research funders and other relevant agencies will be invited to participate in planning as well as in defining requirements and their corresponding activities. Implementation strategies and more detailed research plans will first be developed for the four initial FFCS priority sectors and, at the later stages of implementation, for the other sectors. Promotion and discussion mechanisms such as dedicated virtual forums will be put in place, and these activities should start during the initial stage.

2.3.2 Bridging climate research and services and building communication and cooperation between involved communities

One of the main objectives of the RMP pillar will be to ensure that both research communities and practitioners in climate services, who translate science findings into information products, will cooperate, communicate and share experience and knowledge. Technological limitations and liability considerations sometimes prevent producers of operational climate services from using the latest scientific results in their data processing and prediction techniques. Alternatively, some research groups may have difficulties in shaping their products for use in climate services and verification, or they may experience problems receiving sufficient feedback on their offerings. Expanding possibilities for users to access a wider range of experimental research products, with proper caveats on the strengths and weaknesses of those products, will be mutually beneficial for the users and providers of such information. For the latter it might create a demand and stimulate product development, sophistication, user tailoring, and quality improvement. As a result, one may anticipate an accelerated transfer of research advances into climate services. Opening experimental climate products to the user community will stimulate communication and make the products more valuable.

Enhanced provision of such science-based information will also be an integral part of GFCS institutional and human capacity development and will be instrumental in enabling assessment of climate change impacts and corresponding decision support, including with regard to adaptation to climate change. Making experimental climate information systematically available to users requires the commitment of research groups and modelling centres to provide their contributions to GFCS CSIS on a regular basis and to participate in product-related discussions through UIP and CSIS. This communication will allow creating and delivering guidance on the proper interpretation and use of research outcomes. Such arrangements could also help address the concerns of end service providers related to their potential liability inherent in relying on experimental climate products in their service offerings.

One area that has can establish bridges between climate science groups and the variety of users of climate information is regional climate prediction, projection, and downscaling. Because climate anomalies predominantly manifest themselves on the regional scale, the availability of regionally downscaled climate information to users, including experimental predictions and projections, should be enhanced as a matter of urgency, along with proper documentation of the data and methods used, the known uncertainties they involve, and other relevant guidance on data quality and known or likely limitations. The real scientific question is how much genuine additional value the higher resolution climate products offer. Making such predictions or projections available to the regional communities that have agreed to review and evaluate them will create a foundation for calibrating the models better, especially in cases where regional climate variations result from local small-scale processes and phenomena.

Establishing the first elements of delivering systematic science products to climate services during the early stages of GFCS will engender service-focused imperatives for observations, modelling and prediction. For example, routine production of predictions with longer ranges and lead times will require more reliable ocean and land-surface observations. Increasing the number of available diagnostic and prognostic climate products will lead to the need to assess their comparative usefulness for practical applications, creating a demand for more versatile and comprehensive verification of climate products. In turn, the expanding verification practices will help identify gaps and deficiencies in various components of the data processing chain, from observations to providing information to users. Incentives for closing the gaps and improving the system will become stronger and would justify allocating resources for system improvement. The emerging market of climate products for industries and communities and the existence of platforms for tailoring existing products to more specific user needs will help speed up the process of turning research advances into more operational products and services.

It is proposed to make experimental climate information more widely and regularly available to users of CSIS. A portal would direct users to operational or quasi-operational information in the WMO Global Data-processing and Forecasting System (GDPFS) and to experimental climate information produced by WCRP-affiliated projects such as the Coupled Model Inter-comparison Project (CMIP), CORDEX, and the Climate-system Historical Forecast Project (CHFP). Such experimental climate information is openly available and increasingly accessible through the Earth System Grid (ESG) Framework. Recommendations on optimal repeat cycles and lead times for experimental prognostic runs of climate models for different time scales should be prepared based on actual or anticipated prediction skill, technical capabilities, and other relevant considerations. UIP can help in discussing such arrangements.

2.3.3 Research in GFCS priority areas

There is an urgent and largely unmet need for actionable, science-based climate information for planning adaptation to climate change and climate-related risk management. It is also needed for supporting various aspects of sustainable development, including mitigation of the effects of climate change. To address this need, one of the key objectives of the GFCS research component will be to accelerate the development of science-based climate information to enable practical applications in the four near-term GFCS priority areas described in the HLT Report. The four GFCS priority areas in the near-term are agriculture and food security, water resource management, disaster risk reduction, and human health. The requirements for actionable climate information in support of these sectors determine the priorities for the RMP's initial efforts.

To enable applied research in the four areas of the GFCS near-term priorities, arrangements will be sought for sustained and effective communication between providers of climate information and representatives of services, as well as among experts developing and using the resulting information for specific applications and for providing services to the targeted sectors. Involving scientists representing "core" climate knowledge in these interchanges will help inform its participants about the latest developments in climate science and about existing opportunities for developing certain products, including possible limitations to their use where science or technology is not yet ready to deliver. Effective liaison of the WCRP Working Group on Regional Climate (WGRC) with the GFCS UIP working bodies will help to achieve these objectives. Direct liaison between scientists affiliated with the RMP pillar and the users of climate information is also recommended on the regional, national, and local levels.

A more detailed description of research activities in the GFCS priority areas is available in Appendix 2.

2.3.4 Research in support of the developing and improving core climate information products of significance to climate services in multiple sectors

In preparing this Annex, core climate information requirements were identified for each of the four priority areas of near-term GFCS development. Several of them were common to all of these areas. Consolidation of these requirements resulted in a list of more universally required climate information products, the availability of which would enable many climate-reliant practical applications. Developing, improving, and evaluating these core information products in partnership with the community of users is an important part of the RMP agenda.

The consolidated list of climate information products required by all four priority areas includes:

- Reliable and comprehensive information on past and current climate conditions including, inter alia, series and statistical distributions of relevant hydrometeorological and oceanographic variables such as temperature, precipitation, wind, visibility, wind waves, and storm surges, with special attention to the long-term evolution of their long-return period values ("extremes");
- Prognostic information:
    - Evolution of regional and sub-regional air temperature, precipitation, wind, water balance components, and state of the land surface on time scales from sub-seasonal to seasonal up to one or two years;
    - Predictions of individual significant anomalies of temperature and precipitation including droughts, floods, heat waves, cold spells, monsoon onset and phases, with lead times and ranges beyond the ones of numerical weather prediction;
    - Improved prediction of El Niño and La Niña and other dominant modes of climate variability;
    - Tropical cyclone (typhoon, hurricane) season predictions and assessments of potential future changes in their frequency, intensity, and paths;
    - Feasible guidance on severe/extreme events with limited predictability, e.g. tornadoes;
    - Long-term predictions of climate change short- and long-term forcers, air pollution, atmospheric chemicals, and UV radiation anomalies;
    - Water balance for lakes, reservoirs, and river basins including its cryospheric components; water reserves and availability of water for various uses; lake and reservoir levels; groundwater;
    - Oceanographic predictions, including sea-ice prediction in polar regions and marginal seas;
    - Global and regional sea level variability and change, including extremes and their statistics; and
    - Variables describing the coastal zone state: inundation risks, impact of climate change on the coastal environment, etc.

High impact anomalies of regional climate may occur on sub-seasonal, seasonal, inter-annual, and decadal time scales. Research on their prediction is progressing, but at present it is still not sufficiently clear whether practically useful predictions are feasible on all timescales and for all regions of the world. It is also unclear how to extract useful information from ensemble products, in which each element may have very limited skill. Research activities to generate the corresponding information products fall broadly into three categories, as follows:

- Research on climate predictability and improving skill of prognostic information;
- Research on adding value to climate information for its use in services;
- Research on observations, their processing and climate record production;
- Research on the value of climate services.

As implementation of GFCS progresses and new global products continue to emerge, there will need to be greater focus and efforts on regional climate science and services. For example,

monitoring regional anomalies and extreme events, with EWSs and alerts for temperature, droughts, floods, and air quality, will become even more important. A more detailed description of the planned activities in these domains and of the motivations for them are presented in Appendix 3.

2.4 Initial implementation activities/projects

In the early stages of GFCS implementation, RMP efforts will be aimed at creating conditions for overall implementation of the pillar. These efforts will involve detailed planning of activities while gathering commitments from research organizations to contribute to developing the scientific foundation for climate services. Such planning will be developed, and commitments will be sought, on the global, regional and national levels. Partnerships will be established between scientific groups and climate service practitioners who in this instance will act as climate science users. Developing successful research in the four GFCS initial priority areas also requires some acceleration. CD will be an integral part of this.

An effort will be made to make scientific experimental climate information, especially predictions and projections, more readily accessible and better characterized for decision-makers and practitioners. This will require the commitment of research groups to make their information publicly available. The incentive for these groups to do so will be that they will receive impartial feedback from interested users about their experimental products. Shorter scale climate predictions, on time scales from weeks up to a season, will capitalize on existing results, plans, and momentum obtained from predictive research advances made under the auspices of both the World Weather Research Programme (WWRP) and the WCRP. A series of experiments and activities will also be organized under the Polar Prediction Project focusing on similar time scales.

The WCRP CMIP5 and CORDEX projects will produce unprecedented volumes of global and regional predictive information on decadal and centennial time scales. This will be highly relevant for research on adaptation to climate change. Research activities aimed at maximizing the benefits of using this information in climate risk management, for creating generic adaptive capacity at national and household level, and for overall support to adaptation to climate change, should start during the earliest stages of GFCS implementation. Developing an integrated global greenhouse gas information system will help substantiate information on the radiative forcing of climate and will lead to multiple improvements in climate projection that will help in estimating future emissions.

Extending the time period covered by reanalyses, expanding their scope and improving their data assimilation schemes, will be very important for creating datasets that are useful for scientific research, prediction verification, understanding of underlying processes, and developing practical applications for such data. This work should take advantage of the ongoing reprocessing of satellite data records using improved retrieval algorithms and quality control at all stages of data processing.

After completing the IPCC AR5 and assessing the available knowledge about the causes and consequences of sea-level rise, with gaps still remaining in our understanding and in our capacity to model and project all factors determining future sea-level standing, WCRP will formulate a comprehensive research programme addressing practical risks associated with sea level variability and change both globally and regionally.

Finally, the RMP pillar will lead a GFCS-level activity to improve users' ability to incorporate uncertain climate information into their decision-making processes in order to prepare for and manage climate-related risks.

2.5 Implementation approach (including operational and organizational aspects)

The main pathways to achieving benefits of having GFCS in climate science-reliant sectors will be:

- Detailed planning of the core climate and applied research activities;

- Building communities of researchers, practitioners and users of climate information and facilitating communication within such communities with the help of UIP;
- Seeking commitment to support RMP activities from operational agencies and research funders;
- Making regularly updated experimental climate diagnostic and prognostic information available to users through GFCS CSIS while facilitating informative and useful feedback on the information products from their users;
- Focusing climate research on sustained improvement of the climate information identified as most needed for GFCS implementation;
- Supporting applied climate research into developing practical applications through pilot and demonstration projects bringing together all five elements of the GFCS, with a primary focus on integrating and delivering climate information to users and decision-makers.

GFCS development will require strengthening connections, coordination, and cooperation between the research and operations communities. Organizing and supporting such interaction requires establishing the pillar management structure on a variety of regional levels. This structure will be proposed after high-level GFCS governance decisions are made and in the course of executing RMP planning activities as indicated in section 2.4.

The initial RMP activities outlined in section 2.4 will be conducted under the leadership of representatives of key stakeholders such as WCRP, WMO, WHO, FAO, UNESCO and its IOC as well as IHP, ICSU, and others. Completion of the detailed RMP implementation plan will be complemented by a proposal for an RMP oversight mechanism at the global, regional and national levels. For example, WMO Regional Associations will be able to assist in developing climate services at the regional level. The IOC regional alliances will also be expected to support implementation of the GFCS in various parts of the world's oceans, to develop their capacity to make required ocean observations, and to guide the preparations of a range of oceanographic products for their respective zones of interest, including coastal zones. Regional WCRP sub-projects possess the necessary expertise for addressing many of the identified research needs, and scientists affiliated with them will be invited to participate in RMP activities. Regional programmes, activities and offices of FAO, WHO, ICSU offer great potential for reaching out to interested partners. Early participation of research funding agencies in planning the pillar activities that establishes partnership relations with them, along with their involvement in developing and overseeing of this pillar, will be essential for securing and maintaining timely access to required resources.

2.6 Monitoring and evaluation of the implementation

Mechanisms for reviewing and monitoring RMP activities will be developed during more detailed planning of RMP activities in the initial stage of GFCS implementation. Indicators of performance and progress, along with assessment measures for RMP work, will be developed individually for each of the main activities. The RMP pillar will support project assessment and performance evaluation and will document results to share them with other GFCS pillars and with the overall GFCS oversight and governance mechanism(s). Strengthened commitment to deliver climate science information to CSIS will be evaluated in cooperation with WIS and CSIS. User feedback will be the cornerstone of the open-ended GFCS UIP, the main vehicle directing applied climate research. One of the tasks for climate scientists participating in the UIP working constituencies will be to report progress and/or lack thereof, and identify corresponding stumbling blocks. Close cooperation between the GFCS management, contributing partners and participating programmes and organizations will ensure timely reaction to any feedback about the performance of projects and activities.

2.7 Risk management in implementation of activities

The risk management principles and arrangements for other GFCS pillars that are associated with institutional complexity, management, resources, etc., will also apply for RMP; their description is

not repeated in this Annex. Describing anticipated risk management practices and considerations will be a standard requirement when soliciting proposals in response to all calls for funding activities under RMP. Risk management practices of funding agencies will apply, as a rule, to all RMP funded research activities. Specific consideration of risk management will be requested from the initial planning activities of the pillar, as indicated in the last column of Table A in section 5.

A key element of RMP pillar risk management will be a robust evaluation process and complete documentation for any new GFCS product or service. This will help avoid any potential user misunderstanding or misinterpretation of such a product or service. Participation of multiple research groups in providing climate information and predictions will help ensure the possibility of comparing, validating, and calibrating the products. Early notification of slow progress or of failure to deliver will also be facilitated by increased and active user involvement in RMP research activities.

3 ENABLING MECHANISMS

3.1 Synergies with existing activities and building national, regional and global partnerships

There are many synergies between various RMP activities and activities largely addressing the objectives of other GFCS pillars. RMP activities will be built, where possible, on consolidation, targeting and strengthening existing climate research and ongoing research in socio-economic sectors, with user communities actively participating. For example, the existing WWW practices of providing access to long-range forecasting products under GDPFS can be extended to enhance user access to experimental climate information. Existing WCP working mechanisms can serve as building blocks for effective start-up of research on climate data applications in the four initial GFCS priority areas. Human health and well-being depends significantly on factors related to food, water and safety. This was summarized and used in constructing the list of core climate products in section 2.3.3 of this Annex. Synergies of RMP with the OBS pillar, based to a large extent on research outcomes, have been emphasized already in this Annex. Global observing programmes will benefit greatly from RMP activities and vice versa. Synergies between weather and climate research are multiple and will materialize mainly from practically implementing "seamless" prediction systems.

To a significant degree, synergies between applied and fundamental climate research, observations, modelling and prediction can be extended from the global to the regional and national levels. Each of the agencies and programmes, as well as many large-scale projects, has regional and national counterparts and focal points. Their work also benefits from a variety of synergies on the regional scale. However, connections between various disciplinary activities at the regional level are usually much weaker than the relationships within disciplines on the global and regional levels.

For example, activities of the WMO Regional Associations have considerably stronger links with global WMO Programmes than the ones they have with corresponding IOC regional bodies or with activities coordinated by the ICSU regional offices. Establishing connections between various organizations and programmes to work on GFCS implementation on the regional level may result in considerable mutual benefit for everyone involved. Active participation of national organizations and groups in RMP activities will involve their expertise and capabilities in GFCS build-up and will enhance the potential for bringing additional resources and incentives to bear in expanding the scope of their activities and improving their products.

3.2 Communication Strategy

The GFCS will be built on the basis of proactive, intensive development of two-way communication with user communities concerning new opportunities and on the corresponding feedback and description of the latter's needs to the provider communities. The research community will act as a catalyst for interactions between these communities. This means that GFCS and RMP communication strategies should serve both internal connections within the pillar and external relations. Proper documentation of activities and their output, use of the open source approach (whenever possible), frequent reporting of project progress or lack thereof, and constant liaison with the "receiving" end should be tirelessly promoted. For efficient internal communication within the pillar it will be important to start by building connections, communication channels and arrangements between the providers and users of interim products. It is their interaction that determines the eventual ability of the overall system to succeed. Communication of GFCS and RMP successes and their value to society helps break the vicious circle whereby the usefulness of climate services is not known to potential users and funders, with the resulting lack of interest, support, and funding slowing down needed progress in socially relevant research.

Advances in RMP activities will be reported and promoted both individually by participants and through a special section on the website of GFCS, along with reports on the websites of

participating programmes and organizations. Available experimental climate products will be widely announced to the user communities identified in this Annex. New IT technologies will be used to promote RMP activities, including controlled distribution of information through the Earth System Grid Federation and the social networks.

Complementing GFCS efforts, WCRP is developing a communications strategy for the Programme. GFCS issues relevant to WCRP will be highlighted in implementing that strategy. The WCRP outreach and communications strategy target audiences include scientists, media and the general public, sponsors and funding agencies, decision makers, students and early career scientists, affiliates of scientific climate assessments, and global and regional environmental conventions. The effectiveness of the strategy and the measures for implementing it will be evaluated at regular intervals. Involving experts engaged in the GFCS CD activities in assessing the GFCS communication strategy may help improve its efficiency and effectiveness.

4 RESOURCE MOBILIZATION

Investments in climate services will help create stronger overall resilience to climate variability and change using improved adaptation pathways in conjunction with risk mitigation and management approaches. Climate research is a key vehicle for increasing significantly the return on investments in GFCS. Recognizing the great value that can be derived from climate change science, the World Climate Conference-3 called for major strengthening of the essential elements of GFCS, including WCRP, underpinned by adequate computing resources and increased interaction with other climate research initiatives.

The main idea of GFCS is to convert available climate knowledge into action and to develop new knowledge where needed. Hence, an important focus of RMP research activities will be to develop practical climate science applications, while continuing to promote research on less-understood aspects of the Earth's climate system. To provide the required basic and specialized climate information to the various economic sectors and geographic regions that are vulnerable to climate variability and change, the RMP pillar will need to make an optimal combination of investments in both fundamental and applied climate research. Without adequate funding of fundamental research, this research will slow down and very soon climate science will be incapable of addressing the rapidly emerging and complex need for climate information. In addition, fundamental research is needed for addressing the many unresolved issues in climate science.

Without demonstrating the practical benefits of climate information to society, research loses its credibility and support base. In turn, society becomes more vulnerable to environmental risks. This vicious circle, which is typical of almost any emerging activity including climate services, can be avoided with the help of an effective communication strategy and proactive involvement of multiple stakeholders.

Successful initial development of the GFCS and the resulting delivery of more effective and efficient services to customers will help promote the proposed activities and justify the need to allocate funding for designing and coordinating the system. However, the shortage of initial funding is acute. Early and effective promotion of GFCS and RMP, making sure that governments and funding agencies assign resources for the initial GFCS development, is critically important for successful GFCS implementation. The cost-efficiency of RMP research and early assessments of the long-term and short-term returns on investment in GFCS and RMP should thus be a part of initial planning and evaluation. Along with efforts at finding external resources, at the beginning of GFCS implementation there will be a need to do more with existing capabilities and knowledge, demonstrating as early as possible the value of RMP and GFCS to potential funders.

Initial funding should come from participating agencies such as NMHSs, national and international research funding agencies, space-based Earth observation agencies, academies of sciences, and universities willing to invest in their own research to support practically-focused climate science and associated CD activities. NMHSs and government agencies may be willing to invest in regional observing systems as well as in national infrastructure for climate monitoring, research and prediction. It is extremely important to ensure fruitful cooperation of RMP with national and international research funding agencies so that they will call for research opportunities relevant to the GFCS. It should be noted that the science support for developing climate services is high on the agendas of many research-funding agencies such as the European Commission, the Belmont Group of funding agencies, and many of the national research funding agencies. There are thus many well-supported research opportunities relevant to the GFCS. To get them to cooperate efficiently and add value requires adequate resource for coordinating them under the RMP pillar. Specialized agencies may be willing to invest seed funding into forming communities of climate scientists and practitioners in the areas of their interest. Research proposals on developing user-tailored products may attract the interest of corresponding governmental agencies or industries. Such creative and flexible partnerships will be critical to the success of the RMP pillar and of GFCS overall.

Briefings for international and national research funding agencies and other stakeholders should be organized early on in the GFCS implementation and should continue on a sustained basis. An assessment of the effectiveness of the services offered, including their economic and societal benefits as a measure of return on investment, will be instrumental in justifying funding. Sharing lessons learned, both positive and negative, should be an integral part of discussions with funding and sponsoring organizations.

5 COSTED SUMMARY OF ACTIVITIES / PROJECTS

The Table A below lists the planned initial implementation activities. Some of these activities will be continued during later stages. Costs are given for the initial two-year period only. The total cost of initial coordination and pillar management activities is estimated at US$ 4.2 Million.

Table A

Planned initial implementation activities of the RMP pillar

No.	Activity	Deliverables	Indicators	Assessment measures (sources of verification)	Timelines	Partners and Stakeholders	Linkages with other activities	Cost, M US$ for 2 years	Potential Risks
1	Strengthening coordination of the ongoing and planned research activities of main organizations, agencies, and programmes of direct relevance to GFCS with a focus on mid- and longer-term perspectives	More detailed plan of research activities in support of GFCS in the mid- and longer-term perspectives	Agreed and published planned document containing activities, responsibilities, management arrangements, resources, etc. for all planned activities. RMP M&E arrangements	Input and expressed commitments of main stakeholders	2013-2014 with later update	WCRP, WMO, UNESCO and its IOC, other UN Partners, ICSU, PROVIA, etc.	Regional partners, interested national organiza-tions. Input from all pillars is crucial.	0.20	Complexity, balance of interests
2	Briefings to main research funding agencies on GFCS Implementation pPan and on RMP activities in the mid- and longer-terms	Involvement and commitment of research funding agencies to support GFCS and RMP activities	Funding level for GFCS relevant projects. Funders adopting and using the RMP project identification criteria. Funders monitoring performance and data policy adherence according to GFCS requirements	Communication with funding agencies	2014	WCRP, WMO, ICSU	IGFA and Belmont Forum members, other funding and operational agencies	0.10	Mismatch of objectives, conflict with earlier commitments
3	Developing partnership of communities producing experimental and regular climate information, including predictions, and making research products more broadly available to climate service users for assessment	Experimental climate products available to users. Feedback of users on research community products	Number of openly available and accessible climate information products including predictions at a range of time scales, suitable for support of diverse applications in GFCS priority sectors	Monitoring of available products and of user feedback on them	2014 with subsequent continuation	WCRP constituencies, WWW, CBS, CSIS	WCP, leading modelling centres	0.40	Insufficient commitment, concerns for possible liability due to use of pilot products in services

4-1	Develop GFCS climate and health research and communication strategy and set targets and priorities to support health and climate research at regional and national levels	Strategy as a document. Improved frameworks, communication and partnerships	Translation of strategic recommendations into regional and national research and development plans. Proposals on research CD development	Inquiry with countries	2012-2014	WHO, GECHH, others	WCP, CSIS, WCRP, WGRC, PROVIA, EWSs for air quality and their health implications	0.20	Complexity, dependence on regional and local levels of development that may be insufficient
4-2	Develop virtual forum on climate and health research	Web portal	Active posts and exchange of views on the portal	Website monitoring	2012-2014	WHO, GECHH, others		0.05	Negligible
5	Develop GFCS climate, water management and hydrological cycle research strategy and set targets and priorities to support research at regional and national levels	Strategy as a document. Improved frameworks, communication and partnerships	Translation of strategic recommendations into regional and national research and development plans. Proposals on research CD	Inquiries with countries	2012-2014	GEWEX, WMO CHy, IHP of UNESCO	Satellite agencies, regional stake-holders, EWSs for hydrology	0.20	Organization-al complexity, inadequate knowledge of partner communities
6-1	Develop GFCS climate, food security and agriculture research strategy and set targets and priorities to support research at regional and national levels	Strategy as a document. Improved frameworks, communication and partnerships	Translation of strategic recommendations into regional and national research and development plans. Proposals on research CD	Inquiry with countries	2012-2014	FAO, CGIAR, WFP, WCRP, PROVIA	Regional stakeholders	0.20	Complexity, inadequate knowledge of partner communities, divide between communities
6-2	Develop virtual forum on climate and food research	Web portal	Active posts and exchange of views on the portal	Website monitoring	2012-2014	FAO		0.05	Negligible
7	Mechanisms to coordinate research on attribution and prediction of climate extremes and transfer of its outcomes to climate services for DRR sector, adaptation measures, and development of corresponding EWSs	Improved attribution and skilful prediction of extreme events and their statistics, guidance to users	Publications on attribution of extreme events, increased percentage of predicted events and improved guidance on extreme events for decision making. Proposals on research capacity development	Verification scores for meteorological variables associated with extreme events, insurance loss data	2014 with subsequent continuation	Research groups affiliated with WCRP, especially CLIVAR and GEWEX, WCP, NMHSs	IRDR, PROVIA, regional stakeholders	0.20	Multi-disciplinary challenges, resources required to resolve tails of distributions

8	Development project on improving skill of global and regional climate predictions for time scales from weeks to seasons	Improved skill and enhanced availability of predictions	Number of centres producing predictions, regular availability of experimental forecasts, EWS and alert systems for climate variables	Positive evolution of standard verification scores of predictions by leading centres	2012-2017 with initial activities before 2014	WWRP/WCRP Sub-seasonal to Seasonal (S2S) Initiative	CSIS, THORPEX, CHFP, user feedback through UIP	0.30	Complexity of research field, technical complexity of experiments
9	Global Integrated Polar Prediction System for time scales up to a season and beyond	Experiments aimed at improved skill and enhanced availability of predictions	Number of centres producing predictions, availability of experimental forecasts, and improvement in availability of polar observations for model initialization and verification	Positive evolution of standard verification scores of predictions by leading centres, reduced systematic errors of models	2012-2022 with initial activities before 2014	WWRP Polar Prediction Project in close collaboration with WCRP Polar Climate Predictability Initiative	Other WWRP working bodies, WCRP, CBS, IASC, creation of a Polar Climate Outlook Forum	0.30	Large number of unknowns
10	Coordinated research on global and regional climate predictions and projections on time scales from decades to centuries for climate risk management and adaptation to climate change	Databases of predictions and projections, regional and national studies	Volume of downloaded data, publications on data use and interpretation, improvement in indicators of model quality	Information from centres responsible for data holdings	2013 with subsequent continuation	WCRP CMIP and CORDEX, WGRC	WCRP projects, PROVIA, regional and national partners	0.20	Complexity of experiments, unknown predictability, resources
11	Coordinated reprocessing of fundamental climate data records and their use in regional climate services	Substantiated fundamental climate data records and their assessment	Number of fundamental climate data records generated, publications on regional trends and impacts	References to datasets, publications	2014 with subsequent continuation	WCRP affiliated research centres, WCRP WDAC	GEWEX, OBS, GCOS, links to UIP and CD pillars	0.20	Technical challenges, resources required
12	Coordination and extension of reanalysis activities	Expanded scope and increased accuracy of reanalyses, contribution to assessment of products	Number of years and variables covered, use of coupled models and data assimilation techniques in producing reanalysis, publications based on the data use	Documentation from responsible centres	2014 with subsequent continuation	WCRP, Responsible centres	WCRP WDAC, GCOS, OBS, links to UIP and CD pillars	0.20	Technical challenges, resources required

13	Design of an integrated global greenhouse gas information system (joint with OBS pillar)	Provision of timely, regionally-specific information related to the state of GHG, the rate of GHG increase, and projections for future decades	Increased availability of enhanced GHG observations and data	Publications, regional assessments, and products available through dedicated webpage	Preparation for implem-entation in 2015-2020	GAW, GCOS, GEO-Carbon and regional projects such as ICOS in Europe, Carbon North America (CarboNA), and other similar efforts and existing networks around the world	IGAC, WCRP, UNFCCC, groups using GHG forcing in climate prediction and projection	0.20	Difficulties of transition between research and operations
14	Development of an interagency program on regional sea-level rise and its future extremes	Interagency research programme to address uncertainties in assessment of future sea-level	Agreed planned document	Publications, regional assessments	2014 with subsequent continuation	WCRP, JCOMM, IOC, CD and UIP, especially for SIDS	Partners involved in geodetic research, hydrological community, etc.	0.20	Complexity of the inter-disciplinary coordination
15	Improving decision-making processes in climate related risks	Case studies to demonstrate how climate information can improve decision making in GFCS priority sectors. A proposal for a corresponding research project	Reports on techniques to extract useful and actionable information for decision making and to more effectively exploit the emerging prediction capabilities with account of uncertainty in climate information and limits of its use. Guidance on verification of climate information products	User feedback through UIP, report assessment	2014 with subsequent continuation	WCRP to form a consortium with inclusion of NMHSs, sector lead agencies, local decision makers, users of climate information, etc.	Groups involved in experimental prediction, PROVIA, UIP, etc.	1.00	Multi-disciplinary challenges, complexity of the issue

APPENDICES

APPENDIX 1

Existing research and development activities

Under the RMP pillar the needs of climate services will be promoted in research agendas of main stakeholders, encouraging improvement of climate information, including predictions and projections for the time and space scales of concern to decision-makers, and development of practical applications in partnerships with corresponding users. The bulk of the research contributing to the setup of the GFCS will be conducted in nations at research divisions of NMHSs, universities, and academies of sciences, research laboratories or various national agencies, etc. Representatives of research and application communities will also be engaged in activities shaping the GFCS UIP and CSIS. Within the GFCS communities, providers of tailored climate information to the end-users will be a major category of customers for the climate research community. Their assessments of climate information qualities will help to further develop climate data and predictions. The RMP pillar will also help to communicate to the broader audience the views of the research community on the important issues of climate impacts on society and the role of science in addressing them. Coordination of such a system is difficult unless the pillar has a well-defined structure that is capable to maintain links between its interacting parts. To design such a structure, the first step would be to identify the main international stakeholders coordinating research and development in the four initial priority sectors for GFCS implementation and to engage, with their help, the main programmes conducting relevant research.

International research coordination helps to achieve greater progress in understanding and predicting climate variability and change and to address complex scientific challenges that cannot be tackled by individual nations. The leading programme in this area is the World Climate Research Programme (WCRP) co-sponsored by the WMO, International Council for Science (ICSU), and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. The WCRP Strategic Framework 2005-2015 “Coordinated Observation and Prediction of the Earth System” (WCRP, 2005) targets climate research on the development of multiple practical applications of direct benefit and value for society. WCRP has expressed a commitment to support the development of the research pillar of GFCS and is updating its research priorities, structure and modus operandi to address this objective. Regional panels and WCRP core projects (CLIVAR, GEWEX, SPARC, and CliC) will be able to offer their expertise for addressing regional issues of importance for various domains of applications.

A series of consultations were held in 2007-2011 to define how climate research can help support and develop climate services. In 2007, GCOS, WCRP, and International Geosphere – Biosphere Programme (IGBP) conducted a Workshop “Future Climate Change Research and Observations: GCOS, WCRP and IGBP Learning from the IPCC Fourth Assessment Report” (GCOS, WCRP, IGBP, 2008). The workshop identified gaps in knowledge and salient science issues and corresponding research needs for adaptation to and assessment of risks posed by climate change, treatment of uncertainty and providing relevant climate information on regional scales. The WCRP Implementation Plan 2010-2015 (WCRP, 2009) includes a series of research activities to address the identified gaps in knowledge. The activities proposed in the Plan are of extreme relevance to the GFCS.

The WCRP Joint Scientific Committee at its 31st session (Antalya, Turkey, 15-19 February 2010) held a joint session with the 15th session of the WMO Commission for Climatology Technical Conference "Changing Climate and Demands for Climate Services for Sustainable Development" (Sivakumar et al., 2010). The WCRP Open Science Conference (OSC, Denver, USA, 24-28 October 2011) was devoted to the Theme “Climate Science in Service to Society” (Asrar et al., 2012) and had successful sessions on the private sector interest in climate services.

Based on the above consultations and broad discussions, the Joint Scientific Committee for WCRP in October 2011 identified six Grand Challenges in climate research, which are defined as specific

barriers (i.e. gaps) to progress in understanding and predicting climate variability and change but are tractable through targeted research efforts with the likelihood of significant progress over 5-10 years. These grand challenges relate to understanding, attributing, modelling, and skilfully predicting or projecting:

- Regional climate;
- Regional sea-level rise (which also includes assessment of the change and variability of the global mean sea level);
- Cryosphere in a changing climate (including ice sheets, water resources linked to glaciers and snow, permafrost and carbon);
- Clouds, circulation, and climate sensitivity;
- Past and future changes in water availability (with connections to water security and hydrological cycle);
- Extreme climate/weather events.

These challenges are very relevant for RMP pillar, and activities aimed at addressing them are included in the initial and subsequent RMP initiatives. The recent Accomplishment Report (WCRP, 2013) provides multiple examples of successful climate research aimed at serving the needs of the society.

WCRP represents the research component of the World Climate Programme (WCP). The other components of WCP are GCOS, the World Climate Services Programme (WCSP), and the emerging Programme of Research on Climate Change Vulnerability, Impacts and Adaptation (PROVIA).

A wealth of relevant climate information and valuable guidance come from periodic scientific assessments of the WMO/UNEP Intergovernmental Panel on Climate Change (IPCC), which impartially reviews latest achievements of climate science and provides policy-relevant but not policy-prescriptive information on climate. Planning of the GFCS research activities, presented in this Annex, takes IPCC activities and their expected outcomes into account, together with other science-based environmental, energy, and water related assessments.

The WMO Executive Council Research Task Team (ECRTT) has made very important recommendations concerning the strategic way forward in environmental research, modelling and prediction. In the Report “Challenges and opportunities in research on climate, weather, water and environment” (WMO/TD-No. 1496, 2009) the Team recommended to develop “a unified approach to multidisciplinary weather, climate, water and environmental prediction research, step up high-performance computing investments to accommodate the increasing complexity and detail of models, and to accelerate the development, validation, and use of prediction models”. Implementation of this recommendation should lead to improvement of basic climate information products needed to generate user-tailored climate services. The Task Team also highlighted a need to further develop predictive capabilities through a mix of research and operations, involving all Earth System science disciplines and addressing corresponding needs on regional scales. The approach is illustrated in Figure A showing how research and service delivery communities could work together towards operational implementation of research outcomes across weather and climate time scales.

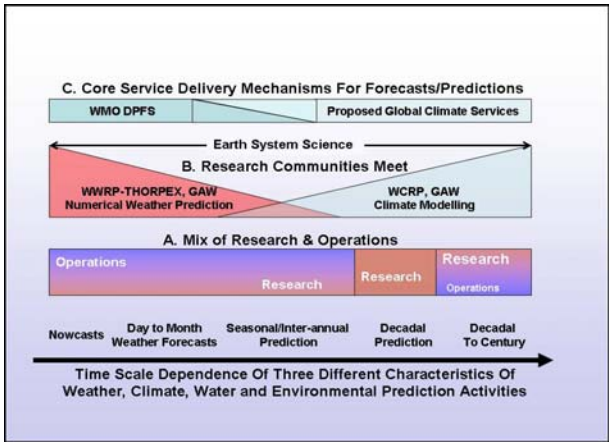

Figure A: Time scale dependence of various aspects of weather, climate, water, and environmental prediction (ECRTT Report, 2009)

The research activities and programmes that are indicated above in this section represent only the tiny above-surface part of the whole GFCS-relevant activity iceberg. There are many other international research programmes and agencies that conduct research work of significance to the RMP pillar. Their non-exhaustive list includes IOC constituent bodies and co-sponsored programmes; WMO Programmes, Technical Commissions and Regional Associations; activities and programmes of other UN agencies and programmes; and leading international observing programmes such as WIGOS, GCOS, GOOS, GTOS, etc.

The UN Food and Agricultural Organization (FAO) and UN World Food Programme (WFP) are the main stakeholders managing support to and coordination of agriculture and food security. Building the sector capacity of delivering climate services will involve corresponding enhancement of their main existing activities, such as the FAO Global Information and Early Warning System (EWS) on food and agriculture (GIEWS), Famine Early Warning Systems Network (FEWS NET) of USAID, etc. The WMO Commission for Agricultural Meteorology reviews the main meteorological information requirements of agricultural, livestock, forestry, and fisheries communities. A significant part of these requirements concerns climate information. The communities associated with the Consultative Group on International Agricultural Research (CGIAR), particularly their climate-related programmes, e.g. the Research Programme on Climate Change, Agriculture and Food Security (CCAFS) would be able to contribute to identification of additional research priorities for climate services for food security and agriculture. The outcomes of the Earth System Science Partnership project “Global Environmental Change and Food Systems”, which was completed in 2011 (Ingram et al., 2010), and the ongoing CCAFS project outcomes could inform such planning. There is a vast network of researchers in the food security and agriculture sector, and significant resources are invested in this research through partnerships that are already in place.

There are many international agencies and organizations coordinating water management, hydrological activities, and associated research. The Earth System Science Partnership Global Water System Project (GWSP) spearheads international research on global sustainability and water. The WCRP Global Energy and Water Exchanges (GEWEX) project is the main international research programme focusing on the observations, understanding, modelling, and synthesis of the complex relationship between the Earth’s energy and water cycles. For the success of the GFCS it is essential to identify opportunities for specific and high impact contributions from flagship water research programmes such as the International Hydrological Programme of UNESCO. The United Nations World Water Development Report, released every three years in conjunction with the World Water Forum, provides the most authoritative assessment of the fresh water resource status for the world and related requirements. The WMO Commission for Hydrology and the Hydrology and Water

Resources Programme are a valuable source of expertise and could assist in establishing the essential connection between international hydrological research and water-related climate information services to be provided to decision-makers through the GFCS. Three main initiatives in corresponding observations are the World Hydrological Cycle Observing System (WHYCOS), Integrated Global Water Cycle Observations (IGWCO) Community of Practice of the Group on Earth Observations, and several Global Terrestrial Networks: for Hydrology (GTN-H), River Discharge (GTN-R), Lake level/area (GTN-L), Glaciers (GTN-G), and Permafrost (GTN-P).

The strategy and the current momentum of the World Health Organization (WHO) activities to enhance the capacity for assessing and monitoring health vulnerability, risks, and impacts due to climate variability and change mainly date back to the 2008 World Health Assembly, which asserted the need to address significant gaps in the knowledge and research on climate and health. WHO is thus mandated to continue close cooperation with appropriate UN organizations, other agencies and funding bodies, and Member States, to develop capacity to assess the risks from climate change for human health and to implement effective response measures by promoting further research and pilot projects in this area. The five priority areas of this work include:

- Interactions of climate change with other health-related determinants and trends;
- Direct and indirect climate impacts on human health;
- Effectiveness of various strategies to contend with climate-related health impacts;
- Health implications of climate mitigation and adaptation strategies;
- Means to enhance public health systems.

WHO is also committed to support enhanced applied research on the linkages between climate and policies addressing climate change and health outcomes (D. Campbell-Lendrum et al., 2009). There are several WHO-affiliated research programmes for the climate and health sector. One example is the Special Programme for Research and Training in Tropical Diseases (TDR) co-sponsored by the United Nations Children's Fund (UNICEF), the United Nations Development Programme (UNDP), and the World Bank. In addition to the WHO-led global research agenda (WHO, 2009), other existing climate and health research agendas include the Earth System Science Partnership scientific strategy for Global Environmental Change Human Health (GECHH, 2007), the US-Interagency Report Outlining the Research Needs on the Human Health Effects of Climate Change (Portier et al., 2010), and the Special Programme for Research and Training in Tropical Diseases that has a focus on climate change and tropical and neglected diseases.

As indicated in the second biennial (UNISDR, 2011) Global Assessment Report on Disaster Risk Reduction, which is a key resource for understanding and analyzing global disaster risks, the national and regional paths of development are strongly sensitive to the risks associated with the climate change. The Hyogo Framework for Action 2005-2015 defines the strategy for building up the resilience of nations and the communities in accordance with the UN International Strategy for Disaster Reduction. ICSU and the International Social Science Council sponsor the Integrated Research on Disaster Risk Programme (IRDR). Natural disaster risk reduction has been endorsed as a priority for the WMO by the Sixteenth World Meteorological Congress and is addressed by the WMO DRR Programme. WCRP is developing the scientific basis for attributing and predicting climate extremes in near real-time for risk management and mitigation purposes. The main customers of climate information on natural disasters are civil protection agencies and industries involved in developing projects with environmental risks and those offering insurance and re-insurance against such risks. Various communication and experience or practice sharing platforms are emerging in the disaster risk management areas, for example, such as “Understanding Risk” (http://www.understandingrisk.org), CAPRA (http://www.ecapra.org), etc.

Under the leadership of the programmes and agencies indicated above it will be possible to develop a RMP agenda of applied research in the four initial GFCS priority areas. To enable practical

applications of climate information, such applied research should rely on availability of supporting climate information. At present, there are two major pathways of getting access to climate information including predictions. Firstly, under the WMO World Weather Watch, the Global Data-processing and Forecasting Systems (GDPFS) generates and makes available to Members a variety of real time and non-real-time climate information products. They include climate-related global and regional diagnostics, such i.e. 10-day or 30-day means, summaries, anomalies, etc. The network of Global Producing Centres (GPC) of long-range forecasts issue predictions for ranges between one month and up to two years. Some climate information products are available from other sources, including the WCP Climate Information and Prediction Services (CLIPS) project, which is being transitioned into GFCS. This work includes development of the concepts for National Climate Centres (NCC) and National Climate Services (NCS) and the establishment of Regional Climate Centres (RCC) around the world, along with standardized processes for the generation and dissemination of RCC products. The CSIS will facilitate coordinated access to such quasi-operational climate information. Secondly, WCRP and partners also produce experimental climate products through their global and regional prediction and projection activities such as the Coupled Model Intercomparison Project (CMIP), Coordinated Regional Downscaling Experiment (CORDEX), Climate System Historical Forecast Project (CHFP), and Climate Chemistry Model Validation (CCMVal). At the time scale of numerical weather prediction (NWP), THORPEX, a WMO World Weather Research Programme experiment, has enabled reliable access to the THORPEX Interactive Grand Global Ensemble (TIGGE) of 1-day to 2-week high-impact weather forecasts. TIGGE has become a hallmark in research on ensemble forecasting and predictability. The Common Metadata for Climate Modelling Digital Repositories (METAFOR) initiated the development of a Common Information Model standard for data and model outputs. Similar efforts are being extended to the analysis and re-analyses of historical and modern observational records by the major centres around the world. Specific attention is being paid to the issues of availability and ease of access to data through existing information networks. For example, the Earth System Grid promotes open and distributed access to data and information that is subject of a set of common standards, formats, and consistent description of the methodologies used to generate the data and includes error characteristics of the available information.

The two major sources of climate information, coordinated by the World Weather Watch, and WCP, on one side, and by various research programmes, on the other side, operate largely independently. Exchange of experience by communities involved in them, comparing operational and experimental products, further developing them in partnership with users, and interpreting them from the perspective of practical applications could bring a step-change in the usefulness of the climate information products and speed up their further development.

The emerging “Future Earth“ Initiative, which will likely substitute the Earth System Science Partnership and include in its body several currently existing research programs, such as the IGBP, International Human Dimension Programme on Global Environmental Change (IHDP), and Diversitas, could become a key WCRP partner in contributing to the GFCS development.

The development of capacity in research on climate and in climate-related applications should build on already existing strong links with and commitments by professional CD organizations such as START, IAI, APN, and many other aid organizations in the domain of climate change and adaptation to it, such as the Climate Change Adaptation and Development Initiative (CCDARE) of UNDP and UNEP.

APPENDIX 2

Detailed description of research activities in GFCS priority areas

This Appendix offers a detailed description of research activities in the areas of research on the development of climate services in the sectors of human health, food security and agriculture, water resource management, disaster risk reduction, energy, transport, and environmental resource protection and management.

GCFS research on health and climate

The health and climate sector has already developed a coherent programme of initial research activities. It is based on the analysis of the environmental determinants of human health and measures to address the associated problems.

Environmental determinants of human health include direct effects of climate conditions on health through, e.g. thermal stress (both due to heat and cold conditions), exposure to UV radiation, air pollution, etc., and a number of other factors. Nutrition, water availability, natural disasters also strongly affect the health sector, for example through:

- Reduced healthcare and drug access due to destruction of health infrastructure in floods and storms, reduced household income due to impacts of extreme events and livelihood stress, migration and displacement following extreme events as well as reduced long-term habitability, depletion of pharmaceuticals stock during extreme events, reduced availability of appropriate health staff for preventative health care because of the reallocation to health crisis response;
- Weakening of the support networks following economic and agricultural livelihood losses including malnutrition;
- Increases in health risks due to loss of shelter and livelihoods following extreme events;
- Risk of increased mental health concerns via experience of extreme events, family and livelihood loss.

Adequate measures to address these issues should be initiated through the appropriate sector activities. Environmental factors affecting health that are additional to the effects on food, water and disaster risk, include:

- Temperature effects on food-borne diseases;
- Temperature, rainfall, humidity, dust effects on vector borne diseases (malaria, dengue, leishmaniasis, filariasis, schistosomiasis, trypanosomiasis, rift valley fever, kalazar, chickungunya, plague, etc.);
- Temperature, humidity, wind and dust effects on disease transmission (i.e. meningitis);
- Temperature and rainfall effects on air pollution and aeroallergen levels;
- Risk of eye infections and respiratory diseases related to high atmospheric aerosol/dust concentrations;
- Temperature and precipitation effects on water-borne diseases;
- Effect of floods and droughts on food and waterborne diseases (e.g. leptospirosis);
- Risk of dermatological and eye infections (via reduced hygiene practices) related to water scarcity/reduced access;
- Water quality impacts due to increased fertilization;
- Risk of micronutrient deficiencies via loss in dietary diversity;
- Risk of diarrhoea and respiratory infections (via reduced hygiene practices) related to water scarcity/reduced access;

- Emergence or spread of pathogens via climate change driven biodiversity loss and changes in ecosystem habitats (changing expanse of ecological niches);
- Impact of UV radiation on skin cancer;
- Biodiversity loss reducing availability of traditional medicine species.

Many necessary research tasks to address the above issues require multidisciplinary guidance and oversight (e.g. in reviewing and periodically revising the global research agenda, or producing "best-practice" guidance for economic assessments on climate change and health), or technical projects (such as global assessments of the current and future burden of disease attributable to climate change). In order to ensure coherence, these processes should have access to relevant climate expertise.

Activities

An inventory and assessment of climate information, products, and services currently available to (and used by) the health sector, which can be optimized and improved, will be conducted. Based on this inventory and as well on the analysis of the gaps in current research agendas, an assessment will be made of what is optimally required for climate-related risk management and adaptation to climate change in the health sector. In doing this, the positive experience of several initiatives in the climate and health sector that can serve as building blocks for future developments will be used. This includes, for example, the Meningitis Environmental Risk Information Technologies (MERIT) initiative, which has gained valuable experience in setting research strategies based on effective dialogue between health researchers, practitioners, and their environmental counterparts. Existing practices and arrangements such as the Malaria Outlook Forum (MALOF) will also be used and strengthened as much as possible. The national level health EWS and climate-sensitivity models will be evaluated to identify best and standard practices and cost-effectiveness. A systematic analysis will be conducted of current health actor capacity/readiness to make climate informed decisions and inventory of common approaches used, including case studies on benefits of health and climate service collaboration. Research will also be conducted to evaluate the cost-effectiveness and cost-benefit of climate informed health operations. Most of these activities will start at the initial stage of the GFCS implementation and contribute to the development of the strategic implementation plan of research on climate services for the human health.

GCFS Research on food security and agriculture

The food dimension of life support is extremely complex and diverse. Agriculture requires data on processes and phenomena affecting plant growth (zone and season), health, and processes that affect them, such as erosion, soil and water quality, pests, conditions of harvest collection and storage, and ultimately processing and dissemination of food products that affect human health and security. Livestock is highly dependent on grazing conditions. Forestry is most vulnerable to fires and pests. Fisheries and aquaculture critically depend on a range of oceanographic, biogeochemical, and ecological conditions in the coastal zone, and, as an example, in the long run they may be interested in knowing how coastal upwelling systems will be affected by the climate change. All sectors of food production and distribution are vulnerable to storms and have well defined real-time weather prediction requirements. In terms of climate information, very significant value resides in combined long-term predictions of temperature and precipitation anomalies, and particularly of their extremes such as droughts. Corresponding requirements for climate information differ for regions, sub-regions, and nations.

Activities

At the initial phase of the GFCS implementation a detailed research agenda will be developed to guide global and national efforts in agricultural and food security research. Research activities will be aimed

at improving the understanding of the impacts of climate change and extremes such as droughts on agriculture and food systems, developing capacity to assess the risks from climate change for agriculture and to implement effective response measures, promoting research in sustainable agriculture and a secure food supply in a changing climate, formulating climate information requirements to support climate and agriculture research in favour of agriculture policymaking, planning and operations, and building the economic and political case for the application of climate services to protect agriculture from climate-related risks.

GCFS research on water resources and their management

The water sector is a nexus of challenges and opportunities associated with livelihood of people, ecosystems and economic development. It is affected strongly by climate variability and change on one hand, and influences the evolution of Earth's climate on the other hand. Water is essential for food, energy, transport, and many other aspects of life support. The needs for water resources related information and services vary with regions and are different for short- and longer-time scales, from days to seasons and decades. However, there are mainly three types of data/information that can benefit significantly every water-related application: (1) levels and capacity of fresh water reservoirs; (2) water availability and access; and (3) risks associated with quantity (scarcity or excess) and quality of fresh water. They depend on environmental factors such as precipitation, snow/ice melt, evaporation, etc., and on human factors such as water withdrawals, consumption, and reuse. Water availability anomalies including droughts and floods depend on dominant modes of atmospheric and oceanic circulation, land-surface and soil moisture conditions and their seasonal and longer-term variability. Seasonal prediction of these anomalies on a regional scale, particularly prediction of anomalies associated with monsoon systems, still presents a bold challenge to climate, weather and hydrological sciences.

Activities

A strategy for coordination and integration of meteorological and hydrological research, including coupling climate-hydrological models for weather and climate prediction that is essential to the success of the GFCS in this sector, will be developed. Because the improvement of the quality of observations and models for predicting the onset, distribution and quantity of precipitation depends on the progress in our ability to represent in models all components of the hydrological cycle and related atmospheric and land surface processes, research will engage in the development of a new generation of nested high-resolution hydrological models with inclusion of aspects of water quality and biogeochemistry, and human intervention, along with data assimilation systems and reanalysis capabilities. Another focus of the research will be measurement and modelling of clouds and precipitation at a spectrum of time- and space-scales. Climate science will work on enabling assessments of climate change impacts on all elements of the hydrological cycle, on global and regional level, including its extremes, involving floods and droughts. As in the case of the food security and agriculture sector, a detailed research agenda will be developed at the initial phase of the GFCS implementation to guide global and national efforts in the hydrological and water resource research. The activities associated with the two WCRP Grand Science Challenges, namely the water availability and the cryosphere, will be particularly relevant.

GCFS research on climate services for disaster risk reduction

The need for climate services arises to a large extent because of the societal risks related to extreme hydrometeorological events. The risk is growing partly because the societal infrastructure is becoming more exposed to weather-related risks as the global economy expands and population grows, and partly because of the climate change. Provision of information and warnings for high impact weather, air quality–related and health-hazards are high priority objectives for the emerging multi-hazard Early

Warning Systems. The climate dimension of disaster risk reduction has two major sets of requirements. The first one is understanding (i.e. knowledge development) of the causes and enabling prediction of individual extreme climate events, such as long-term anomalies of temperature and precipitation, leading to droughts, floods, and storminess, especially with respect to tropical cyclones (typhoons, hurricanes) and extratropical storms. The second set of requirements is associated with information support for decision-making, i.e. use of available knowledge, for example, of the climate defined as weather statistics. The probability distribution of weather events in a changing climate is non-stationary implying that the return periods of extreme events related to floods, avalanches, mud slides, drought, heat waves, wind, storm surges, weather related diseases, etc. are undergoing significant changes in many regions of the world. Due to the non-stationary character of current climate records, past climate information may be no longer representative for the future. The geographical distribution of environmental risks is uneven and there are areas of particularly high exposure to hazards, for example, low-lying deltas, and areas impacted by tropical cyclones and floods. It is essential therefore to ensure that climate information requirements for decision-making purposes in the DRR sector are identified in an interactive manner between the research community and users.

Exposure to hazards turns into vulnerability due to systemic socio-economic and political conditions, such as poverty, underdevelopment, lack of resources and inadequate infrastructure. It may be exacerbated by long- and short-term decision-making failures and even cultural factors affecting behaviour. Thus the target audience for climate services in the DRR sector should involve governance and development agencies, such as those responsible for land use and livelihoods planning.

Activities

In the DRR area, the climate science community will engage industries and interested communities into a wide discussion on climate variability and change aspects of hazard risk estimation and safety reinforcement in sectors with identified vulnerability. This communication should result in a broad programme of research activities on adaptation of the DRR sector to climate change and to inform risk assessment and reduction. Industry-specific engineering design criteria related to activities safety and insurability sectors will be reviewed. New civil engineering and safety standards will be proposed that take into account climate predictions and their inherent uncertainties. Internationally accepted guidance on climate information for construction and operation safety codes and related basis for insurance coverage will be a very important outcome of this initiative. The expertise of the insurance and reinsurance industry will be invited and used to promote the timely adoption and implementation of new practices. This may include development of financial risk transfer products for climate risks (such as weather index insurance) for agriculture, water resource management, and natural disaster risk reduction sectors. In addition, availability of environmental information useful for identifying hazards induced by climate variability and change and preparation of related advisories and warnings should be reinforced in this process. The use of climate predictions in the disaster risk assessment practices, development of EWSs, and in support of safety precautions will be promoted.

GCFS research in other sectors

Climate information products enabled during the initial stage of GFCS development to meet the needs of initial priority areas will be also instrumental for provision of climate information services in other key areas, for example, the energy sector, protection of ecosystems and the environment, ocean and coastal zone management, transport and tourism, life support and environmental protection in megacities, international environmental policy, etc. The list of future applications of climate service that is given below is by no means comprehensive and only illustrates the multitude of sectors needing adequate climate information support.

Energy sector

The primary environmental, economic, and governance concerns in the sector of energy generation, supply, transmission, and consumption are similar to the ones in the agriculture and water sectors, which is reflected in an increasingly popular term “water-energy-agriculture nexus.” Intensive applied research in this sector is underway and is highly dependent on the contribution of climate science. Research is also developing on alternative sources of energy and its transmission, which requires new types of data, e.g. on the wind regime, duration of sunshine, frequency of snow storms, icing, etc. Energy production and transport are at present strongly dependent on fossil fuel sources and are expanding strongly in developing countries.

Activities

Research activities will be aimed at provision of data on the emissions from energy sources and the impact of these industries on global climate. Research to support the development of growth of and reliance on renewable energy (e.g. solar, wind, bio-energy, etc.) production, globally regionally, will be promoted.

Transport

Greenhouse gas emissions from transport are an essential contributor to the climate warming and a source of air and water pollution. Requirements for climate information and services for transport depend very strongly on the sector and are normally aimed at efficiency and safety. For example, changing ocean routes and the need to ensure optimal ice-bearing capacity of ships or their storm-worthiness are typical information requirements related to marine transport. For ports and harbours there is a well-defined set of climate information requirements. The main safety concern for terrestrial pipelines in cold regions is the carrying capacity of permafrost-affected soils. Aviation and airport operations also have well-established requirements, especially for local climate information.

Activities

A large body of applied research will have to be stimulated in the transport sector to ensure the safety and increase economic efficiency of operations. Climate aspects of the research agendas of expert communities working in the transport industry should be enhanced and liaisons established to ensure that latest achievements in climate research are picked up in the development of practical applications.

Other major sectors of environmental management including tourism, megacities, coastal zone management, etc.

Environmental management is a fast and extremely important developing area of activity. It requires support by “traditional” climate data products with constantly increasing volume of ecological and biogeochemical climate-dependent information. The main scientific development needed in this area is accurate coverage by observations and representation in predictive models of interactions between climate variability and climate change, air and water quality, land cover and land use changes, vegetation, and all other aspects of terrestrial ecosystems, atmosphere and ocean biogeochemistry. There is very significant regional specificity of the required information. Just as an example, changing frequency and intensity of dust storms are important for North Africa, Middle East, and West Asia. Climate change and its impact on aerosols and air quality is a very significant concern in other parts of the world, especially South-East Asia. Such list of examples can be continued.

Requirements for climate information for tourism are very diverse and require a systematic study. There are significant distinctions between information requirements of terrestrial tourism, e.g. for

alpine resorts, which are sensitive to availability of snow and vulnerable to mountain hazards such as avalanches, and marine resorts sensitive to sea level, storms, and changes in sunshine, to name just a few essential factors. Ecological and aesthetical aspects of the environment and its protection are of primary significance with a greater emphasis on ecosystem services and valuation of natural resources as a national wealth index. An essential aspect of climate services for tourism is its environmental impact, which should be minimized if it is negative.

Urbanization is one of the key features of the modern society. It has huge implications for all aspects of human life and largest environmental footprint. Their climate aspects need to be investigated. Continuing urbanization and migration of population to coastal zones create an urgent demand for specialized environmental services, such as sea-level predictions, predictions of the storm threats, especially from tropical cyclones and the associated extreme winds, precipitation, and storm surges. Salt water intrusion in coastal aquifers is a significant issue and exhibits dependence on the sea level. Urban adaptation to climate change and contribution to mitigation strategies require active research and adequate information support.

Activities

Research will be conducted on adequate representation of aerosols and ozone in climate models and further improvement of modelling of the biogeochemical and hydrological cycles. Methods to estimate essential chemical components of water such as carbon, (reactive) nitrogen, phosphorus, sediments, and other constituencies will be developed. Efforts will be made to establish or strengthen a climate–oriented research agenda in support of tourism, urban development and management, and integrated coastal zone management.

APPENDIX 3

Motivation and description of RMP research activities in support of the provision of core climate information products

The set of RMP activities with regard to core climate information will focus on developing and improving the skill and value in corresponding products and the capabilities of the decision-makers to use them. The focus will be on supporting the development of methods and products included in the list of the universally required climate information products given in section 2.3.4 of this Annex. The activities described below fall into three categories:

- Research on climate predictability and improving skill of prognostic information for a range of time scales;
- Research on adding value to climate information for its use in services;
- Research on observations, their processing, and climate record generation.

Research on climate predictability and improving prognostic skill: sub-seasonal to seasonal time scales

Research on improving predictive skill at the traditional interface between weather and climate is a high priority not only for meteorological services but also for the GFCS. Predictions covering the timescale from weeks to a season are essential for support to various socio-economic decisions and risk management strategies related to almost all GFCS sectors. Factors and processes determining weather and climate predictability at these time scales need to be actively studied so that they can be captured in observations and represented in models. Such factors include Madden-Julian Oscillations, stratospheric processes with longer time scale than tropospheric processes, sudden stratospheric warming and cooling events, solar radiation effects, slowly varying initial conditions at the surface such as SST, sea-ice, snow height and cover, soil moisture anomalies, and possibly vegetation. Predictability of climate at sub-seasonal time scales is driven by a complex interaction between atmospheric predictability on weather timescales and the state and phase of dominant modes of the atmospheric and ocean larger-scale variability, such as North Atlantic Oscillation, Southern Annular Mode, Indian Ocean Dipole, El Niño and La Niña. A focus of research on modes of organized convection and the interactions between tropical and extra-tropical latitudes, as part of the Year Of Tropical Convection (YOTC) project, has recently shown promising results and may help to identify additional predictability factors for mid-latitude regions. Unprecedented changes in the Polar Regions, especially the Arctic, which is demonstrating accelerated warming with markedly decreasing multi-year sea-ice cover, have significant implications for sub-polar and mid-latitude climates and require dedicated research.

Predictions on sub-seasonal to seasonal timescales are strongly dependent on the availability of accurate initial conditions for all components of the Earth System, including those that have a longer memory than the atmosphere. Hence, progress in prediction on the sub-seasonal and seasonal time scales can be expected due to more comprehensive observations, which will not only serve as the main means of initializing climate models but also are the foundation for better understanding and improved representation in models of the key phenomena and processes. It has also been concluded in the WCRP experiments on seasonal climate predictions that, even on this relatively short climate scale, it is important to ensure that models used for seasonal prediction have adequate long-term climate forcing. In the case of seasonal predictions this means the need to ensure an update for the atmospheric composition prescribed in the model.

Activities

Several RMP activities will address predictability and predictive skill on the sub-seasonal to seasonal time scales.

In the near-term perspective, the initial focus will be on improving predictions on the sub-seasonal time scale. This will be pursued by the weather and climate modelling communities through the joint WWRP – WCRP sub-seasonal to seasonal (S2S) initiative, to be developed in cooperation with the WMO system for long-range forecasts and building on the experience of the THORPEX Interactive Grand Global Ensemble (TIGGE) database for medium-range forecasts (up to 15 days) and the Climate-system Historical Forecast Project (CHFP) for seasonal forecasts. Research on and modelling of multi-scale convection processes, ocean–atmosphere and ocean–atmosphere interactions, dominant tropical modes of atmospheric variability and assessment of the research needs to identify and capture predictability of monsoon phases will be included. Procedures for specification of initial conditions for sub-seasonal predictions will be reviewed. The project is envisaged to have a 5-year lifespan with the intention to demonstrate the initial benefits within the next two years. Polar prediction at the weather and climate interface will be pursued by the WWRP through the Polar Prediction Project (PPP), which is a contribution to the Global Integrated Polar Prediction System (GIPPS). Existing professional working groups, such as the Societal and Economic Research Applications (SERA) Working Group of WWRP, are planning to analyse socio-economic benefits of this research and make recommendations to maximize it. Further recommendations will be made on using the research outcomes in practically important application areas, for example, in studying seasonal predictability of tropical cyclone activity.

The strategy to improve the skill of multi-time-scale numerical prediction systems is associated with using ensembles of “coupled” models (atmosphere, ocean, land surface and cryosphere), implicit inclusion (parameterization) and explicit resolution of all significant processes determining interactions between various components of the climate system, and creating a so-called seamless suite of forecasts that optimizes longer range products based on information already available for shorter time scales. This may require a range of models tailored to specific prediction and projection needs with optimal sharing of model code and infrastructure in a manner that allows and promotes flexible configuration of the modelling system for the problem of interest. In addition to optimizing the model runs, significant benefit with this approach may reside in the exhaustive use of information available for all time scales, in preparation of a forecast. Dedicated research efforts will be made to start implementing at least initial elements of such a comprehensive prediction approach and assessing their cost-benefit ratios in terms of improving prediction skill versus resource requirement and development complexity. Coordination of climate model development will continue through intercomparisons, process-based model evaluation, and development of guidance on the use of (multi-model) ensemble prediction schemes. The current skill of modelling and prediction of precipitation and its anomalies will be assessed to derive recommendations on ways of its improvement.

Teleconnections and interactions between tropical and extratropical latitudes and between the troposphere and stratosphere will be investigated, including the means of representation of their predictable elements in models. Seasonal predictability of polar and sub-polar regions also will also be investigated, especially with respect of the rapid changes taking place in these regions and the emerging needs for services. Similarly, the ability of predictive models to adequately simulate fluxes of energy, mass, and momentum between the atmosphere and underlying ocean or land surface will be systematically reviewed, which is a prerequisite for exploiting the predictability associated with long-term climate variability and the interaction of the atmosphere with the underlying upper layer of the ocean, the ocean thermocline, and the upper layer of soil.

The research under RMP will target the improvement of both deterministic (e.g., single model run) and probabilistic (e.g., mode run ensembles and evaluation of uncertainty) predictions of significant events and corresponding variables such as heat waves, cold spells, monsoon phases, precipitation and air temperature anomalies, tropical cyclone season characteristics, sea-ice conditions, etc.

Research on climate predictability and improving prognostic skill: decadal to centennial time scales

Decadal-centennial time scale is extremely important for adaptation to climate change and variability. Yet it is the scale where feasibility and reliability of climate predictions and projections is very difficult to estimate. Massive efforts are therefore required from the climate research community to address the corresponding scientific and technological challenges in support of major governance decisions at global, regional, national, and local levels.

The quality of the future climate projections on decadal–centennial time scale is dependent on the quality of long-term data for radiative forcing, which is influenced by the concentration of greenhouse gases in the atmosphere, including carbon dioxide, methane, ozone, nitrous oxide, halocarbons, reactive nitrogen, particulate matter including black carbon and mineral dust, as well as on accuracy of treatment in models of feedback processes related to clouds and atmospheric water vapour and land surface processes. The evolution of the concentration and distribution of radiative forcing agents is therefore a crucial factor in future climate projections. Their specification results from the assumptions with respect to future emissions of anthropogenic greenhouse gases, first of all carbon dioxide, particles, and ozone-depleting substances.

The 17th Conference of Parties of the UNFCCC set up a process that envisions a legal agreement on climate change by 2015. Climate research advances would contribute to this process by providing relevant guidance on mitigation policies including informative metrics, such as cumulative carbon, which is responsible for practically irreversible elevated temperatures for hundreds of years or a millennium, and consideration of short-lived climate forcing agents, reduction of which would result in "trimming the peak" of warming on shorter time scales. For adequate support to adaptation to and mitigation of climate change, better understanding of the past and future climate evolution and forcing factors that determine it, and enabling more comprehensive climate projections and restorations, research and more regular atmospheric chemistry observations should continue to develop. This is the domain of the WMO GAW Programme and of some research projects such as the IGBP International Global Atmospheric Chemistry and the WCRP SPARC project. For enabling corresponding services, more sustained operational delivery of GAW products and support to its infrastructure will be needed.

For the decadal and longer time scales, there is a pressing need for developing quantitative research supporting climate change impact and vulnerability assessments and adaptation measures. The recent analysis of the Global Research Priorities of PROVIA (PROVIA, 2013) has identified 33 research topics that include, *inter alia*:

- Developing indicator and monitoring systems;
- Quantifying vulnerability and risks of extreme climate events;
- Advancing vulnerability reduction and adaptation solutions;
- Improving approaches to adaptation;
- Enhancing communication and stakeholder-public participation;
- Studying specific adaptation needs in key systems and regions;
- Initiating research on emerging adaptation topics.

The climate science and VIA communities have many common interests. They share several methodological approaches. For example, the climate impact researchers are starting to undertake major model intercomparisons (MIPs) and uncertainty analyses similar to the ones developed and routinely used by climate scientists. Emerging needs for tailored climate information can be expected as impact and adaptation models become refined over time. New methods of incorporating climate information (especially on high-frequency variability) into impact assessments require heightened attention, both with respect to the techniques of application and the robustness of the information being transferred.

Very significant risks for coastal zones are associated with uncertainties in assessments of the future sea level, both its global mean and its regional variations. Recent observations indicate a likelihood of accelerated sea-level rise in comparison with estimates made by IPCC in its AR4 in 2007. Significant remaining uncertainties are related to still insufficient knowledge of all mechanisms involved in the ice sheet response to a warming climate and big potential range of forcing factors. The progress in sea-level research is fast but the remaining issues are, nevertheless, very challenging. There is also a clear need to translate conclusions of sea-level assessments into effective guidance for coastal zone protection and management.

Activities

For the decadal-centennial time scale, the climate research community will continue to work on experimental decadal predictions and centennial projections of climate change and changes in climate variability. The focus will be on identifying phenomena that offer some degree of predictability, enhancing the observing and data assimilation systems that would capture the predictability signal in forecasting initial conditions, developing prediction systems able to realistically represent processes associated with all forms of climate predictability, and process the output of these systems to provide probabilistic forecasts with skill sufficient for planning and decision-making purposes. Research on decadal prediction of Atlantic multi-decadal variability and Pacific decadal variability shows more perspective results for the Atlantic sector, which may be instrumental for subsequent prediction of climate variations over Europe, Africa and parts of the Americas. This will be the emphasis of main experimental research efforts. Some coherent changes in the global atmosphere follow major volcanic eruptions. If such an eruption occurs, there may be a need to consider its impact on climate prediction on decadal and climate projection on centennial timescales.

Systematic research will continue on the radiative forcing agents of climate and scenarios of future emissions of anthropogenic greenhouse gases, particles, and ozone-depleting substances. Past and present emissions and fluxes of radiative forcing agents will be validated against observed fluxes and concentrations of these gases. Such validation will be an essential contribution to the development of an integrated global greenhouse gas information system. Climate reanalysis and projections using model systems that have been compared with observations of greenhouse gases and their fluxes and demonstrated a skill in describing the cycling of radiative forcing agents will used to provide best possible information for climate change mitigation measures.

A major deliverable of climate research will be its contribution to the forthcoming IPCC AR5. The assessment will include four reports, namely on the Physical Science Basis; Impacts, Adaptation and Vulnerability; Mitigation of Climate Change; and a Synthesis Report. After the publication of AR5, which will start in September 2013, the RMP activities under GFCS and some other components of the GFCS Implementation Plan will need to be reviewed and adjusted based on the new findings. Potential directions and themes of future research will include the role of the long- and short-living climate forcers in climate change, changes in frequency of occurrence of extreme events in temperature, precipitation, tropical and extratropical storms in changing climate, variations in tropical cyclone activity on decadal time scale, processes responsible for greenhouse gas exchange with terrestrial ecosystems, interactions of clouds, aerosols, precipitation, and radiation and their contributions to climate sensitivity using a range of scientific approaches including a hierarchy of models, etc. Plans for a significant volume of research on VIA are in preparation (PROVIA, 2013).

A comprehensive programme of research on all factors contributing to the sea-level global mean and regional change, with a view of significantly reducing the remaining uncertainties and developing informative recommendations for coastal zone management, will be developed. It will rely on related activities in other sectors and the outcomes of the IPCC AR5. Among the many specific future products, WCRP with partners, such as the Global Cryosphere Watch (GCW), will aim to produce an

assessment of the state of the cryosphere in the 21st century with estimates of cryospheric contributions to future water resources and an assessment of regional variations in sea-level rise with guidance on expected sea-level extremes.

Most difficult issues of predictive climate science

There are several extremely challenging problems in climate science, for which the progress in developing skilful predicting techniques has been considerably slower than desirable. They include prediction of monsoon phases and associated precipitation, of blocking events, attribution of trends and variations in tropical cyclone activity, and, to some extent, reduction of some systematic errors in climate models. Achievement of progress in these areas of climate research cannot be timed precisely or even guaranteed. Further advances in computing power will enable coordinated development of climate models of increased sophistication and related experimentation with focus on model dynamics, boundary layer processes, clouds, convection, precipitation (including the use of "super-parameterization" for more explicit treatment of some sub-grid scale processes), gravity waves, aerosols, land surface processes, and their interactions across scales. Any positive outcome in addressing these "stubborn" problems of climate science will be communicated for implementation in more operational services and decision-making purposes.

Treatment of uncertainty and improving decision-making in climate related risks

The range of potential skilful deterministic prediction of weather and its elements is assumed to be up to two weeks due to the inherent non-linearity of the system. Prediction of climate and its anomalies is nevertheless possible, to a certain degree, because it is a prediction of weather statistics, which evolves at longer time scales due a number of reasons, including natural and anthropogenic forcing, and is modulated by interactions of the atmosphere with the ocean and land and the annual cycle. The use of multi-model ensembles helps in assessing the climate prediction uncertainty, in particular, by relating it to the spread of trajectories of individual climate predictions. This approach can be very efficiently used for weather prediction and shorter-term climate predictions, but longer-term climate projections cannot be often validated against observations. Their credibility thus needs to be assessed through multiple lines of evidence, such as the agreement across models and methods, the performance of models in representing observed climates and key processes, understanding of the effects of systematic model biases and understanding of the processes that underlie the projected responses. The complexity of all these approaches results in a large gap that presently exists between users' needs for actionable and valuable information and the climate services capability to serve those needs.

To be useful for climate information services, climate research has therefore an obligation to provide effective guidance on climate information and enable users to exploit it more easily and more effectively, minimizing possibilities of misinterpretation or misuse of complex climate information and helping to understand the limits of the climate information use. Ultimately, users are primarily interested in the *value* of using the forecast information, which is distinctly different from its quality or uncertainty. Value pertains to the benefits resulting from the use of climate information and is therefore related to the ability of users to make informed decisions and manage climate risks. Approaches to inform decisions on climate–dependent matters may be specific in the Framework's priority areas.

Activity

This activity will focus on improving the ability of users to incorporate uncertain climate information into their decision-making processes in order to prepare for and manage climate-related risks. The activity will engage both the users and the providers of climate information in developing techniques to extract useful and actionable information for their decisions and to more effectively exploit the emerging prediction capabilities in climate science. For example, it will review knowledge in this area and

develop guidance on characterizing the probability density function for predicted climate conditions and optimizing the climate information, products, and services for users with identified requirements. Complementary ways of estimating the uncertainty for multi-model ensemble runs will be considered. Interdisciplinary case studies will demonstrate how existing climate information can improve decision-making for each of the Framework's priority sectors. A multi-disciplinary research project aimed at improving decision-making processes and climate risk management will be developed.

Research-based climate observations and dataset development

Most of the proposed activities in this area are common with the OBS Annex. Developing, optimizing and sustaining the observing system for climate are important GFCS requirements. The RMP Annex describes only activities with a strong research component.

In the area of observations, (re-)processing, and (re-)analysis of historical observations, there is an urgent need for research and development of observing techniques capable of helping to close the gaps in observations in the polar and mountainous (i.e. cold climate) regions, enhance the observations in the deep oceans and the upper part of atmosphere, and start to more actively observe the atmosphere, ocean, and land chemical and biological variables. Scientific research can help to make the case for sustainable investments in observing systems by demonstrating the added value to products emerging from the observations. There is also a need to ensure that modern observing systems include variables important for initialization, calibration, and validation of predictive climate models. This includes ocean observations and sea-ice cover. The Global Ocean Data Assimilation Experiment (GODAE) project has developed the foundations of ocean data assimilation for climate change detection and experimental climate prediction. Now ocean observations can be regularly assimilated in models to produce consistent datasets representing state of the ocean up to a certain sufficiently large depth.

As mentioned above, significant advances are required in the understanding of past and current evolution and hence observations of the atmosphere and ocean chemistry, to include spatial and temporal distributions of long-lived greenhouse gases, reactive species, aerosols and corresponding estimates of radiative forcing. For example, many important chemistry-related observations are developed and carried out mainly in the research domain and often at academic institutions. Such research concerns the chemical composition and physical properties of aerosol, carbon fluxes between the earth's surface and the atmosphere, and feedback mechanisms between biogeochemical cycles of nitrogen and carbon. The vitality of the WMO GAW Programme, which to a significant degree is driven by academia and is research oriented, is instrumental for the global exploration and mapping of greenhouse gases and aerosols in the radiative forcing context. Systematic and resourceful transition of such observations, made in research mode, into a more operational mode, is required.

Activities

Research will continue on satellite climate observations including their algorithms and calibration (Trenberth et al., 2011). The quasi-operational sustained Coordinated Processing of Environmental Satellite Data for Climate Monitoring (SCOPE-CM) will be created. Retrieval algorithms for additional Essential Climate Variables will be developed and Fundamental Climate Data Records (CDRs) and Thematic CDRs will be created. Possibilities for successful cross-calibrations for old and new satellite sensors, which require major scientific input, will be reviewed. Independent observations and analysis of observations made by other means and systems will be used to improve the reliability of conclusions on various aspects of detection of climate variability and change. An international assessment of research priorities required for filling the existing gaps in climate monitoring continuity, accuracy, and efficiency, both from space and *in situ*, and building an operational global climate observing system will be conducted. This assessment will result in recommendations for transition

from research to operational capability and identification of the overlaps needed to prevent critical gaps in the climate-relevant observations administered by many national and international agencies.

Research-intensive coordinated climate data reprocessing will continue in participating agencies and centres. The scope and period of coverage of meteorological reanalyses will be extended, and new types of reanalyses (e.g. for atmospheric chemistry, cryosphere, etc.) particularly involving coupling between different components of the climate system will be initiated. Metadata standards and indication of the dataset “maturity” will be further developed. Development of standards for presentation and documentation of model- and observation-generated climate data following the Climate and Forecast (CF) metadata convention will continue. Data reprocessing and reanalysis, as well as palaeoclimate observations and research will strongly benefit from the strengthened climate data rescue activities planned through the OBS Annex.

RMP pillar will make relevant climate data more and more accessible. A single repository for all gridded and processed observational datasets that is analogous to the CMIP archive of model data, provides users with easy access to data/information in a standard format, and facilitates their comparisons and accurate citation, will be promoted, likely following the approach proposed by the Obs4MIPS initiative. Metadata standards and conventions, such as Climate and Forecast, and indication of the dataset “maturity” will be further developed. Similarly, WCRP will continue wide communication on all aspects of reanalysis activities to create a knowledge base for all users of reanalyses and facilitate further development and greater use of reanalysis products beyond the current highly specialized group of users (http://reanalysis.org). This work will be coordinated with CSIS and rely on the capabilities, functionalities, and the data standards provided by the WMO Information System (WIS).

Based on the outcomes of the predictability studies, requirements for advances in ocean observations, especially in the Polar Regions, will be promoted. Research will intensify on data assimilation for ocean temperature, salinity, and dynamic topography in all oceans including deeper layers than currently accessible to the Argo program. New satellite sensors will be used for this purpose. This will enable issue of novel ocean data syntheses and production of a range of oceanographic predictions including sea-ice prediction in Polar Regions and marginal seas with sea-ice cover. Ocean biogeochemical and ecosystem observing systems will be promoted as well.

As indicated in the OBS Annex, an integrated global greenhouse gas (GHG) information system, including enhancing regional scale chemical measurements, will be developed. It will provide regular regionally specific information related to the state of greenhouse gas-driven warming, the rate of GHG increase, and projections for future decades, during which adaptation measures will take place and upon which the success of adaptation measures will depend. Necessary coordination among WMO, GCOS, GEO-Carbon and regional projects such as ICOS in Europe, Carbon North America (CarboNA), and other similar efforts and existing networks around the world will be ensured.

APPENDIX 4

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APPENDIX 5

Used acronyms

APN	Asia-Pacific Network for Global Change Research
CarboNA	Carbon North America
CAPRA	Disaster Risk Information Platform
CAS	WMO Commission for Atmospheric Sciences
CBS	WMO Commission for Basic Systems
CCAFS	Research Program on Climate Change, Agriculture and Food Security
CCl	WMO Commission or Climatology
CCMVal	Chemistry-Climate Model Validation
CD	Capacity Development
CDR	Climate Data Record
CGIAR	Consultative Group on International Agricultural Research
CHFP	Climate-system Historical Forecast Project
CHy	WMO Commission for Hydrology
CLIPS	WCP Climate Information and Prediction Services
CliC	Climate and Cryosphere Project
CLIVAR	Climate Variability and Predictability Project
CMIP5	Coupled Model Intercomparison Project, Phase 5
CMIP	Coupled Model Intercomparison Project
CORDEX	WCRP Coordinated Regional Downscaling Experiment
CSIS	Climate Services Information System
CTB	Climate Test Bed
DRR	Disaster Risk Reduction
EC	Executive Council
ECMWF	European Centre for Medium-range Weather Forecasts
ECPORS	WMO EC Team of Experts on Polar Observations, Research and Services
ECRTT	WMO Executive Council Research Task Team
ESG	Earth System Grid
ESSP	Earth System Science Partnership
EWS	Early Warning System
FAO	Food and Agriculture Organization
FCDR	Fundamental Climate Data Record
FEWS NET	Famine Early Warning Systems Network of USAID
GAW	Global Atmosphere Watch
GIEWS	FAO Global Information and Early Warning System on food and agriculture
GCOS	Global Climate Observing System
GCW	Global Cryosphere Watch
GDPFS	Global Data-processing and Forecasting System
GECHH	Global Environmental Change and Human Health
GEO	Group on Earth Observations
GEWEX	Global Energy and Water Cycle Experiment
GFCS	Global Framework for Climate Services
GHG	Greenhouse gas
GODAE	Global Ocean Data Assimilation Experiment
GOOS	Global Ocean Observing System
GPC	Global Producing Centres
GTN	Global Terrestrial Network
GTN-G	Global Terrestrial Network for Glaciers
GTN-H	Global Terrestrial Network for Hydrology

GTN-L	Global Terrestrial Network for Lake Level/Area
GTN-P	Global Terrestrial Network for Permafrost
GTN-R	Global Terrestrial Network for River Discharge
GTOS	Global Terrestrial Observing System
GWSP	Global Water System Project
HLT	High Level Taskforce
IAI	InterAmerican Institute for Global Change Research
IASC	International Arctic Science Committee
ICOS	Integrated Carbon Observation System
ICRC	International Committee of the Red Cross
ICSU	International Council for Science
IGAC	International Global Atmospheric Chemistry
IGBP	International Geosphere – Biosphere Programme
IGFA	International Group of Funding Agencies for Global Change Research
IHDP	International Human Dimension Programme on Global Environmental Change
IHP	International Hydrological Programme of UNESCO
IOC	Intergovernmental Oceanographic Commission of UNESCO
IRDR	Integrated Research on Disaster Risk
IRI	International Research Institute for Climate and Society
IT	Information Technology
JCOMM	Joint WMO/IOC Technical Commission for Oceanography and Marine Meteorology
MALOF	Malaria Outlook Forum
MERIT	Meningitis Environmental Risk Information Technologies
METAFOR	Common Metadata for Climate Modelling Digital Repositories
M&E	Monitoring and Evaluation
NCAR	(US) National Center for Atmospheric Research
NCC	National Climate Centre
NCS	National Climate Services
NGO	Non-governmental organization
NMHS	National Meteorological and Hydrological Service
NOAA	(U.S) National Oceanic and Atmospheric Administration
OBS	Observations and Monitoring
Obs4MIPS	Observations for Model intercomparisons initiative (NASA)
PPP	WWRP Polar Prediction Project
PROVIA	Programme of Research on Climate Change Vulnerability, Impacts and Adaptation
RCOF	Regional Climate Outlook Forum
RCC	Regional Climate Centre
RMP	Research, Modelling, and Prediction
S2S	Subseasonal to Seasonal Initiative
SERA	WWRP Working Group on Societal and Economic Research Applications
SIDS	Small Island Developing State
SPARC	Stratospheric Processes And their Role in Climate Project
SST	Sea-surface temperature
START	Global Change System for Analysis, Research, and Training
THORPEX	The Observing System Research and Predictability Experiment
TIGGE	THORPEX Interactive Grand Global Ensemble
UIP	User Interface Platform
UN	United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
UNFCCC	United Nations Framework Convention on Climate Change

UV	Ultra-violet
VIA	Vulnerability, Impact, and Adaptation
WCP	World Climate Programme
WCRP	World Climate Research Programme
WCSP	World Climate Services Programme
WFP	World Food Programme
WGRC	WCRP Working Group on Regional Climate
WIGOS	WMO Integrated Global Observing System
WIS	WMO Information System
WHO	World Health Organization
WMO	World Meteorological Organization
WWRP	WMO World Weather Research Programme
WWW	World Weather Watch
YOTC	Year of Tropical Convection

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