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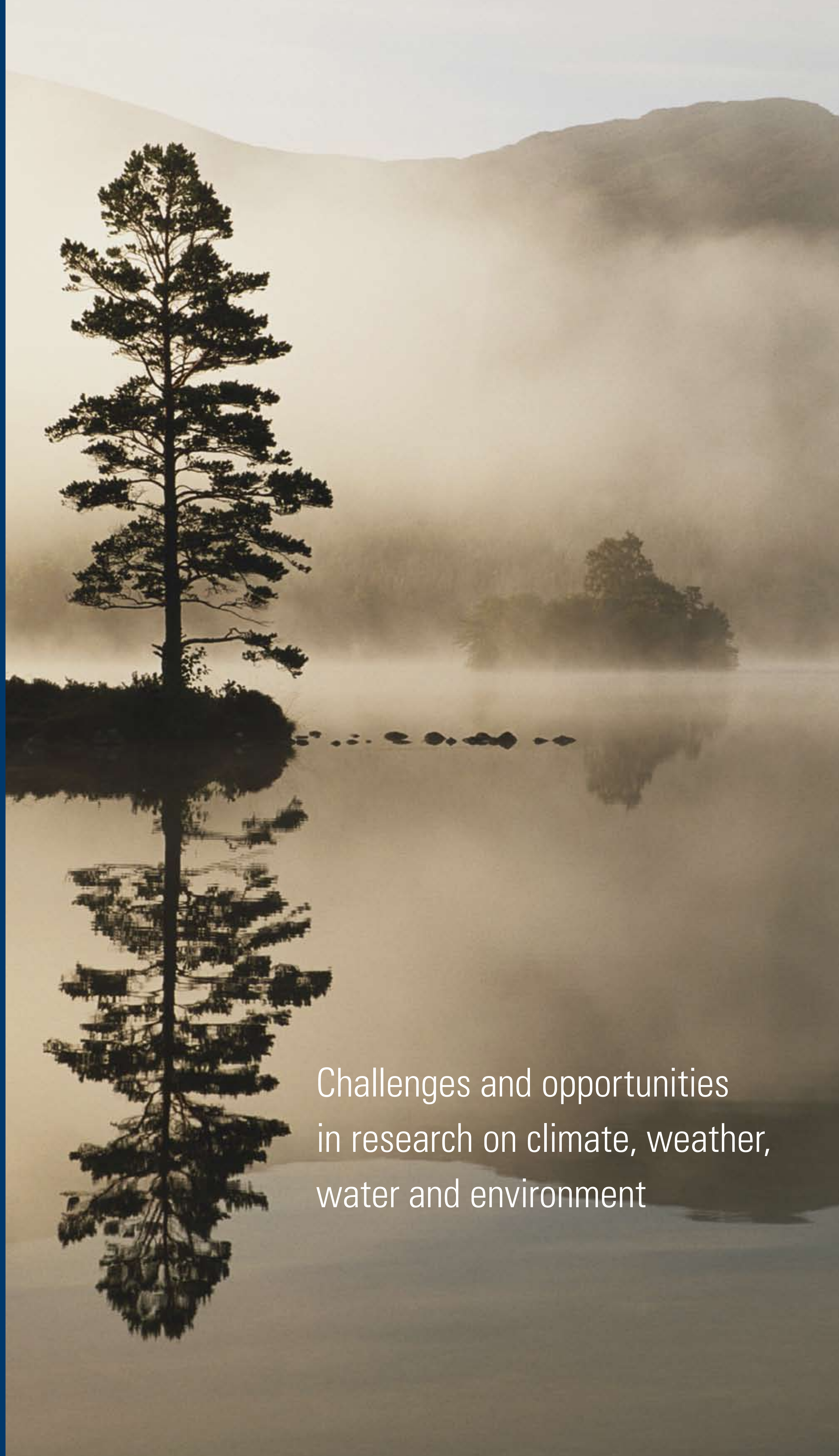

Challenges and opportunities in research on climate, weather, water and environment

WORLD METEOROLOGICAL ORGANIZATION

Challenges and opportunities in research to enable improved products and new services in climate, weather, water and environment

A Report of the Executive Council Task Team (EC-RTT)

on

Research Aspects of an Enhanced Climate, Weather, Water and Environmental Prediction Framework

WMO/TD-No. 1496

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FOREWORD

For over a century, the World Meteorological Organization (WMO) and its predecessor the International Meteorological Organization (IMO) have provided leadership in the international coordination of scientific assessments, research and development, in particular concerning societal issues related to weather, climate, water and the environment. In 2007, the Fifteenth World Meteorological Congress called for a new approach to WMO operations by introducing a results-based management system and by requesting appropriate organizational changes to implement it effectively. This led to a reorganization of the WMO Secretariat on 1 January 2008 that involved restructuring of some technical departments.

In June 2008, the 60th session of the WMO Executive Council decided to identify seamless weather, climate, water and environmental prediction and services as a major focus in WMO activities. It endorsed the concept of an enhanced climate, weather, water and environmental research initiative within the broader framework of linking research, observations, operational prediction and service delivery, and established to this effect a Research Task Team chaired by Prof. John Mitchell, with the mandate described in Annex I of this report. The Executive Council also requested a report to be prepared and submitted for its consideration at its 61st session in June 2009.

This report and its recommendations were reviewed and endorsed by the 61st session of the Executive Council, which also decided that a prioritization scheme would contribute to focus activities, collaboration and eventual funding decisions. The Council further suggested that a follow-up process be established to: (1) support this prioritization process; and (2) monitor and measure progress in the implementation of the different recommendations.

WMO is now in the process of reformulating its Strategic Plan and priorities for the period 2012-2015 for consideration by the Sixteenth World Meteorological Congress, to be held in May 2011. The Plan will address improved services related to climate, weather, water, oceans and the environment and in particular the reduction of the risks related to natural disasters. I believe the recommendations in this report and the follow-up prioritization process are quite timely and will contribute to improve existing services and to implement new climate, weather, water and environmental services that are part of the WMO mandate, while serving the needs of WMO Members, including those of the National Meteorological and Hydrological Services (NMHSs) and their national research and service delivery partners. On behalf of WMO, I therefore wish to thank the Task Team and expert reviewers who kindly volunteered their time and efforts to perform this analysis.

Jarraud

(M. Jarraud)
Secretary-General

EXECUTIVE SUMMARY

Advances in the geophysical sciences and computing have led to a number of opportunities for WMO. First, the distinction across timescales from weather to climate prediction is becoming more blurred; second the incorporation of chemical, hydrological and biological processes into weather and climate models will allow a much broader range of environmental parameters to be forecast, including air quality, flooding, sand and dust storms, changes in vegetation etc. Third, many of the applications and impacts of weather and climate share a common underlying scientific basis.

These and other considerations led to EC-LX forming the Task Team on the research aspects of an enhanced climate, weather, water and environmental prediction framework. The mandate of the Team was to "strengthen and promote the linkages between climate, weather, water and environmental research to enable NMHS and other related services to provide improved services in the next decade. A summary of the three General Recommendations and associated Specific Recommendations is given below.

General Recommendation 1 (Section 2.2)
Coordinating and Accelerating Prediction Research: 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, accelerate the development, validation and use of prediction models through Specific Recommendations:

Bridging Inter-disciplinary Gaps in Prediction Research (Section 2.2.1)

Gaps between weather, sub-seasonal and seasonal predictions

1.1 Support collaborative climate/weather efforts on the use of Numerical Weather Prediction (NWP) experiments with coupled ocean-atmosphere models for exploring error growth in simulations of modes of organized convection and of interactions between tropical and extratropical by establishing collaboration between the TIGGE and CHFP projects (Brunet et al., 2007).

1.2 Accelerate efforts to improve traditional parameterizations of atmospheric processes such as convection, boundary layer, clouds, precipitation and atmospheric chemistry in climate and weather models.

1.3 Significantly enhance the computing capacity of the world's existing weather and climate research centres in order to accelerate prediction research (Shapiro et al. 2009, Shukla et al, 2009): the World Modelling Summit recommended computing systems at least a thousand times more powerful than those currently available to strive towards more accurate representation of critical small scale processes.

Decadal and multi decadal predictions as an initial value problem as well as a boundary forced problem

1.4 Subject IPCC-class models to data assimilation and the prediction of short-term weather and ENSO-type variations like in the Transpose AMIP Integrations (Williamson et al. 2008, Brunet et al., 2007)

Interactively coupled weather and hydrology prediction systems

1.5 Follow the recommendations of HYMEX, HEPEX and the second phase of AMMA to develop stronger links with these efforts and develop a general strategic vision to be developed to address the broader issue of collaboration between weather and hydrological research, including coupled meteorology/hydrology models for weather and climate prediction.

Application of air pollution predictions and analysis to problems of human health, ecosystems, climate change and the cycling of greenhouse gases

1.6 WMO provide advice, coordination of projects and capacity building in air quality forecasting globally.

1.7 WMO coordinate globally the technical work on the very long range transport of air pollution between regions and continents.

1.8 WMO take the lead in coordinating globally the technical analysis of how climate variability and change and air pollution interact both ways on a regional basis.

1.9 WMO play a lead role globally in the analysis of carbon sequestration and reactive nitrogen in view of how the quality of the water supply is affected by reactive nitrogen runoff, and how the reactive nitrogen cycle interferes with air pollution, the carbon cycle and climate change.

Incorporating aerosols and ozone interactively in operational analysis and prediction systems

1.10 Provide global coordination of projects to incorporate aerosols and ozone as radiatively and cloud/precipitation active constituents in operational analysis and prediction systems, and thereby, enhance predictive capability for societal use.

Implementing coordination mechanisms to optimize global and integrated observing systems (Section 2.2.2)

1.11 WMO promote development of observation systems and sensitivity experiments based on the most advanced operational NWP data assimilation systems.

1.12 Build capacity for integrated observations globally through WIGOS working in collaboration with WMO research programmes.

1.13 WMO Members extend distribution and access to observations for research and associated application development through the new WMO Information System (WIS).

1.14 There is an urgent need to initiate a few pilot research projects in the area of coupled-model data assimilation.

1.15 Accelerate the utilization of data assimilation techniques for climate model development.

Promoting Earth-System Reanalysis Projects (Section 2.2.3)

1.16 Take an interdisciplinary weather-climate approach on data-assimilation methodologies in future reanalysis projects

Improving and Innovating Weather, Climate and Environmental Products (Section 2.2.4)

1.17 Encourage liaison programmes such as the project Weather And Society*Integrated Studies (WAS*IS).

1.18 Encourage linkages between weather, climate and hydrometeorological service providers

1.19 WMO promote hydrological forecast research demonstration projects.

1.20 WMO support research as an essential component of end-to-end systems for weather, climate, water and environmental services such as the Global Framework for Climate Services that is an expected major outcome of WCC-3.

General Recommendation 2 (Section 3.3). Linking Research, Operation and Service Delivery: Develop closer linkages between research, operations and users through Forecast Demonstration Projects (FDPs) that accelerate technology transfer, through Specific Recommendations:

2.1 Increase the two-way interactions between research, users and operations that begin early in the defining of a research problem and continue through the research process. Such interactions will help focus basic and applied research on user needs and make a more rapid transfer of research to operations and end users. Operations and users could also increase the efficiency of this process by providing data, in real-time when possible, to meet research needs and facilitate the testing of new research approaches.

2.2 WMO should play a major role in identifying and facilitating mechanisms to implement the two-way interactions between research, users and operations.

2.3 Increase the involvement of scientists and users from developing countries in FDPs, particularly from NMHSs and their national partners in the research activities of the WMO.

2.4 Focus on distilling research advances into products, especially at the regional level, that can be readily made available and, through training activities, enable their use by those needing information (some research advances, such as ensemble prediction, have great utility but with interaction with users are difficult to distil into user-friendly information).

General Recommendation 3 (Section 4.3). The Role of WMO Commissions and the Visibility of Science: Implement a process to review and rationalize the roles and mandates of the Commissions, and to improve their effectiveness in enhancing WMO Member capabilities in research, observations, prediction and services, through Specific Recommendations:

3.1 EC and the Secretariat work closely with the PTC and the Research Department so that any necessary modification to the Commissions' structures and their linkages with the organizational structure is effected to maximize the impact of the proposed paradigm change in prediction research. Simplification and clarity of the roles of the Commissions and the Departments should be the guiding principles of any final decisions.

3.2 Develop a process to harmonize research input, and cross-coordination between different Commissions.

3.3 Set up a mechanism connected with budgetary decision making, whereby cross cutting project proposals developed jointly by at least two Commissions, and one Regional Association could be reviewed and prioritized by the presidents of technical commissions, for consideration by EC and the Secretariat for eventual implementation.

3.4 Recognizing that WMO is fundamentally a science and technology based Organization, establish efficient mechanisms to ensure that optimal science input is provided to WMO decision making processes and bodies (Cg, EC and Secretariat).

3.5 Reaffirm and support international WMO science and technology leadership in its areas of competence, by nurturing a culture of excellence, relevance and impact, whilst recognizing that the increasing complexity of atmospheric related environmental issues necessitates an increasingly partnership approach.

Given the breadth of the remit of the Task Team and limited time available to report, we have not made a comprehensive list of specific recommendations. Instead, we have focussed on making some specific recommendations which can be implemented quickly, if not immediately. Some of the other recommendations may take some time to develop and implement, particularly where they require people from different working cultures (e.g. research and services) to work much more closely together. This will be the case where, for example, research and operational departments are on different geographical sites, or where research on the various components (for example weather, climate, hydrology, air quality) is carried out in different institutions. However, this should not be a reason to delay action, indeed it is quite the reverse - the sooner WMO initiates the changes, the sooner the potential benefits will be realised by the NMHSs and their users.

1. INTRODUCTION

1.1 WMO's Role in Prediction Research and Related Services

The World Meteorological Organization (WMO) and its parent the International Meteorological Organization (IMO) have been coordinating scientific and technical activities among more than 180 nations around the world to serve the needs of these nations in saving lives, protecting properties and supporting economic development around the world for more than 135 years.

Most WMO sponsored or co-sponsored programmes and organizations contribute in a meaningful way to the development of prediction research, stretching across weather, climate, water and air quality applications of today; prediction research that has the potential to provide a full suite of environmental predictions of tomorrow. Whilst the breadth of environmental prediction extends beyond the remit of WMO, it is the atmosphere that provides the fastest and most fundamental linking mechanisms across the coupled physical-biological-chemical components of the Earth system. As a result, WMO is in a unique position to lead initiatives that enhance our understanding and ability to predict or project future states of the Earth system in service to global society.

The Need for a Major Change in the Paradigm for Prediction Research

The last three decades have seen impressive successes in Numerical Weather Prediction, especially in forecasting extreme events, predicting weather elements and extending the range of predictability. Over the same period, climate modelling has progressed from atmospheric models with a simple representation of the oceans to fully coupled Earth system models complete with biological and chemical processes. At intermediate timescales, many research and operational centres around the world now produce numerically-based seasonal predictions using observed initial conditions that extend beyond the period of conventional deterministic predictability. In addition, the range of variables in weather prediction has extended from traditional meteorological variables to wave and swell forecasts, air quality, visibility and, in the case of seasonal prediction, crop production and other aspects of the environment more traditionally associated with the prediction of climate change and its impacts.

The traditional boundaries between weather forecasting, seasonal forecasting and climate prediction are fast disappearing since progress made in one area can help to accelerate improvements in the other. For example, improvements in the modelling of soil moisture made in climate models can lead to improved forecasting of showers over land in summer, and data assimilation, which has been restricted to the realm of weather prediction, is now becoming a requirement of coupled models used for longer term predictions through seasons to decades (Brunet et al, 2007)

As the scope of numerical weather prediction and climate prediction broadens and overlaps, the fact that both involve modelling the same system becomes much more relevant, as many of the processes are common to all time scales. There is much benefit to be gained from a more integrated or "seamless" approach. Unifying modelling across all timescales will lead to efficiencies in model development and improvement by sharing and implementing lessons learnt by the different communities, such as for example, enabling climate models to benefit from what is learnt from data assimilation in numerical weather prediction models, enabling weather prediction models to learn from the coupling of climate models with the oceans, and sharing validation and benchmarking of key common processes. The inclusion of atmospheric chemistry will improve not only prediction of air quality, but also weather prediction and predictions of climate change. Predictions of flood events will require better representation of hydrological processes at local, regional, continental and global scales, which are also important for predictions of climate change. In order to adapt to climate change, much improved simulation of regional climate and the modes of climate variability (El Niño Southern Oscillation (ENSO), North Atlantic Oscillation (NAO) etc.) are needed, and much of this is already being tested in seasonal predictions (Shapiro et al, 2007). Users of forecasts and predictions prefer integrated sets of products from as few sources as possible with accuracy estimates (expressed probabilistically) that are simple to understand and to use and in a format they can understand and use.

Future development of forecasts and predictions to bring together different timescales and aspects of the Earth system will require multidisciplinary research teams in increasingly international networks. The extraordinary complexity of the modelling tools that are needed over the next decades, as well as their rapidly increasing needs for observations and supercomputing power, is forcing a complete re-examination of the prediction process, with the view of containing or at the very least, optimizing the costs of production (e.g. World Modelling Summit, 2009, Shukla et al, 2009).

These challenges and opportunities have led to the publication of several papers in the open literature calling for close cooperation between the existing weather and climate research and development communities. This has led to the formation of this Task Team by the WMO Sixtieth Executive Council with the mandate to identify and recommend what actions WMO must take to support this unifying effort towards accelerating greater progress in the future (Annex I).

A Time-Scale Based Perspective on Weather, Climate, Water and Environmental Prediction

Developing a unified approach to weather, climate, water and environmental prediction requires a broadened Earth System perspective beyond the traditional geosciences and environmental science disciplines. The development of climate prediction and ultimately environmental prediction is not simply a trivial extension of numerical weather prediction. As such, this may have rather important personnel and organizational implications when implementing a unified approach to prediction. For example, as delineated in Annex III the operational numerical weather prediction community supported by the Commission for Basic Systems has specific time scale definitions for the range from nowcasting to climate prediction. Thus for instance, in CBS terminology thirty days to two years is long range forecasting and anything longer is climate forecasting. In contrast, the climate and Earth system prediction community use a different terminology. It is useful to view various characteristics of prediction research and operations according to the time-scale of a forecast or prediction product. (Figure 1)

Figure 1 schematically portrays the time scale dependence of three characteristics of weather, climate, water and environmental prediction:

(a) The mix of research and operations entailed in any particular prediction product, be it nowcasts, seasonal predictions or decadal to century predictions;

(b) The relative roles of weather, climate and Earth System science community in prediction research; and

(c) The relative role of prediction delivery systems from week to two week forecast to seasonal prediction to century projections.

The WMO Data Processing Forecast System (DPFS) that exists world wide and is supported by the Commission for Basic Systems has a well established network that is already delivering seasonal forecasts operationally through major global and regional centres while WMO and its climate partners are considering a climate prediction services system (represented in italics in Fig.1 to emphasize that it is tentative). Note that the weather and climate prediction research community overlap strongly in the monthly to inter-annual prediction range and both benefit from reanalysis.

Collaboration among many scientific disciplines is required to support weather, climate, water and environmental prediction across all time scales. Such efforts span disciplines of meteorology, atmospheric chemistry, hydrology, oceanography, marine and terrestrial ecosystems, to just name a few.

While atmospheric nowcasting and very short-range weather forecasting are primarily initial value problems, extension to short-, medium-, and extended-range weather forecasting begins to bring in the coupling with Earth system components such as atmosphere/land surface processes (soil moisture feedback, soil dust aerosols) and atmosphere/ocean coupling (heat exchange, seas salt aerosols). Long-range forecasting through seasonal to inter-annual prediction involves atmosphere-ocean coupling with the initial conditions of the memory inherent in the upper ocean leading to longer lead-time predictive skill. Decadal climate prediction is determined by both initial values and boundary value forcing. On these times scales, deeper oceanic information and changes to radiative forcing from greenhouse gases and aerosols play determinant roles. When considering inter-decadal to centennial climate projections, not only do future concentrations of greenhouse gases, aerosols and ozone need to be taken into account, but also changes in land cover/dynamic vegetation and carbon sequestration governed by marine ecosystems. In addition, regionally specific predictive information will be required across these time scales for environmental prediction such as air quality and water quality.

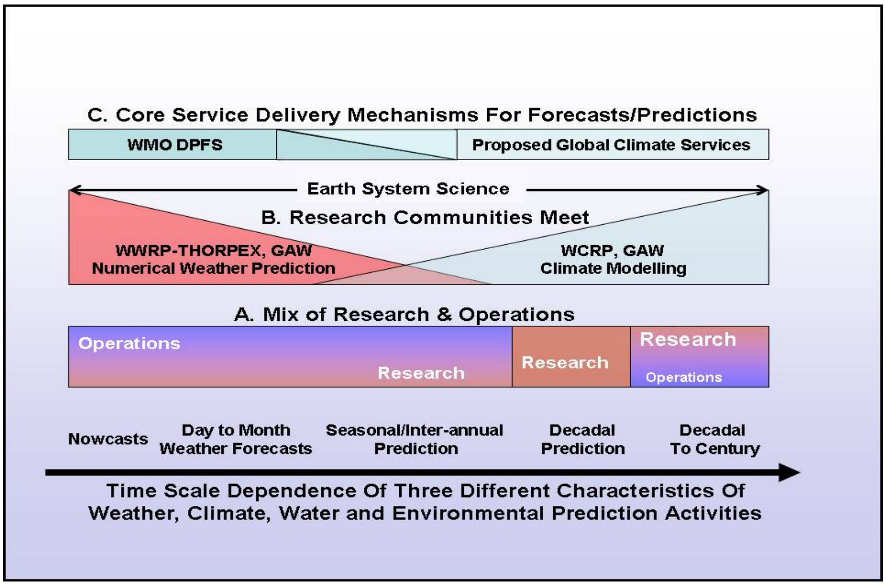


Figure 1- Time scale dependence of various aspects of weather, climate, water and environmental prediction

With this brief background and the context that describes a need for accelerating the prediction research and establishing efficient mechanisms for both coordinating such a research and delivering the research results in a timely manner to service providing organization, the following chapters will focus on the opportunities, rationale, and recommendations for this purpose. In the next chapter (2) we consider the coordination and acceleration of research. In chapter 3, we consider ways of improving the links between research, operations and users. Chapter 4 addresses opportunities within WMO to facilitate the recommendations made in the earlier chapters. A summary of all the recommendations and a few cautionary remarks are given in the executive summary.

2. COORDINATING AND ACCELERATING PREDICTION RESEARCH

2.1 Rationale

There is a growing societal demand for environmental predictions that include a broad range of space and time scales, and that include a complete spectrum of physical, chemical and biological processes (e.g., meteorology, oceanography, hydrology, biogeochemistry, ecosystems, air-quality, fisheries, costal zone science…). Meeting this demand necessitates a unified approach that will challenge the traditional boundaries of weather, climate, water and environmental science in terms of the interactions of the bio-geophysical systems, the supporting computational infrastructure and science, and how these forecasts are communicated to society.

There are many potential opportunities and benefits in meeting this growing demand for unified or seamless predictions of weather, climate, water and environment: the five listed below are by no means an exhaustive list, but do provide relevant examples:

(a) First, there is the opportunity for increased efficiency. For example, in any one country there may be a number of disparate efforts in air-quality modelling and prediction that separately consider different space and time scales. A unifying strategy provides the opportunity to consolidate these disparate efforts into a single prediction system that covers the spectrum of space and time scales;

(b) Second, a unified modelling and prediction strategy affords the opportunity to tap into potential predictability due to interactions among the components of the prediction system. For example, there is potential predictability in how air-quality impacts local meteorology, which can be mined through prediction systems that include the relevant interactions;

(c) Third, there are benefits to both the weather and climate communities through improved data assimilation and reanalyses;

(d) Fourth, the water cycle is a key process for the accuracy of forecasts or scenarios on both weather and climate time scales; at the same time, a side benefit is improved watershed simulations, as well as floods, droughts and river flow forecasts;

(e) Fifth, there is the benefit of cross-fertilization of ideas and enhanced interdisciplinary approaches associated with this unified approach.

One of the consequences of a unified prediction approach is increasing demand on model space and time resolution. In our example of air-quality, high resolution meteorological predictions are required to forecast the regional details. Conversely, to capture how the regional details of air-quality impacts meteorology requires increased resolution and complexity. Put simply, the demand for significant increases in model resolution goes beyond resolution for resolution sake – the scientific needs of environmental prediction drive the demand for increased model complexity and model resolution.

The remainder of this Section has two distinct goals: (i) identifying how this unifying approach to prediction has the potential to foster the transition of prediction research to operations and to the end-users; and (ii) highlighting how the scientific interactions across disciplinary boundaries and space and time scales could potentially lead to interactions or synergies that improve prediction research directly. In order to meet these goals, a specific overarching unified approach to modelling and prediction is necessary.

2.2 Recommendations

General Recommendation 1.
Coordinating and Accelerating Prediction Research: 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, accelerate the development, validation and use of prediction models through Specific Recommendations

2.2.1 Coordinating and Accelerating Weather, Climate, Coupled Chemistry and Hydrology Model Development, Validation and Use

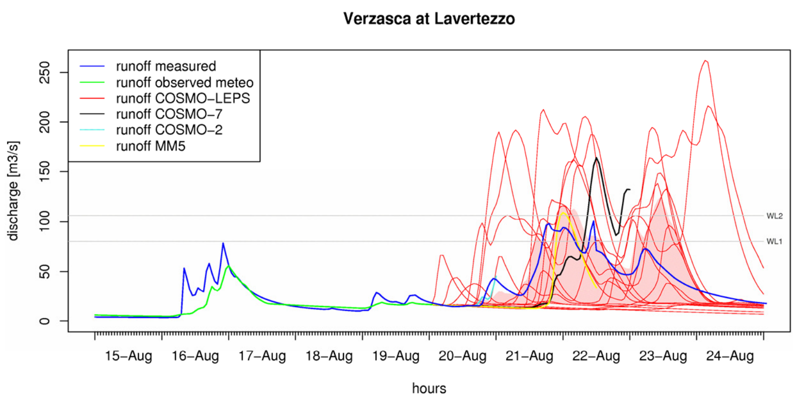
Bridging weather, sub-seasonal and seasonal predictions

The task team identified a need for close collaboration in current climate/weather research related to the use of Numerical Weather Prediction (NWP) experiments that explore the error growth in simulations of modes of organized convection (for example the Madden Julian Oscillation (MJO)) and the interactions between tropical and extratropical weather and climate systems, a common barrier to improved weather and climate prediction. This will require metrics/description of the daily, sub-seasonal, and seasonal characteristics of organized convection that encapsulate our knowledge of these interactions, and permit model/forecast validation with the aim of guiding future research.

Bringing Weather and Hydrology Together To Improve Flood Prediction

Demonstration of Probabilistic Hydrological and Atmospheric Simulation of Flood Events in the Alpine region (MAP D-Phase)

The main objective of this Forecast Demonstration Project of the Mesoscale Alpine Programme (MAP, a WWRP RDP), was to show the benefits in forecasting heavy precipitation and related (flash) flood events, as gained from the improved understanding, refined atmospheric and hydrological modelling, and advanced technological abilities acquired through research work during the Mesoscale Alpine Programme.
An end-to-end forecasting system for Alpine flood events over many river basins was implemented during the Summer and Autumn of 2007, to demonstrate state-of-the-art forecasting of high impact precipitation. This system included probabilistic forecasting based on ensemble prediction systems with a lead time of a few days, followed by short-range forecasts based on high-resolution deterministic models, and was completed with real-time nowcasting tools. Many of the above systems were coupled to hydrological models in real-time thus providing runoff-forecasts for over 40 catchments all over the Alps. Throughout the forecasting chain, warnings were issued and re-evaluated as a potential flooding event was approaching, allowing forecasters and end users to alert and make decisions in due time. 45 civil protection and flood warning agencies participated in the project. The project was evaluated very positively by these end-users. It will serve as a prototype for an operational flood warning system in Switzerland.



Hydrological forecast, starting on 20 August 2007, for the Verzasca Basin in southern Switzerland using different atmospheric models to drive the hydrological forecast. The 16 ensemble members of COSMO-LEPS (red) are shown with the corresponding interquartile range (area of 'middle 50% probability'; shaded). Atmospheric forcing by 3 deterministic models (COSMO-7: black; COSMO-2: turquoise; MM5: yellow) is additionally shown. Observed runoff: blue line and runoff modelled with observations only: green line.

The D-PHASE Visualization Platform was critical to the success of the project as it allowed forecasters and end-users easy access to these data sets through a single web portal. The platform contained an unprecedented volume of information as MAP D-PHASE included 7 ensemble and 23 deterministic atmospheric models, 7 coupled hydrological models and various nowcasting tools. An appealing aspect of the platform was that fact that all warnings displayed in the visualization system were based on the same thresholds and procedures. MAP D-PHASE also demonstrated a variety of ways to communicate uncertainty information to end-users, such as the figure above, where the observed runoff is well within the shaded area indicating the forecast of the “middle 50% probability” of occurrence within the ensemble forecast.

A resolution in the range of 1km is ultimately required to adequately represent convection processes but even with a coarser resolution (~3km) basic properties of convective cloud systems and their effects on larger scale phenomena in the tropics can be captured (Matsuno, 2008). An ongoing international research project on the Year of Tropical Convection (YOTC) is being conducted jointly by the WWRP-THORPEX and WCRP Programmes (see box). Present computer capacity precludes cloud-resolving representations of moist convection in global sub-seasonal-to-seasonal deterministic prediction models and Ensemble Prediction Systems (EPSs). It is therefore important to accelerate efforts to improve traditional convective parameterizations. We can also investigate technological advances like variable model resolution across the forecast range that offers a possible practical solution for seamless forecast systems (Buizza et al., 2006).

In the longer term, the World Climate Modelling Summit advocated the establishment of one or more multi-national centres with a corresponding thousand fold increase in current computing capacity (World Modelling Summit, 2009, Shukla et al., 2009). This would permit scientists to move towards the kilometre-scale modelling of the climate system which is crucial to more reliable prediction of the change in convective precipitation especially in the Tropics.

Some centres are already promoting innovation and computer-wise efficiencies using a unified approach to modelling on a wide range of temporal and spatial scales (Côté et al., 1993, Cullen, 1993, Martin et al. 2000). This will speed up the transfer of advanced knowledge and predictive skill of organized convection into improvements for operational NWP and climate models through links with key groups within GEWEX/CLIVAR/THORPEX, as well as WGNE and operational prediction centres.

There is a clear impact of the atmospheric composition on the systematic errors of NWP as well as climate models (Rodwell, 2005). Accurate trends in greenhouse gases and aerosols are now considered as essential elements of seasonal forecasting systems (Liniger et al., 2007). Also, due to volcanic emissions there is a large inter-annual variability of the aerosol load of the stratosphere. There is growing evidence that this is impacting the climate fluctuations in several regions of the globe. There is a need to account for this variability when calibrating seasonal forecast systems.

A central science issue is the development and use of ensemble-based modelling in order to improve probabilistic estimates of the likelihood of high-impact climate/weather events. As an example it now appears possible to predict the frequency of tropical storms for the upcoming season with multi-model ensemble systems (Vitard et al., 2007; Graham et al., 2008; Rodwell 2006). Because of the relatively small scale of many events, there will be an ongoing need to improve model resolution and develop alternative downscaling techniques (e.g. regional climate models), especially for specific user-applications such as for hydrology and coastal zone eco-systems (e.g. Chesapeake Bay).

Both the WWRP THORPEX Integrated Global Grand Ensemble (TIGGE) (Worley et al. 2008) and WCRP CLIVAR Climate-system Historical Forecast Project (CHFP) communities are planning multi-model multi-institutional numerical experiments using state-of-the-art models and computing systems, which generate large data sets that need to be shared. The sharing of sub-seasonal to seasonal prediction EPS datasets, from both retrospective forecasts and near real-time forecasts, requires a common framework for comparison and diagnostic activities to bridge the TIGGE and the CHFP research communities. In particular, a limited number of data archive centres need to be identified to support the scientific end user communities. Note that TIGGE is already providing such support to the participating centres for Multi-Model Ensemble Prediction Systems (MEPS), but limited to two-week forecasts. The requirements for both EPS methods and greatly increased spatial resolution imply an unprecedented need for enhanced computational power and data storage (Brunet et al., 2007, Shukla et al., 2009, Shapiro et al., 2007).

Specific Recommendation 1.1
Support collaborative climate/weather efforts on the use of Numerical Weather Prediction (NWP) experiments with coupled ocean-atmosphere models for exploring error growth in simulations of modes of organized convection and of interactions between tropical and extratropical by establishing collaboration between the TIGGE and CHFP projects.

Specific Recommendation 1.2
Accelerate efforts to improve traditional parameterizations of atmospheric processes such as convection, boundary layer, clouds, precipitation and atmospheric chemistry in climate and weather models.

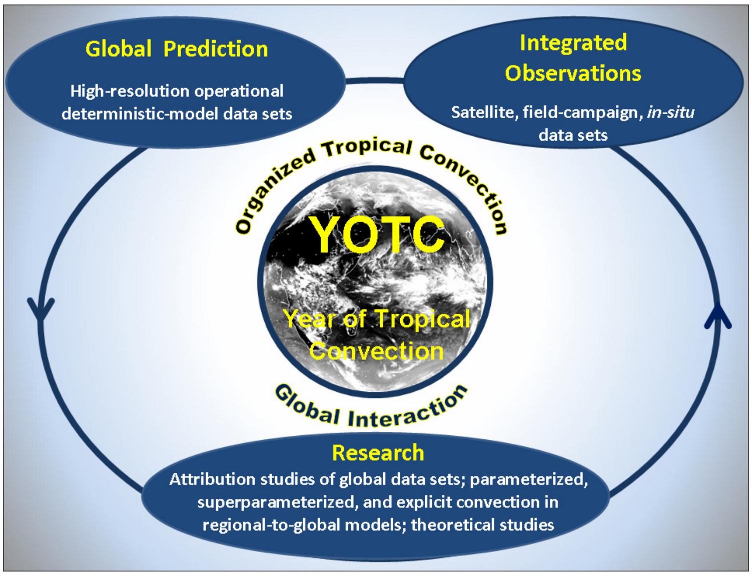
Specific Recommendation 1.3
Significantly enhance the computing capacity of the world's existing weather and climate research centres in order to accelerate prediction research (Shapiro et al. 2007, Shukla et al, 2009): the World Modelling Summit recommended computing systems at least a thousand times more powerful than those currently available to strive towards more accurate representation of critical small scale processes.

Decadal and multi decadal predictions as an initial value problem as well as a boundary forced problem

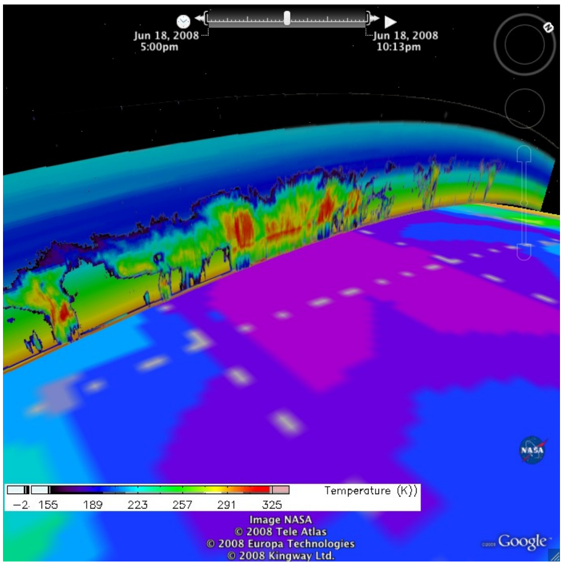
The seamless prediction framework requires that decadal and multi-decadal predictions should move towards consideration of climate change as an initial value problem in addition to being a boundary forcing problem. There is compelling evidence from several modelling centres that the systematic errors of models at short-range (few days) and long-range (years) are to some extent similar (Figure 2, based on Senior et al, 2009). Therefore working to improve the short-range systematic errors of models is also beneficial for climate prediction. The testing of "climate modelling in a deterministic prediction mode" needs to be carried out more widely (Morel, 2007; Rodwell and Palmer, 2007). This will ultimately require that the state of the ocean-atmosphere-land-cryosphere should be correctly initialized.

Bringing Weather and Climate Research Together to Solve Problems in Tropical Prediction

Significant societal benefits could be realized from coordinated research to reduce common barriers blocking the path to improving both weather and climate prediction. One such barrier to weather and climate prediction is the representation of tropical convection in numerical models of weather, climate and the environment. The Year of Tropical Convection (YOTC) is the first large-scale international collaboration between WCRP and WWRP via the THORPEX programme. YOTC is designed to be a focal point for studies aimed at better understanding and predicting the multi-scale organization of tropical convection and its interaction with the global circulation. This focus is timely given the recent advances in operational modelling and data assimilation, in high resolution, cloud-system modelling, and in the wealth of new observing capabilities including satellite remote sensing and in-situ systems in the tropics. The implementation of YOTC is ongoing in 2009. As part of the project, the ECMWF has created and made available a high-resolution (T799; ~25km) archive of global analysis and 10-day forecasts that includes, for the first time, wide-spread dissemination of those model variables central to understanding the parameterization of tropical convection. Satellite agencies are providing high resolution observations of convection and clouds, many of which have yet to be exploited to address tropical convection. These combined model diagnostic and observational data sets will provide modellers with a unique data set to use high resolution models with grid spacing of order 1km or less to test and improve parameterizations of convection, clouds and precipitation formation.



(Right: NASA Giovanni A-Train Data Interface illustrating CloudSat profiles of reflectivity overlaid on a cloud-top temperature map from MODIS)



An expected outcome of YOTC is improved accuracy of climate and weather predictions, not only in the tropics, but also at higher latitudes where the large-scale responses to organized tropical convection often occur. YOTC takes advantage of recent advances in observational capability, such as remote sensing from space that has increasingly revealed detailed information on the vertical structure of clouds and precipitation within tropics.

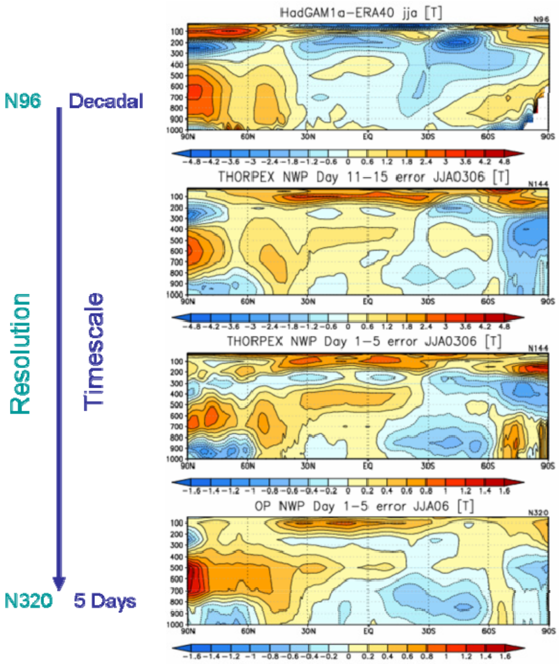


Figure 2 - Systematic zonally averaged temperature errors in the Met Office Unified Model. The top panel is from a climate run (multiseasonal mean, 150km resolution)) through THORPEX runs (next two panels showing the average 11-15 and 1 to 5 day errors respectively, 100km resolution) , and NWP (day 1-5 errors, 40km resolution). Some errors, for example, the excessive warming at 500mb in the northern extratropics, are apparent from the start of the weather forecast and persist on all timescales and hence reducing this error is likely to bring benefit at all time scales. Other errors, for example, the cooling at 200mb at 30S are not initially evident and develop with time. (Senior et al., 2008)

Specific Recommendation 1.4
Subject IPCC-class models to data assimilation and the prediction of short term weather and ENSO-type variations like in the Transpose AMIP Integrations (Williamson et al. 2008, Brunet et al., 2007).

Interactively coupled weather and hydrology prediction systems

Collaboration between the climate and hydrological research communities has been helped by the organizational structure of the WCRP primarily through the inclusion of GEWEX. No such formal link exists between the weather and hydrological research community, although the WWRP has had successful research collaborations with hydrological prediction and user communities that have led to new operational advances, as evidenced by the MAP D-PHASE project.

The increasing availability of rainfall predictions at catchment scale as the resolution of regional models increases, allowing direct coupling of meteorology and hydrology.

The scientific issues addressed include:

- How to formulate the coupling between ensemble systems used in hydrology and weather prediction;
- How hydrological forecasts can make use of cloud system resolving numerical weather prediction model products, and high resolution data assimilation in both disciplines.

The new directions in hydrological research and operational needs are leading to increases in collaboration between hydrological research programmes and the WWRP such as proposed by HYMEX, HEPEX and the second phase of AMMA and such steps should be accompanied by a strategic vision for establishing such linkages. (See first box in this section.)

Specific Recommendation 1.5
Follow the recommendations of HYMEX, HEPEX and the second phase of AMMA to develop stronger links with these efforts and develop a general strategic vision to address the broader issue of collaboration between weather and hydrological research, including coupled meteorology/hydrology models for weather and climate prediction.

Five air chemistry prediction issues stand out where WMO can make a significant contribution:

Application of air pollution predictions and analysis to problems of human health, ecosystems, climate change and the cycling of greenhouse gases

The forecasting of air pollution in urban areas is an important service in order to allow the population to take precautions on a daily basis and to identify policy measures to reduce emissions so that pollution target levels can be met. Changes in climate and changes in emissions are also likely to change air quality in the future.

WMO already enhances through the WMO-GAW GURME project the capabilities of NMHSs and national partners to provide air quality forecasting, illustrating the linkages between meteorology and air quality (http://www.wmo.int/pages/prog/arep/gaw/urban.html).

The challenge is to couple mesoscale meteorology and air pollution chemistry in a dynamic way in numerical weather prediction and climate models. Near-real-time delivery of environmental data is an important component of forecasting urban pollution. Reliable emission data requires working with environmental agencies. Both the near-real-time delivery of urban observations and the forecasting activity should be pursued at the international, national and local levels.

There is air pollution emission growth in the Far East; and in South America, while emissions in Europe and North America are levelling off or being reduced. The economy is globalized with important consequences for intercontinental transport of air pollution; aircraft emissions (ICAO); and shipping emissions (IMO). Changes in farmland practises and in physical climate give rise to more biomass burning and forest fires. Increasing attention is needed to the intercontinental transport of air pollution and its contribution to the pollution levels and ecosystem impacts in various regions (including Europe, the Arctic, marginal seas, etc.). Hindcast analysis and scenario calculations with dynamically coupled (global) numerical weather prediction and chemistry models are important to properly account for the dynamics of the relevant exchanges between the atmosphere and the land and ocean surfaces and ecosystems (see the assessment report from the EMEP Task Force on Hemispheric Transport of Air Pollutants, http://www.htap.org/assessment/2007_interim_report/HTAP%202007%20EB%20version.pdf)

Aerosols, ozone and longer-lived greenhouse gases are well recognized as "essential climate variables" (IPCC 2007; GCOS, 2003). Since 1990, climate modellers have recognized more and more the importance of including the effects of these atmospheric constituents in projections and analyses of future climate change on time scales of decadal to century. The latest IPCC 2007 global radiative forcing synthesis (Figure 3) clearly places these variables in the forefront of climate forcing and also uncertainties related to climate forcing.

Climate variability and change have consequences for atmospheric composition through the modification of the distribution and variability of temperature, surface properties (drought and plant cover), cloud cover, precipitation including length of dry periods, boundary layer mixing properties etc. The adaptation of societies to climate change has consequences for atmospheric composition e.g. through changes in the emissions from energy consumption as the energy production system moves towards more extensive inclusion of renewable energies including biofuels.

The atmospheric component of the biogeochemical cycle of reactive nitrogen including its relation to the sequestration of carbon in ecosystems, is not well known. Issues at stake of relevance to WMO are the quality of the water supply and the link between the reactive nitrogen cycle and air pollution and climate change.

Specific Recommendation 1.6
WMO provide advice, coordination of projects and capacity building in air quality forecasting globally.

Specific Recommendation 1.7
WMO coordinate globally the technical work on the very long-range transport of air pollution between regions and continents.

Specific Recommendation 1.8
WMO take the lead in coordinating globally the technical analysis of how climate variability and change and air pollution interact both ways on a regional basis.

Specific Recommendation 1.9
WMO play a lead role globally in the analysis of carbon sequestration and reactive nitrogen in view of how the quality of the water supply is affected by reactive nitrogen runoff, and how the reactive nitrogen cycle interferes with air pollution, the carbon cycle and climate change.

Incorporating aerosols and ozone interactively in operational analysis and prediction systems

As the skill of numerical weather prediction models gradually improved over the past two decades due to assimilation of satellite observations, improved model physics and higher resolution, the relative importance of model uncertainties related to chemical variables compared to other sources of uncertainties has grown. Now it is becoming clear that aerosols, in particular, through their role in direct radiative forcing, indirect radiative forcing and precipitation formation (WMO/IUGG Review; 2009), need to be included internally in numerical weather prediction models. Much like water components, they are highly variable in time and space in the troposphere (generally residence times of 3 to 14 days) and therefore cannot be represented by climatological distributions.

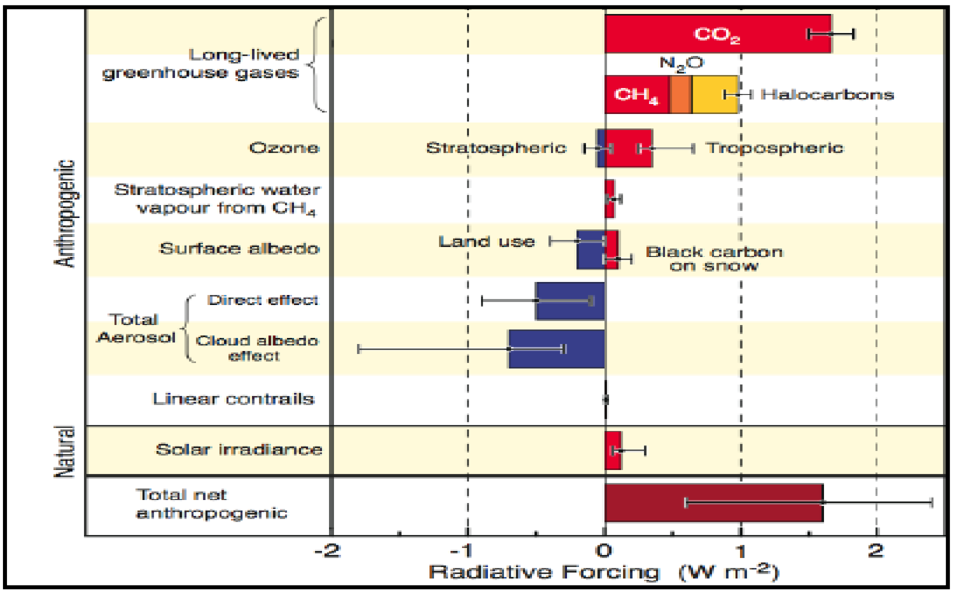


Figure 3 - Global radiative forcing estimates for anthropogenic greenhouse gases and other important agents and mechanisms 2005 (IPCC 2007)

Bringing Weather and Atmospheric Chemistry Together to Improve Weather and Air Quality Forecasts and to Better Utilize Observations in Attributing Sources of Pollution

The EU FP6 Global and regional Earth-system Monitoring using Satellite and in-situ data (GEMS) project

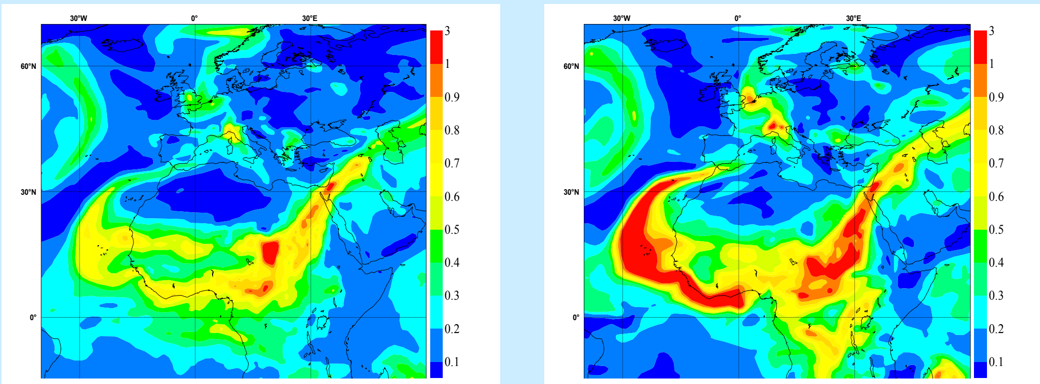
GEMS is a good example of the unified modelling approach developing comprehensive monitoring and forecasting systems for trace atmospheric constituents important for climate, weather and air quality. The systems will provide the basis for value-added data and information services to be developed as part of Europe's Global Monitoring for Environment and Security (GMES) initiative and WMO research programmes. These services will:

- *Provide global data in support of conventions and protocols on climate change, depletion of stratospheric ozone and long-range transport of atmospheric pollution;*
- *Provide information in support of development and implementation of European environmental policy;*
- *Address areas of key uncertainty in climate forcing identified by the Intergovernmental Panel on Climate Change (IPCC);*
- *Provide improved operational air-quality forecasts for health-related applications;*
- *Provide improved monitoring and forecasting of UV radiation and solar-energy resources.*

GEMS builds on the global weather forecasting system operated by the European Centre for Medium-Range Weather Forecasts. ECMWF and its partners in the project have added a capability for analysing and modelling the distributions of key greenhouse gases, chemically reactive gases and aerosols.

In the next five years, GEMS improvements will have positive impacts on the quality of medium- and long-range weather forecasts through the use of the detailed, daily varying, atmospheric composition in the computation of radiation effects in the weather forecast model. Examples of strong feedbacks are: (i) use of daily varying ozone content in the Antarctic ozone hole and its impact on the southern hemisphere circulation; (ii) use of daily 3D maps of Saharan dust amount and its impact on weather in several regions of the globe, including Europe; and (iii) use of daily varying amounts of CO_2 *to extract more accurate temperature information from satellite infra-red sounders instruments.*

Figure: example of the aerosol optical depth in a Saharan dust event (6th March 2004) in a free-running forecast forced by parameterized emissions (left) and in an analysis using the MODIS imager observations (right) verified by surface based in situ and remote sensing observations coordinated by the WMO-GAW programme.



New initiatives are emerging in the research community that are moving toward the incorporation of aerosols, ozone and greenhouse gases into numerical weather prediction forecast models as active constituents that can be assimilated in near real time or in reanalysis mode. An important project in this regard was the Global and regional Earth-system (Atmosphere) Monitoring using Satellite and in-situ data (GEMS) 2005 -2008 (see box above).

In the next decade, this project will be matched by many other initiatives leading towards operational systems that have aerosols, ozone and greenhouse gases built into them for the benefit of improved weather forecasts, carbon source/sink tracking as well as air quality prediction.

Specific Recommendation 1.10
Provide global coordination of projects to incorporate aerosols and ozone as radiatively and cloud/precipitation active constituents in operational analysis and prediction systems, and thereby, enhance predictive capability for societal use.

2.2.2 Implementing Coordination Mechanisms to Optimize Global and Integrated Observing Systems

Sustain and optimize existing networks

We need to strongly support the strategy for guiding the evolution of observing systems within the CBS rolling requirements review process, the Implementation Plan for the Evolution of the Global Observing System (GOS) (http://www.wmo.int/pages/prog/www/OSY/GOS-redesign.html) and the implementation of the Strategic Plan:2008-2015 of the Global Atmospheric Watch (GAW) air chemistry programme (http://www.wmo.int/gaw).

We need to promote observation system and sensitivity experiments based on the most advanced operational numerical weather prediction data assimilation systems. These have become the standard way of defining requirements for the global observing system (Kelly and Thepaut, 2007) as described in the Report on the Fourth 2008 WMO Workshop on "The Impact of Various Observing Systems on NWP" (http://www.wmo.int/pages/prog/www/OSY/Reports/NWP-4_Geneva2008_index.html).

Specific Recommendation 1.11
WMO promote development of observation systems and sensitivity experiments based on the most advanced operational NWP data assimilation systems.

Implement new observations as required by models and maximize utilization of existing observations

In order to provide long-term capability for process studies, data assimilation and enhanced prediction and to establish data bases for diagnostic studies, there is an urgent need to maintain existing observations and to implement new ones to fill gaps related to weather, climate, water and atmospheric composition in collaboration with the WMO Integrated Global Observing System (WIGOS) that includes GOS and GAW mentioned above. These include observations made from surface-based (in situ and remote sensing) networks, aircraft and satellites. In particular the tropics have large gaps (Brunet et al., 2007)

Integrated process studies of observed organized convection based on satellite and ground-based remote sensing (including 3D Doppler radar), with in situ measurements to provide improvements and validation of high-resolution models are used in the WWRP-THORPEX/WCRP Year of Tropical Convection YOTC (http://www.wmo.int/yotc).

Specific Recommendation 1.12
Build capacity for integrated observations globally through WIGOS working in collaboration with WMO research programmes.

Extending access by users to observations

With the continual drive towards forecast and climate models of higher resolution, there is a growing interest in high resolution observations in support of global applications. This has created a need to distribute observations to global users at a space/time resolution that was formally only appropriate for regional/national applications. To this end, WMO Members should consider wider distribution of their observations, within the context of the new WMO Integrated Global Observing System (WIGOS) and the WMO Information System (WIS).

Specific Recommendation 1.13
WMO Members extend distribution and access to observations for research and associated application development through the new WMO Information System (WIS).

Integrating observations through data assimilation

Data assimilation that blends models and observations should be a key component in climate and weather model development. This already occurs for numerical weather prediction, but is less common for climate models. The coupled seamless prediction system requires unified data assimilation and model development. Such a link has already been forged for the middle atmosphere through the WCRP SPARC programme (Brunet et al., 2007). Ocean assimilation is now part of seasonal prediction programmes. Environmental monitoring initiatives have also linked assimilation with models of atmospheric composition (see GEMS box above).

It is recognized that coupled model data assimilation for the Earth-system will ultimately be needed but is at the moment a very challenging problem. It is recommended that a few pilot research projects start quickly in this area.

Specific Recommendation 1.14
There is an urgent need to initiate a few pilot research projects in the area of coupled-model data assimilation.

Specific Recommendation 1.15
Accelerate the utilization of data assimilation techniques for climate model development.

2.2.3 Promoting Earth-System Reanalysis Projects

New resources would accelerate the development of seamless coupled model and data assimilation systems for the benefit of weather and climate applications. One mechanism to achieve this is through the various re-analysis projects which are designed to provide a historical record for weather and climate studies. Reanalysis projects are essential for historical forecast projects (HFPs). Global reanalyses of the atmosphere (Uppala et al, 2005), the ocean (Balmaseda et al, 2007) and the continental surfaces are increasingly necessary to serve as initial state and verification for seasonal and decadal climate forecasts. Recent improvements in observation and model bias corrections techniques lead to hope that future reanalysis programmes will allow depicting climate trends faithfully (Uppala et al, 2008). In the past, reanalysis has been based on operational numerical weather prediction systems; most of the resources were directed towards gathering and quality controlling the observations and performing the assimilation. Future-generation reanalysis projects would increasingly not rely only on operational forecast systems but benefit from an interdisciplinary weather-climate research programme on data-assimilation methodologies (Brunet et al. 2007).

Specific Recommendation 1.16
Take an interdisciplinary weather-climate approach on data-assimilation methodologies in future reanalysis projects.

2.2.4 Improving and Innovating Weather, Climate and Environmental Products

There is a need for closer ties among weather, climate and air chemistry research centres that can provide state-of-the-art weather and climate forecast information in a form that can be easily accessed by non-atmospheric scientists, user groups interested in applying the information, and intermediaries who understand both the scientific and socioeconomic issues. To develop and transfer related diagnostic and prognostic information tailored to user needs for accurate weather and climate forecasts and their socio-economic decision making, we need to encourage liaison programmes such as Weather and Society*Integrated Studies (WAS*IS) (Demuth et al. 2007, Brunet et al., 2007).

The recent development of a large database of operational forecast products, such as TIGGE (Worley et al, 2008) for the medium-range and the WCRP CLIVAR Climate-system Historical Forecast Project (CHFP) for the seasonal range, offers new opportunities to improve methodology for seamless environmental products spanning several time scales. Trenberth (2008) outlined the need for a Global Climate Information System, supported by comprehensive observations and a 21st century Earth System Prediction capability (Shapiro et al., 2009) and a network of experts to provide the best knowledge and information on climate variability and change to existing and emerging users for decision making. Historical forecast projects (HFPs) are essential to assess forecast error characteristics in view of developing new and improving products. Linkages are needed with weather, climate and hydrometeorological service providers. Examples of existing and proposed linkages include: (i) the Hydrological Ensemble Prediction Experiment (HEPEX), an international project to advance technologies for hydrological forecasting comprised primarily of researchers, forecasters, water managers, and users (Brunet et al. 2007); and (ii) a Global Framework for Climate Services, which is an expected outcome of the World Climate Conference 3.

Specific Recommendation 1.17
Encourage liaison programmes such as the project Weather And Society*Integrated Studies (WAS*IS).

Specific Recommendation 1.18
Encourage linkages between weather, climate and hydrometeorological service providers

Specific Recommendation 1.19
WMO promote hydrological forecast research demonstration projects.

Specific Recommendation 1.20
WMO support research as an essential component of end-to-end systems for weather, climate, water and environmental services such as the Global Framework for Climate Services promoted as a major outcome of WCC-3.

3. LINKING RESEARCH, OPERATIONS AND SERVICE DELIVERY

3.1 Opportunity

The practical goal of addressing Members' needs dictates that the linkages between research, operations and service delivery must be addressed. Accelerating the current rate of progress in operations and service delivery, developing appropriate solutions in the developing world and establishing service delivery for the new products and services outlined in chapter three require a greater emphasis on developing effective links between research, operations and service delivery.

3.2 Rationale

3.2.1 User Involvement

WMO research advances science in order to meet the needs of Members for information about climate, weather, air chemistry and water. The WMO research portfolio has and should continue to include applied research closely linked to users and basic research. This will benefit from coordinated international effort and is expected to lead to major advances in our predictive capability and knowledge of the variations in weather, water, climate and air quality. The research activities from basic to applied should continue to take into account user needs in order to maximize the benefits to society. An example is the focus by the WCRP to downscale projections of global climate change to national, regional and even local scales to meet the needs of policy and decisions makers about the future of water resource management, urban planning, coastal management, agriculture practices, and a host of human and environmental decisions. Such downscaling requires numerous basic research advances on improving the treatment of physical processes to the need to assess and verify predictions on high-spatial scales.

User needs are driving new areas for research to meet the critical societal needs of the 21st Century. Possible new thrusts could be a focal point for weather research on shorter time-scales on the needs for improved multi-hazard prediction for large urban centres and regional megacities following the Shanghai MHEWS project. Another example could be focusing monthly and seasonal prediction research in the context of improved food security for critical regions. The movement of climate predictions and water from deterministic modelling to ensemble predictions is another developing area as the uncertainty in modelling non-linear processes dictate information be conveyed in probabilistic form.

Once a research area is established significant benefits could be realized by increasing user involvement, earlier and more often to maximize benefit to operations and service delivery aspects of air chemistry, climate weather, and water would be well served by interactions with the users early and often. In the example of regional climate, interactions with the users will help researchers understand the accuracy and spatial scales required by the users and allow users to gain knowledge of the uncertainties and risks in the prediction process so that expectations are not set too high and reasonable decisions are made on the sound use of the information. Research advances often lead to changes in the level of uncertainty with, in general, a decrease in the level of uncertainty.

Bringing Research and Operational Weather Prediction Together with Users

The WMO Severe Weather Forecasting Demonstration Project was initiated by the Commission for Basic Systems to test a new concept for capacity building of National Meteorological and Hydrological Services (NMHSs) in developing and least developed countries to improve warning services to communities. The project took place from November 2006 to 2007 and utilized Global Data Processing and Forecasting System centres at the ECMWF, NCEP (USA) and the Met Office UK to provide deterministic and ensemble products from global centres via the RSMC Pretoria (Regional Specialized Meteorological Centre) at the South African Weather Service to NMHSs in Botswana, Madagascar, Mozambique, Tanzania and Zimbabwe. The South African Weather Service distributed forecasts and guidance up to 5-days in advance for heavy rain or strong winds to the participating NMHSs, which maintained their own control of issuing warnings at the national level. RSMC La Reunion, which is the RSMC responsible for tropical cyclone forecasts in the South Indian Ocean, maintained their normal operations and supported the project with valuable information on tropical cyclones used to prepare the guidance products. The concept is being broadened to the other nations in Southern African and serves as a model for the flow of information to users in the developing world. The Commission for Atmospheric Science and WWRP-THORPEX are joining the project in the next phase to enhance access to innovative new prediction tools.

The project enabled the Mozambique NMS to provide warnings of strong winds and heavy rain to the populace ahead of the Tropical Cyclone Favio, which made landfall on the 23rd February 2007. The effectiveness of the project is demonstrated by the much lower fatalities on this occasion as compared to the devastating floods in early 2000 caused by a similar Tropical Cyclone.

Tropical Cyclone Favio, 23 February 2007

Some advances in knowledge can lead to increased uncertainty about some issues or changes in the information that require changes in the decision making process. Close interactions between users and research helps to avoid misunderstanding in such instances.

In order for the users to be closer to research, the research activities coordinated by the WMO need to identify mechanisms to bring research, operations and users together, particularly for end users where the mechanisms are weakest. The WWRP, for example, has a Working Group on Societal and Economic Research and Applications (SERA, see Annex IV Figure 2) and the requirement that projects of the WWRP scientific working groups include a SERA component. Even with these mechanisms in place, the WWRP has had mixed success with the user-research-operations interactions. One lesson learned is that different approaches will be required for mid-users (e.g., NMHSs) versus end users in order to reflect the differing expectations and differing use of information. The WMO through its direct links to mid-users (NMHSs) and existing links to end users should assist in the facilitation of more applied aspects of research. The WMO should facilitate collaboration between research, NNHSs and users in characterizing and communicating uncertainty to reducing the barriers users face in utilizing such information.

The user and operational community also need to know that their activities could further research advancements. One issue is to make measurements available for research such assessment of atmospheric chemistry and surface measurements (e.g., rainfall, streamflow) for the evaluation and initialization of high spatial and temporal predictions of weather, climate, air chemistry and hydrology. For operational prediction, the real-time dissemination of data for example through the WMO WIS and via the Internet is critical.

3.2.2 Involvement of Developing Country Scientists in International Research Projects

Developing nations have specific needs for climate, weather, water and air chemistry information. For example, such countries have a greater number of fatalities from hydro-agrometeorological disasters and their fragile economies lack the resiliency to deal with such events. For example, devastating flooding in Mozambique in 2000 resulted in a decrease in the GNP from 8 to 2.1%. Locusts outbreaks and drought over parts of Sahelian Africa in 2004 led to disaster declarations and international humanitarian assistance. The involvement of scientists from developing countries should be encouraged with particular efforts aimed at targeting those areas of research and prediction where developing nations have stakes in the outcome as users of forecast information. Areas to be targeted could include statistical and dynamic downscaling of weather and climate information for use in application models, another is involvement in the measurements to support. Numerous successful examples (e.g., involvement of African scientists in the WMO Sand and Dust Storm Warning Advisory Assessment System (SDS-WAS), African THORPEX, IRI activities, IPCC, etc.) exist where research is targeted specifically to meet needs and have involvement of developing nations.

Efforts to involve more researchers from the developing world should recognize and tailor involvement to meet the diversity among capabilities in developing nations' research. Some nations are developing the capacity for possible research partnerships as human resources and technical infrastructure have advanced or are rapidly improving. Such nations would greatly benefit from the inclusion of their scientists in international efforts, particularly to expose the next generation of scientific leaders to international research. In Member nations where capacity has not sufficiently advanced, training and a long-term vision for building a research infrastructure is needed. Examples of which include the following. As noted in the IPCC AR4 (IPCC 2007), there is a pressing need for climate information on regional scales for adaptation. The study of regional climate impacts will require the development of regional climate models and downscaling techniques that involve detailed knowledge of the climate system on regional scales. The provision of useful and interpretable regional climate information for developing nations is dependent on the active engagement of scientists within the region. Similarly, field programmes and process studies in developing nations will also benefit from substantive involvement of personnel from the NMHS. While being cognizant of the time demands on scientists, important use of local knowledge and relevant data sets is to be had by engaging the NMHSs in basic and applied research that will ultimately transition into operations and products for the region.

3.2.3 Distillation of Research Results into Operational and User-Driven Products

It is important to involve user communities in the development of weather, water, air chemistry and climate prediction systems. One aspect of early involvement will be to identify model deficiencies as well as the improved utilization of existing model products so that basic and applied research is focused on areas where improvement in the prediction systems would greatly benefit society.

As research systems and results become more mature, it is again critical to bring the user, research and operational communities together to develop new products that better meet the needs of society. The development of research products and services should match with client capacity and needs. For example, communication in the developing world means that it is often impractical and counterproductive to ship large datasets so that efforts should be made to develop and utilize graphical products. For disaster mitigation, such graphical information should be easily and quickly understood with no ambiguity in the message, whether working with developed, developing or least developed Members.

The WMO has the capability to use a common lexicon for products across the climate and weather timescales and in some cases across the disciplines of water, weather, climate and air quality (see Figure 1 of Section 1). For example, all these fields are working toward characterizing uncertainty through ensemble predictions. The NMHS's and national partners are the first users of the ensemble products and need to realize the important of using ensemble products in their improvement of those of high-impact weather, air chemistry, water and even climate. The user-targeted probabilistic product should be based on ensemble products in those area as flooding event, extreme climate events and severe weather forecast in order to mach the needs of decision makers. A mechanism should be explored for those services to communicate with users to develop those kind products. It is also necessary to train the user to understand the uncertainties of the forecast and to use those probabilistic products for their decision making.

3.2.4 Challenge of Ensemble Products

Reanalysis and reforecasts for both deterministic and ensemble systems can play a greater role than up to now in defining and meeting user needs. This would enable the development of products and projects that compare weather, climate and environmental prediction products with climatology. The European METEO ALARM system has successfully illustrated the importance of such an approach in alerting the public and users of disasters. There is a need to develop and apply similar systems elsewhere for disaster mitigation for weather and water. Climate information can also benefit from such an approach as users are interested in both changes in extreme events and the distribution of extreme to moderate events.

3.2.5 Develop Forecast Demonstration Projects Involving Research, Operations and Users

Research and Development Projects (RDPs) are focused on the development of new research techniques, models and concepts in an operational environment; while Forecast Demonstration Projects (FDPs) focus on demonstrating the potential of research models, tools and techniques in an operational setting and the initial stages of the transfer of research to operations. FDPs and RDPs have proven to be a successful model for the transfer of research models, techniques, and concepts to the operational and user community. These efforts also serve the research community as a focal point for inter-comparison between various research techniques and models that have resulted in identifying areas for improvement in the observing strategies, data assimilation, physics and dynamics of these models. The inter-comparison aspect is particularly true for nowcasting, high resolution and regional modelling where the models are often tailored and applied in a specific limited region without a venue for intercomparison with other models. Successful examples for both the research and operational communities are Beijing 08 and MAP PHASE-D for FDPs and MAP for an RDP. Unfortunately, the human and resource level for both NMHSs and the research community has limited the number and scope of such efforts.

Efforts should be made to generate data in formats that are compliant with the likely WMO formats of the future (e.g., WIS) for both RDPs and FDPs to speed the operational implementation of lessons learned and to aid interactions between the research and operational communities. FDPs and RDPs have included a societal component that attempts to bring research to users and quantify the benefits of these new approaches. The RDP and FDP approach should include, where appropriate, efforts to reach users in innovative ways (e.g., web, mobile phone, use of radio stations or community structures in rural areas) to maximize the benefits to users especially in the developing world where innovative techniques could result in significant benefits.

The implementation of these recommendations for demonstration projects (e.g., exploitation of modern technology, greater involvement of scientists in the developing world) requires the development of new partnerships. Such partnerships would maximize the benefit of improvements in predictive skill for existing and new users for weather, seasonal and climate information.

Resource mobilization for demonstration projects by WMO research programmes in the developing world should include a growing focus on non-traditional partners. Non-traditional funding agencies (philanthropic foundations, aid organizations etc.) have recently expressed interest in demonstration projects that can directly benefit the developing world through approaches that lie outside of the traditional methods and partnerships utilized by the NMHSs. The UCAR African initiative funded by google.org with links to MERIT and THORPEX Africa is a good example of a success story where research activities will benefit the developing world and was achieved through a new approach to mobilising funding.

3.3 Recommendations

General Recommendation 2
Linking Research, Operation and Service Delivery: Develop closer linkages between research, operations and users through Forecast Demonstration Projects (FDPs) that accelerate technology transfer, in particular:

Specific Recommendation 2.1
Increase the two-way interactions between research, users and operations that begin early in the design of a research project and continue through the research process. Such interactions will help focus basic and applied research on user needs and make a more rapid transfer of research to operations and end users. Operations and users could also increase the efficiency of this process by providing data, in real-time when possible, to meet research needs and facilitate the testing of new research approaches.

Specific Recommendation 2.2
WMO should play a major role in identifying and facilitating mechanisms to implement the two-way interactions between research, users and operations.

Specific Recommendation 2.3
Increase the involvement of scientists and users from developing countries in FDPs, particularly from NMHSs and their national partners in the research activities of the WMO.

Specific Recommendation 2.4
Focus on distilling research advances into products specially at the regional level that can be readily made available and, through training activities, enable their use by those needing information (some research advances, such as ensemble prediction, have great utility but with interaction with users are difficult to distil into user-friendly information).

4. THE WMO TECHNICAL COMMISSIONS AND THEIR LINKAGES WITH DEPARTMENTS AND OTHER INTERNATIONAL INSTITUTIONS

4.1 Issue: Effectiveness, Efficiency and Crosscutting Collaborations of WMO Technical Commissions

The EC-RTT was of the opinion that the present structures and roles of the WMO Technical Commissions, and as well their linkages with the newly created Departments were not optimal for the implementation and delivery to the WMO Members of the benefits of the proposed new prediction research paradigm change. The structures of some Commissions seem unduly complicated. The linkages between the different OPAGs, working groups, ad-hoc committees, within and across Commissions appear complex, and probably a source of significant overhead cost. The budgets of many Commissions are stressed at the limit, with a steadily increasing share going to fixed costs (salaries), with less and less being available for supporting outside involvement in WMO's Programmes, making the launching of new initiatives almost impossible. For some Commissions, almost all the flexibility is spent on the organization of the quadrennial meeting, with almost no funding available for ongoing operational costs. More importantly, the Commissions were basically left unchanged after the recent reorganization which created delivery departments. This reorganization led to apparent misfits between the Commission's mandates and the department's missions. A case in point is the Commission for Atmospheric Sciences, which relates to only a fraction of the so-called research department e.g., the WCRP is not a programme under CAS. Moreover, some CAS activities are highly relevant to other departments and Commission's mandates and missions. This situation will be further exacerbated by the gradual transition to an integrated approach, including close collaboration within WMO, across Commissions and Departments, cutting across many new S&T disciplinary areas, and involving increasing external collaborations with scientific institutions and bodies.

The present structure and mandates of the Commissions does not facilitate cross-cutting interactions or activities. The presidents themselves officially meet once a year, and on an ad hoc basis will meet during the annual EC meeting. Their Advisory Management Groups seldom involve participation from other Commissions. The same is true for their sub-structures. There is generally no financial flexibility to initiate cross Commission projects. There is no clear path between the Commissions and the co-sponsored research programmes sitting outside the Commissions' worlds. Thus, there are no efficient mechanism in place, organizationally or budgetary, to foster crosscutting activities.

4.2 Rationale

The EC-RTT has noted that many of the above concerns have been raised at the PTC meeting held at WMO HQ, 2-4 February 2009. The president of CAS has brought forward a number of points of relevance to the research function in WMO. The question of the ideal number of Commissions under the new organizational structure was briefly discussed, and it was decided that for the time being, it would be more productive to explore means of addressing the pressing financial issues, without changing the nature or structure of Commissions, recognizing that this could lead to a long and complex process with involvement of Congress, and potentially unexpected results. This then leaves open the issue of the mismatch between departments and Commissions, a mismatch that is bound to increase as we move forward with the new prediction research framework. A straw man proposal from the Secretariat was presented to the presidents for their consideration, which suggests, inter alia, replacing the expensive quadrennial meetings by biennial meetings, where all Commissions would meet simultaneously, with representation from their different clients and stakeholders. This would potentially increase the amount of interactions between the Commissions, whilst reducing the costs devoted to this budget item. It was seen as a step in the correct direction. Whatever the final decisions on this issue, the EC-RTT felt that ultimately a solution should be found that would lead to a better fit between the new research framework, the programs and the members' needs. The role and structure of Commissions has changed in the past, and the EC-RTT feels that we are fast approaching a point in time where such change is needed.

Although each Commission has a technical advisory and coordination function, CAS (and the Research Department) has by far the most focused set of activities related to research (as opposed to technology) and science, and the most extensive partnerships with other international science bodies and networks. The Research Department and CAS, because of their extensive science outreach and collaborations internationally, rightly or wrongly, often see themselves as playing science watch for WMO and its Members. The creation of the new research department (now including the WCRP), recent scientific developments, the expanding needs of Members of WMO, and the enrichment of the WMO mandate in the UN framework have had impacts on the programmes. CAS and the Research Department are now more and more moving towards research and development activities under the framework of integrated or seamless modelling, requiring multidisciplinary approaches. The fundamental driver for this transition is the science itself, but a side benefit is the possibility to develop an enlarged set of environmental prediction products, targeted towards hydrology, agriculture, transport, health, food production, and risk reduction and mitigation in general (CHy, CCI, CAgM, CAeM, CBS). At the same time, these developments create new demands on the global observing systems (CBS, CIMO, and JCOMM). Thus, there is a rapidly increasing urgency to "break down the walls" between the different Commissions and departments.

Finally, it should be recognized that WMO, as an Organization, is highly dependent on Science & Technology (S&T). In order to meet Members constantly evolving needs, as well as the frequent socio-economic pressures WMO must accommodate in trying to do more with often dwindling resources. It has not only to keep abreast of the best that science can offer and produce in its areas of competency, but it has a moral and institutional obligation to lead or facilitate the development of the tools that will enable its Members to provide up to date, accurate and relevant meteorological information and services at the lowest possible cost. A necessary, but not sufficient, condition for this to happen is that science be part of the decision making process at all important levels or in bodies of the Organization. This is best accomplished in an organization where a culture of excellence, relevance and impact is maintained and shared by its staff and constituent bodies. At the same time, this culture facilitates immensely the establishment of the many needed collaborations with other international institutions, because of the credibility it provides the WMO in developing linkages with other potential partners and co-sponsors. The task team emphasized that such linkages are required since much of the science needed for broadening the scope of prediction to wider environmental parameters can be provided by WMO and its Members with expanded partnership.

4.3 Recommendations

General Recommendation 3
The Role of WMO Commissions: Implement a process to review and rationalise the roles and mandates of the Commissions, and to improve their effectiveness in enhancing WMO Member capabilities in research, observations, prediction and services, in particular:

Specific Recommendation 3.1
EC and the Secretariat work closely with the PTC and the Research Department so that any necessary modification to the Commissions' structures and their linkages with the organizational structure is effected to maximize the impact of the proposed paradigm change in prediction research. Simplification and clarity of the roles of the Commissions and the Departments should be the guiding principles of any final decisions.

Specific Recommendation 3.2
Develop a process to harmonize research input, and cross-coordination between different Commissions.

Specific Recommendation 3.3
Set up a mechanism connected with budgetary decision making, whereby cross cutting project proposals developed jointly by at least two Commissions, and one regional association could be reviewed and prioritized by the presidents of technical commissions, for consideration by EC and the Secretariat for eventual implementation.

Specific Recommendation 3.4
Recognizing that WMO is fundamentally a science and technology based organization, establish efficient mechanisms to ensure that optimal science input is provided to WMO decision making processes and bodies (Cg, EC and Secretariat).

Specific Recommendation 3.5
Reaffirm and support international WMO science and technology leadership in its areas of competence, by nurturing a culture of excellence, relevance and impact, whilst recognizing that the increasing complexity of atmospheric related environmental issues necessitates an increasingly partnership approach.

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ANNEX I

Membership and Terms of Reference of the Executive Council Task Team on Research Aspects of an Enhanced Climate, Weather, Water and Environmental Prediction Framework (The Research Task Team)

(ANNEX II to paragraph 3.2.10.2 of the report of the Sixtieth Session of the WMO Executive Council)

Terms of reference

With the overall goal to strengthen and promote the linkages between climate, weather, water and environmental research to enable National Meteorological and Hydrological Services and other related organizations to provide improved services in the next decade, the Research Task Team will be guided by the following terms of reference:

1. Propose a strategy focusing on strengthening prediction research and related scientific assessments in support of enhanced climate, weather, water and environmental services in the next decade;

2. Take into account recommendations of:

   (a) The World Modelling Summit on Climate Prediction;
   (b) The white paper developed by the weather and climate research communities of the World Weather Research Programme (WWRP), the World Climate Research Programme (WCRP) and the International Geosphere-Biosphere Programme on the socioeconomic and environmental benefits of a revolution in weather, climate and Earth-system prediction; and
   (c) The white paper developed by the climate and weather research community on a seamless approach to weather and climate prediction and services delivery;

3. Propose effective actions and mechanisms for maximizing research impact on the future development by WMO and its Members of an end-to-end service delivery and capacity building system;

4. To assess ways to better coordinate the advisory role of prediction research by technical commissions and other bodies supported by WMO;

5. Provide a report to the Executive Council at its sixty-first session in June 2009.

Membership

The Research Task Team should consist of the following: a Chairperson (John Mitchell) appointed by the Executive Council; the president of the Commission for Atmospheric Sciences; chairperson and appropriate representatives of WCRP, WWRP and Environmental Pollution and Atmospheric Chemistry; representatives of Executive Council working groups; and internationally recognized scientists.

Secretariat support

The Research Department would take the lead in organizational support of the Research Task Team with strong involvement of the WMO departments responsible for observations, service delivery and regional activities.

Membership of EC Research Task Team*

	Member	Role	Country
1	John Mitchell	Chair RTT; former EC WG-CWE; WGCM co-chair; WCC-3	UK
2	Michel Béland	Pres. CAS (WWRP and GAW); Ex Off. Member EC WG-CWE; WCC-3; Summit Modelling Committee	Canada
3	Tony Busalacchi	Chair JSC WCRP Ex Officio WC WG-CWE	USA
4	Gilbert Brunet	Chair JSC WWRP; Summit Modelling Committee	Canada
5	Oystein Høv	Chair JSC EPAC (for GAW); Ex Off. Member EC WG-WIGOS/WIS	Norway
6	Massimo Capaldo	EC WGs on DRR&SD and on WIGOS/WIS	Italy
7	Taroh Matsuno	Coordinator of a MEXT's Programme "Innovative Programme of Climate Change Projection for the 21st Century" attended Modelling Summit	Japan
8	Phillippe Bougeault	Research Director, ECMWY; Chair of THORPEX-TIGGE	ECMWF
10	Ben Kirtman	WGSIP (CLIVAR) seasonal	USA
11	Jochen Marotzke	Seasonal to decadal Also on Summit Modelling Committee	Germany
12	Christian Jakob	WGNE; attended Modelling Summit	Australia
13	Meiyan JIAO	Deputy Admin CMA in charge of Weather and climate prediction representing EC Member Zheng Guo Guan Connection to weather and climate services	China

** supported by the Research Department of the WMO Secretariat, Geneva.*

ANNEX III

Definitions of forecast/predictions differ depending on the prediction community for instance the NWP weather based community supported by WMO Commission for Basic System has the following terminology

(This differs considerably from the definitions of climate prediction research community)

1. NOWCASTING : 0 -2 HOURS DESCRIPTION OF FORECASTED WEATHER PARAMETERS
2. VERY SHORT-RANGE WEATHER FORECASTING: UP TO 12 HOURS DESCRIPTION OF WEATHER PARAMETER
3. SHORT-RANGE WEATHER FORECASTING: BEYOND 12 HOURS AND UP TO 72 HOURS DESCRIPTION OF WEATHER PARAMETERS
4. MEDIUM-RANGE WEATHER FORECASTING: BEYOND 72 HOURS AND UP TO 240 HOURS DESCRIPTION OF WEATHER PARAMETERS
5. EXTENDED-RANGE WEATHER FORECASTING: BEYOND 10 DAYS AND UP TO 30 DAYS DESCRIPTION OF WEATHER PARAMETERS, USUALLY AVERAGED AND EXPRESSED AS A DEPARTURE FROM CLIMATE VALUES FOR THAT PERIOD.
6. LONG-RANGE FORECASTING: FROM 30 DAYS UP TO TWO YEARS: 6.1 MONTHLY OUTLOOK 6.2 THREE MONTH OR 90 DAY OUTLOOK 6.3 SEASONAL OUTLOOK
7. CLIMATE FORECASTING: BEYOND TWO YEARS

Background Information on WMO Structure, Research and Partnerships Relevant to the Task Team's Mandate

1. The Organization of WMO relevant to Research and its Links Activities

In order for the task team to address the terms of reference related to the effective management of research and its links to observations, service delivery and capacity building (terms of reference 3 and 4, Annex I) it was necessary for them to understand the organizational components of WMO as a whole (Figure 1) as well as the new structure of the WMO Secretariat.

An understanding of the WMO organization by the Task Team was important in order for it to develop a better perspective on how research fits into the organization and its link to observations, prediction and service delivery. Not all the members of the research task team were familiar with the meteorological services and partner organizations.

WMO is unique amongst UN organizations with a strong central Secretariat, a well established network of six regions served by regional associations and eight commissions that guide and advise on the establishment and implementation of WMO programmes. The programmes are of necessity bottom-up in origin and in Member support but top-down in organization and implementation. This supports a results-based management system structured currently around 3 high level objectives, 5 strategic thrusts and 11 expected results. The governing body is the Congress of 188 countries which meets every four years and its 37 member Executive Council (EC) comprised of the Permanent Representatives to WMO of a sub-set of the membership. EC meets every year to make important decisions raised by the Secretariat, the Commissions, the Regional Associations and the Working Groups or Task Teams of EC. The Commissions of WMO are listed in Table 1.

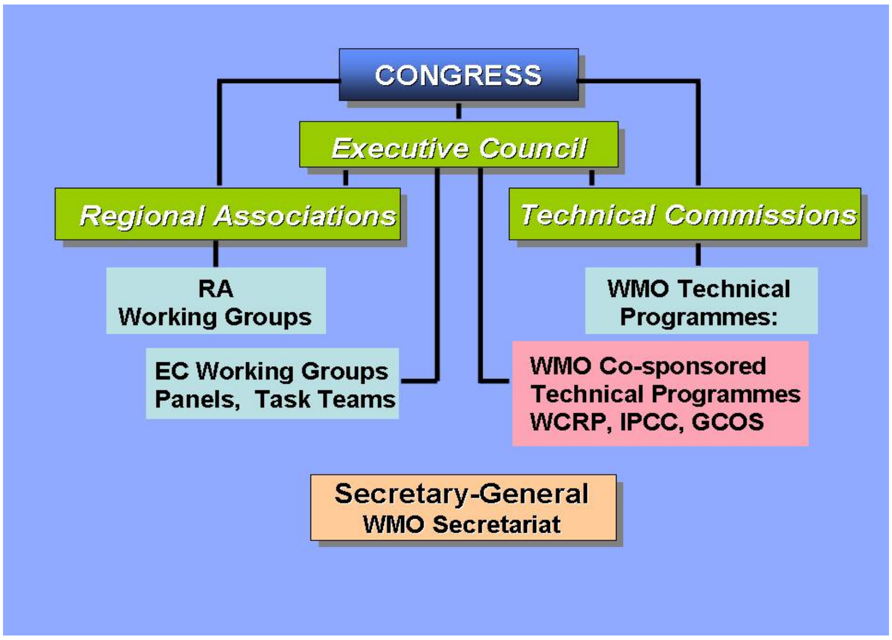

Figure 1- Organizational bodies and components of the World Meteorological Organization

Table 1. Commissions of WMO as of June 2009

CAS	Commission for Atmospheric Sciences
CCL	Commission for Climatology
CBS	Commission for Basic Systems
CIMO	Commission for Instruments and Meteorological Observations
CHy	Commission for Hydrology
CAeM	Commission for Aviation Meteorology
CAgM	Commission for Agriculture Meteorology
JCOMM	Joint WMO-IOC Commission for Oceanography and Marine Meteorology

The Commission for Atmospheric Science has the main lead for research while other commission deal more with operational observations, prediction delivery and weather climate water and disaster risk reduction services. The components of the WMO research programmes and their linkages to other WMO activities are schematically summarized in Figure 2. The World Weather Research Programme (WWRP) including the large trust funded THORPEX programme and the Global Atmospheric Watch (GAW) atmospheric chemistry programme have evolved under CAS. Together with the joint WMO/IOC/ICSU sponsored World Climate Research Programme (WCRP), they constitute the bulk of WMO sponsored research activities. There is a Joint Scientific Committee (JSC) for each of WCRP, WWRP and GAW who provide scientific and technical advice and guidance to these programmes.

Each programme shown in Figure 2 has major activity areas represented by the green boxes with Secretariat support at WMO in Geneva. Those green boxes with a red border are initiatives with not only Secretariat support from WMO in Geneva but also from other budgetary sources. For example, THORPEX is in itself is a major programme that, at the request of CAS XIV was integrated into the WWRP but remains a large self-supported initiative. The yellow components are activities jointly supported by at least two of the four programmes. For example, the Working Group on Numerical Experimentation (WGNE) is a joint CAS/WCRP sponsored activity. It has operated since 1985 and is dedicated to addressing outstanding needs of research and operational prediction from the perspective of model development. The WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) is a joint WWRP-GAW initiative bridging weather and atmospheric chemistry research. It also cuts across research and operational forecasting linked to the Commission for Basic Systems.

Activities that fall within the black oval, in Figure 2, are supported by the WMO Research Department. They are not isolated from other WMO activities and they are supported by more operational or service-delivery oriented departments. The integration and coordination among these programmes also benefit greatly from the active participation of researchers and centers that are interested in an end-to-end chain involving research, observations, prediction and service delivery.

2. International Partner Organizations and Programmes

The activities of WMO in prediction research summarized in Section 2.1, have strong interactions with the global research effort supported by partner UN organizations such as UNESCO/IOC, FAO and UNEP as well as in academic-based International Council of Scientific Unions (ICSU) and its associations under the International Union of Geodesy and Geophysics (IUGG) and other professional scientific and technical organizations. In particular, there are strong links to the International Association for Meteorology and Atmospheric science (IAMAS) and the International Association for Hydrological Science (IAHS) of IUGG.

The International Geosphere Biosphere Programme (IGBP) was established in 1987 by ICSU to provide scientific knowledge to improve the sustainability of the living Earth. IGBP studies the interactions between biological, chemical and physical processes and interactions with human systems and collaborates with other programmes to develop and impart the understanding necessary to respond to global change. Its three goals are to analyze: (i) the interactive physical, chemical and biological processes that define Earth System dynamics, (ii) the changes that are occurring in these dynamics and (iii) the role of human activities on these changes.

The World Climate Research Programme (WCRP) is a joint programme of WMO, ICSU and the Intergovernmental Oceanographic Commission (IOC) of UNESCO. In 1980, it was established as a principal component of the UN World Climate Programme. WCRP and its predecessor, the Global Atmospheric Research Programme (GARP) established in 1967, represent more than 40 years of extremely fruitful cooperation of WMO and ICSU in sponsoring added-value atmospheric and climate research activities. Both WCRP and the GAW programme have strong links to IGBP activities especially in atmospheric chemistry (IGAC), atmosphere-terrestrial interactions (ILEAPS) and atmosphere-ocean interactions (SOLAS). IGBP is major driver of process research especially in biological aspects of Earth System Science and is very well complemented by the WMO sponsored or co-sponsored research programmes that can assist in connecting to systematic global observation systems and to core service delivery mechanisms of WMO.

It is the mandate of CAS to explore potential linkages between specific activities of ICSU and WMO research and advise appropriate mechanisms for joint activities. For instance, the new ICSU programme IRDR (Integrated Research on Disaster Risk) offers possibilities for linkages with the World Weather Research Programme; the WWRP and IRDR could possibly co-host a joint working group on Societal and Economic Research and Applications (SERA) of weather forecast products and services (see Fig. 2).

WMO research, particularly that of WCRP, is a major pillar of the Intergovernmental Panel for Climate Change (IPCC) which was awarded a Nobel Peace Prize for its effectiveness in informing the public through regular global scientific assessments on matters critical to world security and hence peace. WMO cosponsors the IPCC and host the IPCC Secretariat in Geneva.

The Global Climate Observing System (GCOS) co-sponsored by WMO, ICSU, IOC and UNEP is intended to be a long-term, user-driven operational system capable of providing the comprehensive observations required for (i) monitoring the climate system, (ii) detecting and attributing climate change, (iii) assessing impacts of, and supporting adaptation to, climate variability and change, (iv) application to national economic development, and (iii) research to improve understanding, modelling and prediction of the climate system. GCOS, established in the early 1990s, is a major policy interface with UNFCC and partner of WCRP and GAW which serve to implement new systems to fill the gaps in global climate observations identified by GCOS assessments. They do this through research, development, assessment and, in the new restructured WMO secretariat, through having a well defined a path from research to operations and service deliver. The latter is really the goal of an "Enhanced Framework for Weather, Climate Water and Environmental Prediction" the name of this task team.

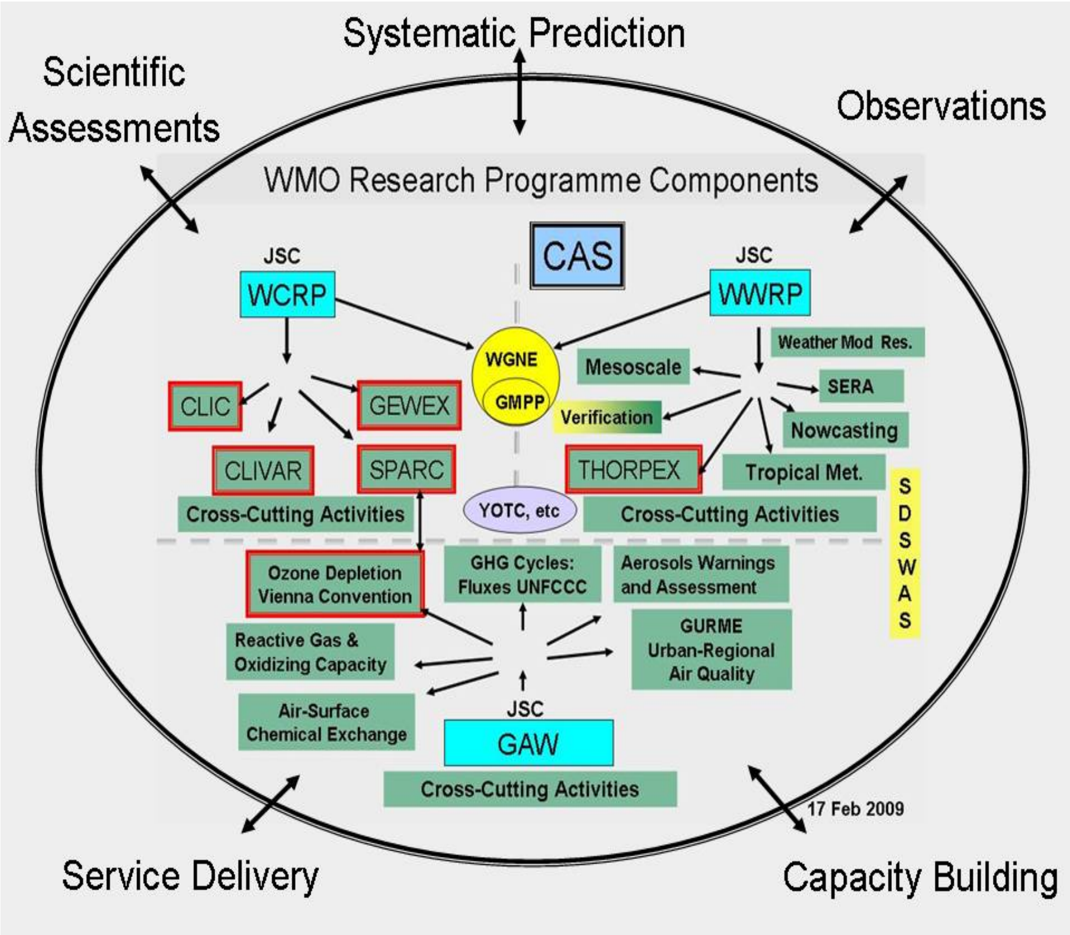

Figure 2 - Advisory bodies, programmes and activities supported by the WMO Secretariat Research Department (see text for explanation)