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WORLD METEOROLOGICAL ORGANIZATION

WORLD WEATHER RESEARCH PROGRAMME

WWRP 2009 - 2


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Societies have long recognized the critical importance of predicting the weather to protect lives and property from the potentially destructive impacts of natural hazards, such as storms, floods, droughts, wildfires and other environmental threats; however, this capability has become ever more important in a world where such risks are being intensified by climate variability and change.

The International Meteorological Organization (IMO) was established in 1873 to contribute to this vital protection, in particular to safety at sea. The IMO became WMO in 1950 and one year later, a Specialized Agency of the United Nations System, which today has 188 Members and a mandate in weather, climate and water.

At the same time that WMO evolved and developed during the second half of the twentieth century, so did the skill of meteorological predictions, at an average rate of about 1 day every 7 to 10 years. This enhanced predictive capability has been at the foundation of numerous services being now provided to different sectors, such as transport, agriculture and emergency management, as well as to the general public.

WMO Members were indeed quick to recognize that user-driven research, coupled with a sustained improvement of observations, is at the root of scientific progress since it provides the capacity to further reduce societal risks. At the same time, WMO’s leadership role in weather research was considerably strengthened through its participation, during the 1950s and 1960s, in a series of international research efforts made in collaboration with partner organizations, such as the International Geophysical Year and the Global Atmospheric Research Programme (GARP), which set the framework for ulterior progress in operational weather prediction and the vision for climate research and prediction.

With these antecedents, WMO established in 1998 its World Weather Research Programme (WWRP), under the scientific guidance of a Joint Scientific Committee (JSC), to support further advances in prediction research over various time-scales. Since then, the WWRP has increasingly contributed to meet user demand for additional improvements in terms of accuracy, lead-time, confidence and societal impacts.

Today, WMO-sponsored weather research includes nowcasting as well as the medium, global and seasonal scales, while WWRP research components contribute to prediction verification and product utilization. In addition, the Fourteenth World Meteorological Congress (Geneva, May 2003) has established the WWRP THORPEX Programme as a ten-year research effort to accelerate improvement in the predictive skill of high impact weather and weather information utilization.

It is therefore a pleasure for me to introduce the first Strategic Plan for WWRP Implementation, including WMO’s WWRP vision for the 2009 to 2017 time-frame. The plan also contains a review of WWRP history, research projects and accomplishments. I wish to thank all WWRP contributing experts from the WMO Commission for Atmospheric Sciences, as well as reviewers and the broader scientific community, for their key contributions.

(M. Jarraud)
WMO Secretary-General
EXECUTIVE SUMMARY

This is the first Strategic Plan of the WMO World Weather Research Programme (WWRP) of the Commission for Atmospheric Sciences (CAS) presenting the direction and plans for the implementation of the WWRP for the next 8 years. The motivation for the WWRP is to meet the needs of WMO Members by providing research to advance both the prediction of high-impact weather and the utilization of weather products for the benefit of society, the economy and the environment.

Although some components which are now part of the WWRP have been active for many decades, WWRP is a relatively young programme, created in 1998 and restructured by the Fourteenth Session of CAS in 2006 to make it a broader, stronger and more comprehensive programme dedicated to improving public safety, the quality of life, economic prosperity and environmental quality by serving as an international mechanism for:

- Advancing the science of weather-related research with a particular focus on advancing our knowledge of high-impact weather, improving the prediction of these events and measuring the improvements in prediction;
- Advancing our understanding of how society is impacted by and reacts to high-impact weather and forecasts of these events in order to improve the utilization of and response to weather information;
- Contributing to the advancement of the science of broader environmental prediction through partnerships and collaborative multidisciplinary research;
- Promoting and facilitating the transfer of these research advances into the operational practice at NMHSs and among their end-users; and
- Serving as the weather research underpinning for WMO efforts related to the WMO Natural Disaster Reduction and Mitigation Programme, operational weather prediction, user applications, and thereby contributing to relevant UN Millennium Goals.

This Strategic Plan begins with a description of the history and an overview of the WWRP, which is an Open Area Programme Group (OPAG) of CAS. Then, the scope, challenges, research priorities and research strategy as well as concrete and detailed implementation tasks for each research area of WWRP are presented. The main criteria for WWRP research activities is whether research advances would result from an orchestrated international collaboration. In selecting priority areas and future tasks, the WWRP considered advances in scientific knowledge and growing technical capabilities in both research and operational prediction. The WWRP vision also reflects society's growing need for weather information as driven by climate change, population growth and demographics that place greater numbers of people at risk for weather disasters. The activities in this plan include modelling intercomparisons, field campaigns, data impact studies, the establishment of specialized archive centres, and long-term research collaborations in critical areas where advancement has proven especially difficult. Since the underlying motivation of prediction is to benefit users, the WWRP also includes projects aimed at transitioning research to operations as well as non-physical science research aimed at understanding how weather information is utilized and how utilization could be improved.

The activities of the WWRP span nowcasting, mescoscale meteorology, global numerical weather prediction, tropical meteorology, forecast verification, weather modification assessment, and societal and economic research and applications. Given the breadth of the WWRP, scientific Working Groups have been set up to initiate and guide the activities in each of these areas. WWRP Working Groups composed of international leaders in weather research, operational weather prediction and the usage of weather information have been instrumental in the preparation of this document. Working Groups report to a Joint Scientific Committee (JSC) of WWRP. In the case of global numerical weather prediction, the Working Groups in the major areas of research have been focused into a single programme called THORPEX with its own internal organizational structure and a budget provided through donor contributions to a Trust Fund at the WMO. The intent of creating a single programme for this research area was driven largely by unmet research
challenges, since there has not been a broad international research programme aimed at global weather prediction since the GARP effort of the late 1960s and early 1970s.

The THORPEX (THe Observing Research and Predictability Experiment) programme

THORPEX is an international research programme whose scope is global and which aims to accelerate improvements in the accuracy of 1-day to 2-week high-impact weather forecasts. High-impact weather forecasts are defined by their effect on society, the economy and the environment. The overall research priorities are to address:

- Global-to-regional influences on the evolution and predictability of weather systems;
- Global observing system design and demonstration;
- Targeting and assimilation of observations; and
- Societal, economic, and environmental benefits of improved forecasts.

As noted earlier, THORPEX is a programme under WWRP with its own internal structure. Thus, THORPEX has an International Programme Office (IPO) within the WMO Secretariat and an International Core Steering Committee (ICSC) that oversee the activities of the programme. THORPEX also has regional committees for Asia, North America, the Southern Hemisphere, Africa and Europe that guide the implementation of the programme and three Working Groups to support the following research areas:

The Global Interactive Forecast System-THORPEX Interactive Grand Global Ensemble project supports research into probabilistic forecasting. An international database and archive of operational, global ensemble forecasts called TIGGE has been developed to enhance collaboration on development of ensemble prediction, internationally and between operational centres and universities and to develop a deeper understanding of the contribution of observation, initial and model uncertainties to forecast error. An important aspect of TIGGE research is to explore the value of
combining data from various systems for probabilistic forecasting of severe weather events. If justified by scientific results, a system for high-impact weather forecasting called GIFS may be developed in collaboration with the WMO Commission for Basic Systems, with an initial focus on tropical cyclones and heavy precipitation forecasting.

The Data Assimilation and Observing Systems research seeks to understand and improve how data assimilation and observations limit forecasts of high-impact weather. This research ensures that THORPEX contributes to the international efforts to optimize the use of the current WMO Integrated Global Observing System (WIGOS) and to develop well-founded strategies for the evolution of observations to support Numerical Weather Prediction primarily for the 1 to 14 day weather forecasting.

The Predictability and Dynamical Processes research provides the connection between the academic dynamical meteorological community and the operational numerical weather prediction centres. It encourages this community to carry out dynamical process studies with the specific aim of improving the understanding of the relationship between particular processes and the forecast accuracy for high-impact weather. An outcome of these activities is knowledge concerning the barriers to improving forecast skill and the extent to which these barriers can be reduced.

Specific international collaborative projects currently include the THORPEX Pacific Asian Regional Campaign (T-PARC), a major field campaign supporting the THORPEX as well as the WGTMR research priorities; the IPY-THORPEX project cluster, addressing key issues related to the analysis and forecasting of polar weather, better use of satellite data, etc; and the Year of Tropical Convection (YOTC), a collaboration with the World Climate Research Programme (WCRP) addressing the representation of tropical convection in atmospheric models.

Mesoscale Weather Forecasting Research
The purpose of Mesoscale Weather Forecasting Research is to promote weather forecasting research on the meso-gamma scale (~500m – 3km), covering time scales from 0 - ~48h, and to strengthen international cooperation, knowledge transfer and capacity building in this field. Mesoscale prediction systems are driven toward this high resolution because the largest impacts on society tend to be regional or even local in nature. The Working Group on Mesoscale Forecasting research guides WWRP activities in:

- Mesoscale data assimilation: investigations on the strengths and limitations of different data assimilation approaches, and observation impact studies;
- The representation of convection and complex terrain in mesoscale models;
- The role of the surface in mesoscale modelling and assimilation systems, and the ways to represent and consistently assimilate surface characteristics in mesoscale models; and
- Predictability at the mesoscale, and the design and performance evaluation of mesoscale ensemble forecast systems.

Nowcasting Research
The focus of WWRP Nowcasting Research is to promote detection and forecasting weather over the 0 to 6 hour time frame, to advance nowcasting science, and to undertake capacity building and expertise sharing within the WMO framework. Nowcasting systems fill an information need for a variety of users (e.g., emergency services, defence forces, security agencies, the transport industry, hydrologists, the agricultural community, recreational groups and air quality agencies), since such systems often outperform numerical weather prediction in the first several hours of a forecast. The research priorities established by the Working Group on Nowcasting Research for WWRP efforts include:

- Improving nowcasting predictive skill and characterizing uncertainty;
- Promoting physically based nowcast prediction through high resolution model development and data assimilation;
- Developing improved observational capability in nowcasting;
- Characterizing observational errors and algorithm processing errors and their impact on nowcasting; and
- Improving automated nowcast processes, optimizing the role of humans and developing supporting systems for the rapid detection and effective dissemination of information.

Tropical Meteorology Research

The goal is to support tropical meteorology research internationally that will lead to improved observation, analysis, forecast, and warning systems for high-impact tropical weather events, and thus contribute to disaster prevention and mitigation. The highest research priorities stem from the most significant health and safety threats where improved science can reduce the impacts. Hence, WWRP Tropical Meteorology Research has two foci, which are supported by panels in Tropical Cyclone and Monsoon research. The priorities established by the Working Group on Tropical Meteorological Research include:

- To advance understanding and capability to forecast tropical cyclone landfall and its impacts, which require a prediction of structure, intensity, and movement of these systems; and
- To advance understanding and capability to predict heavy monsoon rainfall events and their impacts. These forecasts cover time-scales from nowcasting to medium range forecasts and collaborations with the climate research community where substantial interests in monsoon systems exist.

Verification Research

WWRP Verification Research is a joint activity with the Working Group on Numerical Experimentation (WGNE). Its purpose is to encourage and facilitate focused research on forecast evaluation methods. Verification research is a critical component of the WWRP research agenda as the end result of this research is to demonstrate new research advances in an operational environment and quantify both the gains in skill and the user benefits. The members of the joint working group in this area represent both the operational and research communities. Research priorities include:

- Development of forecast evaluation measures that are meaningful in terms of forecast use/value;
- Approaches to partition forecast error as a function of spatial and temporal scales;
- Verification methods for forecasts of probability distributions produced by ensemble prediction systems;
- Verification methods for weather extremes, including severe weather warnings;
- Techniques targeted toward high-resolution forecasts (e.g., spatial forecast verification methods using radar, satellite or lightning data); and
- Understanding the properties of verification methods and measures (i.e., meta-verification) to provide guidance on appropriate application of verification approaches.

Weather Modification Assessment

The Expert Team on Weather Modification Research has been established as a component of the WWRP by the Fifteenth WMO Congress in 2006 to promote scientific practices in weather modification research. Its main foci are:

- To review relevant research, to advise on issues requiring attention related to weather modification and to suggest mechanisms for addressing such issues; and
- To lead a review every three years of the “WMO Statement on Weather Modification” and the “WMO Guidelines for the Planning of Weather Modification Activities”

For details of weather modification assessment activities and the WMO statement and guidelines see http://www.wmo.int/wxmod
Societal and Economic Research and Applications (SERA)

The purpose of the WWRP Societal and Economic Research and Applications activities are to advance the science of the social and economic application of weather-related information and services. The SERA community includes multidisciplinary social, economic or decision scientists, organizations that engage users in the development, application and use of weather and related information and representatives of users that benefit from this information. The emphasis is on weather conditions that directly influence mortality, morbidity, significant loss of property and critical infrastructure and resources required to support communities. WWRP SERA is a joint activity with the Integrated Research on Disaster Risk programme of the International Council of Science Unions governed by a SERA Working Group. Research priorities include:

- Estimation of the economic (societal) value of weather information;
- Understanding and improving the use of weather information in decision making;
- Understanding and improving the communication of weather forecast uncertainty;
- Development of user-relevant verification methods; and
- Development of decision support systems and tools.

WWRP Challenges and Strategy

Considering the complexity of the scientific issues to address as well as the need to transfer research advances to operations in order to improve weather services, the overarching WWRP challenges are:

a) To be the international focal point for weather research by maintaining a tradition of excellence in research through initiating, leading and/or participating in major international field campaigns, and major weather research programmes and projects;

b) To bring together the different WWRP research and operational communities to develop improved data assimilation, observing, verification, application and modelling strategies through the sharing of expertise and approaches among the various components of the WWRP;

c) To further broaden and enhance its research collaborations in environmental prediction with groups such as EPAC, CHy and WCRP, to address scientific issues of common interest and to help develop new collaborative Earth-system projects to face new demands and to address a variety of environmental, economic, social and policy issues;

d) To maintain and enhance the WWRP focus on priority operational needs and on operational demonstration and implementation of research advances; and

e) To maintain a strong focus on training opportunities for young scientists, in particular from developing countries.

To meet these challenges, the primary research strategy will be to promote, initiate, coordinate or manage

- Field campaigns, long-term research projects and programmes that are well suited for international collaboration and are designed to advance the underlying science of weather forecasting, to use research to advance forecasting techniques and to enhance the utilization of weather information;
- The establishment of archive centres that bring together international data sets that would not be easily accessible through other means and to set up reference datasets that form the basis for testing, comparing and improving modelling and data assimilation strategies.
- End-to-end Research and Development Projects (RDPs) to advance understanding of weather processes, improve forecasting techniques and increase the utility of forecast information with an emphasis on high-impact weather;
- Forecast Demonstration Projects (FDPs) to evaluate research techniques, tools and concepts in an operational setting to facilitate the transfer of research results into operational practice; and
The WWRP will also promote and conduct training courses, organize or sponsor workshops and conferences, and publish results, in order to share knowledge and train scientists, in particular in developing countries.

The WWRP will also promote and engage in broader collaborations. It will continue to largely represent CAS in collaborative activities of WGNE on the study of physical processes in atmospheric models, on verification techniques, on linkages with the operational NWP Centres and on data assimilation research. It will continue to collaborate with the CBS for the improvement of weather forecasting systems, in particular, by promoting research on forecast systems, developing rigorous approaches for evaluating the performance of forecast systems and partnering on the operational implementation of research advances. The WWRP has already established links with hydrological prediction teams that focus on hydrological models driven by observations and/or the output of atmospheric weather models. The MAP D-PHASE project was a success in this regard. These collaborations may be driven by improvements in modelling capabilities that are making quantitative precipitation forecasts more usable to hydrologists as well as growing observational capabilities from ground-based radar and space-borne remote sensing. In the future, collaborations could grow in the areas of ocean coupling and storm surge modelling.

WWRP will also build more collaboration with the Global Atmosphere Watch air chemistry research programme of WMO and promote the inclusion of aerosols and chemical constituents in future generations of operational weather analysis and forecasting systems for improved weather and provision of many types of environmental prediction. The WWRP has taken the lead, in collaboration with GAW, for the WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS). The SDS-WAS mission is to enhance the ability of countries to deliver timely and quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities. This mix of research and operational communities is required because of the immaturity of the science related to aerosols and their inclusion in weather models.

The Shanghai Integrated Multi-Hazard Early Warning System (MHEWS) project is a critical component of the Shanghai disaster preparedness strategy, illustrating the benefits of a multi-hazard approach, with the Shanghai Meteorological Bureau (SMB) as the key management and implementation agency. The WWRP is involved in a RDP on early warning systems for tropical cyclones forecast and verification with a planned real-time use of GIFS-TIGGE data sets that may be supplemented with regional ensemble modelling.

Finally, the WWRP will also seek to expand its partnerships with the WCRP largely through THORPEX. This motivation, in part, is driven by recent work that shows some of the important biases in climate modelling are evident in 3 to 5 day weather forecasts. The WWRP has also already established four areas of collaborative research with the WCRP for the improvement of sub-seasonal to seasonal predictions. The development of Ensemble Prediction Systems (EPSs), tropical convection and its two-way interaction with the global circulation, data assimilation for coupled models as a prediction and validation tool for weather and climate research, and socio-economic applications of sub-seasonal to seasonal predictions. In addition, the WWRP through its Working Group on Tropical Meteorology Research (WGTMR) works together with the relevant components of WCRP on tropical cyclone and monsoon research. The Tropical Cyclone Panel and the Monsoon Panel of the WGTMR have set up Expert Teams on Climate Impacts on Tropical Cyclones and Monsoon Weather, respectively, with the participation of WCRP researchers and projects. The Monsoon Panel, in particular, works closely with the WCRP monsoon programmes including CLIVAR and GEWEX Monsoon Panels, and field programmes such as the Asian Monsoon Year 2008-2011.

This WWRP Strategic Plan does not only present general research priorities and strategies, it also describes detailed and specific implementation tasks for each component. More than 200 implementation tasks are presented in this plan, to ensure that the proposed direction will indeed become a reality, that the expected research outcomes will be attained, and that effective transfer towards operational systems will be facilitated.
The WWRP has already produced very tangible research results, many of which have been successfully transferred to operations. Some examples are described in this plan. Nevertheless, an unacceptably large number of people are still killed, injured, suffer from disease, or are displaced as a direct or indirect result of weather-related events, especially in developing nations. In all regions the material and economic costs of weather-related hazards are substantive and are growing based on substantial available evidence. With this plan, the WWRP will foster and orchestrate targeted international collaborative research activities of high quality that will help WMO Members improve the accuracy, the spatio-temporal resolution and the advanced warning of weather forecasts and services, enabling decision makers to minimize the negative impacts of weather hazards while improving the mitigation actions. The WWRP will also foster greater collaboration with various groups to accelerate the development of environmental predictions where weather plays a crucial role.
1. INTRODUCTION

This document is the first Strategic Plan for the Implementation of the World Weather Research Programme (WWRP) of the World Meteorological Organization (WMO). It describes the strategic approach, defines the programme components and specifies implementation plans for WWRP in the next eight years. This Strategic Plan reflects the reorganization of the WWRP by the Fourteenth Session of the Commission for Atmospheric Sciences in 2006 (WMO Tech. Doc. 1002) when the Tropical Meteorology Research Programme, the THORPEX Programme, and new research activities in societal applications and mesoscale forecasting were combined with the existing activities of the WWRP. Now, WWRP is a large diverse programme, with a unifying theme: predicting weather events that have a significant impact on the quality of life, are economically disruptive, significantly degrade the environment or are life threatening. High-impacts events include severe weather, hydrological and environmental events with strong, obvious detrimental effects (e.g., fog, heat waves, cold air outbreaks, air pollution episodes, sand and dust storms), but also less extreme everyday situations where an improved forecast can lead to significant economic benefits or other desirable effects. Given the diversity in user demands and scientific challenges, the activities of the WWRP span weather prediction time-scales from minutes to hours of "nowcasting" weather with a heavy reliance on observations to forecasts of the days, weeks and even seasons. In terms of phenomena, the WWRP activities include middle latitude weather, tropical systems such as tropical cyclones and polar regions where climate change is already evident.

The activities of the WWRP lie at the intersection of challenging scientific research and society’s need for improved weather prediction. The WWRP aims to accelerate progress in the skill and in the utilization of high-impact weather forecasts. To accomplish these aims, WWRP research spans the spectrum from fundamental research to applied research to develop and test the strategies for advancing prediction and utilization of weather information. The fundamental research component is included to ensure sustained progress. To benefit users and National Meteorological and Hydrological Services (NMHSs), the WWRP activities also include technology transfer and training. Since the WWRP is first and foremost a research programme, the operational transition and training efforts will focus on transferring the results of research to operations and on novel, new uses of weather information. The WWRP seeks to involve and benefit WMO Members in the developing world and in the least developing countries, particularly in training. The WWRP has and will continue to establish a variety of collaborative efforts within and outside of the WMO to meet these goals.

1.1 The rationale for the World Weather Research Programme (WWRP)

The underlying motivation for the WWRP is to meet user demands for improvements in the accuracy, lead-time, confidence and utilization of forecasts of weather that have a significant impact on society, the economy and the environment.

A major focus is on disasters as they exert huge impacts on the health and safety of populations. The frequency of disasters worldwide is illustrated in Figure 1. Weather events account for approximately two thirds of the natural disasters in the form of floods, wind storms, slides (e.g., primarily mud slides and avalanches induced by precipitation), extreme temperatures, and wild fires (typically associated with high winds, low humidity and high temperatures). Floods and wind storms (primarily tropical cyclones) are by far the most common type of disasters that impact our planet accounting for over half of the disasters. Weather also factors into other disasters as droughts occur or are intensified at time-scales between weather and climate, while famine, epidemics and insects are typically tied to or intensified by hydrometeorological events. In terms of the frequency of disasters, geological events are clearly secondary to hydrometeorology accounting for only 10% of the frequency of events.

An important aspect of natural disasters is how their frequency has increased with time. For example, approximately 100 natural disasters per decade occurred between 1900-1940, while that number has risen to almost 2800 events per decade in the 1990s (ICSU 2008).
In contrast to the growing number of disasters, fatalities from weather-related disasters have decreased dramatically between the 1950s (~2.7 million per decade) and the 1990s (250,000 per decade). The time frame of this decrease corresponds to great scientific and technological advances such as the deployment and utilization of ground-based and space borne remote sensing, the development of forecasting systems from nowcasting to numerical weather prediction, and more rapid means of processing and communicating information. These advances have generated constant improvements in forecast accuracy and lead times, allowing societies to better inform and protect their populations.

While the decrease in direct fatalities from weather events over this time period is certain, wide discrepancies exist in the total number of fatalities from disasters. For example, the OFDA/CRED data base reports an average of less than 100,000 fatalities a year from all disasters over the period from 1985 to 2005, while the Science Plan for the programme on Integrated Research on Disaster Risk states “Hundreds of thousands of people are killed each year and millions injured, affected or displaced each year because of disasters…”. A higher estimate of the fatalities from hydrometeorological disasters can also be found in Platz et al. (2005) where it is estimated that the effects of climate change on the frequency, intensity and location of hydrometeorological events alone accounts for ~150,000 fatalities annually. Presumably, the number of fatalities from the entire spectrum of hydrometeorological events is a far larger number.

One explanation for these differences is the indirect effects of weather events that reach beyond the immediate aftermath of an event. For example, three of the larger causes of health related fatalities across the globe (malaria, diarrhea and malnutrition) are closely linked to variations in weather and seasonal conditions. Malaria accounts for approximately one million fatalities and two million children die each year from diarrhea, primarily in the developing world. Thus, it is clear that the indirect and longer time-scale impacts of weather disasters and other high-impact weather events are significant and perhaps as large as the immediate toll of a disaster. In addition, while disasters receive by far the most intense scrutiny by the public, governments, aid organization and the media, the day-to-day variations of weather also can have detrimental impacts on society through traffic accidents, health emergencies and economic disruptions, which is reflected in the larger numbers of fatalities.

In addition to health and safety impacts, the economic cost of disasters to society are huge, reaching nearly 500 billion (US dollars) per decade with the costs of hydrometeorological disasters increasing by a staggering factor of 7 in the time period of 1997 to 2007. The dramatic increase in cost is due to a number of factors including the increase in the number of disasters, the expanding
material wealth of segments of society, the exponential growth of the world's population, climate change, globalization that expands the geographical footprint of any event, changes in land use such as deforestation and demographic shifts associated with concentrating populations into urban areas, flood plains, coastal regions and other vulnerable areas. These factors will continue to place a growing strain on the ability to mitigate the costs of hydrometeorological disasters.

More generally, weather events, even mild ones, have tremendous economic impacts. A small but growing literature has emerged over the past 40 years that documents and estimates the use and value of weather and climate information. Katz and Murphy (1997) provide one of the most critical and comprehensive collections of referenced work and critique a wide spectrum of methods available to determine economic value. Many researchers focus on particular sectors, for example studies have been completed for aspects of agriculture (e.g., Johece et al., 2001; Fox et al., 1999), energy (e.g., Roulston et al., 2002), health (e.g., Ebi et al., 2004), forestry/fire management (e.g., Gunasekera et al., 2005), tourism (e.g., Anderson-Berry et al., 2004), transportation (Keith, 2003; Stewart et al., 2004), and water resources management (e.g., Hamlet et al., 2002). In some cases, even small improvements in predictive skill may result in large benefits if the information is effectively applied in decision-making: for example, net present value of benefits to U.S. electrical utilities derived from improving temperature forecast by 1C were estimated to be $1.2B (e.g., Teisbert et al., 2005). Others have examined a particular component of the monitoring and forecast system, such as the impact of a new delivery service (e.g., Weatheradio, Cavlovic et al., 1997) or an expanded network of Doppler radar infrastructure (Vodden and Smith, 2003). This latter study found that the discounted benefits of the improved national radar programme in Canada would amount to CA$433M relative to costs of CA$88M over a ten-year horizon.

Complementing these efforts are broader evaluations of multiple sectors and public or household willingness-to-pay for weather services (e.g., Rollins and Shaykewich, 2003; Lazo and Chestnut, 2002; Brown, 2003). Such studies most often examine the value of information that is currently received or that could be obtained with some specified level of improvement in quality (i.e., precision, accuracy, delivery frequency or medium). The numbers can be quite staggering—a recent analysis by Lazo et al. (2009) suggests that weather forecasts generate about US$31.5 billion worth of benefits each year to U.S. households relative to an estimated US$5.1 billion expended by public agencies and the private sector in the research, development and delivery of meteorological weather information and services.

From these statistics we can conclude that advances in weather prediction over the past century have likely contributed to reductions in casualties and increases in the efficiency and production of goods and services (e.g., agricultural yields, transportation). Nevertheless, an unacceptably large number of people are still killed, injured, suffer from disease, or are displaced as a direct or indirect result of weather-related events, especially in developing nations. In all regions the material and economic costs of weather-related hazards are substantive and are growing based on substantial available evidence.

The rationale for the WWRP is based on the understanding that research and the transition of research to operational activities in NMHSs will benefit users by accelerating the rate of improvement both in the predictive skill and in the ability of society to use weather information. Furthermore, as the scientific issues to be addressed are complex and frequently interlinked, a single coherent international effort on weather research will maximize the benefits to society by synthesizing efforts of the various research components to address key challenges faced by NMHSs, such as “What is the optimal design of observing systems from the perspective of the prediction of high-impact weather?”, “What are the barriers to improving prediction skill and can these barriers be reduced, and, if so, how?”.

1.2 The mission of the WWRP

The WWRP exists to develop, share and apply knowledge that contributes to societal well-being, principally by helping to manage weather-related risks to safety and property but also by enabling individuals, businesses, and institutions to take advantage of opportunities afforded by
weather conditions. Fundamental aspects of this knowledge include an improved understanding of atmospheric processes that give rise to weather phenomena and enhanced ability to predict weather events and their consequences with sufficient spatio-temporal precision, accuracy, and advanced warning to support decisions.

The mission of the WWRP is thus to improve public safety, the quality of life, economic prosperity and environmental quality by bring together researchers, scientists from operational centres and users together to serve as an international focal point for:

- Advancing the science of weather-related research with a particular focus on advancing our knowledge of high-impact weather, improving the prediction of these events and measuring the improvements in prediction;
- Advancing our understanding of how society is impacted by and reacts to high-impact weather and forecasts of these events in order to improve the utilization of and response to weather information;
- Contributing to the advancement of the science of broader environmental prediction through partnerships and collaborative multidisciplinary research;
- Promoting and facilitating the transfer of these research advances into the operational practice at NMHSs and among their end-users; and
- Serving as the weather research underpinning for WMO efforts related to weather prediction, user applications, disaster mitigation, and thereby contributing to relevant UN millennium goals.

Accomplishing this mission will require ensuring:

- The relevance of WWRP activities through obtaining knowledge of the needs of WMO operationally-driven components, NMHSs, and end users for weather information;
- The structure and work of the WWRP efficiently covers the key activities of NMHSs (e.g., nowcasting, mesoscale/limited area modelling, medium range prediction, verification/assessment) and their key service demands (e.g., societal research and applications, tropical and polar prediction);
- The talents and respective strength of the research enterprise within the academic, research institutes and NMHSs come together to accelerate progress in the understanding and prediction of high-impact weather events and their impacts on society; and
- The sharing of ideas, observations, forecasting techniques and modelling advances among researchers.

Specific actions of the WWRP are:

- To promote, initiate, endorse, coordinate and/or manage:
  o Field campaigns, long-term research projects and programmes that are well suited for international collaboration and are designed to advance the underlying science of weather forecasting, to use research to advance forecasting techniques and to enhance the utilization of weather information;
  o The establishment of archive centres that bring together international data sets that would not be easily accessible through other means and to set up reference datasets that form the basis for testing, comparing and improving modelling and data assimilation strategies.
• End-to-end Research and Development Projects (RDPs) to advance understanding of weather processes, improve forecasting techniques and increase the utility of forecast information with an emphasis on high-impact weather; and
• Forecast Demonstration Projects (FDPs) to evaluate research techniques, tools and concepts in an operational setting to facilitate the transfer of research results into operational practice.
• Archive centres that bring together international data sets that would not be easily available through other means and to set up reference datasets that form the basis for testing, comparing and improving modelling and data assimilation strategies

• To develop and apply methods, in conjunction with other WMO programmes, for assessing the cost-benefits of improved forecasts of high-impact weather events;

• To promote and conduct training courses to further the exchange of information between the research, NMHSs and user communities and to transfer research advances into operational practice among NMHSs and weather-related applications (e.g., hydrology, health and agriculture, climate and seasonal prediction services);

• To organize, sponsor and/or cosponsor workshops, conferences, symposia and other meetings designed to further the exchange of information among researchers and between researchers, other WMO entities, NMHSs and end-users; and

• To publish the results of WWRP activities as well as assessments of the state of knowledge and recommendations of best practices in WMO publications, scientific journals and other venues including informing the public by working with the WMO and NMHSs to link with the media.

References


2. **ORGANIZATION**

2.1 **Roots of research within the WMO**

A leadership role in weather research for the WMO can be traced back to 1953 and 1960 when formal agreements were established between the WMO and the International Council of Scientific Unions (ICSU) and its component efforts. The general philosophy of this partnership was for the WMO to bring its expertise in “the scientific problems of the professional applied meteorology”, while ICSU brought “the scientific strength of the universities”. These agreements led to the WMO participation in the International Geophysical Year in 1957 and in the wide variety of activities associated with the Global Atmospheric Research Programme (GARP) of the late 1960s and 1970s. The GARP effort, in particular, was a landmark activity for atmospheric research that established the framework for operational weather prediction. The immediate legacies of the GARP effort relevant to the WWRP today include the establishment of the Working Groups on Numerical Experimentation (WGNE) and on Tropical Meteorology. The Working Group on Tropical Meteorology was designed to focus on those aspects of research that had the potential for significant social and economic benefit. The WMO body responsible for overseeing these research efforts within the WMO was the Commission on Aerology, which subsequently became the Commission for Atmospheric Sciences (CAS), which remains the technical commission that oversees research within the WMO. In addition, the World Climate Research Programme was another effort that can be traced to GARP; it is jointly sponsored by the WMO, ICSU and other partners. Atmospheric chemistry research has its own long history at the WMO with the establishment of the World Ozone Data Centre in Toronto in 1960.

In addition to tropical meteorology, another early research area of the WMO was weather modification and cloud physics. These activities began in 1954 in association with summary reports that addressed the scientific foundation of weather modification, where activities at that time took place in the commercial sector. The need to subject the claims of weather modification to stringent scientific tests led to the WMO coordinated research efforts such as the Precipitation Enhancement Project in 1975. The efforts in this area grew in scope so that the 10th WMO Congress established a Cloud Physics and Weather Modification Research Programme in 1987. In an attempt to meet the broader needs for weather prediction research, two additional working groups were established by CAS in the 1980s. The first was on Short and Medium Range Weather Prediction Research and the second was on Long-range Forecasting. The working group activities were diverse and included oversight of a variety of research projects, organizing workshops, symposium and other scientific meetings, preparing and publishing technical reports and organizing data catalogues and data sets.

2.2 **The founding of the WWRP**

The WWRP was established in 1998 when the Executive Council accepted the CAS recommendation to consolidate prediction research efforts by working groups on time-scales ranging from very short range to long range forecasting. A Science Steering Committee was created to provide scientific oversight of the WWRP within the context of the general priorities dictated by CAS, WMO Executive Council and WMO Congress. The Science Steering Committee was proactive in its role and established frameworks for the types of projects that would take place under the WWRP and a formal mechanism for reviewing and approving these projects. The design, evaluation and approval of such projects have been a focus of the Science Steering Committee since its first meeting in 1998. These projects generally brought together expertise from the research and operational community in nowcasting, mesoscale (e.g., regional) modelling, verification, and societal impacts. The two types of projects¹ under this framework are:

- **Research and Development Projects (RDP)** are designed to address challenging forecast problems where progress will be accelerated through organized international collaboration. The goals of RDPs include improving skill in numerical weather prediction models and nowcasting systems, developing improved and more cost effective forecasting

¹ The criteria for RDPs and FDPs are included in Annex 6.
techniques, and advancing knowledge of critical atmospheric processes and their treatment in the forecast process. RDPs can range from observational-based field experiments to activities focused solely on modelling, data assimilation or other components of the forecasting system.

- **Forecast Demonstration Projects (FDPs)** that serve to exhibit and formally quantify the benefits to be derived from improved understanding and enabling new technologies and techniques. The improved understanding and technological advances, the benefits of which are to be demonstrated, may or may not be a direct consequence of other WWRP activities, although in practice there has been a strong link between WWRP research and FDPs. In addition, the FDPs must address the objectives of the WWRP. A criteria for FDPs is that it will involve the dissemination of forecast information to real users in real time. Candidate FDPs will be selected on the basis of readiness of the science, timeliness of the demonstration, and feasibility of technology transfer and training. The guidance from CAS has been to extend this concept to Members from the developing world and accordingly the Science Steering Committee developed criteria for FDPs in developing nations.

### 2.3 Overview of the current WWRP

From these early roots, the WWRP has become a comprehensive and broad effort for weather research addressing prediction research from minutes to subseasonal for high-impact weather phenomena from the tropics to polar regions. The concept of an active science steering committee to guide the programme remains today and is currently called the Joint Scientific Committee (JSC). The components of the WWRP are shown in Figure 2.

**The WWRP has one programme, which is the THORPEX (THe Observing Research and Predictability Experiment) programme.** THORPEX was established in 2003 by the 14th WMO Congress as a ten-year research programme designed to accelerate the current rate of improvement in predictive skill in the 1 to 14-day range of high-impact weather and to improve the utilization of weather information. The implementation phase of THORPEX began in 2005. To date, the strengths of THORPEX include bringing the academic and operational communities together to select paths where coordinated research is thought to lead to improvements in forecast skill and then develop and implement a multi-year research effort to conduct this research. These long-term efforts do not readily fit the RDP and FDP conventions. Examples to be discussed subsequently in this document include: i) A multi-model, multi-centre global research archive containing the ensemble members of ten ensemble modelling systems called the THORPEX Interactive Grand Global Ensemble (TIGGE); ii) Regional field campaigns (e.g., A-TReC, T-PARC, E-TReC) and data impact studies designed to make recommendations on the optimal design of the global observing system for high-impact weather; iii) A collection of ten projects under the International Polar Year that is designed to advance under standing and improve prediction of high-impact weather in polar regions; iv) The Year of Tropical Convection. As will be discussed in Chapter 4, embedded within THORPEX are three Scientific Working Groups and five Regional Committees. As a programme supported in large part by a Trust Fund from Member Contributions, THORPEX has its internal management structure and an International Project Office. The JSC makes scientific recommendations on THORPEX efforts for consideration by the THORPEX management structure. Although THORPEX is involved in predictions on the 1 to 14-day time-scale, in practice, the primary focus of THORPEX has been on global numerical weather prediction.
Working Groups on Nowcasting Research (WGNR) and on Mesoscale Weather Forecasting Research (WGMWFR) that cover prediction research on time-scales of minutes and hours (nowcasting) to 2 days (mesoscale forecasts). To date the WGNR has been primarily focused on the testing, improvement and technology transfers of nowcasting systems developed for improving the prediction of convective rainfall in the time period where such systems outperform numerical weather prediction (e.g., often a 0 to 3-6 h time-frame). The WGNR has been the lead proponent of FDPs and RDPs, such as FDPs during the Sydney and Beijing Olympic Games and the MAP D-PHASE FDP. Such a focus is a natural outcome of nowcasting research as these systems are often run locally without any intercomparison. In contrast, of course, global modelling systems have a framework for modelling. The FDP approach, which often includes testing and intercomparison of nowcasting systems years before the event has typically had the benefit of initiating improvements in the various research and operational nowcasting systems that participate in these projects. The FDPs are also associated with training to further transfer the benefits to Members. The WGMWFR was established at the CAS XIV in 2006 and fills a critical void between the THORPEX tendency to focus more on global modelling and the nowcasting efforts on the scale of radars and radar networks. The WGMWFR is focusing on the forefront of limited area modelling, concentrating on modelling systems with scales (~1 km) that begin to resolve convective systems. This relatively new working group includes representatives who contributed to MAP D-PHASE FDP; the group was also involved in the Beijing RDP on mesoscale ensemble forecasting.

The Working Group on Tropical Meteorology Research (WGTMR), one of the earliest research focus of the WMO, has been maintained as a research activity in the WWRP due to the societal impacts of weather systems on Member nations from tropical regions with large population centres and, in some cases, developing and least developing status of affected nations. Another reason for this group is the specialized nature of tropical meteorology. Up until CAS XIV in 2006, this effort was a separate programme under tropical meteorology; CAS XIV incorporated these tropical activities into WWRP as a working group. In comparison to the other Working Groups in CAS, the
WTMR is relatively large with two panels dealing with specific issues generally focused on activities related to tropical cyclone and monsoon rainfall. The strengths of the WGTMR include: i) Training designed to expose forecasters to research advances and concepts; ii) Workshops that include broad segments of the research, operational, user and other communities to recommend research priorities and operational strategies for advancing forecasting and user response to forecast information. The International Workshop on Tropical Cyclones (IWTC), with its strong partnership between the WMO’s operational Tropical Cyclone Programme and WGTMR, is one example of an effective means of establishing and implementing actions on research and operational priorities. The International Workshop on Monsoons (IWM) and its associate Monsoon Training Workshops have become a forum for sharing WWRP and WCRP monsoon expertise, and as a result have helped to introduce both weather and climate aspects of monsoon research advances to the operational NMHSs. The intent is to build upon these strengths to be a focal point to initiate and guide international research projects, programmes, RDPs and FDPs on these topics.

The Joint (WWRP-WGNE) Working Group on Verification Research (JWGVR) plays a broad role in the WWRP by having projects focused on verification of forecasts, while also guiding the implementation of the various RDPs, FDPs and other projects of the WWRP. The JWGVR is at the forefront of developing and testing new verification techniques including the development of a real-time verification system and special techniques for precipitation verification. The group has also an extensive outreach effort including web-based tools, tutorials, workshops, WMO technical documents and publishing of special issues in the scientific literature. An important current focus of the working group is on techniques to evaluate predictions with km-scale models, such as object oriented approaches, which provide assessments of skill and also information on model strengths and shortcomings.

The Working Group on Societal and Economic Research and Applications (WGSEMA) was established at CAS XIV in 2006. Before this time, the WGSEMA was a working group within THORPEX where it was intended to address the major societal issues. The intent of the 2006 change is to have the WGSEMA serve broader activities of the WWRP, with a small, but active societal and economic research and applications component built into the RDPs and FDPs. This mode of action has worked relatively well (e.g., MAP D-PHASE had tens of active users involved in the FDP and these users financially supported the operational continuation of the project after its completion as a WWRP effort). The establishment of activities has proven difficult for several reasons including getting a critical mass of technical experts. To meet this need, the WGSEMA is being established as a joint committee with the ICSU Programme on Integrated Research on Disaster Risk, which has other formal co-sponsors.

The Expert Team on Weather Modification Research (ET-WMR) is another entity within WWRP with long historical roots. This expert team continues to play an important role in assessing the state of weather modification research and providing guidance on the scientific validity of weather modification to WMO Members.

Cross-cutting projects are also an important component of the WWRP. These projects increase the scope, reach and impact of the WWRP through collaborative efforts which are frequently multidisciplinary. In some cases these projects can be quite extensive such as the Sand and Dust Storm Warning, Advisory and Assessment System between the WWRP and the Global Atmospheric Watch, and the ten projects of the IPY-THORPEX cluster. In all cases these projects have made unique contributions to support research activities, such as the modelling archive of the THORPEX-WCRP Year of Tropical Convection project, which makes all the forcing terms necessary to understanding the treatment of precipitation in the global model of the ECMWF easily available to the international research community. These projects are described in more detail later in this plan.

2.4 Governance of the WWRP

The WWRP is an Open Programme Area Group (OPAG) of the CAS, one of the eight Technical Commissions within the WMO. The Commission meets every four years and consists of
representatives of WMO Members. As a research programme, these representatives often include national experts in research and operational prediction. The CAS provides overall direction on the status and orientation of the programme and is responsible for major decisions of the WWRP (e.g., establishment or abolition of working groups, new research directions, recommendations on the formation of new long-term programmes). The CAS plays a major role in recommendations that will be brought to the WMO Congress, such as the recommendations for new programmes, major changes in the research agenda of the WWRP or recommendations on how the WWRP interacts with other components of the WMO. The WMO Congress also meets every four years.

A major programme such as the WWRP cannot function with advice on activities every four years as research advances occur and new projects develop and are implemented on a more rapid time-scale. Thus, the WWRP looks toward the annual meetings of the CAS Management Group, the WMO Executive Council and the WWRP JSC for guidance. The terms of reference for the WWRP JSC appear in Annex 2. The day-to-day running of the WWRP is a partnership between the JSC Chair, the Working Group Chairs/Co-chairs and the WMO Secretariat in consultation with the CAS President. As noted earlier, THORPEX has its own governance structure, but this management is also guided by the CAS Management Group, the JSC of the WWRP and the WMO Executive Council. The governance of THORPEX is described in Chapter 4.

As the current programme illustrates, the WWRP covers a broad range of topics, scales and phenomena associated with weather prediction research. In some cases, the focus areas of research associated with the WWRP reach back many decades, while in other cases the projects and Working Groups are relatively new. In some cases, this difference has resulted in different modes of operation between groups. The mode of using FDPs and RDPs versus long-term research foci is one example. Another is the difference in the focus on outreach and training between the various components. While it is not the intent of this plan and associated planning exercise to force the activities of the different components to be standardized in technique, it is hopeful that this first exercise in overall planning will spread the effective strategies and approaches between the different components. In this regard, a template for terms of reference for the Working Groups appears in Annex 3. To date, both the WWRP and THORPEX within the WWRP have had regional rapporteurs. To streamline this process, regional rapporteurs will represent the entire WWRP including THORPEX. Their terms of reference are in Annex 4.

### 2.5 National Meteorological and Hydrological Services (NMHS)

A strength of the WWRP is the involvement of the staff of the research and operational departments of the NMHSs. Their participation extends not only to meetings and Working Group membership, but also includes active involvement in RDPs, FDPs and other modelling, data assimilation and observational studies. Their actions enable the WWRP research activities to be far more vibrant due to this large reservoir of research talent with their access to super computer facilities, operational models and data. The NMHSs are also a source of direction for the research activities since user needs and the deficiencies of operational models and forecasting systems help drive the selection of research topics within the WMO. The combination of interested academic researchers with these operational efforts are relatively unique strengths of the WWRP.

### 2.6 WMO Secretariat support

Within the WMO Secretariat, the WWRP is administered within the WMO’s Research Department, which also deals with the World Climate Research Programme (WCRP) and the Global Atmospheric Watch (GAW). Within the Research Department, the activities of the WWRP are administratively and technically supported by the World Weather Research Division (WWRD) and the THORPEX International Project Office (IPO). Activities are quite varied and run from support of meetings, publications, web sites to assistance in the oversight of the variety of WWRP projects and activities. The staff of the WWRD including the THORPEX IPO consists of the Chief of the Division, an administrative assistant, a full-time senior technical officer, and portions of three part-time technical officers.
3. CHALLENGES

3.1 Background

Whether on an urban or planetary scale, covering a few minutes or a few months, the activities of the WWRP are dedicated to improving the prediction of high-impact weather. This challenge, at the crossroads of scientific research and society’s need, is considered to be among the leading environmental challenges of our time. Since the groundbreaking work of C. Abbe (1901), V. Bjerknes (1904) and L.F. Richardson (1922), the challenge of weather forecasting has been related to an initial value problem of physics governing fluid flow and has been resolved using computer models. The success of the first numerical prediction by Charney, Fjortoft and von Neumann (1950) followed the implementation of a global observing and communication network that later incorporated the successful use of weather remote sensing technologies (e.g. radar, satellites, etc.) launched the unprecedented thrust of recent decades in scientific research on weather and environmental prediction. The weather research has a history of challenging science and scientific advances from the work of E. Lorenz in the early sixties on 'chaos' and the 'limits of predictability' that served to guide the early goals of numerical weather prediction to investigations of turbulence, cloud physics, organization of convective systems, non-linear system dynamics, radiative transfer and wave theory to name but a few topics. Thus increases in prediction skill of the weather forecasting systems operated in NMHSs in the last fifty years can often be directly traced to theoretical advances, major international measurement field campaigns and to the sophisticated interplay of research and development advancements in observing technologies (radars, profilers, satellites, etc.), numerical methods (spectral methods, finite element, etc.), sub-grid scale physics parameterizations (deep convection, cloud, mountain, etc.), data assimilation of surface, upper air and satellite observation systems and high performance computing systems.

A unique aspect of weather prediction that drives these advances in skill is the necessity to forecast the weather on a daily basis. Rather than diminish the science, operational weather prediction products have proven to be a rich source of information for those wishing to develop new scientific concepts and theories. Indeed weather prediction systems provide the opportunity to develop, test and improve theories and techniques through assessment, verification and quantification of the forecast improvements every day against observations. The forecast enterprise includes constant pressure from users and operational centres to improve their prediction products in order to save lives and reduce fatalities, improve public safety and the quality of life, protect the environment and insulate economic sectors from danger and, if possible, to increase profits. These pressures and the competitive and co-operation among operational centres has ensured that the best relevant ideas of research will be incorporated into forecast systems when practical. Thus, weather forecasting has become increasingly complex over all time and space scales with the tendency to also cover related environmental applications (e.g., water quantity and quality, air quality). These complexities culminated in the 1990s in a clear need for WMO to coordinate internationally these interdisciplinary research activities.

The WWRP was created at the 12th session of CAS in 1998. This was done by merging two existing programmes of the WMO (Very Short- and Short-Range Weather Prediction Research and Medium- and Long-range Weather Prediction Research). The WWRP began to focus heavily on the initiation, endorsement and/or management of international multidisciplinary projects, often including field measurements, and the organisation of symposiums, conferences and workshops to establish research priorities and to share research results, operational advances and user needs. As an example, the successful Mesoscale Alpine Project (MAP) was WWRP’s first effort. The WWRP was reorganized at the 14th CAS session in 2006, with the addition of the long-standing Tropical Meteorology Research activity, the recently created THORPEX Programme, and new research activities in societal and economic research and applications and in mesoscale forecasting.

An active WWRP of multidisciplinary research and development scientists (meteorologists, hydrologists, computer experts, chemists, physicists, economists, social scientists, etc.) will make cutting-edge contribution to weather and environmental prediction in close collaboration with NMHSs. WWRP will contribute to both advancing knowledge of the barriers that currently limit our
ability to improve the accuracy and lead-time of high-impact weather forecasts and the development, testing and implementation of strategies designed to reduce those barriers and improve prediction. The activities of the WWRP cover the broad range of time-scales associated with society’s need for weather information from minutes to hours to days to weeks, up to seasons (in collaboration with WCRP and seasonal prediction efforts at operational weather prediction centres). Tropical, middle latitude and polar weather are covered. WWRP also fosters collaborative research initiatives with other departments and Commissions of WMO and other organisations involved in broader environmental prediction research.

Since shortcomings in how weather prediction information is communicated and acted upon by society can limit the benefits of improved prediction, the WWRP includes research on societal and economic applications. There is also a major emphasis on the transfer of research advances into operations and on training and development opportunities, in particular for developing countries. The WWRP is thus a major contribution to the WMO Natural Disaster Reduction and Mitigation Programme.

3.2 WWRP accomplishments

From a historical perspective, it is important to note that some groups who are now part of the WWRP Programme, such as Tropical Meteorology Research, existed decades before the creation of the WWRP. Here are some examples of early accomplishments.

**United Nations Development Programme (UNDP) Inter-Country and Regional Projects**

In the 1970’s, invaluable support was provided by UNDP for the developing countries participating in the former Tropical Cyclone Programme (TCP). These projects provided expert and consultancy services, equipment, fellowships and group training and support to arrangements which contributed directly to the improvement of the warning systems in the regions. These consequently led to improvements to tropical cyclone disaster mitigation arrangements which have substantially reduced the loss of life and property damage caused by cyclones and associated floods and storm surges.

**Radar Infrastructure**

Radars which are mainly used for tropical cyclone monitoring have been provided by Australia for Fiji, including one for the regional centre and by Japan for Bangladesh and Pakistan. These radars have contributed substantially to the detection, monitoring and forecasting of tropical cyclones in the recipient countries.

**Typhoon Operational Experiment (TOPEX)**

In the 1980's the Typhoon Committee carried out the TOPEX to test the typhoon warning system under real typhoon conditions. The 3-year project produced a useful data set and enabled Typhoon Committee Members to greatly improve their forecasting ability and measures related to disaster preparedness.

**Special Experiment Concerning Typhoon Recurvuration and Unusual Movement (SPECTRUM)**

Under the auspices of the Typhoon Committee, the field experiment phase of SPECTRUM was carried out by its Members in August and September 1980. It is the most comprehensive meteorological observation programme ever mounted to study typhoons in the western North Pacific. The data sets from the experiment were used in researches aimed at improving operational typhoon forecasting. This resulted in the publication by TCP of a series of research papers and the conduct of four technical conferences organized by TCP for the Typhoon Committee.

Since its creation in 1998, the WWRP has continued the tradition of excellence in research combined with targeted priority applications, training and transfer of research advances into operations.
The Mesoscale Alpine Programme (MAP)
The first WWRP Research and Development Project (RDP) was an international research initiative devoted to the study of atmospheric and hydrological processes over mountainous terrain. It was aimed towards expanding our knowledge of weather and climate over complex topography, thereby improving current forecasting capabilities. A large-scale field campaign in the Alpine region took place from 7 September to 15 November 1999.

The Sydney 2000 Olympics
The WGNR organized research activities in support of the Sydney 2000 Olympics focusing on nowcasting subtropical summer convection. A Forecast Demonstration Project (FDP) on advanced nowcasting systems was held during the Olympics and provided enhanced support to the operational forecasters.

MAP Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region (D-PHASE)
MAP D-PHASE is a WWRP FDP led by the WGMWFR in collaboration with the WGNR, aimed at demonstrating some of the many achievements of MAP, in particular the ability of forecasting heavy precipitation and related flooding events in the Alpine region. MAP D-PHASE built on the research advances of MAP. The FDP has addressed the entire forecasting chain ranging from limited-area ensemble forecasting, high-resolution atmospheric modelling (km-scale), hydrological modelling, and nowcasting to decision making by the end users. This end-to-end forecasting system was demonstrated between June and November 2007. Following the D-PHASE project, the forecast system has continued operationally and has served as a model for multi-hazard warning systems in Switzerland.

The Convective and Orographically-induced Precipitation Study (COPS)
COPS was an international field campaign, from June to August 2007, initiated to identify the physical and chemical processes responsible for the deficiencies in QPF over low-mountain regions with the goal to improve their model representation. This was a research collaboration between the WGMWFR and the THORPEX programme.

The THORPEX Interactive Grand Global Ensemble (TIGGE)
TIGGE is the first step in the development of the Global Interactive Forecast System (GIIS). Under TIGGE, the collection of global ensemble forecasts from ten production centres has been organized. Archiving of the data is done at three centres (CMA, ECMWF and NCAR), which in turn make this unique data set accessible to researchers.

Research on the Verification and Assessment of Forecasts
The JWGVR has made lasting contributions to verification approaches at operational centres through research into verification techniques and the transfer of these techniques into operational practice. Recently the JWGVR has finished a focus on verification of precipitation forecasts by publishing the WMO TD No. 1485 “Recommendations for the Verification and Intercomparison of QPFs and PQPFs from Operational NWP Models”. The approach of the WG has been to have web-based tool boxes and tutorials on their recommended verification approaches as well as new research concepts. These tool sets are utilized by operational centres, researchers and undergraduate and graduate students in atmospheric sciences and statistics.

The T-PARC field campaign
The THORPEX Working Groups and three of the THORPEX regional committees (NARC, ARC and the ERC) have been involved in executing an ambitious T-PARC field campaign in collaboration with the WGTMR. The T-PARC campaign is a major field and modelling campaign completed in August–September 2008 and January–March 2009. T-PARC will permit an enhanced understanding and predictability of tropical convection and the various phases of typhoon and storm development and movement in the Pacific Ocean. T-PARC includes a variety of research objectives including process studies and operational testing of adaptive measurement strategies.
THORPEX IPY cluster
Within the IPY framework the THORPEX Programme has accomplished a set of projects to address key issues related to the analysis and forecasting of polar weather. This is a major contribution to the International Polar Year 2007-2008. With the enhanced observational networks, the sophisticated use of new observations and a better understanding of physical processes in Polar Regions, IPY has given a similar leap forward in NWP science as was achieved by the FGGE year in 1979.

Collaboration with the WCRP - the Year of Tropical Convection
A key element of the THORPEX strategy is the collaboration that has been developed with the WCRP to address common requirements for observations and modelling for the prediction of weather and climate for two weeks and beyond. As an initial activity WCRP and WWRP-THORPEX have orchestrated a period of coordinated observing, modelling and forecasting of organized tropical convection and its influences on predictability.

Beijing 2008 Olympics FDP
The WGNR has organized a Field Demonstration Project in support of the Beijing 2008 Olympics, with a focus on summer convection. The JWGVVR contributed significantly. Verification statistics show that overall QPF performance was much better than during the Sydney 2000 Olympics. It was realized that verification could be used to better understand the nowcasting systems and find ways to improve their performance. The interactive case study (forecast simulation) was recognized to be an effective training method. The forecast demonstration component was able to bridge the gap between researchers, operational forecasters and end-users. The FDP has had a lasting impact on operational nowcasting in Beijing and the development of a greater focus on services with the intent to transfer these advances elsewhere in China and then through Asia through training.

Workshops and symposia
The various components of WWRP have organized numerous workshops, symposia and training events, every year. Each event served as a forum for the interaction between researchers, partners, international organization representatives and forecasters. These are also occasions to train new scientists, in particular from developing countries. Reports on the outcomes of these workshops and other related publications can be found on the WWRP website.

For example, the international symposia on data assimilation, held every four years, as well as more specialized technical workshops, have greatly promoted and disseminated variational and Kalman filter data assimilation techniques; the symposia on numerical methods in weather prediction have allowed the spread of spectral methods, semi-implicit and semi-lagrangian techniques, worldwide, which has been critical to the success of NMHSs everywhere.

3.3 Challenges of the WWRP components
Societies, their institutions and private businesses face risks and opportunities due to the changing weather and climate conditions. Events like severe storms and poor air quality create risks to the health and safety of world populations. Our changing climate exacerbates those risks to which societies need to adapt. Weather and emerging new technologies also offer economical opportunities that we need to foster (e.g. wind energy). The NMHS programmes provide information needed to surmount these issues 24 hours a day, 365 days a year. WMO member countries, their communities and policymakers also need weather and climate information and predictions to understand our past and present climate, the future climate and its uncertainties. Using this knowledge, they can determine the safety, health and economic impacts of weather and then with the right decision-making tools, they can manage the vulnerabilities and opportunities resulting from those impacts.

Economic sectors (like energy, agriculture, forestry, fisheries, air and marine transportation) and their government regulators need information to anticipate, understand, and manage the risks and vulnerabilities due to the changing weather, climate and environmental conditions that affect...
the safety and efficiency of their operations, their cost-effectiveness, and their prosperity. According to US government studies, about one-third of the US GDP is sensitive to weather and climate; this is likely also the case in other developed countries and this ratio is probably greater in developing countries. This represents an inherent large sensitivity of the economy to the quality of weather and climate information, so its improvement is thus important to ensure continued and improved prosperity and quality of life.

Contributing to the overall WMO mission, the WWRP

- Orchestrates worldwide the coordination of the different research activities in weather and environmental prediction in view of establishing priority areas, creating new activities in these areas, and through seeking efficiencies and synergies in ongoing areas;
- Creates new opportunities to accelerate the technological transfer of weather and environmental prediction innovations to NMHSs and to developing countries through the WMO by means of appropriate training programmes; and
- Maintains a technology watch for the benefit of all WMO members, particularly those who cannot afford the in-house expertise to do so.

These efforts need to include international cooperation in i) observational campaigns with related theoretical, assimilation, modelling, verification and societal research and application activities, ii) creating archives of data and numerical forecast products not readily accessible through other means, iii) fostering collaboration between researchers and operational scientists undertaking data impact studies and those developing and testing data assimilation and numerical modelling approaches, iv) undertaking efforts to understand and improve the use of weather information, and v) the utilization of newly developed remote sensing observations including both satellites and radars. Major new initiatives and projects result from all of these types of efforts. In addition, applied research, capacity building, and technological transfer are also important to ensure that NMHSs of the developing countries can receive maximum benefit from the research advances.

The major challenges of the WWRP components are described in the following.

- The THORPEX programme challenges are to:
  i) Increase knowledge of global-to-regional influences on the initiation, evolution and predictability of high-impact weather. It will promote the development of advanced data assimilation and ensemble prediction systems and contribute to the development and application of advanced methods that enhance the utility and value of weather forecasts to society, economies and environmental stewardship;
  ii) Conduct regional and global campaigns as demonstrations and assessments of new observing technologies and interactive forecast systems. Thereby, THORPEX will provide guidance to the World Weather Watch (WWW) and forecast centres on improvements to forecast systems, and to relevant bodies, such as the WMO Commission for Basic Systems (CBS), concerning optimisation of global and regional observing systems;
  iii) Address the influence of inter-annual and sub-seasonal atmospheric and oceanic variability on high-impact forecasts out to two weeks, and therefore aspire to bridge the “middle ground” between medium-range weather forecasting and climate prediction. This provides a link with programmes addressing the improvement of sub-seasonal, seasonal, and global climate change prediction systems; and
  iv) Coordinate with the World Climate Research Programme (WCRP) and the relevant components of WWRP to address the observational and modelling requirements for the prediction of weather and climate for two weeks and beyond.
• The WG on Mesoscale Weather Forecasting Research (WGMWFR) challenges are to:

  i) Promote weather forecasting research on the meso-gamma scale, and strengthen international cooperation, knowledge transfer and capacity building in this field. The goals of the WG are to push operational forecast capabilities world-wide towards smaller spatial/temporal scales, and to improve our understanding of the weather predictability at those scales;
  ii) Incorporate high resolution modelling within nowcasting systems;
  iii) Improve sub-grid scale physics parameterization in collaboration with THORPEX and WGNE; and
  iv) Integrate Earth-system modelling with mesoscale NWP models for atmospheric chemistry, oceanic and surface applications and their evaluation in weather forecast mode with lead time of few hours to 2-day.

• The WG on Nowcasting Research (WGNR) challenges are to:

  i) Use the latest observational technologies to detect and forecast weather over the 0-6 hour time frame for rapidly evolving small scale phenomena that realize high-impact over short periods. Emergency services, defence forces, security agencies, the transport industry, hydrologists, the agricultural community, recreational groups and air quality agencies regularly depend upon nowcasting services;
  ii) Develop automated approaches for the rapid detection and effective dissemination of information; and
  iii) Develop linkages and on-going compatibility with longer time scale forecasts in the context of a unified approach to forecasting.

• The WG on Tropical Meteorology Research (WGTMR) challenges are to:

  i) Promote tropical meteorology research among the WMO members that will lead to improved observation, analysis, forecast, and warning systems for high-impact tropical weather events, and thus contribute to disaster prevention and mitigation;
  ii) Contribute to advancing the representation of tropical convection and its interaction with the large-scale through participation in the YOTC project initiated by the WCRP and THORPEX;
  iii) Develop and implement improved and cost-effective forecasting techniques with emphasis on high-impact weather associated with tropical cyclones and monsoons;
  iv) Conduct activities to advance understanding and capability to predict tropical cyclones in collaboration with the THORPEX programme, the WGMWFR and the WGNR; and
  v) Conduct activities to advance understanding and capability to predict the heavy monsoon rainfall events and their impacts in collaboration with the THORPEX programme, the WGMWFR and the WGNR.

These priorities are driven by those aspects of tropical meteorological systems that have the most detrimental effects on Members from the tropics and have been established through close connection to the NMHSs of those Members.

The Joint WG on Verification Research (JWGVR) efforts will continue to make progress toward the development and implementation of methods for the evaluation of high-resolution and ensemble forecasts. Areas of critical focus in the long-range will include methods for extremes; observational uncertainty; and the application of remotely-sensed observations in regions with sparse coverage by traditional measurements. Outreach will continue to gain importance as forecasting services and research groups face increasing needs to quantify forecast improvements and increased requirements for more holistic and detailed forecast evaluations.
• The JWGVR challenges are to:

i) Promote and provide training on verification methods and encourage (a) the appropriate selection and use of verification approaches for specific evaluation problems and (b) the implementation of improved methods in operational and research settings;

ii) Provide clear connections between research and operational needs and constraints. NMHSs have expertise in the evaluation of many types of forecasts, including user-centric evaluation of nowcasts and public weather forecasts and evaluation of global NWP and ensemble forecasts;

iii) Advance verification methods for forecasts of probability distributions for high-impact weather;

iv) To develop techniques targeted toward high-resolution forecasts; and

v) Assess uncertainty in verification statistics.

These priorities together represent many of the challenges of concern in the forecasting and evaluation communities related to processes of (a) quantifying the performance of forecasting systems, and (b) demonstrating the levels of enhancement in services and capabilities associated with efforts toward organisational and infrastructure improvements.

• The WG on Societal and Economic Research and Applications (WGSERA) challenges are to:

i) Develop, review and promote societal and economic-related demonstration projects focused on high-impact weather (HIW) and information;

ii) Estimate the economic (societal) value of weather information;

iii) Understand and improve the use of weather information in decision making;

iv) Advance the communication of weather forecast uncertainty;

v) Develop user-relevant verification methods; and

vi) Develop decision support systems and tools.

These WGSERA priorities apply and may be explored across the full spectrum of societal, economic and environmental interests and issues facing humanity. Nevertheless, given the mandate of WWRP and WMO, it seems appropriate to concentrate research and applications where weather conditions and meteorological information directly influence: i) mortality, morbidity, and significant loss of property; and ii) critical infrastructure and resources required to support communities and livelihoods, with emphasis on water, energy, food, and transportation.

3.4 Overarching WWRP challenges

The consequence of high-impact weather and environmental phenomena on society and its economy is growing and is getting more costly, causing infrastructure damage, injury and the loss of life. The policy debates around some of these issues are intense – driving intense information demand based on better scientific models and simulations. The current science and technology trend underlying the WWRP will soon make it possible to expand and significantly improve weather and environmental applications for NMHSs to an unprecedented extent, including economical opportunities (e.g., wind energy forecasting systems).

Internationally, the increasing demand for accurate weather and environmental prediction has led to significant attention being given to investments in Earth observing, numerical weather and environmental forecasting and High Performance Computing systems. The WWRP has a major role to play in maximizing the world-wide socio-economic benefits from these large investments. In this context, the primary overarching WWRP challenges to fully meet its mission are:

i) To be the international focal point for weather research by maintaining its tradition of excellence in research by bringing together world experts in each specialty area and through initiating, leading and/or participating in major international field campaigns and
major weather research programmes and projects driven by the need to improve prediction of high-impact weather and society’s utilization of weather information;

ii) To bring together the different WWRP research and operational communities to develop improved data assimilation, observing, verification, application and modelling strategies through the sharing of expertise and approaches among the various components of the WWRP;

iii) To further broaden and enhance its research collaborations in environmental prediction with groups such as EPAC, CHy and WCRP, to address scientific issues of common interest and to help develop new collaborative Earth-system projects to face new demands and to address a variety of environmental issues (air quality, water quantity and quality, environmental emergencies, the decline, invasion and adaptation of species, etc.), economic issues (renewal energy, reducing loss of forests due to fire, and insect and disease infestations, etc.), social issues (mapping flood plains, etc.) and political issues (climate change, bulk water exports, the ozone hole problem, etc.);

iv) To maintain and enhance the WWRP focus on priority operational needs and on operational demonstration and implementation of research advances, through

a) Continuous contacts with representatives of the operational community, such as the CBS, to review research needs and adjust research priorities;
b) Careful selection of RDPs and FDPs that will demonstrate new research capabilities and ease their operational implementation; and
c) Scientific support to the NMHSs in the required realignment of operational forecast systems, including the evolution of the role of forecasters and the move towards probabilistic forecasting;

v) To maintain a strong focus on training opportunities for young scientists, in particular from developing countries, so that as many countries as possible will be able to contribute to and benefit from the research advances.

At the dawn of this new century, significant research and development challenges remain to be met before acceptable meteorological and environmental forecasts can be produced worldwide over every spatial scale (from urban to planetary) and time scale (from a few minutes to seasons). The success of this endeavour will depend, of course, on the collaboration, commitment, excellence and strength of the weather, climate and Earth-system research communities. On this point, the 20th century track record provides a solid base for confidence.

3.5 General Criteria for developing WWRP Projects

This strategic plan contains a variety of WWRP project types, including FDPs, RDPs, data archives, and integrated research environments (such as proposed by the WGMWFR). For THORPEX projects, the ICSC is responsible for the delivery of the programme to CAS and the WWRP. JSC decisions are required on non-THORPEX projects against the following general criteria for WWRP projects:

i) Consistency with the WWRP mission, objectives and research priorities;

ii) Quality of the effort including the research impacts, the potential for operational transition and the likely benefits to users;

iii) Likelihood of success including track record of the investigators, funding or the likely path for funding, management of the project and availability of the necessary facilities;

iv) Degree of international involvement; and

v) Impact of the project on the resources of the WWRP and its Working Groups.
FDPs and RDPs have additional stringent criteria described in Annex 6. Investigators wishing to initiate WWRP projects should first inform the JSC Chair, the WWRD Chief within the WMO and the appropriate WGs chairs within the WWRP. The WGs will provide guidance on the development of the project proposal. Proposals need to be brought to the JSC through the appropriate WGs with WG recommendations on the effort. The proforma for proposal submission will be on the WWRP web site. Investigators are requested to complete the proposal submission 3 months prior to the JSC. Investigators with “out of cycle” proposals should contact the JSC Chair and the WWRP Chief within the WMO. Such situations may arise when projects are developed in response to calls for proposals with short time-lines for submission.

Investigators who have national projects motivated by and aligned with the WWRP objectives may also seek to become affiliated with the WWRP. Such an affiliation of national projects may occur when investigators want to broaden the international involvement or where a closer alignment with the goals of the WWRP may assist the investigators in obtaining national resources. In these situations, the lead investigator(s) for the project must make a formal request to the JSC Chair and the WWRP Chief within the WMO. Depending on the scope of these efforts, the investigators may be asked to report on research outcomes to the JSC.
4. ACTIVITIES

This chapter presents the activities of the main bodies of the WWRP OPAG: the THORPEX Programme and the 5 WWRP Working Groups.

4.1 THORPEX Programme

4.1.1 Scope and research priorities

THORPEX is an international research programme whose scope is global and which aims to accelerate improvements in the accuracy of 1-day to 2-week high-impact weather forecasts. These improvements will lead to substantial benefits for humanity, as we respond to the weather-related challenges of the 21st century. High-impact weather forecasts are defined by their effect on society, the economy and the environment. As such, THORPEX is an element of the WMO World Weather Research Programme and is a major contribution to the WMO Natural Disaster Reduction and Mitigation Programme.

THORPEX priorities are to address:

- Global-to-regional influences on the evolution and predictability of weather systems;
- Global observing system design and demonstration;
- Targeting and assimilation of observations; and
- Societal, economic, and environmental benefits of improved forecasts.

4.1.1.1 Organizational structure

An International Core Steering Committee (ICSC) is responsible for the delivery of THORPEX to the leadership of the WWRP and the Commission for Atmospheric Sciences (CAS). Membership of the ICSC is open to all WMO Members under the authority of the CAS. Observers from a number of international organisations participate in meetings of the ICSC. An Executive Committee (EC) (composed of a small number of ICSC members and observers) maintains oversight of the Trust Fund and provides guidance on the conduct of the programme. The JSC of the WWRP may ask for reports on major THORPEX activities, especially those where collaborations across the WWRP may occur, and then provide scientific guidance to the ICSC. However, the ICSC is responsible for decisions related to the delivery of THORPEX.

The International Programme Office (IPO)

The THORPEX International Programme Office (IPO) at the WMO Secretariat (Geneva) is responsible for planning and implementation of THORPEX. The IPO supports the activities of the ICSC and its main working bodies.

Working Groups

Two THORPEX Working Groups have been charged by the ICSC to develop and coordinate specific activities for three of the four THORPEX sub-programmes:

- Predictability and Dynamical Processes Working Group (PDP WG) – global-to-regional influences on the evolution and predictability of weather systems; and
- Data Assimilation and Observing Systems Working Group (DAOS WG) – global observing system design; targeting and assimilation of observations

The WWRP Societal and Economic Research and Applications Working Group has, as one of its tasks, the responsibility for the co-ordination of the assessment of the societal, economic and environmental benefits of improved forecasts for the THORPEX Programme. The Joint Working Group on Forecast Verification Research also has the opportunity to play a role that cuts across THORPEX and the other activities of the WWRP.
To complement and support the work of these Working Groups, the ICSC established the Global Interactive Forecasting System (GIFS) – THORPEX Interactive Grand Global Ensemble Working Group (GIFS-TIGGE WG). The initial task given to the GIFS-TIGGE WG was to develop and test a global multi-model ensemble prediction system and this is a continuing task. The GIFS-TIGGE WG also is overseeing explorations into the establishment of a limited area modelling version of TIGGE called TIGGE-LAM.

Regional Committees

Nations and consortia of nations have established THORPEX Regional Committees (RCs) that define regional priorities for participation in THORPEX within the framework of the THORPEX International Science and Implementation Plans. These THORPEX Regional Committees develop regional activities within the framework of the international plans and their plans are discussed by the EC and reviewed and approved by ICSC. They facilitate provision of funding, logistical and other support, planning, coordination and implementation of THORPEX activities conducted by the region with respect to the THORPEX International Research Implementation Plan. To date Regional Committees have been established for Asia (ARC), Africa (AfRC), Europe (ERC), North America (NARC) and the Southern Hemisphere (SHRC).

Organizational structure

Since November 2008, the organisational structure for THORPEX is as illustrated below.

![Organizational structure diagram]

4.1.1.2 Research programme - content, goals and objectives

The THORPEX International Science Plan (WMO/TD-No. 1246; WWRP/THORPEX No. 2) was published in November 2003 and this was followed by a THORPEX International Research Implementation Plan (WMO/TD-No. 1258); WWRP/THORPEX No. 4) in December 2004 (both plans are available on www.wmo.int/thorpex/plans.html).

In order to implement the THORPEX Science Plan and the THORPEX Implementation Plan, two sub-programmes have been developed to coordinate research on three of the THORPEX priorities and to foster collaboration with other programmes.

- Predictability and Dynamical Processes; and
- Data Assimilation and Observing Systems.

These sub-programmes have been designed to

- Increase knowledge of global-to-regional influences on the initiation, evolution and predictability of high-impact weather;
- Contribute to the development of advanced data assimilation and ensemble prediction systems;
- Contribute to the design and demonstration of global interactive forecast systems (GIFS) that allow information to flow interactively among forecast users, numerical forecast models,
adaptive data-assimilation systems and observations to maximise forecast skill (this includes the THORPEX Interactive Grand Global Ensemble (TIGGE) that develops and evaluates multi-model/multi-analysis ensemble prediction systems);

- Contribute to the development and application of advanced methods that enhance the utility and value of weather forecasts to society, economies and environmental stewardship;
- Carry out THORPEX Observing System Tests (TOSTs) and THORPEX Regional field Campaigns (TReCs). TOSTs: i) test and evaluate experimental remote sensing and in-situ observing systems, and when feasible, demonstrate their impact on weather forecasts; ii) explore innovative uses (e.g., targeting) of operational observing systems. TReCs are operational forecast demonstrations contributing to the design, testing and evaluation of all components of interactive forecast systems;
- Contribute to the development and application of advanced methods that enhance the utility and value of weather forecasts to society, economies and environmental stewardship;
- Contribute to the development and application of advanced methods that enhance the utility and value of weather forecasts to society, economies and environmental stewardship;
- Carry out THORPEX Observing System Tests (TOSTs) and THORPEX Regional field Campaigns (TReCs). TOSTs: i) test and evaluate experimental remote sensing and in-situ observing systems, and when feasible, demonstrate their impact on weather forecasts; ii) explore innovative uses (e.g., targeting) of operational observing systems. TReCs are operational forecast demonstrations contributing to the design, testing and evaluation of all components of interactive forecast systems;
- Address the influence of inter-annual and sub-seasonal atmospheric and oceanic variability on high-impact forecasts out to two weeks, and therefore aspire to bridge the “middle ground” between medium-range weather forecasting and climate prediction. This provides a link with programmes addressing the improvement of sub-seasonal, seasonal, and global climate change prediction systems;
- Demonstrate all aspects of THORPEX interactive forecast systems, over the globe for a season to one year to assess the utility of improved weather forecasts and user products;
- Coordinate THORPEX research with the World Climate Research Programme (WCRP) and the relevant components of WWRP to address the observational and modelling requirements for the prediction of weather and climate for two weeks and beyond; and
- Facilitate the transfer of the results of THORPEX weather prediction research and its operational applications to developing countries through the WMO by means of appropriate training programmes.

Regional programmes

In addition to the THORPEX Science and Implementation Plans, the Regional Committees have developed a series of regional plans that reflect key issues in their areas of interest. Further details and references are provided in sections 4.1.2 and 4.1.3.

4.1.2 Research strategy

Each THORPEX Working Group and Regional Committee prepares activity plans which are considered and approved by the EC and ICSC. In this section a brief outline is given of the broad strategy for each of these areas as well as for a number of the generic and collaborative international activities. Specific Implementation Tasks for all of these areas over the next few years are listed in section 4.1.3.

4.1.2.1 Global Interactive Forecast System-THORPEX Interactive Grand Global Ensemble Working Group (GIFS-TIGGE WG)

Support for research into probabilistic forecasting

Under the guidance of the GIFS-TIGGE WG, an international database/archive of operational, global ensemble forecasts called TIGGE has been developed to explore the value of combining data from various systems for probabilistic forecasting of severe weather events. Currently, the TIGGE archive is hosted by three archive centres (ECMWF, NCAR and CMA) containing the data from 10 NWP ensemble generating centres: BOM, CMA, CMC, CPTEC,
The TIGGE archive, which is growing in real-time and increasing in the number of users, provides a research facility to enhance cooperation between universities and the operational weather prediction centres and is aimed at promoting the concept of probabilistic forecasts and development of new methods of combination and verification of forecasts. The TIGGE archive also has proven useful for efforts by operational modelling centres to improve their models.

A TIGGE-LAM Panel has been established to coordinate the regional LAM EPS contribution to TIGGE. The Panel is addressing the interoperability aspects related to the exchange and archiving of LAM EPS products and the provision of initial and boundary conditions by the TIGGE global systems. Having in mind a future adaptive component of the GIFS, the concept of LAM EPS relocatable systems to be activated on demand will be analyzed and designed. As regards the archiving of TIGGE LAM products, a sub-set of high priority parameters will be archived at the three TIGGE Archiving Centres. Considering the regional nature of LAM EPS systems, the three archiving centres will host data from different LAM EPS systems to avoid duplication of data. The future more comprehensive TIGGE LAM archive should be based on a decentralized system. Due to the regional nature of LAM forecasting, efforts will be made to coordinate activity with the THORPEX Regional Committees. Stronger links will be also established with the WGMWFR and with the WGSERA.

A Global Interactive Forecasting System

If justified by scientific results (from using the TIGGE archive of ensemble data and other THORPEX research findings) an internationally coordinated system for high-impact weather forecasting called the GIFS may be developed in collaboration with the WMO Commission for Basic Systems (CBS). Initial development will focus on tropical cyclone and precipitation forecasting as GIFS prototype products for two of the highest priority application areas. Probabilistic forecast products will be specifically designed for and tested in a few selected regions where the transfer of new technology can have the greatest benefit, for example for less developed and developing nations, using the experience with the CBS Southern Africa SWFDP.

Subject to positive scientific results, additional investments may include telecommunication upgrades, and international agreements on data exchange policy and the use of products. Products would be made available using a common web interface to be developed for GIFS applications. The GIFS system would follow CBS guidelines on operational systems and requirements, using the WIS infrastructure and would undergo thorough pre-implementation testing and evaluation period. Should the system become operational, arrangements will need to be made for sustainable production and distribution of products.

Provided that the benefits of adaptive procedures can be demonstrated, a second, more comprehensive, end-to-end phase of GIFS would subsequently be implemented. In the end-to-end phase, GIFS would be further enhanced by the introduction of adaptive procedures in the entire forecast process, potentially including the observing, data assimilation, numerical forecasting and user application systems. This would increase the ability of the forecasting system to respond to user needs and thus maximize the utility of weather forecasts.

It is clear that GIFS development efforts will require close collaboration with many WWRP, WCRP and CBS groups.

4.1.2.2 Data Assimilation and Observing Systems Working Group (DAOS WG)

The DAOS WG was established to ensure that THORPEX contributes to the international efforts to optimise the use of the current WMO Global Observing System (GOS) and to the development of well-founded strategies for the evolution of the GOS to support Numerical Weather Prediction primarily for 1 to 14 day weather forecasting.
To achieve its mission the DAOS WG, in collaboration with the CBS OPAG-IOS,

- Addresses data assimilation issues including the development of improved understanding of the sources and growth of errors in analyses and forecasts;
- Promotes research activities that lead to a better use of observations and the understanding of their value in forecast systems; and
- Provides input and guidance for THORPEX regional campaigns for the deployment of observations to achieve scientific objectives.

The DAOS WG will support field experiments and provide guidance on observational and data assimilation issues. Based on studies carried out over the last few years, field studies should adhere to the following principles:

- Observation campaigns should be designed with science plans that take into consideration assimilation issues;
- Decisions to undertake observation campaigns would benefit from pre-project evaluation of expected value (e.g., using 'calibrated' OSSEs or OSEs);
- Regional (compared with highly localised) and systematic targeting during low predictability flow regimes on a continuous basis (for periods of days to weeks) should be explored; and
- Adaptive processing and data selection of satellite data should also be explored.

4.1.2.3 Predictability and Dynamical Processes Working Group (PDP WG)

The PDP WG provides the connection between the academic dynamical meteorology community and the operational numerical weather prediction centres. It encourages this community to carry out dynamical process studies with the specific aim of improving the understanding of the relationship between particular processes and weather forecast accuracy. In particular, the PDP WG contributes to the design of field programmes; promotes the use of data sets compiled by THORPEX (currently, TIGGE, T-PARC, YOTC); organizes sessions on the dynamics and predictability of high-impact weather events and on research issues relevant to seamless prediction at scientific meetings; organizes summer schools to educate the next generation of scientists on designing techniques that lead to better forecasting capabilities; and compiles reports on research results that are the most relevant to a better understanding of atmospheric predictability and to improving forecast accuracy.

4.1.2.4 International collaborative projects

The THORPEX Pacific Asian Regional Campaign (T-PARC)

The THORPEX Pacific Asian Regional Campaign (T-PARC) is a cross-cutting activity within the WWRP that includes a focus on the research goals of THORPEX and the WGTMR. The field campaign of T-PARC consisted of two phases – a Summer Phase (1 August 2008 through 8 October 2008) produced data on the evolution of a number of tropical cyclones and the Winter Phase (January – March 2009) provided data to study mid-latitude predictability. T-PARC research is inherently multi-scale and the measurements strategies were motivated by the societal need to improve both shorter range (1-5 day) forecast skill for high-impact weather events that affect the Western North Pacific and East Asia regions and medium range (3-7 days) forecast skill for “downstream” locations such as the Arctic, North America, Europe and North Africa.

Observational activities during the field phases included enhanced use of operational resources (e.g., implementing rapid scan modes for satellite systems and supplemental radiosonde launches), research vessels measuring atmospheric and oceanic properties, research aircraft carrying advanced remote sensing systems that included Doppler radar, wind lidar and water vapour lidar, deployment of dropsondes from research aircraft, stratospheric balloons called driftsonde, and robotic aircraft. The measurements for the Summer Phase, in particular, relied on
collaboration with the associated national efforts in China, Korea and Japan as well as the US’s Tropical Cyclone Structure-08 (TCS-08) Experiment that has strong links to the WGTMR.

The two phases of T-PARC have provided valuable data bases which will enable comprehensive studies of the predictability of tropical convection and the various phases of typhoon and storm development and movement in the Pacific Ocean and mid-latitude predictability of weather systems. T-PARC is a focal point for a number of modelling and assimilation activities, including investigation of the impact of targeted in-situ data, adaptive satellite measurements and airborne remote sensing measurements, on forecast skill over the Pacific. T-PARC modelling studies range from cloud-system resolving models in the research community to operational global models. Several SERA-type projects also took place in conjunction with T-PARC.

T-PARC is essentially a model for future THORPEX field experiments; planning for a new European-lead field experiment, T-NAWDEX (see section 4.1.3.8 below), will be based closely on the experience obtained during T-PARC.

The IPY-THORPEX project cluster

The First International Polar Year took place in 1882-1883 and established a precedent for international science cooperation. The second took place 50 years later in 1932-1933, and investigated the global implications of the newly discovered “Jet Stream”. The third – the International Polar Year (IPY) took place in 2007-2008 and was an international programme of coordinated, interdisciplinary scientific research and observations in the Earth’s Polar Regions.

From an enhanced observational network, the sophisticated use of new observations and a better understanding of physical processes in Polar Regions, it is hoped that the International Polar Year 2007 - 2008 will eventually lead to a similar leap forward in the skill in numerical weather prediction such as was achieved by the FGGE (GWE) year in 1979.

Within the IPY framework, WWRP-THORPEX has developed a comprehensive set of projects to address key issues that relate to the analysis and forecasting of polar weather, better use of satellite data etc. The IPY-THORPEX project cluster currently includes ten individual IPY projects from nine countries with the following main strategic objectives:

- Explore the use of satellite data and optimized observations to improve high-impact weather forecasts (for Polar THORPEX Regional Campaigns (TReCs) and/or provide additional observations in real-time over the WMO Global Telecommunication System);
- Improve the understanding of physical/ dynamical processes in polar regions;
- Achieve a better understanding of small-scale weather phenomena;
- Utilize the TIGGE weather forecasts for polar weather prediction; and
- Utilize improved forecasts for the benefit of society, the economy and the environment.

A research and implementation plan has been written to help coordinate overall activities. The projects span a wide range of scientific issues from climate research to weather prediction. The IPY-THORPEX cluster already has several important legacies including improvements in regional modelling capabilities in the poles and additional research efforts such as the continuation of the Antarctic campaign called CONCORDIASI outside of the IPY period.

The Year of Tropical Convection (YOTC)

A key element of the THORPEX strategy is the collaboration that has been developed with the World Climate Research Programme (WCRP) to address common requirements for observations and modelling for the prediction of weather and climate for two weeks and beyond.

The realistic representation of tropical convection in global atmospheric models is a long-standing grand challenge for numerical weather prediction and climate projection. To address this challenge, WCRP and WWRP/THORPEX have implemented a year of coordinated observing,
modelling and forecasting of organized tropical convection and its influences on predictability as a contribution to the United Nations Year of Planet Earth to complement the International Polar Year (IPY).

This effort is intended to exploit the vast amounts of existing and emerging observations, the expanding computational resources and the development of new, high-resolution modelling frameworks, with the objective of advancing the characterization, diagnosis, modelling, parameterization and prediction of multi-scale convective/dynamic interactions, including the two-way interaction between tropical and extratropical weather/climate. A unique aspect of YOTC is an extensive operational modelling data set that includes the forcing terms necessary to investigate the treatment of convection in the model widely available to the international research community for the first time. This activity and its ultimate success will be based on the coordination of a wide range of ongoing and planned international activities (e.g., outcomes from T-PARC, GEWEX/CEOP/GCSS, THORPEX/TIGGE, EOS, GOOS), strong collaboration among the operational prediction, research laboratory and academic communities, and the construction of a comprehensive data-base consisting of satellite data, in-situ data sets and global/high-resolution forecast and simulation model outputs relevant to tropical convection.

The YOTC began on 1 May 2008. The approach and integrated framework of this effort is intended to leverage the most benefit from recent investments in Earth Science infrastructure as well as entrain a new generation of young scientists into tackling the outstanding problems in the field of weather and climate prediction.

4.1.2.5 Asian Regional Committee (ARC)

Asian Regional Plans and activities have included the new Ensemble Prediction System (EPS) introduced by Korea in 2006, the OSE work conducted by Japan concerning tropical cyclones and the ideas for distributing targeting information for tropical cyclones. Important Asian contributions to T-PARC were associated with studies of typhoons, extratropical transition, and downstream propagation.

Within the regional activities THORPEX-China has focussed on establishing the THORPEX-China research plan, making progress with TIGGE at the CMA and EPS developments at CMA. The T-PARC China component sought to enhance international collaboration, to test new techniques for adaptive observations and study the mechanisms and predictability of high-impact weather events that affect China and eastern Asia more generally.

4.1.2.6 North American Regional Committee (NARC)

The NARC engages in and supports a wide range of collaborative activities particularly T-PARC and the IPY. It also has a particular focus on ensemble prediction including TIGGE and the NAEFS. A further strong regional interest is in tropical-extratropical interactions, the improved representation of organised tropical convection in numerical models and the effects on middle latitude weather. The region has a strong interest in YOTC and the international project office is supported by the US. Longer term and on-going efforts include capacity building and developing specific projects for societal research. The strategies for societal research have been developed through a North American regional SERA meeting.

4.1.2.7 Southern Hemisphere Regional Committee (SHRC)

The SHRC has developed Science and Implementation Plans that reflect the key common issues across the Southern Hemisphere. These plans develop a rationale for a Southern Hemisphere regional focus for THORPEX that emphasises a number of important features that are of common interest across the hemisphere. An Implementation Plan was subsequently developed and finalised at a three-day workshop held in Melbourne, Australia, in May 2007. Overall this Plan has been deliberately designed at this stage to be modest. There are, for example, no plans for
“big science” or new field programmes. The Plan projects largely draw on focussing and coordinating existing and planned research to contribute to the areas of common interest. Working groups have been set up in areas of SERA, DAOS and PDP.

4.1.2.8 **African Regional Committee (AfRC)**

The overall economic and societal goals of the African Science and Implementation Plans are to provide the research to reduce the adverse effects of meteorological, hydrological and climate-related natural disasters in Africa. Of high importance to the THORPEX AfRC is to provide more timely and precise advisories and early warnings of high-impact weather and to enable governments, societies and economic sectors to realize the benefits of weather and climate-related information in critical decision-making. Also of importance is the promotion of multidisciplinary collaboration between research, operations and user communities to deliver the benefits of improved earth observations, advanced communications and forecast systems in Africa. The long-term plans of the THORPEX AfRC include an African High-Impact Information portal and forecast demonstration projects that build on the SWFDP (Severe Weather Forecasting Demonstration Project) effort.

4.1.2.9 **European Regional Committee (ERC)**

The European plan builds upon the overall THORPEX Science Plan and focuses on implementation and prioritisation of the scientific issues that are specific to European interests, and recommendations for actions to be initiated within Europe. The most important links to other organisations and programmes inside and outside THORPEX, and inside and outside Europe, are documented.

The plan reflects the special circumstances of meteorological research in Europe. Most important is the large number of nations, each with its own research funding structure, and its own national meteorological service. These are supplemented by trans-national organisations at the European level, including EUMETNET, EUMETSAT and ECMWF, as well as trans-national research and coordination agencies, such as the European Community Framework Programmes, and the Co-Operation in Science and Technology (COST) Programmes.

The diversity of meteorological research in Europe influences the priorities in the plan, notably the significant emphasis on limited-area modelling, data assimilation, multi-model ensembles, and model development.

4.1.3 **Implementation tasks**

The implementation tasks of each THORPEX Working Group, Regional Committee and collaborative project are presented in Annex 1.

4.1.4 **Long-range outlook**

In the framework of increasingly powerful high end computing and the expected increasing resolution and sophistication of numerical models the WWRP-THORPEX programme will remain focussed on making significant improvements in the short-period prediction of high-impact weather worldwide, extending markedly the range of useful forecasts and encouraging a globally integrated approach through the careful evaluation and scientific assessment of the potential benefits of the introduction of the GIFS. One aspect of this development is FDPs that utilize the GIFS-TIGGE concept.

A most important issue remains understanding and addressing the societal and economic imperatives for improved forecasts including aspects related to health, agriculture, energy etc., and ensuring that user relevant verification of forecasts is employed throughout. This approach requires
strong cross-community collaboration between scientists, social scientists and economists. Other scientific priorities that need to continue to be addressed include:

- Basic issues of predictability and key dynamical processes;
- The required initial conditions and implied observational coverage;
- Strategies for observations targeting in critical situations;
- Tackling the problem issues in data assimilation especially at high resolution;
- Handling of the tropics particularly organised convection, TCs, and ET and tropical-extratropical interactions;
- Polar weather; and
- Seamless prediction of weather and climate from days to weeks and seasons.

4.2 Working Group on Mesoscale Weather Forecasting Research (WGMWFR)

4.2.1 Scope and research priorities

The purpose of the WGMWFR is to promote weather forecasting research on the meso-gamma scale, and to strengthen international cooperation, knowledge transfer and capacity building in this field. The goals of the WG are to push operational forecast capabilities world-wide toward smaller spatial/temporal scales, and to improve our understanding of the weather predictability at those scales.

The focus of the WG’s activities is on horizontal scales at which most mesoscale weather models will operate in practice in the period 2008-2015: ~500m – 3km. Thus, the term “mesoscale”, as used in this section, refers to this meso-gamma scale. NWP models at such horizontal resolutions generally are not fully convection-resolving, but rather convection-permitting. In terms of forecast length, the mesoscale range covers time scales from 0 - ~48h. On one end mesoscale weather research has moved into the nowcasting (0-6h) range, on the other end, an overlap exists with the lower end of the time scales covered by the THORPEX programme (1-14d).

To achieve its objectives, the WG intends to foster research in at least the following areas:

- Mesoscale data assimilation: investigations on the strengths and limitations of different data assimilation approaches, and observation impact studies;
- The representation of convection and complex terrain in mesoscale models;
- The role of the surface in mesoscale modelling and assimilation systems, and the ways to represent and consistently assimilate surface characteristics in mesoscale models; and
- Predictability at the mesoscale, and the design and performance evaluation of mesoscale ensemble forecast systems.

4.2.2 Research strategy

An Integrated Mesoscale Research Environment (IMRE):

The four topics mentioned above are interrelated and difficult to investigate in isolation; studies in one area generally require either knowledge of, or assumptions on, the behaviour of one or more of the other aspects. Extensive, spatially dense, high-quality datasets that have been gathered within RDPs and FDPs (e.g., COPS/MAP D-PHASE), can provide detailed information on a broad range of physical quantities and processes, and are therefore indispensable to study aspects of assimilation, parameterizations, surface characterization and predictability in a coherent manner. Such reference datasets form the basis for integrated mesoscale research environments (IMREs) with the capability to investigate all of these aspects, separately or in conjunction with each other. The WG will promote setting up several such regional IMREs worldwide, using a few excellent, generally available reference datasets from IOP’s covering different geographical areas and climate regimes. The prerequisites of and scientific issues to be addressed by the research environment for data assimilation, model parameterizations, surface and predictability aspects are
formulated below. These issues in turn define the types of experiments to be considered within each regional environment. The envisaged types of experiments, and some suitable reference datasets, are described below.

The main scientific questions to be considered for each of the above mentioned four areas, and the proposed activities aiming at obtaining answers to them, are as follows:

Mesoscale data assimilation:

- How should we address the fundamental research issues of nonlinearity and non-Gaussianity in mesoscale data assimilation for high-impact weather, specifically in relation to the analysis of moist processes and mesoscale circulations?
- How do we assess the information content of components of high-density, mesoscale observation networks, and their contributions to analysis and forecast error?
- Can we use adjoint- and ensemble-sensitivity techniques to design optimal networks and thinning strategies for the range of high-density remote sensing data types available to mesoscale data assimilation?
- Can ensemble forecasts be used to effectively define the highly flow-dependent nature of the forecast error with only a limited ensemble size in mesoscale NWP?
- Can hybrid variational/ensemble DA approaches be applied successfully at the mesoscale?
- How do we evaluate the performance of current mesoscale data assimilation systems?
- How can we ensure intercomparisons of different approaches to mesoscale data assimilation are carried out in a rigorous manner?
- How can we minimize uncertainties in initial conditions and reduce spinup problems, so as to make mesoscale NWP information more suitable for nowcasting applications?
- What are the best methods for characterizing observation and background errors, and how best to deal with spatial error correlations and model bias effects?

The IMRE concept has been successfully applied within the WRF community’s Data Assimilation Testbed Center (DATC) and elsewhere. Additional IMREs will be set up in order to study and intercompare the technical aspects of assimilation systems (data usage, observation operators, computational requirements, etc), as well as to study the impact and handling of new data types in two different environments:

- Assimilation systems for present or near-future operational models at resolutions of 3-10 km, with the aim to share knowledge on ways to improve present short-range (0-24 h) forecasts. In particular, experiments should be targeted on forecast quality of intense convective precipitation, which presently is one of the hardest parameters to predict; and
- Experimental assimilation systems for very high resolution models (0-12 h, horizontal resolution <3 km), in order to explore the potential and cost-effectiveness of future DA systems for convection-resolving models.

Suitable reference datasets for DA research activities, which can provide a wide range of observations and relevant case studies, can be obtained, e.g., from the archives of the COPS/MAP D-PHASE and B08FDP/RDP projects. The availability of many new experimental observation types in the COPS database in particular offers excellent opportunities for impact studies for non-standard instruments and mesoscale network design. In addition, the areas around e.g., London, Tokyo and Helsinki also have dense observation networks.

A major challenge for mesoscale DA is the provision of analyses and 0-3h forecasts of adequate accuracy for nowcasting purposes. Together with the WGNR, the WGMWFR intends to organize a workshop dedicated to this issue, aiming to make an inventory of the prospects of mesoscale DA for nowcasting, and the main problems to be tackled there.
Representation of convection and complex terrain:

- What are the key processes determining the life cycle and organization of convection, and how to describe them in models at various scales?
- What is the role of orography and surface characteristics in triggering and organization of convection (through lifting, local flow patterns, altered vertical exchange, etc.)?
- What is the impact of turbulence and aerosol-cloud microphysics on simulations of deep convection? Is the application of unified, combined parameterizations of these processes required?
- Convension-permitting models (CPMs) at resolutions of 1-3 km just enter the range at which deep convection is thought to be resolved; shallow convection, however, is clearly not. To what degree do CPMs resolve the initiation and organization of deep convection and what parameterizations are required for ‘partly resolving’ resolutions?
- How should orography and sub-gridscale orography be represented in mesoscale models? How best to handle up/downscaling?
- To what extent is convection predictable, and how is this related to large-scale flow characteristics? How best to handle ensemble prediction methods for convective phenomena?

To answer these questions, hindcast experiments can be performed using existing observational data sets (the COPS database would be quite suitable) and models at various resolutions. A set of reference data sets should be defined as part of IMRES, covering different climate regimes, by means of which case studies and process studies can be made. Given the availability of the COPS/D-PHASE and Beijing 2008 data sets, there is a need for additional data (e.g., experimental campaigns) from at least coastal, mountainous (steep terrain) and semi-arid climates. Also, synthetic reference cases may be defined for well-defined model intercomparisons.

In steep terrain, very high model resolutions (<1 km) and corresponding turbulence parameterizations, i.e., LES, are required to resolve orographic effects; otherwise, some form of orographic parameterization may still be needed. When observations from a dense network are available in a mountainous region (e.g. along a transect across a mountain valley), deficiencies of the representations of orography in models can be studied by comparing observations with model behaviour for a variety of resolutions. Re-analysis of MAP IOP’s or the Vancouver 2010 FDP may present opportunities in this direction.

Surface:

- What is the best way to specify surface characteristics in physiographic datasets, and how should these data be translated to specify surface fields in mesoscale models?
- What is the impact and interaction of surface with weather, moist processes in particular (e.g. snow, canopy)? How does it affect convective activity or the evolution of the atmosphere under stable boundary layer conditions?
- What are the best assimilation techniques to assimilate evolving surface parameters such as snow cover or vegetation state, and which observations have the greatest potential for initializing the surface? How to best specify evolving surface variables in the absence of data assimilation?
- What is the impact of surface on the predictability of mesoscale phenomena?
- What is the effect of urban areas on weather, and how best to describe urban surface characteristics and urban weather?

Within the NWP community, expertise on physiographic data, and the derivation of model climate fields from them, is quite limited. Thus, there is a need for a targeted exercise to document the state-of-the-art in this area, and to establish recommendations on best practices. The WG aims to gather experts in this field in an international workshop dedicated to this purpose. It is hoped that, as a follow-up, a more permanent expert team may be formed that is able to formulate and promote guidelines for handling physiographic data.
The impact of snow and canopy on the surface-upper air interaction has proven to be particularly difficult to describe in mesoscale models. In-depth observation of these interactions and validation of their representation in mesoscale models again requires extensive datasets, from either supersites or IOP’s describing the boundary layer and surface fluxes in great detail. The existing Helsinki and Hydrology test beds, the data from the COPS and B08RDP/FDP observing periods, and observations from special sites such as ARM or Cabauw are examples of suitable data sources for such process study and validation exercises. The Vancouver 2010 FDP that is presently being planned may offer a good possibility to make specific studies of surface behaviour under steep orography winter conditions.

Extensive observational datasets obtained in programmes such as COPS offer a good scope as part of IMREs for surface data assimilation experiments and impact studies. In the absence of surface analysis systems, the question is how evolving variables should best be specified. In this respect, recommendations on the time frequency on which model climate data should be specified for the mesoscale range can be of help.

In view of the increasing urbanization world-wide, urban weather and the impact of urban areas on the atmosphere are topics of increasing importance. Cities can affect the development of the boundary layer, turbulent mixing and clouds, and show local impacts such as heat island and wind tunnelling effects. Urban modifications of surface exchange parameterizations are available, but might require serious improvement if resolution is further increase (and thus lowest model layers are closer to the surface). Also, verification is a major problem, as routine observing systems are usually not well geared to cover urban areas. The WMO guidelines on urban observations should be much better established. The WG will seek opportunities for new activities to be developed on this issue.

Predictability:

- What influences predictability on the mesoscales, and what are its limitations?
- How to practically describe mesoscale predictability? Which sources of uncertainty are the most important?
- What are practical methods of generating perturbations describing this uncertainty? How should operational mesoscale ensemble systems ideally be set up (e.g., a multi-model approach, or a single model, multi-nested system)?
- What is the potential for cross-fertilization of data assimilation and ensemble forecasting techniques?
- What is the best physics description to be used in a mesoscale EPS (scale-dependent)?

For a quantitative assessment of the potential and practical limitations of present or new predictability techniques and ensemble systems, programmes such as MAP D-PHASE and Beijing 2008 provide regional datasets with which to study the performance of a variety of ensemble approaches. Process studies on the most appropriate physics to be used in high-resolution ensembles can be based on extensive regional datasets obtained from IOP’s such as COPS and Beijing 2008. These datasets can be exploited further, e.g., for research on the applicability of ensemble methods for severe weather, for the testing of new perturbation methods, and for assessing the potential of hybrid ensemble assimilation techniques.

Theoretical research on the causes of limited predictability at the mesoscale is still fairly rare. The underlying mechanisms for predictability are a subject of study within the THORPEX programme, but mostly with a synoptic, medium-range perspective. A possibility to focus more attention on mesoscale predictability aspects and gather together the international expertise on this field, would be to organize a WMO Symposium on this subject.
The WGMWFR contribution will be:

- To define requirements for reference data sets. In general, data sets should cover as completely as possible the process chain from land-surface exchange and boundary layer development to the development and organization of clouds and precipitation;
- To define reference cases from these data sets covering a range of stages of convection and environments. These reference cases will allow model intercomparison in a hindcast mode and may become standard instruments to assess model performance;
- To evaluate the possibility and limitations of defining suitable simple synthetic ‘theoretical’ reference cases (such as the GABLS exercise for boundary layer studies or theoretical solutions for mountain waves);
- To organize workshops related to the themes and issues above in order to start activities (e.g., new field campaigns for additional IMREs) or foster scientific collaboration; and
- To promote and coordinate international research proposals on these topics.

Linkages

The WGMWFR will maintain close linkages with other WGs within WWRP:

- WGNR, for the application of mesoscale models to nowcasting;
- JWVGVR, on the development and application of verification and validation methods suitable for the mesoscale;
- WGSERA, on the assessment of socio-economic benefits of mesoscale forecasting;
- TIGGE-LAM, on the construction and added value of mesoscale LAM EPS systems; and
- WGTMR, on mesoscale aspects in the tropics.

Other linkages are also required, with:

- WGNE, in particular its subgroup on the parameterization of convection, clouds and precipitation;
- WCRP, on the development and testing of parameterizations such as unified turbulence / shallow convection schemes and aerosol-cloud-precipitation microphysics;
- observation networks: WMO/CBS and regional initiatives, e.g., EUMETNET/EUCOS; and
- WMO and regional programmes focusing on important applications and user of mesoscale weather forecasting, such as hydrology and air quality modelling.

Knowledge transfer and capacity building

In the past decades, WMO has organized symposia on a roughly quadrennial basis on subjects relevant for mesoscale forecasting, in particular on quantitative precipitation forecasting (QPF) and, more recently, also on mesoscale data assimilation. A natural consequence of the re-structuring of the WWRP is that the responsibility of continuing these series of symposia for a world-wide audience of scientists will now be taken up by the WGMWFR.

The possibilities for capacity building activities on specific topics in the form of dedicated workshops or visiting programmes will be explored. Examples of these that have been mentioned earlier are the workshops on DA for nowcasting, and on physiographic data and their use in mesoscale models, and a symposium on mesoscale predictability. Links to available on-line tutorials and training material can be collected on a central website and promoted.

Products and services

- Output of RDP’s and FDP’s:
  - Reports and refereed publications on the outcome of RDP’s and FDP’s and the insights obtained therein;
  - Demonstrations in FDP’s of the performance of mesoscale deterministic and ensemble forecasting systems and their impact on applications such as hydrology; and
Regional observational and model datasets, obtained in the experimental phases of RDP’s and FDP’s, which can be used in further research activities;
- Organization/triggering of regional IMRE activities in the fields of DA, convective parameterization, surface and mesoscale ensemble forecasting;
- Dissemination of state-of-the-art knowledge on specific aspects of mesoscale weather research through the organization of symposia and dedicated workshops; and
- Collection on the WG website of information on RDP and FDP projects and products, IMRE activities, reference datasets, workshops and symposia organized by the WG, and links to recommendations on best practices (e.g., mesoscale verification).

4.2.3 Implementation tasks
The implementation tasks for Mesoscale Weather Forecasting Research are presented in Annex 1.

4.2.4 Long-range outlook
Initiatives can be expected to strengthen research and development in the following areas:
- Sub-km scale mesoscale forecasting;
- Urban meteorology;
- Mesoscale predictability of atmospheric variables; and
- Integrated Earth system modelling on the mesoscale:
  - Coupling of mesoscale NWP models with atmospheric chemistry and ocean;
  - Combined surface-atmosphere, Earth system data assimilation systems;
  - Evaluation of Earth system models by their operation in weather forecast mode; and
  - Applications in hydrology.

4.3 Working Group on Nowcasting Research (WGNR)

4.3.1 Scope and research priorities
The scope of nowcasting in the current context is focused on the detection and forecasting of weather over the 0-6 hour time frame. The typical nowcasting problem involves forecasting rapidly evolving small-scale phenomena that realize high-impact over short periods. It is the forecast on the very time scale of impact. Hence the information provided is often the most crucial part of the weather forecast process with significant impact on user decisions. A non-exhaustive examination indicates a diverse user community. Emergency services, defence forces, security agencies, the transport industry, hydrologists, the agricultural community, recreational groups, and air quality agencies regularly depend upon nowcasting services.

The purpose of the WGNR is to promote nowcasting, the advancement of nowcasting science, and as appropriate undertake capacity building and expertise sharing within the WMO framework.

Nowcasting employs a range of techniques. Short-term extrapolation is particularly effective at the shorter time periods and can be realized through a number of techniques: heuristic methods, statistical approaches, conceptual models, data mining, artificial intelligence, and fuzzy logic schemes are all employed. Beyond about three hours the use of numerical prediction techniques becomes increasingly effective. Advancing nowcasting depends on improving the effectiveness of these various underlying components and how they operate in combination. This activity is a priority for the WGNR.

As part of the above process, minimizing the error induced by each stage of the process becomes important. The nowcast model and of course the initial state errors contribute, and the latter can dominate the total error. The scope of research can become wide given the variety of
techniques. Improved use of various remote sensing techniques (to provide an accurate initial rain field, or say delineation of fog, etc.) to developing advanced mesoscale data assimilation techniques and high-resolution, cloud-resolving numerical models come into scope. Quantifying the overall uncertainty and the utilization of probabilistic techniques in these activities is also a research priority for the WGNR.

The WGNR views advancing understanding of the dynamics, physics, evolution (especially growth and decay) and predictability of small-scale, high-impact phenomena over very short time scales to be an important activity. This underpins not only our understanding but the development of improved predictive skill. Conceptual models evolve from these activities and are employed directly by the human in the nowcast process. These studies also provide the route to improved representation and prediction of mesoscale/convective scale processes within numerical prediction models.

Given the scope of nowcast utilization and potential impact, the very practical issue of optimizing information content and delivery to affected users is a consideration. With nowcasting and the very short time scales, particularly with high-impact events, e.g., microbursts affecting the aviation industry, development of automated approaches for the rapid detection and effective dissemination of information is paramount. Research and development linked to improving nowcast processes, and optimizing the role of the humans and developing supporting systems is in scope, i.e., the underlying WGNR strategy involves both scientific development directed at improving physical understanding coupled with appropriate forecast system and process development. The outcome expected is timely, consistent, and user-relevant information delivered to various disciplines. Developing linkages and on-going compatibility with longer time scale forecasts is also an important consideration in the context of a seamless approach to forecasting.

Consistent with the WWRP strategy, the WGNR activities are viewed as promoting end-to-end nowcasting in conjunction with end-user groups and driven by the needs of NMHSs. Establishing multidiscipline linkages (e.g., for the utilization of precipitation nowcasts in hydrological applications, and working with service organizations within WMO to effectively transfer research outcomes to NMHSs) becomes essential. Quantification of impact (e.g., through verification and socio-economic studies) is considered essential.

4.3.2 Research strategy

The WGNR will facilitate and initiate nowcast research projects with high potential impact and international significance. Projects will occur primarily through the WWRP mechanisms of RDPs (for primarily research-driven outcomes), FDPs for end-to-end research and demonstration in an operational framework (testing involving a real-time delivery), and more permanent end-to-end testing and research through testbeds. Past examples of such projects include FDPs undertaken in conjunction with the Sydney 2000 Olympics (nowcasting subtropical summer convection), the Beijing 2008 Olympics FDP (nowcasting summer convection), and the MAP D-PHASE FDP (precipitation nowcasting coupled to very short term hydrological forecasting in mountainous terrain).

The key components of the research strategy undertaken by the WGNR may be summarized as follows:

a) The Promotion and Facilitation of Nowcasting Science

Research activities of importance include:

1. Improving predictive skill and characterizing uncertainty

This is to be achieved through:

i) Improving the accuracy of the initial state. For example quantitative nowcasting of rain amount is seriously impacted by initial errors (about ~50-100%);
ii) Understanding the scale dependence of predictability and associated error growth in
the nowcast model. Smaller scale features are less predictable but are typically where
the high-impact growth occurs. Developing effective approaches to treat this problem
within nowcasting remains a high priority;

iii) Developing post-processing techniques to remove errors related to bias and to better
represent systematic processes, e.g., orographic forcing; and

iv) Providing a probabilistic framework for nowcasting. This will lead to linkages across
time scales as part of the seamless approach to forecasting coupled with increased
utility, impact, and characterization of uncertainty.

2. Promoting physically based nowcast prediction through high resolution model development
and data assimilation

With rapidly growing computer power convection-resolving numerical modelling is making
significant and rapid gains relevant to nowcasting. Significant skill is now evident with dry
orographic forcing but the extension to obtain skill with moist storm scale forcing requires more
research. Significant potential benefit could be realized for winter and summer based nowcasting.
Linking with the WGMWFR is of importance. Primary areas of interest include:

i) High-resolution data assimilation;
ii) Improving model performance through treatment of the spinup problem, appropriate
modeling of dynamical and physical processes, etc;
iii) Characterizing model uncertainty (given the significant error growth at the convective
scale). Investigation of error estimation methods and their limitations;
iv) Characterizing the predictive skill of high resolution modelling; and
v) Integrating high resolution ensemble NWP with probabilistic nowcasting.

b) Nowcasting System and Process Development

The main areas of interest include:

i) Developing improved observational capability in nowcasting. Specific research themes
(but not limited to) include the use of remote sensing techniques;
ii) Characterizing observational errors and algorithm processing errors and their impact on
nowcasting. The Radar Quality Control Quantitative Intercomparison (RQQI) activity
undertaken jointly with CIMO ET on Upper Air and Remote Sensing and the GEWEX
GRP-WGPRN is the primary activity. It is aimed at undertaking systematic
intercomparison and validation of radar QPE/QC algorithms (tested under a variety of
environmental conditions), an assessment of quality control processes employed in
radar-based QPE, and characterization of errors involved in radar-based QPE. The
activity builds and links directly with the EU Operational Project for the Exchange of
Weather Radar Information (OPERA); and
iii) Optimizing nowcast system development including the role of the human.

c) Information Exchange and Capacity Building

The WGNR will promote information exchange through symposia, focused workshops, and
capacity building workshops.

Large symposia provide an effective mechanism to optimize information exchange and
enhance research for the entire community. The symposia will be conducted every four years
building on the first WWRP Symposium on Nowcasting and Very Short-Range Forecasting
conducted in Toulouse, 2005.
Smaller focused workshops will address key nowcasting issues and typically be constituted by invitation only. Past examples of workshops include:

1) The Montreal 2005 Heuristic Probabilistic Nowcasting Workshop. This workshop reviewed the current status of precipitation nowcasting, and then discussed concepts to advance probabilistic nowcasting; and

2) The “International Workshop on Very-short-range Forecasting of Severe Weather” sponsored by Ship and Ocean Foundation and hosted by the Japan Meteorological Agency, Tokyo, Japan in 2004. The focus was the current status and perspectives on very-short-range forecasting (nowcasting) techniques related to severe weather.

The WGNR will facilitate and participate in capacity building workshops to provide basic knowledge of the underlying science of nowcasting, promote the use of latest nowcasting science, and build capacity in nowcasting service provision. The WWRP WGNR has conducted nowcasting training workshops in Australia 2000, Brazil 2003, South Africa 2005, and Australia 2007. The workshop sessions typically include case studies demonstrating how nowcasting science and technology can enhance the overall nowcasting process.

d) Enhancing Transfer of Nowcasting Research to Operations within WMO

The key link in this activity is through the joint PWS-WWRP Joint Steering Committee on Nowcasting Applications (JONAS). This has been established to enhance service related outcomes within the WMO framework. The proposed Shanghai World EXPO Nowcasting Service Demonstration Project (WENS) is being executed jointly with PWS to demonstrate how Nowcasting applications can enhance multi-hazard early warning services (MHEWS) during the Shanghai 2010 World EXPO.

4.3.3 Implementation tasks
The implementation tasks for Nowcasting Research are presented in Annex 1.

4.3.4 Long-range outlook
The long term direction will involve close collaboration with the WGMWFR to enable further application of numerical modelling techniques to nowcasting problems. As significant problems remain, especially over the 0-1 hour time frame, it is expected continued investment will continue in “traditional” nowcasting techniques and blending them with numerical modelling. Exploitation of probabilistic nowcasting techniques coupled to user decision models as part of the seamless approach to forecasting will develop which will involve increased automation in detection and dissemination of warnings building on more rapidly available data. The process will optimize the human role to maximize impact of nowcasting to the users.

4.4 Working Group on Tropical Meteorology Research (WGTMR)

4.4.1 Scope and research priorities
The WGTMR was reorganized in 2007 to have two components: Tropical Cyclone Panel and Monsoon Panel. Both the tropical cyclone and monsoon components have the goal of promoting, supporting and being a catalyst to initiate tropical meteorology research among the WMO Members that will lead to improved observation, analysis, numerical prediction systems, forecasting and warning systems for high-impact tropical weather events, and thus contribute to disaster prevention and mitigation. The unique aspect of the WGTMR is the direct working relationships with the National Meteorological and Hydrological Services (NMHSs) to develop and implement improved and cost-effective forecasting techniques with emphasis on high-impact weather associated with tropical cyclones and monsoons. The WGTMR approach is to understand
the physical mechanisms of tropical cyclones and monsoons, foster the development of improved predictive systems, and then transfer research achievements to the operational forecasting community and to encourage cooperation among the NMHSs related to improving observations, modelling, and forecast techniques for tropical cyclones and monsoon heavy rainfall. The tropical cyclone component of WGTMR has had a long and fruitful working relationship with the World Weather Watch Tropical Cyclone Programme and the NMHSs of the WMO members affected by tropical cyclones. The monsoon component of WGTMR has similar relationships with NMHSs of WMO members affected by high-impact monsoon weather events, and NMHS leaders serve as members on the Monsoon Panel and its expert teams.

Both tropical cyclone and monsoon components of WGTMR have keystone quadrennial workshops (International Workshop on Tropical Cyclones—IWTC, and International Workshop on Monsoons—IWM) to re-enforce and expand this tight linkage between forecaster requirements and their research agendas. The reviews of progress in tropical cyclone and monsoon research and forecasting, the discussion of opportunities for forecasting advances from new research and technology, and the formation of specific recommendations for future research activities make these IWTCs and IWMs invaluable components of the WGTMR activities.

The highest research priority for the tropical cyclone component is to advance understanding and capability to predict tropical cyclone landfall and its impacts. The accurate prediction of the impacts of landfall requires accurate prediction of the track, structure (e.g., size and characteristics of the rainfall and damaging wind field) and the storm intensity. Better understanding of the dynamics and thermodynamics of the storm and of the cloud and precipitation formation processes, as well as optimal use of land and space-based observations are critical to prediction improvements. Genesis is also a critical research issue to provide extended warnings; it is an area where improved representation of tropical convection in models may lead to improved prediction. As recommended by the WMO Executive Committee Research Task Team, coupled models to predict wave fields and storm surges are a high priority, as well as the interaction of tropical cyclones with orography. A number of other relevant research priority items for tropical cyclones are mentioned in the YOTC Science Plan. The panel also intends to provide guidance to the development of GIFS-TIGGE RDPs and FDPs relevant to tropical cyclone activity.

The highest research priority for the monsoon component is to advance understanding and capability to predict the heavy monsoon rainfall events and their impacts. Advancement on this research priority will require efforts across the scales from nowcast heavy rainfall with radar and satellite to assessing the benefits of non-hydrostatic numerical modelling relative to coarse resolution global systems. Another critical research area is whether global deterministic and ensemble models can provide some longer-term warnings of heavy rainfall events and whether coupled weather-hydrological deterministic and ensemble systems can provide advance warning of damaging floods. Basic scientific issues exist including understanding the mechanisms for monsoon onset, intraseasonal oscillations, active and break periods, what processes lead to heavy monsoon rainfall, and what additional observations and/or improved data assimilation and/or improved parameterization of physical processes are required.

These tropical cyclone and monsoon priorities involve circulations and processes from the global scale to the convective scale, and the impacts are strongly modulated by topographic effects and infrastructure considerations. Consequently, the large-scale circulation science objectives of the THORPEX in Section 4.1 and of the WGMWFR in Section 4.2, as they apply in the tropics, are also relevant WGTMR science objectives. Similarly, the approaches of improved observations (including targeting), advances in data assimilation, improvements in model physics, and probabilistic forecasts based on global and regional ensembles are also relevant for WGTMR if they are adapted for the tropics. Perhaps the best test case for demonstrating the societal, economic, and environmental benefits of improved weather forecasts is in the case of tropical cyclone landfall since a more effective warning system that would elicit the proper response by the public could save lives and mitigate the damage in many countries.
4.4.2 Research strategy

4.4.2.1 Tropical cyclone field experiments

The outcomes of WGTMR meetings impact the tropical meteorological research agenda. For example, based on the recommendations at the first International Workshop on Tropical Cyclone Landfall Processes (IWTCLP), the WGTMR organized a major field experiment in the western North Pacific during August and September 2008 called Tropical Cyclone Structure (TCS08). In collaboration with the THORPEX Pacific Asian Regional Campaign (T-PARC), the TCS08 collected atmospheric and oceanographic observations and numerical weather prediction products to study tropical cyclone formation, structure and structure change, recurvature, extratropical transition, and downstream impacts. This was the first international tropical cyclone field experiment in the western North Pacific since 1990, and a unique set of aircraft (radar, Stepped Frequency Microwave Radiometer, wind lidar, and dropsonde) and satellite (including rapid scan periods) observations was collected. One objective was to gather in situ observations of tropical cyclone intensity to validate the many satellite-based techniques that have been developed since 1990.

The WGTMR arranged for a number of international tropical cyclone experts to participate in a workshop in La Reunion hosted by Météo France to plan the Southwest Indian Ocean Experiment (SWICE) field experiment. The primary foci of this field experiment will be in situ validation of the Megha-Tropique satellite instrumentation in the Southwest Indian Ocean and a targeted observation programme to improve tropical cyclone track predictions. Additional foci may include shipboard and airborne oceanographic observations in the region of tropical cyclones and possibly the interaction of tropical cyclones with the topography of a small island such as La Reunion or a large island such as Madagascar. This project has since been endorsed by the JSC; it will likely be expanded to include a tropical cyclone forecast project with GIFS-TIGGE.

The T-PARC and TCS-08 experiments illustrate the advantages of having broad international research collaborations and the involvement of the major NWP centres. In addition to these major international efforts, the WGTMR will also encourage international participation in tropical cyclone field campaigns initiated in other countries through i) bringing researchers from other countries in WMO Regions into these projects, ii) facilitating special observations by the international community, iii) incorporating the participation of their tropical cyclone forecasters from other nations as appropriate by organizing a focused Forecast Demonstration Project, iv) finally transferring knowledge gained in these field experiments to researchers and forecasters in other WMO Regions via the IWTC series or other workshops such as the Second IWTCLP that is in the planning stage. A number of projects are candidates for these activities. One is field experiments conducted in China from 2009 to 2012 on land falling tropical cyclones from the western North Pacific and South China Sea. A number of efforts are also planned in the US focusing on forecast improvements, satellite instrument validation, genesis, and a major oceanographic field experiment to observe the ocean response to typhoon passage.

4.4.2.2 Strategies to advance tropical cyclone modelling

The observations from TCS-08 provide an important data set for advancing both understanding and modelling of tropical cyclone formation and the subsequent evolution in structure and intensity. Research on these topics is on-going. One of the top achievements of the Tropical Cyclone Structure (TCS08) and THORPEX Pacific Asian Regional Campaign (T-PARC) was to collect a series of observations in Typhoon Sinlaku prior to a period of strong interaction with the Central Mountain Range of the island of Taiwan and then a later period in which the tropical storm re-intensified to a typhoon and finally underwent extratropical transition. This event was associated with heavy rainfall on the island and along the mainland. The period leading up to the interaction with the Central Mountain Range is particularly important because all four of the aircraft associated with the combined TCS08 and T-PARC field experiment were flying in the storm, and thus the structure of the typhoon can be defined upstream of the land.
The availability of the upstream TCS08/T-PARC aircraft observations upstream of the island represent a unique opportunity to carry out a mesoscale model intercomparison of a typhoon interacting with the topography of the island since for the first time an accurate specification of the upstream conditions is possible. In addition, the advanced meteorological observation network over Taiwan can provide the necessary validation data set for the models. The objectives of the proposed model intercomparison are to: (i) advance understanding of the typhoon-topography interaction (which included a slowing and looping motion); (ii) advance understanding of the role of model physical representations for tropical cyclone landfall prediction; (iii) explore the minimum model representation (e.g., model horizontal and vertical resolution) for accurate predictions of the landfall impacts such as the heavy precipitation; and (iv) shed light on the limits of predictability in such complex typhoon-topography interaction scenarios.

This modelling intercomparison will be brought to WGNE to enhance international involvement of the operational centres. The WGTMR will also consider selection of other tropical cyclone events from T-PARC/TCS-08 and other field campaigns for modelling intercomparisons.

4.4.2.3 Climate change and tropical cyclones

The WGTMR made the controversial topic of tropical cyclones and climate change as a central focus of IWTC-VI. A comprehensive review was prepared and discussions by researchers and forecasters at the workshop led to a Statement on Tropical Cyclones and Climate Change that was widely distributed (and accepted as an official statement by the American Meteorological Society). The WGTMR Expert Team on Climate Impacts on Tropical Cyclones is tasked to continue these studies. An updated review has been prepared and will appear in a book, and an updated Statement is to be issued in early 2009 by this Expert Team, which is also helping to arrange the first International Conference on Indian Ocean Tropical Cyclones and Climate Change in Oman during March 2009.

4.4.2.4 Seasonal and interannual forecasts of tropical cyclone activity

Based on a recommendation from IWTC-VI, a review of the status of seasonal forecasts of tropical cyclones was published in the WMO Bulletin. In addition, a workshop was sponsored to plan a website that would contain seasonal tropical cyclone forecasts that are consistent in areal and temporal coverage, and would be updated at common times. Documentation and information on how a forecaster may use the website is to be prepared.

The WWRP JSC has also noted the importance of advancing knowledge and improving predictive skill for the interannual variation of tropical cyclones. The establishment of research collaborations with WCRP on this topic will be pursued.

4.4.2.5 Field experiments on high-impact monsoon weather

Lack of adequate upper air radiosonde observations is a major problem in the subtropical and tropical monsoon regions, even over some land areas. Therefore, increase in the radiosonde coverage and frequency as well as improvement in satellite data assimilation are important, since AMMA research has shown that both improve prediction.

Mesoscale convection and heavy precipitation can only be studied with mesoscale experiments that are designed for a specific locality and for specific scientific goals. Thus, most of these experiments have been national or local projects. The WGTMR Monsoon Panel will facilitate cooperation and coordination among these experiments, which will advance research on monsoon severe weather by understanding the physical processes that are common to heavy precipitation in the context of local topography, special environmental conditions (land/sea, etc.), seasonality, and even climate changes.
East Asia is considered to be a model area for the study on severe monsoon weather. The heavy rainfall associated with the East Asian summer monsoon rain belt (Meiyu/Baiu/Changma front) extending from the South China Sea to southern China, eastern China, Taiwan, Okinawa, East China Sea, Korea, and southern and central Japan, as well as rainfall that is usually associated with a surge of the southwesterlies after typhoon passage, are to be the targets of research.

The first efforts will be directed at forming an alliance of field experiments in this area, with the goal of setting up an international virtual laboratory and/or an alliance of virtual laboratories on severe monsoon weather/heavy rainfall. Initial tasks will include: (i) a survey of relevant experiments, laboratories, and research projects in the area; (ii) discussions of the requirements and opportunities to set up a data centre for study of severe monsoon weather; and (iii) reviews of the relevant studies.

Intraseasonal oscillations, monsoon onsets and active/breaks are important research topics on severe monsoon weather that overlap with the World Climate Research Programme (WCRP) CLIVAR and GEWEX monsoon projects. The best way to accomplish field experiments on these larger-scale monsoon topics is to coordinate monsoon weather experiments with these cross-cutting WCRP projects. The coordination will be done in the Asian Monsoon Year 2008-2011 (AMY) in which the Terrain-induced Monsoon Rainfall Experiment-Southwest Monsoon Experiment (TIMREX-SOWMEX), and Pukyong University – HyARC/Nagoya University Observation Network over East China Sea (PHONE) will join with the monsoon experiments of CLIVAR and GEWEX to conduct coordinated field programmes.

4.4.2.6 Quadrennial International Workshops on Monsoons

A major activity of the monsoon research component of the WGTMR continues to be the quadrennial IWM Series. In these workshops members of the Monsoon Panel, including the Expert Team on Severe Monsoon Weather and the Expert Team on Climate Impacts on Monsoon Weather and additional invited experts, review the progress of monsoon studies and identify and discuss the issues most important to advancing the research of severe monsoon weather and improving its forecasting. These workshops also include special focus sessions aimed at the NMHSs forecasters, most of them from developing countries, in which researchers and forecasters discuss their respective areas of interests, with the researchers sharing the most recent research results with the forecasters while learning the special concerns and problems of the forecasters. Application of recently developed forecast products such as those related to the THORPEX Interactive Grand Global Ensemble (TIGGE) in monsoon forecasting is also an appropriate topic.

Compared to extratropical and developed country NMHS operations, short-term severe weather forecasting in the developing countries in the tropical and monsoon regions tends to rely more on knowledge and guidance of climate variability. A substantial part of the reason is that operational mesoscale forecasting is more difficult due both to the serious lack of data coverage and the many challenges of numerical prediction of tropical convection. Thus it is important that these workshops bring together researchers in severe monsoon weather and those in climate aspects of the monsoon to discuss the monsoon forecast research across a wide spectrum of time and spatial scales. Cooperation with WCRP monsoon activities in organizing these workshops is desirable, and the mechanism is built into the WGTMR Monsoon Panel structure through the Expert Team on Climate Impacts on Monsoon Weather.

4.4.2.7 International Training Workshops on Monsoons

The International Training Workshops on Monsoons are conducted in a lecture mode in which the lecturers are invited experts on monsoon research and/or forecasting and the trainees are NMHS forecasters. For example, the seventh and eight International Training Workshops were held in 2004 and 2008, in conjunction with the IWM-III and IWM-IV to take advantage of monsoon
experts. The purpose is to update the trainees’ scientific knowledge including recent developments in monsoon research that are applicable to forecasting. Because operational forecasting of high-impact monsoon weather involves both short-term climate scale and mesoscale issues, topics on both the severe monsoon weather and the climate impacts on high-impact weather are important.

4.4.2.8 Monsoon Data Archive Centres

A major difficulty in tropical and monsoon research is the lack of routine conventional observations in the tropical and subtropical regions. For more than 30 years, a number of important field experiments took place in which large amounts of resources were spent to make special or intensive observations over selected locations of interest. The data from these field campaigns have been invaluable as the main observation bases to advancing tropical and monsoon research. These data were created and used by various organizations and research groups and their storage status is quite varying. Researchers who wish to access these data often have to contact a variety of places to obtain the data. With the passing of time there is a danger that some of the data will be difficult to find. At the First Monsoon Panel Executive Committee Meeting, October 2008, Beijing, panel members concluded that an urgent task is to foster the establishment of a Centre for Monsoon Field Campaign Legacy Data Sets to archive radiosonde, aircraft and ship data sets from past and future monsoon and tropical field campaigns and related data for monsoon research. The NMHS representatives also recommended the establishment of a radar meteorology data information centre to categorize the various sources of radar data that are being collected in different parts of the Asian monsoon region for easy retrieval by researchers and to serve as a focal point for the international collaboration and exchange activities in the study of severe monsoon weather in this region.

A third data centre highly valuable to support both monsoon research and operational priorities is a centre for the monitoring and assessment of extreme weather and climate events. The idea of this centre was discussed by NMHS representatives at the Asian monsoon forecast sessions during the Fifth WMO Forum on Regional Association II Climate Monitoring, Assessment and Prediction. In the region, both extreme weather and extreme climate events are mainly associated with the multi-scale Asian monsoons. They result in very high-cost impacts to society due to the disasters they often cause. The establishment of a unified database and monitoring platform can help foster research on high-impact monsoon weather.

4.4.2.9 Linkages with other WWRP components

- THORPEX for continuing analyses of combined TCS08 and T-PARC field experiment;
- TIGGE for studies of ensemble tropical cyclone track predictions and monsoon rainfall;
- JWGVR for seasonal tropical cyclone activity and for mesoscale model verification methods; and
- WGMWFR for tropical and monsoon region mesoscale observation studies, mesoscale data assimilation, representation of convection and complex terrain, and predictability of mesoscale heavy rainfall events.

4.4.2.10 Linkages with other agencies

- NMHSs for forecaster requirements related to tropical cyclones and monsoons and research-to-operations transitions;
- WWW Tropical Cyclone Programme for co-sponsorship of IWTC series and NMHS coordination as in above linkage;
- WCRP CLIVAR and WCRP GEWEX Monsoon Panels for research-to-operations transitions and climate effects on monsoon studies;
- WCRP for cooperation in climatic effects on tropical cyclones;
- WGNE for continuing evaluations of global model performance in tropical cyclone prediction; and
- WGNE for (proposed) international mesoscale model intercomparison for Typhoon Sinlaku.

4.4.2.11 Products and services

- Update of book *Global Perspectives on Tropical Cyclones*;
- Update of *Global Guide to Tropical Cyclone Forecasting*;
- Website for seasonal forecasts on tropical cyclones;
- Published review and updated Statement on Tropical Cyclones and Climate Change;
- Abstracts from International Workshop on Monsoons-IV;
- New WMO Technical Document on Monsoons;
- Update of book *The Global Monsoon: Research and Forecasting*;
- International Monsoon Forecasting Training Workshop materials for forecasters;
- Catalogue of Monsoon Field Campaign Legacy Data Sets;
- Catalogue of Monsoon Radar Meteorology Data Information; and
- Consulting to NMHSs in monsoon regions on research and forecasting opportunities.

4.4.3 Implementation tasks
The implementation tasks for Tropical Meteorology Research are presented in Annex 1.

4.4.4 Long-range outlook
The need for an active WGTMR will only increase in the future as the tropical cyclone threat grows due to continued population and industry movement to coastal areas. Thus, the focus of the Tropical Cyclone Panel will be on improved understanding and predictions of tropical cyclone genesis, structure, intensification and landfall, and their impacts. Because a recent sensitivity study has demonstrated that further significant track improvements will not arise from finer model horizontal resolution alone, the research pathway to advancements is in specification of the initial conditions and the physical process representations in the models. Better utilization in the data assimilation system of satellite remote sensing for both the environment and the inner-core of the tropical cyclone is an essential research task. Similarly, effective utilization of aircraft radar observations (where available) in the data assimilation system will be a future research thrust. Targeted observation strategies for improved tropical cyclone structure prediction are also expected to be a future research direction. More accurate and location-specific forecasts and warnings of the tropical impacts (high winds, heavy precipitation, high surface waves and storm surge) will be the goal of the research programme. In most cases, these impacts will need to be expressed in probabilistic terms for appropriate risk management, taking advantage of anticipated improvements in ensemble prediction systems. Additional collaboration with the societal impacts researchers will be required to improve the public response to those tropical cyclone landfall warnings.

Population growth and infrastructure increases that are occurring in areas affected by heavy monsoon rainfall are the challenge for the Monsoon Panel. Much of the highest impact weather that causes life and economic losses ranging from local damages to major disasters in these areas, where 2/3 of the world population reside, is monsoon related. This weather specifically includes torrential rainfall associated with the summer monsoon surges, including those that are associated with the remote influence of tropical cyclones, and the winter monsoon cold air outbreaks, surges, and storms. Efforts to improve the forecasts of these weather systems require research on the interactions among large-scale flow, mesoscale convection, and local terrain. Research is also clearly needed to identify and reduce, where possible, the barriers to improved prediction (e.g., observational strategies, data assimilation and/or the treatment of physical processes in modelling). These efforts need to include regional cooperation in field observation programmes and experiments, modelling and assimilation studies, the utilization of newly developed remote sensing observations including both satellite and radars, and major new
initiatives using the results of the field experiments. Recent progress in tropical and subtropical intraseasonal oscillations provide an opportunity to develop technologies that extend the forecast of disturbed monsoon weather to more than a few days and also link the interest of the monsoon weather research community with the monsoon climate research community. In addition, applied research, capacity building, and technological transfer are also important to ensure that NMHSs of the developing countries in the monsoon regions can receive maximum benefit from the monsoon research programme.

4.5 Joint Working Group on Verification Research (JWGVR)

4.5.1 Scope and research priorities

The JWGVR is a joint activity of WWRP and WGNE. It encourages and facilitates focused research on forecast verification and evaluation methods. This research benefits the atmospheric science research, modelling, and operational communities by facilitating the development of verification methods that provide meaningful information for operational and user decisions; the use of these tools also impacts the forecast development process and leads to new and/or improved forecasts and models. The JWGVR supports the forecasting and evaluation communities by disseminating new verification techniques and best verification practices via workshops, coordinated publications, and a comprehensive and informative verification web page. In addition to research, the JWGVR promotes and provides training on verification methods – to encourage the appropriate selection and application of verification approaches for specific forecast evaluation problems and the implementation of improved verification methods in operational and research settings. Finally, the JWGVR serves an advisory role, enhancing the understanding of new verification methods, promoting the use of appropriate verification strategies, and aiding in the interpretation of verification results.

Members of the JWGVR represent both the operational and research communities (operational prediction centres, research centres, and universities) to provide clear connections between research and operational needs and constraints. Members have expertise in the evaluation of many types of forecasts, including user-centric evaluation of nowcasts and public weather forecasts, and evaluation of global and mesoscale NWP and ensemble forecasts. In addition, members of the JWGVR have developed new methodologies for forecast evaluation and have helped establish statistically valid protocols for verification applications (e.g., the measurement of uncertainty associated with verification measures; meta-verification).

Research priorities for the JWGVR include the following:

- Development of forecast evaluation measures and approaches that are meaningful in terms of forecast use/value;
- Diagnostic and user-relevant forecast evaluation approaches that provide broad information about many attributes of forecast performance;
- Approaches to partition forecast error as a function of spatial and temporal scales, to provide information regarding forecast performance as a function of scale;
- Verification methods for ensemble forecasts and forecasts of probability distributions;
- Methods for assessment of predictability;
- Verification methods for weather extremes, including severe weather warnings;
- Techniques targeted toward high-resolution forecasts (e.g., spatial forecast verification methods);
- The assessment of uncertainty in verification statistics;
- Understanding and incorporation of information regarding observational uncertainty into verification approaches;
- The processing and use of high-resolution remotely sensed observational data (e.g., radar, satellite, lightning) in verification; and
- Understanding the properties of verification methods and measures (i.e., meta-verification) to provide guidance on appropriate application of verification approaches.
These priorities together represent many of the challenges of concern in the forecasting, modelling, and forecast evaluation communities related to processes of (a) quantifying the performance of forecasting systems, and (b) demonstrating quantitatively the improvements in services and capabilities resulting from forecast and modelling research.

4.5.2 Research strategy

Research and development efforts that focus on new verification methodologies have become essential to respond to needs for more user-relevant verification information, and in response to the advent of high-resolution forecast models and ensemble prediction systems. As new verification methods are developed, it is critical for the methods to be tested and evaluated to determine that they meet basic requirements of statistical validity, and that the results of their application are interpretable and meaningful. A verification test-bed (VTB) process which will facilitate intercomparisons and evaluations of verification methodologies will help to ensure that these needs are met, and will help inform users regarding the capabilities of the methods. Collaborative development and research efforts will also be fostered by the existence of a VTB.

Workshops on verification methods provide an opportunity to focus on relevant verification research topics. These workshops integrate the verification research community, help to foster collaborations, and encourage increased focus on identified areas of concern (e.g., on methods for ensemble forecasts). Specialized workshops concerning specific types of forecasts (e.g., nowcasts, mesoscale model predictions) facilitate the development of methods that are appropriate for particular forecasting situations.

Interactions and collaborations with other WWRP working groups and activities such as RDPs, FDPs, and other WWRP activities (e.g., THORPEX, TIGGE), provide motivation for development of new approaches and enhancement of current approaches. For example, collaborations with the WGMWFR facilitate development of methods that are appropriate for application to high-resolution forecasts; collaborations with the WGSERA help focus efforts on methods that are user-relevant. These collaborations also provide opportunities for interacting directly with researchers, operational forecasters, and forecast users and aid in the transfer of new verification methods and verification practices to the research and operational communities.

The practice of forecast evaluation or verification is not always straightforward, and typically is not an integral part of the educational programme for atmospheric scientists and meteorologists. The ability to effectively apply verification methods and interpret the results of verification studies is a critical need in many operational and research organizations. In addition, new methods to be implemented in research studies and in operational settings must be understood by the users of the methods and by those who interpret the results of the evaluations. Thus, training and outreach are very important aspects of the work of the JWGVR.

Linkages

The JWGVR will maintain close linkages with the other WWRP components, including the following:

- With the WGSERA for development of user-relevant verification approaches, as well as measures and approaches that reflect forecast use and value; and for participation in WGSERA forecast evaluation projects;
- With the WGMWFR for development and application of approaches that are appropriate for high-resolution forecasts, assessment of predictability, development of approaches to take into account observation uncertainty, and development of methods for evaluating forecasts of probability distributions;
- With the WGNR for the development of methods for evaluation of spatial and high-resolution forecasts; development of methods for extreme weather forecasts, short-term severe weather warnings, and other types of nowcasts; and the use of high-resolution remotely sensed observations;
• With the WGTMR for evaluation of seasonal predictions and development of appropriate methodologies for evaluating improvements in tropical cyclone predictions associated with model enhancements (e.g., new data assimilation approaches, ensemble methods); and
• With the THORPEX Programme (i.e., TIGGE and TIGGE-LAM) for developing methods and strategies for evaluating ensemble forecasts of a variety of variables (e.g., cyclone tracks) and aiding in the development of user-relevant strategies for forecast optimization and evaluation.

Strong linkages are also required with

• WGNE to provide methodological guidance for evaluation of NWP forecasts (e.g., for precipitation, clouds);
• WMO regional programmes (e.g., Severe Weather FDP) to provide guidance and methodologies for meaningful verification activities in situations with observational limitations;
• CBS, to aid in the transition of new verification methodologies and practices into operational settings, and to aid in training on these methodologies; and
• Other WMO programmes that have needs for methods for forecast or product assessment (e.g., air quality, climate, hydrology).

Some of these linkages will be facilitated by joint WG memberships (e.g., TIGGE, WGSERA) and through joint workshops.

### 4.5.3 Implementation tasks

The implementation tasks for Verification Research are presented in Annex 1.

### 4.5.4 Long-range outlook

JWGVR efforts will continue to make progress toward the development and implementation of methods for the evaluation of high-resolution and ensemble forecasts. Specific areas of critical focus in the future will include methods for extremes; observational uncertainty; and the application of remotely-sensed observations in regions with sparse coverage by traditional measurements. Other focus areas may include severe weather, hydrometeorological predictions, atmospheric chemistry, and climate metrics; the JWGVR will focus verification research on new forecasting areas as needs become apparent. Outreach will continue to gain importance as forecasting services and research groups face increasing needs to quantify forecast improvements and increased requirements arise for more holistic, user-relevant, and detailed forecast evaluations.

### 4.6 Working Group on Societal and Economic Research and Applications (WGSERA)

#### 4.6.1 Scope and research priorities

The primary purpose of the WGSERA is to advance the science of the social and economic application of weather-related information and services. This will be accomplished in part through the development, review and promotion of societal and economic-related demonstration projects focused on high-impact weather (HIW) and information.

For the purpose of this Strategic Plan, HIW refers to meteorological and hydrometeorological conditions, events, or sequences of events that have a measurable effect on society, whether expressed in terms of lives, injuries, economic costs or a range of other physical variables (e.g., buildings damaged, displaced people, employment, crop yields, energy consumption, etc.). HIW may include acute severe weather (e.g., extreme winds or temperature) and rare events with high consequences (e.g., tropical cyclones) but also encompasses common features of weather associated with chronic hazards that affect large numbers of people or activities over an extended region or period of time (e.g., drought, motor vehicle collisions). Weather information, including forecasts, will only have a high-impact if it can be used by...
individuals or organizations to significantly mitigate impacts and costs, or to enhance benefits (Morss et al. 2008:338).

The WGSERA membership consists of three general types of expertise:

i) Social, economic or decision scientists (i.e., from anthropology, applied health, communications, economics, geography, management sciences, sociology, psychology, or similar disciplines) or other researchers with experience applying social science methods and techniques to weather-related issues;

ii) Representatives of private, public or non-government sector organization that engages users in the development, application, and beneficial use of weather and related information, products, and services; and

iii) Representatives of a user or community of users that benefits directly or indirectly from weather and related information, products, and services.

The membership shares a common interest in developing and sharing knowledge and tools required to increase the effectiveness and application of weather, climate and climate change information and services to reduce loss of life and injury and improve the quality of life, economic prosperity, and environmental protection.

Collaborative research across social and physical science disciplines and involving information providers and users is required to address the following priorities (Morss et al. 2008):

- Estimation of the economic (societal) value of weather information;
- Understanding and improving the use of weather information in decision making;
- Understanding and improving the communication of weather forecast uncertainty;
- Development of user-relevant verification methods; and
- Development of decision support systems and tools.

These priorities apply and may be explored across the full spectrum of societal, economic, and environmental interests and issues facing humanity. Nevertheless, given the mandate of WWRP and WMO, it seems appropriate to concentrate research and applications where weather conditions and meteorological information directly influence:

- Mortality, morbidity, and significant loss of property; and
- Critical infrastructure and resources required to support communities and livelihoods, with emphasis on water, energy, food, and transportation.

Where possible, demonstration projects and case studies should be conducted to facilitate comparisons across geographic regions, jurisdictions, socio-economic, and cultural contexts.

### 4.6.2 Research strategy

Lacking a significant core budget to conduct independent research, the strategy employed by the WGSERA will be incremental rather than comprehensive—essentially build it as they come with whatever you can find. In lieu of hard currency, the WG will offer a strong, yet flexible structure, basic research infrastructure, and collaborative opportunities to create, publish, and transfer knowledge that otherwise would not exist. This should enable the WG to mine past research, leverage on-going and planned projects, and facilitate and encourage new proposals related to one or more of the research priorities defined previously. The long-term strategy of the WGSERA will include promoting the SERA research objectives and being a voice for mobilizing the necessary external resources to further research on these objectives.

Key elements of the WG structure include a core membership; interest groups; liaisons with other WWRP or WMO WGs/expert teams; and partnerships with external organizations. Success will be largely predicated on securing a committed core WG that can define and readily access a distributed network of expertise within and outside of WWRP. Core members will lead one or more
social science “interest” groups focused on particular research priorities, disciplines, weather-sensitive sectors (users), or weather-related hazards. The groups will allow WGSERA to tap into a range of expertise that simply could not be corralled into a small, functional WG. Communicating primarily through e-mail, these groups will be used to assist with reviewing WG documents and to identify pertinent projects, data sources, leveraging, and capacity building opportunities.

The mandate and priorities of the WGSERA necessitate having close ties to each of the other WWRP WGs to establish, define, and translate weather forecast information for application and analysis in WGSERA projects. The WGSERA will also need to use their unique expertise to ensure that the SERA components of FDPs and RDPs of the other WGs are scientifically sound, of high quality and sufficient to reach the desired objectives. This approach will be similar to that undertaken by the JWGVR. Liaisons will be secured with the JWGVR and TIGGE and Regional Committee elements of the THORPEX Programme. Relationships between WGSERA and other parts of WMO (e.g., Public Weather Services, Natural Disaster Mitigation and Prevention, WCRP) will be established in a similar fashion as required.

Linkages with external agencies, particularly with those engaged in natural hazard and disaster reduction activities, will be important to develop and maintain. International organizations, including the International Council for Science (ICSU), International Federation of Red Cross and Red Crescent Societies (IFRC), Earth System Science Partnership (ESSP) (WCP and ICSU), Group on Earth Observations (GEO), World Health Organization (WHO), and World Tourism Organization (WTO) will be approached to determine mutual interests and the potential for collaborations. A more formal arrangement between WWRP and ICSU is being discussed which may possibly lead to a joint WG between WGSERA and the ICSU Planning Group on Natural and Human-induced Hazards and Disasters. Depending on the scope of particular activities and projects, linkages will also be sought with organizations, industry associations, and institutions operating at national and regional scales—the most significant of these being National Meteorological and Hydrometeorological Services (NMHS).

Three sets of WGSERA activities are envisioned for the next three years and described generally below. Specific projects and publications will be dependent to a great extent on the collective capacity and abilities of the core WGSERA whose membership must yet be finalized.

i) Establish a presence and basic research infrastructure. A WGSERA presence will be gained through populating the WG structure, establishing regular correspondence and meeting schedules, and canvassing WG members, NMHSs, WWRP WGs, and WMO programmes to establish a basic inventory of related projects, capacity, contacts and interest in SERA. The inventory will form part of a basic infrastructure—a SERAwx web resource for social scientists to access user-friendly meteorological data; links to socio-economic data; meta-information concerning SERA research, applications, methods, and workshops/training opportunities; and an inventory/database of individual high-impact weather events, high-impact forecasts and impact climatologies. The WGSERA will be a strong voice to assist in the design of future SERA-like efforts within WWRP FDPs and RDPs.

ii) Start-up research projects and applications. Although a number of significant achievements were made during SERA’s tenure under the THORPEX umbrella, it will be important to quickly demonstrate new contributions within the broader WWRP. Early candidate projects to be defined and completed jointly with the JWGVR include a series of regional and sector-based case applications that cut across nowcasting, meso-, and sub-seasonal scales of prediction/decision-making. Development and evaluation of a SERA-friendly TIGGE dataset from multiple user perspectives will likely form one of several collaborations with the THORPEX-TIGGE working group.

iii) Global assessment of the societal and economic benefits (and costs) of weather information. This represents a longer-term and more substantive project that would commence within 18 months and be completed over a 3-5 year period. The project would
involve a synthesis and critical review of existing research by sector and region; development of global estimates based on a meta-analysis and expert opinion; overview of methods and best practices required to yield a more rigorous estimate; and practical guidance/training for NMHSs, researchers, and social science students.

Progress and results from these and other activities will be presented at WMO-related meetings, user-oriented workshops and training sessions, disciplinary conferences, and key international fora (e.g., 2010 Davos International Disaster Reduction Conference, 2012 Madrid +5 conference). Significant findings will be submitted for publication in relevant social science and interdisciplinary journals as well as official WMO publications.

4.6.3 Implementation tasks
The implementation tasks for Societal and Economic Research and Applications are presented in Annex 1.

4.6.4 Long-range outlook
The concept of a seamless system for predicting atmospheric phenomena on scales ranging from seconds to centuries will be rapidly transitioning from a research and development activity into operational reality over the next decade. A key challenge will be to harness the excitement of scientific discovery and improvements in predictive skill for commensurate, if not greater, relative achievements in the safety, quality of life, and productivity of citizens from all nations. It is therefore paramount that SERA in general, and users of all types, be a central component and consideration in the design, construction, and evaluation of seamless prediction. Towards this end, the WGSEERA will find its long-term role in facilitating the identification, development, assessment, and exchange of ideas, research methods, tools, data, and case studies from the social sciences for application to weather-related problems.

References

4.7 Expert Team on Weather Modification Research (ET-WMR)

4.7.1 Scope and research priorities
There is a great world wide interest in the role of clouds and precipitation in weather, climate, water and environmental issues. The Fifteenth Congress of the World Meteorological Organization (WMO TD 1026, para 3.3.4.1) noted that weather modification activities conducted by a number of WMO Members were aimed at improving the economy, for example, to increase a water supply for agriculture, or reducing the risks associated with high-impact weather such as frost, fog and hail. It strongly recommended that such activities be supported by research and modelling that provided a deeper understanding of the effects of cloud modification on cloud/precipitation development and a scientifically accepted evaluation of the weather modification activities. It also asked the WMO Secretariat to establish a trust fund for support of the quadrennial WMO Scientific Conference on Weather Modification and the WMO Expert Team on Weather Modification Research (ET-WMR) that supported training and guidelines for sound scientific practices in weather modification and operations. It urged Members and other parties involved in weather modification to contribute to the trust fund.

The Fourteenth Session of the WMO Commission of Atmospheric Science (WMO TD 1002) in February 2006 recommended that the ET-WMR be part of the World Weather Research Programme. Subsequently, WMO Congress XV (CGXV para. 3.3.1.3) accepted the Report of the
President of CAS and endorsed the changes in Commission for Atmospheric Sciences documented in the report of CAS XIV, and subsequent amendments by the fifty-eighth session of the Executive Council in 2006. For details of weather modification assessment activities and the WMO statement and guidelines see http://www.wmo.int/wxmod.

4.7.2 Research strategy

The strategy of the ET-WMR is as follows:

a) To keep under review, on behalf of OPAG-WWRP and OPAG-EPAC, relevant research, and to advise CAS on issues requiring attention related to weather modification and suggest mechanisms for addressing such issues;

b) To review the criteria for conducting weather modification research to ensure the quality of the science, from the initial design to the final evaluation of field experiments, taking into account advances in supporting fields, including cloud physics, atmospheric chemistry, numerical modelling and SEAs;

c) To serve as a focal point and provide advice and assistance on the manner and means of transferring competence for planning scientific experiments; and

d) To assist in the drafting of WMO documents on the status of weather modification and guidelines for providing advice to Members and to propose revisions to these documents where necessary.

4.7.3 Implementation tasks

The implementation tasks for Weather Modification Research are presented in Annex 1.
5. RELATED ACTIVITIES

This chapter presents other WWRP activities that do not neatly fit within the structure of the WWRP WGs and THORPEX programme, either because these are joint activities with other groups, or because by nature they span more than one WG’s area of responsibility.

5.1 WWRP-WGNE research collaborations

The Working Group on Numerical Experimentation (WGNE) is a joint working group of WCRP and CAS. Its main roles are to review the development of atmospheric models and data assimilation systems and through coordinated numerical experimentation promote the further development of these systems. Since atmospheric models and data assimilation systems are also a key component of WWRP’s mission, several areas of mutual interest exist between WWRP and WGNE that provide great opportunities for collaborative research. This section outlines some of the key research areas in which a close collaboration between WWRP and WGNE is envisaged.

5.1.1 Physical processes in atmospheric models

The representation of physical processes in atmospheric models has always been a crucial area for weather prediction. The prediction of key weather elements, such as rainfall and near-surface wind and temperature, including their extremes as encountered in severe weather events, relies on the faithful representation of a multitude of physical processes such as clouds and moist convection as well as boundary layer and microphysical processes. As these processes act on scales much smaller than traditional model grid-lengths, they have to be included in models by means of parameterization. With the continuing increase in computing power, many local and regional forecast systems are now reaching grid-lengths approaching the scales of deep moist convection, which, combined with the goal of designing seamless prediction system, leads to additional research requirements. While needing to maintain strong efforts in traditional parameterization areas in support of global NWP, seasonal forecast and climate simulation systems, modern regional NWP systems require more emphasis on representing convection at resolutions where key processes are neither resolved nor can they be parameterized by traditional methods. Furthermore, more emphasis will need to be given to improving the representation of microphysical processes. Inherent in this Strategic Plan are numerous activities seeking improvement in the parameterization of physical processes, particularly within THORPEX, the WGMFR and the WGTMR.

The WGNE has recently established a new expert group on physical parameterization with the aim of consolidating and better coordinating activities to improve physical processes in atmospheric models. This group integrates all existing programmes in WMO, such as the GEWEX cloud, land surface, and boundary layer study groups. A strong interaction of the WGNE physics group’s activities with the WWRP efforts is critical for the success of many of WWRP and WGNE’s goals such as the development of seamless prediction systems as well as the improved understanding and prediction of the multi-scale organization of tropical convection. The interaction of WGNE and WWRP in this important area will be fostered by integrating WWRP research efforts on physical processes with those in the WGNE group. Early examples for such integration are the joint research under the auspices of the Year of Tropical Convection (YOTC) as well as the emerging participation of operational regional and local forecast systems in the model evaluation and development activities coordinated by the GEWEX Cloud System Study (GCSS). These activities will be promoted further and new collaborations are expected to emerge.

5.1.2 Verification

As described in section 4.5, WWRP and WGNE together host the Joint Working Group on Verification Research (JWGVR). With the emergence of seamless prediction systems as well as the increasing desire to provide societally relevant forecasts, there are many challenges to develop improved methods of forecast verification and to apply them to an ever-increasing set of forecast products. One area of continuing and increasing collaboration between WWRP and WGNE will be
the evaluation and verification of forecasts. The main areas of research will include developing improved verification methods for high-impact weather forecasts, developing seamless verification methods in support of seamless prediction, as well as developing methods to verify forecasts of parameters of direct relevance to society, such as air quality predictions. In addition to the development and promotion of new techniques, the JWGV also plays a crucial role in the training of weather services in the use of these techniques, in particular in developing nations. This role is likely to increase with the increased complexity of the forecasts systems and products. WGNE has been instrumental in facilitating the development of new verification efforts, such as the verification of operational precipitation forecasts, tropical cyclone track prediction, and the promotion of metrics for climate models. Close collaboration between WWRP and WGNE in the area of verification is of utmost importance.

5.1.3 Link to operational NWP Centres

WGNE plays a crucial role in ensuring the link between the research community and the key operational NWP centres. Hence strong collaboration between WWRP and WGNE is essential for the success of this strategic research programme, not least through supporting the plans of the WWRP working groups and of the NWP-related THORPEX working groups.

5.1.4 Data assimilation

The key activities in data assimilation are through the operational centres and hence WGNE is well placed to monitor new developments and progress in this crucial and expanding area of science. Furthermore, the WWRP/THORPEX DAOS WG represents the main current community activity in DA development so that it is clearly an area for strong WWRP-WGNE collaboration. Major science challenges ahead include assimilation at high resolution - globally and regionally, assimilation of new variables including rainfall and cloud (in support of convection-permitting models) and chemical species (in support of air-quality forecasting), and ensemble assimilation techniques in support of global and limited-area Ensemble Prediction Systems. The WGMWFR has also current and planned activities in the area of data assimilation. High resolution (km-scale) data assimilation is a critical future challenge for NWP. Coordination between WGNE, the THORPEX DAOS and the WGMWFR could accelerate advancements.

5.2 Evaluation and improvement of weather forecasting systems through collaboration with CBS

For more than thirty years, WMO has promoted international collaboration on numerical weather prediction (NWP) research through the Working Group on Numerical Experimentation (WGNE) and other mechanisms. The WGNE has provided a forum for scientists from key operational centres working on NWP. It has led to the continuing and rapid development of numerical techniques and systems that have been readily implemented in operational environments. As well, it has generated consensus on standardized verification methodologies which allow performance evaluation and inter comparison of NWP systems.

In the past, the main output of NWP systems has been in the form of charts for use by operational forecasters in preparation of routine forecasts. Indeed NWP has been a primary reason for the continuing improvement in operational forecasting over the last 25 years. NWP outputs have gradually become the primary guidance to the manual subjective forecasting process.

To improve this forecasting process, many countries have developed forecast tools and systems. While such forecast tools and systems have been developed for about 30 years, work has accelerated over the last decade to the extent that many NMHSs have some relevant development activity. Often this work has been somewhat separated from NWP research, and it has been seen as “system development” rather than “meteorological research”. Indeed, many initial workstation software developments did not involve research as they were focused on automating or facilitating technical tasks, such as plotting maps and viewing observations and NWP products as done in the past, without consideration of developing new forecast processes.
Then came the development of tools to facilitate the production of forecasts, such as text editors, automated generation of telecommunication headers, and for monitoring and alerting purposes such as automated weather watch and checking the validity of current forecasts versus incoming observations.

With the gradual improvements in NWP performance, the nature of operational forecasting has been changing in many NMHSs in recent years. The output of NWP systems increasingly is being fed directly in gridded numerical form into forecast systems. In this environment, forecasters interact with the forecast guidance on computer workstations to generate semi-automatically a range of products for various external clients. For the first time, this now touches the heart of the forecasting process.

As always, the forecasting system must meet the needs of all users served by an NMHS within imposed financial and structural constraints that are different for each country. For this reason, approaches to forecasting systems differ significantly between countries, i.e., centralized versus decentralized; automated or subjective; public, aviation, marine, agricultural forecasts combined or separated between offices, etc. International collaboration has been limited. While it is easy to compare many models running on the same domain, very few simultaneous forecasts are issued by different NMHSs for the same territory and the same clientele, which leads to a very difficult task to validate and intercompare approaches.

In addition, some specialized users are now directly using NWP outputs or MOS (Model Output Statistics) without referring to official forecast issued by NMHSs, and some private sector meteorological firms are issuing forecast independent from those issued by the NMHSs, usually largely based on NWP products.

Finally, the emergence of Ensemble NWP systems has the potential to generate huge amounts of probabilistic forecasts, which create major challenges on how forecasters should-could interact and how such probabilistic forecasts should be presented to users.

The world of operational forecasting is thus changing rapidly. The potential for substantial improvements in services to users is very high, but the historic separation of NWP research from forecast system development is becoming a major obstacle to progress. Optimal outcomes can only be achieved when an integrated system is developed in the recognition that NWP is an integral part of the forecasting process. A scientifically rigorous approach must be used to evaluate options, intercompare forecast systems and choose the best path forward, as this has been done within NWP research.

Because forecast system research is a relatively new field and because it has not been fully integrated with strategic meteorological research, no international forum currently exists for the promotion of collaboration in this field. Just as international collaboration in NWP research has provided the means for NMHSs to make steady improvements in operational forecast accuracy over recent decades, a collaborative approach to forecast systems research has the potential to provide the means for NMHSs to deliver the broader range of higher-quality products that their clients expects from them.

If through international collaborative research, good forecast systems with proper integration of NWP models become available, then developing countries could use such forecast systems and directly benefit from NWP improvements done by developed countries. This could become the optimal solution for NMHSs of many developing countries.

The increasing importance of forecast systems to NMHSs in meeting the expectation of their clients for timely, sophisticated and accurate products is now recognised. The forecast system research needs to be closely coupled to the NWP systems at one end and to the operational requirements of a NMHS at the other end.
Recognizing the emerging importance of forecast systems development, the WMO EC has recently decided that CBS should take the lead in the development of an appropriate programme of activity. The scope of activities that CBS will need to consider is very broad: best approaches to maximize the use of all available information (observations of all kinds, climatology, conceptual models, deterministic NWP, ensembles, MOS); issues related to the choice of interfaces (matrix, point, object, grids, digital forecast databases); technical issues such as automatic text or graphic generation, validation-verification approaches; human issues related to optimizing the role of humans in the forecast process, while the potential for automation based on NWP outputs is becoming real; changing end-user requirements; and dissemination issues.

In the absence of an existing mechanism, it would be appropriate for WWRP to lead and establish a mechanism to promote international collaboration on forecast systems research to meet the needs of CBS. It will be important to discuss fully with CBS to establish detailed research and capacity building priorities. In addition to promoting collaborative research on forecast systems, two general research priorities emerge. First, the evaluation and intercomparison, based on a rigorous scientific approach, of alternative solutions within forecast systems. Second, the full integration of NWP as an essential component of forecast systems.

Implementation tasks
The implementation tasks for the evaluation and improvement of weather forecasting systems are presented in Annex 1.

5.3 Atmospheric chemistry and weather
Aerosols, ozone and longer-lived greenhouse gases are well recognized as “essential climate variables” (IPCC 2007; the Second Report on the Adequacy of the Global Observing Systems for Climate by the Global Climate Observing System, GCOS, 2003). Since 1990, climate modellers have realized 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 clearly places these variables at the forefront of climate forcing and also of uncertainties related to climate forcing.

Until recently, aerosols, ozone and greenhouse gases were not regarded as “essential weather variables”. Atmospheric dynamicists/physicists considered that the greatest barriers to weather prediction were related to inadequate representation of the dynamical and physical properties of the atmosphere. It was assumed that the effects of the “chemical variables” could be taken into account by using climatological mean spatial and temporal distributions. However, as the skill of NWP 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. In addition, the goal of extending the usefulness of forecasts beyond the classic 3 to 5 days to 14 days or even seasons became seen increasingly as possible. For both reasons, 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 (typical residence times of 3 to 14 days) and therefore cannot be represented by climatological distributions.

New initiatives are emerging in the research community that are moving toward the incorporation of aerosols, ozone and greenhouse gases into NWP forecast models as active constituents that can be assimilated in near real time or in reanalysis mode. A flagship project in this regard was the Global and regional Earth-system (atmosphere) Monitoring using Satellite and in-situ data (GEMS) 2005 -2008. GEMS and its successor MACC build on the global weather forecasting system operated by the European Centre for Medium-Range Weather Forecasting (ECMWF). 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. The
resulting integrated system is capable of assimilating a wide range of observational meteorological data, associated ocean-wave and land-surface data, and the increasing amount of remotely sensed data on atmospheric trace constituents that have been provided by satellites in recent years. The broad-scale air-quality products of the global system are complemented by products from an ensemble of finer-resolution forecasts generated by a set of regional air-quality models that have been adapted to run over a common European domain.

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. For instance, many of the models in WMO SDS-WAS (WMO Sand and Dust Storm Warning Advisory and Assessment System) are beginning to assimilate aerosol observations and link them to radiative forcing (see section 5.4). The goals are to reduce societal risk by providing more accurate forecasts of weather, precipitation, monsoons and tropical cyclones out to weeks or even a season. The role of WWRP and its sister programmes in the WMO Research Department, GAW and WCRP, is to support the global community in their need for standardization, observations and next generation predictions.

Implementation tasks
The implementation tasks for Atmospheric Chemistry and Weather are presented in Annex 1.

5.4 WMO Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS)

5.4.1 Scope
WMO is taking a lead in coordinating the Sand and Dust Storm Warning Advisory and Assessment System (SDS-WAS) to develop, refine and provide products useful in reducing the adverse impacts of sand and dust storms and to assess their impacts on society and nature. Mineral aerosols, mobilized during sand and dust storms in arid and semi-arid continental regions, are the dominant component of the atmospheric aerosol over large areas of the Earth (centre part of Figure 3). They play an important role in weather, climate, human health and air quality, air transportation and highway safety, marine productivity and agriculture.

On the 12 to 14 September 2004, an International Symposium on Sand and Dust Storms was held in Beijing at the China Meteorological Agency followed by a WMO Experts Workshop on Sand and Dust Storms. The recommendations of that workshop led to a proposal to create a WMO Sand and Dust Storm Project coordinated jointly by WWRP and GAW. This was approved by the steering body of the World Weather Research Programme (WWRP) in 2005. In 2006, the steering committee of the Sand and Dust Storm Project proposed the development and implementation of a Sand and Dust Storm Warning, Advisory and Assessment System (SDS-WAS). The WMO Secretariat in Geneva formed an Ad-hoc Internal Group on SDS-WAS consisting of scientific officers representing WMO research, observations, operational prediction, service delivery and applications programmes such as aviation and agriculture.

In May 2007, upon the recommendation of CAS, the 14th WMO Congress endorsed the launching of SDS-WAS development with the lead taken by WWRP in collaboration with GAW. It was recognized that SDS-WAS was largely founded in the WMO research community but with strong ties to operational prediction and service delivery programmes in WMO. In June 2008, the EC-LX welcomed the initiatives toward the development of SDS-WAS to assist Members to gain better access to services related to sand and dust storms prediction and warning advisories through capacity building and improved operational arrangements. EC-LX acknowledged the establishment of two key SDS-WAS Regional Nodes for: (i) Northern Africa/Middle East/Europe and (ii) Asia. Each node is supported by Regional Centres kindly resourced by Spain and China, respectively. EC-LX requested the Commission for Atmospheric Science (CAS), in charge of research, to work closely with the Commission for Basic Systems (CBS), in charge of operations.
As of July 2009 twelve centres around the world (Figure 3) provided sand and dust storm research forecasts through freely available websites and three centres in Asia also provided some operational products. Some centres are based in research and/or operations sections of the National Meteorological and Hydrometeorological Services (NMHSs) and some are in separate national or international research institutions.

5.4.2 Mission, objectives and organization
The SDS-WAS Steering Committee (SDS-WAS SC) supported by the WMO Secretariat coordinates activities. It implements the project through a system of Regional Nodes whose activities are planned and implemented through a Regional Steering Group (RSG). As of July 2009 there are two regional nodes acknowledged by WMO for Northern Africa/Middle East/Europe and for Asia. The activities of each Regional Node is supported by a Regional Centre (RC) identified and approved by WMO. An SDS-WAS implementation plan is the basic guidance document for SDS-WAS management.

Figure 3 - The status of WMO SDS-WAS modelling centres and organization as of July 2009. (In the centre: the global distribution of annual average tropospheric aerosol optical depth (AOD) using combined surface-based and satellites observations for the period 1979 to 2004 (courtesy of S. Kinne MPI, Hamburg, Germany). Mineral dust is mainly found in the Northern Hemisphere, in the broad “dust belt” that extends from the eastern subtropical Atlantic eastwards through the Sahara Desert to Arabia and in Asia extending across the North Pacific. On the outside of the Figure: sand and dust modelling groups that produce daily forecasts July 2009. The large blue dots identify SDS-WAS centres that support regional nodes.)

SDS-WAS mission

The SDS-WAS mission is to enhance the ability of countries to deliver timely and quality sand and dust storm forecasts, observations, information and knowledge to users through an international partnership of research and operational communities.

SDS-WAS objectives

The SDS-WAS, as an international framework linking institutions involved in SDS research, operations and delivery of services, will address the following objectives:
i) Provide user communities access to forecasts, observations and information of the SDS through regional centres connected to the WMO Information System (WIS) and the World Wide Web;
ii) Identify and improve SDS products through consultation with the operational and user communities;
iii) Enhance operational SDS forecasts through technology transfer from research;
iv) Improve forecasting and observation technology through coordinated international research and assessment;
v) Build capacity of relevant countries to utilize SDS observations, forecasts and analysis products for meeting societal needs; and
vi) Build bridges between SDS-WAS and other communities conducting aerosol related studies (air quality, biomass burning, marine productivity, etc.)

5.4.3 Research strategy and tasks

In 2009, the immaturity of atmospheric science related to aerosols and their inclusion in weather and climate models meant that a large fraction of activities and partners are oriented toward research and development. For success in the long term, it is important to establish a mix of research and operational activities with a strong capacity building component. SDS-WAS will be sustained through research assisting the delivery of effective operational services and assessments linked to user needs. The following research topics are a priority for further development of SDS-WAS:

i) Improved dust source specification and parameterization;
ii) Influence of local and mesoscale atmospheric processes on dust storm generation and transport;
iii) Advancing knowledge of the barriers to improving prediction (observations, assimilation, treatment of physical processes) and developing strategies to reduce these barriers where possible;
iv) Advanced observing methods of SDS, including surface-based, aircraft and satellite methods;
v) 4-D assimilation of dust-related observations;
vi) Inclusion of direct and indirect radiative forcing effects of dust in atmospheric weather and climate models;
vii) Role of dust as ice nuclei affecting storm development and precipitation;
viii) Dust impact on high-impact hydrometeorological and environmental phenomena (e.g. monsoons, tropical cyclones, mesoscale convective complexes, flooding and droughts);
ix) Developing ensemble systems for SDS prediction;
x) Dust and health issues (e.g. meningitis, valley fever, asthma, etc.);
xii) Dust as a transmitter of disease and contaminants;
xiii) Photochemical effects of dust and its impact on atmospheric ozone and other oxidants;
xiv) Impact of dust on marine productivity;
xv) SDS reanalysis studies producing dust climatologies; and
xv) SDS model validation and model intercomparisons.

The implementation of the SDS-WAS is planned in two phases. In Phase-1 (2009-2010), the emphasis will be to finalize an SDS-WAS implementation plan through inputs of the two Regional Steering Groups for Northern Africa/Middle East/Europe and for Asia recognized by the Executive Council of WMO June 2008. In Phase-2 (2011-2013) cooperative research and development will be performed in the following areas:

- Collection and analysis of data from field campaigns, for a better understanding of the SDS process, and to assess current forecast capabilities and point to areas where improvement can be made;
- Joint verification of the different forecasts with a common real-time verification system;
- Data assimilation and ensemble forecasting experiments will also be undertaken and/or considered;
• User-oriented studies (e.g., case studies of events affecting air/ground transport; studies linking public health and dust, etc.);
• Studies on saltation process and on active dust source areas to validate and complete dust production modules;
• Research on spatial distribution of dry size distribution of soil aggregates in all potential source areas; and
• Model intercomparisons.

Research Partnerships

Participation of agencies and institutions in SDS-WAS is on a voluntary basis. They may link to one or more of the Regional Nodes. Connections with other WMO sponsored international research programmes such as GAW and WCRP or to ICSU programmes such as IGBP, ILEAPS and SOLAS will be encouraged. Cooperation with international organizations such as the UNCCD, FAO, and WHO will also be encouraged.

5.4.4 Capacity building

Capacity building in SDS-WAS involves technology transfer from research and operations to users. Proposed activities include:

1) Regular scientific exchange: A scientific workshop or demonstration will accompany every group meeting to discuss recent developments in SDS modelling and forecasting;
2) Dedicated training, including training on monitoring and modelling methods. Subjects for training and demonstration include:
   a) Satellite data access and analysis;
   b) Dust storm forecast and simulation model output analysis;
   c) Use of new information products;
   d) Measuring and monitoring particulate air quality through remote sensing and in-situ air sampling instruments;
   e) Developing PM monitoring networks for verifying and validating SDS products; and
   f) Characterizing and mapping sand and dust source regions.

5.5 Shanghai Integrated Multi-Hazard Early Warning System (MHEWS) project

Following the recommendations of the Second Session of the Executive Council Advisory Group on Disaster Prevention and Mitigation (EC - AG DPM, January 2007) several demonstration projects were initiated by the WMO Secretariat in March 2007 to develop, demonstrate and document early warning systems (EWSs). Furthermore, Congress XV encouraged WMO and its Members to leverage their capacities to support multi-hazard early warning systems (MHEWS). One of the projects established thereafter was the Shanghai Integrated MHEWS.

5.5.1 Shanghai MHEWS project

The goal of this project is to provide a demonstration case to WMO Members while establishing the Shanghai MHEWS as a critical component of the Shanghai disaster preparedness strategy, illustrating the benefits of a multi-hazard approach, with the Shanghai Meteorological Bureau (SMB) as the key management and implementation agency.

Shanghai, located on China’s central eastern coast, is the country’s largest city in terms of population and one of the largest metropolitan areas, with over 20 million people. Shanghai is frequently affected by natural hazards such as typhoons and its’ associated storm surges, heavy fog, heat-waves, and also atmospheric pollution episodes. The project is to be operational by May 2010. Shanghai has been proactive in using legislation to reduce hazards and in establishing integrated emergency response mechanisms.
The expected outcomes of the Shanghai Integrated MHEWS project are:

- Establishment of an advanced MHEWS to be operational and demonstrated at the World EXPO 2010;
- Increase in the timeliness and effectiveness of responses in monitoring, warning and dissemination;
- Summary and documentation of the experiences in Shanghai MHEWS, mega-city risk management, and emergency response system for WMO Members; and
- Publications, manuals, study tours, and training for WMO Members.

Within the WMO Secretariat, the Shanghai Integrated MHEWS project is coordinated by the WMO Atmospheric Research and Environment (ARE) Branch of the Research Department (RES). The project consists of several components with the main responsibility for each residing in different WMO departments/branches/divisions with extensive collaboration across them.

Project components:

1) Demonstration project for an early detection and warning system for tropical cyclones and marine-associated hazards;
2) WWRP research demonstration project on mesoscale ensemble NWP;
3) Demonstration project on heat and health warning system;
4) Global Atmospheric Watch (GAW) Urban Research Meteorology and Environment (GURME) demonstration project on air pollution;
5) Demonstration project on the application of nowcasting to Public Weather Service delivery; and
6) Project for the development of the MHEWS programme governance, institutional coordination mechanisms and community preparedness.

The project has a clear timeline: it is to be operational and demonstrated at the EXPO 2010, which runs from May until October 2010. After the EXPO, evaluation, documentation and possible revision of activities need to be carried out.

WWRP is involved in two major components of the Shanghai Integrated MHEWS Project namely:

5.5.2 **WWRP RDP on mesoscale ensemble NWP**

**Deliverables:**
Enhanced capacity of the Shanghai Meteorological Bureau to:

i) Provide more accurate warnings and information for high-impact weather with the use of mesoscale data assimilation and mesoscale ensemble NWP;
ii) Improve the local forecasting efficiency and translate forecasts into potential impacts and response; and
iii) Apply the community-based approach in reducing risk from high-impact weather events. Enhanced community understanding and public awareness on high-impact weather and its associated risk reduction and response activities through sustained public information campaign.

Enhanced capabilities of Members for delivering short-range forecast and early warning for high-impact weather.

The RDP will cover the 6 months period of the Expo and will look at the following research themes:

- Mesoscale ensemble;
- Mesoscale data assimilation;
• Mesoscale surface parameterization; and
• Urban meteorology.

Technical details for data archiving and general infrastructure were discussed and, based on this discussion, it was suggested that the RDP will concentrate on an ensemble at 10 Km horizontal resolution so that infrastructure and resources (data handling) would not be overstretched. At the time of this writing, there have been difficulties in obtaining modelling partners for this RDP due to the long period required for the modelling. Thus the RDP may focus on tropical cyclone forecasting, which would not require a continuous modelling effort.

5.5.3 WWRP RDP on EWS for tropical cyclones forecast and verification

Deliverable:

Enhanced capacity of the Shanghai Meteorological Bureau (SMB) to evaluate spatial nowcasts/forecasts of precipitation and convection and tropical cyclone warnings with the establishment of a state-of-the-art real time forecast verification system.

The SMB, the CMA National Meteorological Centre and partners are planning to use TIGGE data and CMA ensembles to look at typhoon tracks to familiarise with probabilistic forecasts. The TIGGE data would be an extension of the real-time access established for T-PARC. Contact with end users could be initiated to understand needs and possible product development. A verification component is required for heavy rain and typhoons. A possibility is to adopt the verification system used during Beijing 08 for utilization during Shanghai MHEWS with the assistance of the JWGVR.
6. **WWRP/WCRP UNIFIED APPROACH FOR SUB-SEASONAL TO SEASONAL PREDICTIONS**

This Chapter is based on the paper “Toward a Seamless Process for the Prediction of Weather and Climate: the advancement of sub-seasonal to seasonal prediction”, from Gilbert Brunet et al, 2009. The paper presents a detailed description of joint WWRP-WCRP research activities which aim to improve the quality of sub-seasonal to seasonal predictions. The text here-in is condensed, briefly presenting the main issues and some implementation tasks.

Collaboration between climate and weather modellers has always existed, as these scientists are facing problems with great similarities. A more formal collaboration between WWRP and WCRP is timely because of the much increased interest in sub-seasonal to seasonal predictions, a time range where both communities can effectively collaborate to better tackle shared critical issues. The next generation of numerical climate and weather prediction systems will greatly benefit from this joint effort.

Four collaborative research areas have been identified: Ensemble Prediction Systems (EPSs), tropical convection, data assimilation, and social and economic benefits from sub-seasonal to seasonal predictions.

### 6.1 Weather/Climate Ensemble Prediction Systems (EPSs)

**Background**

The traditional boundaries between weather and climate are somewhat artificial. As explained in Hurrel et al. (2009) for example, the slowly varying planetary-scale circulation preconditions the environment for the ‘fast-acting’ micro-scale and meso-scale processes of daily high-impact weather. As an example, there is evidence that natural climate variations, such as ENSO and the Northern Atlantic Oscillation\Northern Annular Mode, significantly alter the intensity, track and frequency of extra-tropical and tropical cyclones. Conversely, small-scale processes have significant up-scale effects on the evolution of the large-scale circulation and the interaction among the components of the global climate system.

Operational weather forecast systems provide our best representation of synoptic-scale and meso-scale weather events. These short to medium-range (up to 10 days) forecast systems traditionally have not addressed the longer term interactions, e.g. at the air-sea-ice interface. We know that this is problematic on time scales beyond two weeks. It may also well be an impediment for improving forecasts on shorter time scales, particularly for high-impact weather events. These events include extra-tropical and tropical cyclones that, through interaction with the ocean mixed layer, can precondition the atmosphere-ocean interface for subsequent storms.

Climate prediction systems are built for much longer term simulations. They typically include sophisticated coupled interactions. Being run at lower resolution, they fail to adequately resolve meso-scale weather systems, and they are thus missing up-scale interactions that impact the climate.

In recent years, both weather and climate modellers have been developing ensemble-based techniques for sub-seasonal to seasonal predictions. There is consensus that an ensemble prediction technique is preferable at that forecast range. Furthermore, there is evidence that ensemble prediction has greater use and value from a Multi-model Ensemble Prediction System (MEPS) approach. Evidence is that different physics, numerics and initial conditions of the contributing EPSs provide more useful probability density functions (PDFs) than those obtained from a single EPS. Moreover, the MEPS approach identifies outcomes which are EPS independent, and hence likely to be robust.

Thus, coordinating the research activities of the WCRP CLIVAR Climate-System Historical Forecast Project (CHFP) and the THORPEX Interactive Grand Global Ensemble (TIGGE) on sub-
seasonal and seasonal predictions is timely: it offers the optimum approach to developing useful predictions at that range. This is also the best forecast range for effective collaborative research to tackle two fundamental scientific issues: tropical convection and data assimilation. In addition, user needs must be factored in the research directions: many are risk averse, in that they are often more concerned with quantitative estimates of the probability of occurrence of high-impact events than with the most probable future state. A focus on the eventual socio-economic applications will require proper evaluation of the biases and forecast skill of these predictions. These major areas of research will be covered in the following sections.

Through this collaborative WCRP-WWRP research, not only will our ability to forecast the sub-seasonal to seasonal time-scale improve, but, in addition, both the shorter term weather forecasts as well as the longer term climate projections are expected to benefit, as this research will address key common scientific challenges.

6.2 Tropical convection and its two-way interaction with the global circulation

Background

Tropical convection exhibits a remarkable variability and organization across space and time scales, ranging from individual cumulus clouds, to meso-scale cloud clusters to super clusters organized within synoptic-scale disturbances. Tropical synoptic activity is often associated with equatorially-trapped wave modes of the atmospheric circulation (Wheeler et al. 2000; Yang et al. 2007), which in turn organize tropical convection: a highly nonlinear scale-interaction problem. Forecast skill in the tropics is therefore dependent upon representing both equatorial waves and convective organization.

The limitations of contemporary weather and climate prediction models to realistically represent the life-cycle of equatorial waves and organized convection is usually attributed to inadequacies in parameterizations of moist physical processes. Such basic inadequacies compromise the skill of forecasts on all timescales. It follows that parameterization of organized tropical convection is a critical issue for both the weather and climate communities. A collaborative research effort focussed on the sub-seasonal to seasonal time frame is most appropriate to investigate best approaches.

In the Madden Julian Oscillation (MJO) and other convectively coupled equatorial waves and in monsoons, precipitating convection organizes into coherent structures (convective clusters) on spatial scales up to 1000 time that of an individual cumulonimbus. The MJO excites Rossby wave trains that propagate into the extra-tropical Pacific and North American and Northern Atlantic regions causing episodes of high-impact weather.

There is substantial interaction between the tropical and extra-tropical atmosphere from synoptic to decadal time scales. At the synoptic scale, energy originating at high latitudes propagates into the tropics through Rossby wave dispersion, initiating in regions of upper-level westerly flow in the Pacific and Atlantic storm tracks. Such wave trains frequently excite convection within the ITCZ, transporting moisture from the tropical boundary layer into the upper-atmosphere and transporting it poleward ahead of troughs extending into extra-tropics of both hemispheres (Knippertz 2007). Moisture transport between the tropics and extra tropics is enhanced during such synoptic-scale events. Australia, Europe and North and South America are impacted by the tropical moist intrusions, sometimes leading to sustained episodes of heavy precipitation and flooding.

Thus, advances in the representation of the tropical-extra tropical interactions would lead to more skilful prediction for regional to global weather and climate. This success will translate into socio-economic applications for improving early-warning systems for weather-climate induced hazards, e.g. agriculture, water management and health.
Three major research priorities will lead to improved tropical convection predictions. First, research with cloud-system resolving models (CSRM) should be undertaken using a horizontal grid-spacing of 1 km or finer, as well as CSRM nested in coarse global simulations. Second, as present computer capacity precludes cloud-resolving representations of moist convection in global sub-seasonal to seasonal deterministic prediction models and EPSs, it is therefore essential to accelerate efforts to improve traditional convective parameterizations. Third, studies of tropical-extra tropical interactions must be emphasized, such as MJO-tropical convection.

6.3 Data assimilation for coupled models as a prediction and validation tool for weather and climate research

Background

Data assimilation is the process of fitting a numerical model to observations, allowing for the error characteristics of both. Model errors directly impact the quality of the assimilation, so using a good model is crucial. Historically, data assimilation research and its applications have focussed mostly on the requirements of operational short to medium range forecasts.

As operational forecasts have extended into sub-seasonal prediction, improved data assimilation in the tropics, ocean, upper atmosphere and Earth system have become necessary. In parallel, Morel (2007) advocates the need to test “climate modelling in a deterministic prediction mode”. This has already started for the middle atmosphere through the WCRP SPARC programme. The seasonal prediction time-frame offers a good opportunity for such tests and for collaborative climate-weather research.

Data assimilation innovations (observations minus predictions) allow a diagnosis of errors while they are still small, before they interact significantly with other fields. This can be used for parameter estimation. This established NWP approach is also proving beneficial for climate models, for instance within the WGNE Transpose AMIP programme. The method permits direct comparison of parameterized variables such as clouds and precipitation with synoptic observations, satellite data and field campaign measurements. Since the largest uncertainties in climate and weather models are associated with their physical parameterizations, improvement in these schemes may reap great benefits.

However, if the scheme is not of the correct form, the results of the assimilation may not lead to useful parameter estimates. Hence, the failure of the assimilation process could provide an indication of the inappropriateness of a given scheme without directly indicating how it should be improved. Close collaboration with model developers is needed to interpret assimilation results and address flaws in specific schemes.

Advanced assimilation systems are extremely computer intensive. Practical assimilation methods have to allow for the error characteristics of model forecasts, without the enormous computer costs required to calculate them fully. It will not be possible, with foreseeable computers, to conceive of a single data assimilation method for an Earth system model with the complexity required for seamless prediction. What is possible is a composite system, applying different assimilation steps to different scales and components of the total Earth system model. Recent attempts to build such a composite system use a two-way interaction model for the forecast step, but apply assimilation to each component separately.

Ideally, the assimilation should be coupled, so that observed information in one component is used to correct fields in the other coupled component. One of the few attempts to do this is coupled land-atmosphere assimilation, where soil moisture is corrected based on errors in atmospheric forecasts of near surface temperature and humidity. Yet, many land surface modellers distrust such soil moisture analyses: because of compensating errors they can give soil moisture which reduce atmospheric forecast errors but do not correspond to actual soil moistures nor do they conserve the water budget. Coupled data assimilation must be accompanied by a
much better characterization of the errors and biases in components of a coupled model. Only then can we successfully correct them as part of the data assimilation process.

Significant new resources will be required to advance research on data assimilation. One mechanism to achieve this is through the various re-analysis projects which are designed to provide a historical record for climate studies. The next generation of re-analysis projects can no longer rely only on operational weather forecast systems: they will require an interdisciplinary research programme on data assimilation methodologies.

6.4 Socio-economic applications of sub-seasonal to seasonal predictions

Background

The research programmes described above will require huge infrastructure investments, primarily in informatics (very large computing power, unprecedented mass storage and high-speed telecommunications) and in Earth observation satellites. Such investments can only be justified because the resulting information will influence decisions that contribute to the achievement of societal objectives, including: i) protection of life and property; ii) enhancement of socio-economic well-being; iii) improvement of the quality of life; and iv) sustainability of the environment (Rogers et al. 2007).

However, there is considerable evidence of underutilisation of weather and climate information that may be rooted as much in a lack of understanding of the decision-making context and requirements of users as in the precision or accuracy of atmospheric predictions. This issue is particularly important for sub-seasonal to seasonal predictions which by nature can be difficult to interpret and apply to concrete societal issues.

It is therefore critical to adopt a seamless approach to the application of sub-seasonal and seasonal predictions, through the active involvement of physical and social science researchers, service providers and users-decision makers. The seamless approach extends beyond the realm of atmospheric predictions to include consideration of biophysical and socio-economic factors that are pertinent to successful decision-making. It is thus important to develop linkages between people from diverse expertise areas, and forums to exchange information with various decision-making representatives.

For example, public health decisions may be influenced by seasonal predictions, but only in combination with other pieces of information (e.g., expected disease outbreak patterns, available medical supplies and resources, etc.) Potential benefits are greatest in developing nations, especially in Africa where at least 30 climate-sensitive diseases pose a major threat to the lives and livelihoods of millions of people. More than 500 million Africans live in regions endemic to malaria, which is highly correlated with the seasonal climate, and a further 125 million live in regions prone to epidemic malaria, which is correlated with climate anomalies (Connor and Thomson 2005). As the response time to a particular outbreak is usually measured in weeks (depending on the time required to identify cases, integrate the information from different clinics then orchestrate the response), sub-seasonal to seasonal predictions are the required time-frame to address the user needs.

To address the various user needs, the specific type of research will depend on the weather- or climate-sensitive issue, geographic area, and decision context, as well the most appropriate disciplinary expertise and methodologies. Priority projects may be selected based on their potential contribution to priority societal objectives or where existing programmes, activities and interdisciplinary collaboration can be leveraged.

Examples of such programmes include the Meningitis Environmental Risk Information Technologies (MERIT) project; the Hydrological Ensemble Prediction Experiment (HEPEX), an international project to advance technologies for hydrological forecasting comprised primarily of researchers, forecasters, water managers, and users; the Climate for Development in Africa
Programme (ClimDev Africa), a major effort designed to increase the availability of climate information to communities and economic sectors throughout Africa; the World Bank’s Disaster Risk Reduction programme, which plans to modernize service providers so that the operational services can take advantage of scientific advances in a timely manner; and the Global Environmental Change and Human Health Initiative, one of four joint projects of the Earth System Science Partnership (ESSP), geared to quantifying and modelling health impacts and vulnerability and evaluating adaptation measures.

In all cases, efforts should focus on: i) understanding the relevance of weather and climate information to the issue, the decision context, and the decision-maker’s information needs; ii) identifying new or improved weather- and climate-related information that is likely to help decision-makers address the socio-economic issue; iii) exploring the most effective mechanisms for generating and communicating the decision-relevant weather and climate information; iv) assessing the use and value in decision-making, making refinements as needed; v) implementing strategies for sustainable, effective provision of the most valuable new weather- and climate-related information and vi) transferring knowledge and experiences to other regions.

Implementation tasks

The implementation tasks for the WWRP/WCRP unified approach for sub-seasonal to seasonal predictions are presented in Annex 1.

References


7. **EXAMPLES OF OUTCOMES OF THE WWRP**

This chapter provides a few concise examples of end-to-end success stories of the WWRP. These activities resulted in advances in scientific understanding of a high-impact weather phenomena, improved prediction due to the incorporation of research results into operational practice within NMHSs and the improved utilization of forecast products by end users. These examples were selected subjectively from among a wide range of WWRP activities to illustrate the diverse range of successful WWRP activities. The emphasis on these activities is, by no means, intended to mean that other WWRP projects and efforts were not successful or even less successful than these selected results.

7.1 **Heavy rainfall and alpine flooding**

The MAP (Mesoscale Alpine Programme) was a ten-year cooperative research effort that involved more than 200 scientists and engineers that cumulated in a ten-week special observing period that took place from 7 September to 15 November 1999. MAP was initially proposed by the Swiss Meteorological Institute and the Federal Institute of Technology (ETH Zurich) and grew to include the weather services and science agencies of 13 countries (Austria, Canada, Croatia, France, Germany, Greece, Hungary, Italy, Slovakia, Slovenia, Spain, UK, USA), under the auspices of the WMO. The MAP was the first RDP of the newly established WWRP. The alpine weather phenomena of interest included severe precipitation resulting in flash floods, Foehn/Mistral windstorms, turbulence that effects aviation and poor air quality (primarily in mountain valleys). The motivation for MAP mentions that “Severe weather during Fall on the southern side of the Alps has caused more than 80 losses of lives and more than 10 Billions Euros of damages during the last 6 years. Timely and accurate prediction of such events hold a potentially large benefit for society as catastrophic consequences of severe weather could be mitigated given precise early warning.”

The MAP effort was geared to advancing both scientific knowledge and predictive skill. The experiment was well linked to the needs of operational weather prediction as the planners noted that the operational NWP models of the time were often able to provide guidance that severe events were likely, but were unable to provide accurate forecasts of the timing, severity and location of such events. The experiment was based on the concept that such forecast needs in Alpine areas could be filled by models with higher resolution atmospheric models (e.g., of order 1 km grid horizontal spacing) models, such as used by researchers and by the coupling of atmospheric and hydrological models. However, planners noted that the formulation of such modelling systems required additional high resolution observations. Thus, for the field phase, observational platforms were added to the experiment and included ground-based weather radar, lidars, wind profilers and 8 research aircrafts. These research platforms supplemented operational and enhanced operational strategies such as rapid scanning by METEOSAT 6 at 5 minute intervals on request. The project had extensive operational participation with a forecasters working group formed four years ahead of the field phase. A MAP Operational Centre (MOC) was also established by the Austrian meteorological services involving forecasters from nine Alpine nations plus the US and Canada. At this centre, forecast products involved were available in near real-time in similar format and display convention, in part due to the language differences among forecasters. The forecasts time-scales of interest ranged from nowcasting (0 to 6 h) to the medium range (3 to 6 days). Two years prior to the field phase, the MOC began issuing so-called "MAP alerts" for relevant weather phenomena.

The MAP effort is surely a scientific success by traditional scientific measures. The early results from the MAP Special Observing Period are summarized in Bougeault et al (2001), in issues of the MAP Newsletter (see http://www.map.meteoswiss.ch) and more recently in Rotach et al. (2009). In terms of scientific accomplishments of MAP, in excess of 160 MAP related publications appeared in peer reviewed journals during the 2000-2004 period. MAP had a positive impact on the next generation of research scientists: over 30 PhD-projects were completed in six nations. The MAP effort also included a number of operationally relevant accomplishments: i) pioneering the operational coupling of deterministic atmospheric and hydrological models; ii) triggering a substantial number of improvements in the performance of operational radar products.
in mountainous regions; iii) furthering the use of high resolution (km-scale) models in operational setting; iv) contributing to the design of the next generation regional assimilation and forecasting systems, high resolution ensembles and exploring the development and use of hydrological models.

While these transfers of MAP findings into operational NWP applications did occur, the WWRP JSC challenged the scientists associated with MAP to design and implement a WWRP FDP to further enhance the transfer of research to operations. This challenge led to the MAP D-PHASE (Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region) Project, which had an operational phase from 1 June to 30 November 2007. A more detailed description of MAP D-PHASE is described in Rotach et al (2009). The MAP D-PHASE focused on the development and demonstration of an operational end-to-end forecasting system for heavy precipitation and related flooding events in the Alpine region. The MAP FDP was designed to address the entire forecasting chain ranging from limited-area ensemble forecasting, high-resolution atmospheric modelling (km-scale), hydrological modelling, and nowcasting to decision making by the end users, i.e., an end-to-end forecasting system. MAP D-PHASE included atmospheric prediction systems from nowcasting to more than 30 atmospheric high resolution deterministic and probabilistic models coupled to 7 hydrological deterministic and ensemble hydrological models. The hydrological forecasts were made on 43 catchments. A web-based visualization portal was designed to allow forecasters and other end users (e.g., civil protection, water resources, transportation) to access identically formatted warning products, objective verification, and model intercomparisons.

In keeping with the concept of a WWRP FDP, important components of the project were verification, subjective assessments from end-users and evaluation of the overall gain from the coupling of the various forecasting components. Approximately 45 users participated in these evaluations. In the broadest sense, MAP D-PHASE established the added value of high resolution deterministic atmospheric modelling and pushed the frontier of high resolution (km-scale) atmospheric and hydrological models from deterministic to ensemble systems. Further details of the accomplishments can be found in Rotach et al. (2009) but the most telling aspect of the MAP D-PHASE project is that users supported the continuation of the visualization portal within Meteo Swiss after the project was completed.

7.2 Tropical cyclone landfall

The errors in the prediction of land-falling tropical cyclones has decreased by approximately 50% during the past two decades. During this time, many NMHSs have gone from routinely issuing forecasts of landfall at 48 or 72 h in advance to 5-day warnings. The Tropical Meteorology Research Working Group in conjunction with the Tropical Cyclone Programme has played a significant role in the NMHS reaching these advances. One aspect of these advances was the involvement of the Working Group in a series of field campaigns designed to bring researchers and operational forecasters together to investigate and implement activities to improve the prediction of tropical cyclones. In the Western North Pacific these experiments included TOPEX (Typhoon Operational Experiment), which was a three-year project during the late 1980s, and a major effort in 1990 that involved several international tropical cyclone field campaigns (e.g., SPECTRUM TYPHOON-90 and Tropical Cyclone Motion (TCM) experiment) from Australia, Russia, the Philippines, Hong Kong, Korea, Malaysia, US, and Thailand, followed by TCM experiments in 1992 and 1993. The experiment combined aircraft, ship, and satellite data. The datasets contain standard atmospheric observations plus special sets of data collected especially for the field experiments. The observations include air-borne radar wind profiler measurements, dropwindsondes, special rawinsonde ascents, aircraft, reprocessed cloud-tracked winds, drifting buoy measurements throughout the Philippine Sea, and special ship observations.

One outcome of the TCM experiments was that it was difficult, even with additional measurements, to forecast tropical cyclone movement through determining an observed steering level. Attention was therefore focused on theoretical investigations aimed at addressing this conundrum and on making use of special measurements in data impact and data assimilation
experiments to improve NWP of the tropical cyclone. Since no international projects of this scope took place from TCM until the recent T-PARC and TCS-08 projects (2007), the TCM experiment served as the reference data in the 1990s and 2000s for investigations aimed at understanding and predicting tropical cyclone movement in the Pacific. During this time, critical papers that made use of the TCM data sets range from studies aimed at the development and testing of global and limited area deterministic atmospheric models, investigations of "bogusing" tropical cyclone vortices into the initial conditions of coarse grid models, and early investigations of the impact of non-routine observations including the satellite-derived track winds. More recent uses of these data sets include development and testing of ensemble prediction systems for cyclone prediction and investigations into understanding and predicting the intensity of tropical cyclones. During this time, theoretical concepts of factors controlling tropical cyclone movement have evolved from simple arguments of advection by steering level flow to Beta effects and the role of potential vorticity gradients.

During this time, the WGTMR and the TCP have been involved in the organization and sponsorship of the IWTC workshop series to facilitate the exchange of information between tropical cyclone research scientists and operational weather forecasters. Discussions during the workshops resulted in a number of recommendations addressed to operational forecast centres, the WMO, TC forecasters, and the research community on actions that would further the goal of improving tropical cyclone forecasting and warning systems and reducing the associated risk and damages caused by tropical cyclones. These workshops not only enhanced knowledge of the nature and behaviour of tropical cyclones, but also provided opportunities for prioritizing new observational data and research requirements. The IWTC was also the focal point for the publications on tropical cyclone to ensure the transfer of knowledge and best practices to the operational community including centres in developing nations. Such publications have included the "Global Guide to TC Forecasting", "Global Perspectives on Tropical Cyclones" and more recently the development of the Tropical Cyclone Websites. Other important contributions in this area include forecaster training sessions and a demonstration project entitled "Tropical Cyclone Disasters" that made substantial contribution to the International Decade for Natural Disaster Reduction (IDNDR) and to the development of autonomous aerosonde for operational targeted observations of extreme events, such as tropical cyclones.

7.3 Nowcasting convective weather

Nowcasting software systems that rely heavily on radar measurements and other observations can typically outperform numerical weather prediction models in the first few hours of a forecast (~0 to 6 h). These systems provide critical guidance to forecasters on a variety of applications (e.g., public safety, flood management, transportation, agriculture, etc). As noted in the earlier text, such systems are often run locally on available measurements without a framework that allows intercomparisons between various nowcasting approaches. The lack of a mechanism to inter-compare approaches directly leads to the risk of limited progress in improving such systems. The FDPs lead by the Working Group on Nowcasting Research have served the purpose of having a framework to advance understanding and to improve prediction through community focal points. One such activity was the FDP at the Sydney Olympic Games in 2000. This example describes the outcome of the Beijing 08 FDP that was a direct follow-on to the Sydney effort. The discussion highlights the impacts of the FDP on forecasting services in Beijing.

While the project was in 2008, the planning started in 2005, supported by the China Meteorological Administration (CMA) and the Beijing Meteorological Bureau (BMB) with funding provided by the Beijing Science and Technology Commission, and steered by B08FDP SSC, a team consisting of international researchers, university professors, experienced forecasters as well as managers from the Beijing Meteorological Bureau. In addition to the technical prediction aspects, the FDP included a socio-economic impact assessment of targeted end-user groups. The end-user are stapled to four groups basically, the decision makers, the commercial users, public both Chinese and foreigners, and forecasters.
The main impacts of B08FDP are:

1) Introduction of advanced state-of-the-art nowcasting systems into the BMB. These systems and the associated expertise are being subsequently transferred to other major cities served by the CMA beginning with Shanghai and Guangzhou through focal point projects such as the Shanghai MHEWS and the 16th Asian Games. Thus, the FDP will have a lasting impact beyond Beijing and well beyond the dates of the 08 Olympic Games.

2) Improved understanding of both forecasters’ and end-users’ needs. From the analysis of ten thousands valid survey samples, it is found that, although advanced weather forecast systems can help forecasters generate better forecasts, these better forecasts do not always lead to improved weather services. It depends on whether these improved forecasts can meet the users’ needs and be utilized by end-users. This finding could help weather services to understand how to fit in users’ needs when they develop new products and new services. It is also found that the value of B08FDP was affected significantly by three main factors, FDP product quality, FDP product access channel, and end-users’ capabilities in using FDP products.

3) Enhanced forecaster’s nowcast capabilities by gaining knowledge and experiences from B08FDP experts on nowcasting and use of B08FDP products. During B08FDP, transfer of the expert domain knowledge presented within the B08FDP team to local champions and BMB forecasters was effective through different ways, such as training workshops, discussions about trials and interactive approach during Beijing Olympics demonstration.

4) Noticeable capacity building of BMB and CMA on Societal and Economic Research and Applications (SERA-type) activities and the change of the strategy for meteorological services in the BMB. Such activities are widely accepted now in BMB and CMA, and a research team has been established (contains operational department and research institute) in BMB. User-oriented service strategy is set in BMB service plans for future, and B08FDP SERA survey method is adopted by BMB for gaining users’ information to improve its daily met-service in operation.

5) Increased end-users satisfaction of the meteorological services provided by the BMB.

7.4 Extending useful warnings of disasters and other high-impact weather through multi-model global ensemble systems

With the advent of megacities and the other demographic changes, there is a strong need to extend the accuracy and useful time range of warnings of weather disasters and other high-impact events. One of the accepted pathways to extending warnings is to rely on ensemble forecast systems. This motivation was part of the reason that THORPEX established the TIGGE effort. Although it is too early to make a final judgment on the success of TIGGE in meeting its goals, we discuss early progress of TIGGE. One of the goals of TIGGE is to enhance collaboration on development of ensemble prediction, internationally and between operational centres and universities. In this regard, TIGGE has already been successful with over 225 users from 19 countries as of September 2008; the number of users is steadily growing.

One of the critical questions asked by research users is determining the potential gain in skill from quantitative use of the multi-model approach over the best (or better) individual ensemble system within the archive. The answer to this question is mixed. Based on early research, for example, the gain in skill over the most skillful ensemble is marginal for middle latitude upper-air variables. However, for the tropics, surface temperature and rainfall early research suggests significant gains in skill for the multi-model approach over the most skillful ensemble system. In some studies, the gains in skill can be in excess of two days of added value over the best model (even more for other systems). Given that NWP skill has generally progressed slightly in excess of one day per decade, this improved value is truly significant. One important aspect of this comparison of skill between the individual ensemble systems and the multi-model approach of TIGGE is that leading centres are using this additional TIGGE skill as a challenging benchmark for their individual system and implementing changes in the model and assimilation systems or research directed at improving these systems. Thus, the existence of TIGGE and research using this data base is accelerating skill improvements in the individual model components. Since the
relative advantage of TIGGE can be reduced by employing bias removal or advanced forecast recalibration, TIGGE will also foster greater research into new methods of combining ensembles from different sources and of correcting for systematic errors (biases, spread over-/under-estimation).

Two of the long-term goals of TIGGE include to test concepts of a TIGGE Prediction Centre to produce ensemble-based predictions of high-impact weather, wherever it occurs, on all predictable time ranges and to develop a prototype future Global Interactive Forecasting System. The approach to meet these goals will likely be through FDPs and the first proposal received in this regard is for tropical cyclone prediction. In addition, plans have begun to build on the SWFDP (Severe Weather Forecasting Demonstration Project), incorporating TIGGE products into the FDP as a prototype for the GIFS. The movement to a multi-model system is a major change in paradigm for operational weather prediction. A major consideration of GIFS is the provision to all countries of viable opportunities to develop at small cost (particularly in developing countries) efficient severe weather warning systems focusing on their national needs without becoming overly dependent of one big provider. This shift of paradigm from bilateral cooperation (with a strong partner and a weak partner who needs to adjust to any change decided by the strong) to a multi-lateral cooperation, with the existence of a variety of products of similar quality and standard formats will give developing countries both a sense of independence and of ownership/control of their own 'customized' end-products.

References


8. RESOURCES

Current Status

Resources for WWRP are currently available as follows:

- Regular budget of WMO for WWRP, covering costs for the Secretariat staff, external consultants/experts working for WWRP and THORPEX, selected calibrations, international and expert meetings, travelling costs, general services (reports, computer and transmission facilities, etc.);
- Members or institutions taking direct responsibility for WWRP tasks for which they pay themselves, (e.g., the support of the development of this Strategic Plan by Environment Canada, etc.);
- External financial funding of specific WWRP projects or operations by Member countries or international organizations where execution of work is delegated to specialised persons or institutions providing services as experts or central facilities; and
- Dedicated WMO trust funds requested by Congress to support programmes such as the large THORPEX effort.


Comment

WWRP is implemented in accordance with the principle that all activities pertaining solely to individual countries are within the responsibility of the countries themselves and should be borne by national resources while added value international activities that can only be done collectively are candidates for WMO efforts. When a Member agrees to participate in WWRP including THORPEX, full responsibility is borne by a Member for funding their national experts and contribution to the international project. However there are exceptions. Many countries of the 188 Members require outside support to start, sustain or improve participation. Support is often critical to the success of the activity. In recognition of this, WMO has over many years helped to provide funds for inclusion of key experts or institutions in research projects and capacity building through partial coverage under its regular budget or the THORPEX trust fund. The Secretary-General has been authorised by the WMO Executive Council to seek extra-budgetary funding for implementation of WWRP projects. Generally, this occurs through dedicated trust funds such as that established for THORPEX or weather modification research that are called for by Congress.

Unfortunately, funding needs continue to grow much faster than the required funds can be made available. Especially for capacity building in developing countries, the level of support required by Members still far exceeds the resources available under the regular WMO budget or the THORPEX trust fund. Substantial additional funds are required for supporting additional added-value international activities that are next in priority to those being implemented.

Goals

- To provide regular overviews of costs and available resources and to ensure financial feasibility in the priority setting and planning procedures of WWRP including THORPEX; and
- To make additional funds available as soon as possible. To assist NMHSs and their national research partners in obtaining financial support from national funds by providing,
when requested, the relevant national governments with information on the importance of the WWRP projects both for the national and international communities.

**Implementation tasks**

The implementation tasks for the WWRP Resources are presented in Annex 1.
ANNEX 1

WWRP implementation tasks

This Annex includes the initial implementation tasks of the World Weather Research Programme. These are presented as short, specific bullets, describing a precise task. Usually, a clear timeframe is included. Sometimes, the tasks are ongoing. Sometimes, the precise timeframe has not yet been finalized.

Together, these implementation tasks form an impressive detailed list of concrete activities by which the WWRP will be delivered.

The WWRP JSC will review and update these tasks every year, to ensure continuous progress in the implementation the WWRP.

THORPEX Implementation tasks

This section lists the specific tasks that each THORPEX Working Group and Regional Committee intends to carry out over the next four years, as well as implementation tasks for the special THORPEX projects.

THORPEX GIFS – TIGGE WG

- TIGGE (2009 - 2010)
  - Continue collection of ensemble forecast data at three existing archive centres from 10 ensemble producing centres;
  - Organize a TIGGE User Workshop in conjunction with the Third THORPEX Science Symposium, 2009.
  - Add missing data and a sub-setting capability for extracting ensemble data in time series format from archive centres; and
  - Consolidate requirements and plans for TIGGE-LAM.

- GIFS development phase (2008 - 12) – in collaboration with CBS
  - Addressing the real-time product access, coordinated product generation and a common web interface for data and product access;
  - Interface with the user community in the design and scientific assessment of potential GIFS products and services;
  - Develop and evaluate Tropical Cyclone products based on Tropical Cyclone-related ensemble information exchanged in real-time among ensemble producing centres;
  - Develop and implement software for accessing and interpreting CXML data and derived Tropical Cyclone products, including a common web interface;
  - Develop, evaluate and consider implementation of detailed plans for real-time exchange of ensemble precipitation forecasts among ensemble producing centres and RSMCs;
  - Develop, assess and consider implementation of detailed plans for the design and generation of PQPF-type products for use in selected GIFS demonstration regions;
  - Assess feasibility of a common web interface for accessing precipitation data and derived PQPF-type products;
  - Consider developing additional prototype GIFS products based on 10m wind and 2m temperature ensemble forecasts; and
  - Engage with other WWRP, THORPEX Working Groups and Regional Committees to evaluate and review possible adaptive techniques that might be included in an end-to-end GIFS system.
• GIFS Implementation phase (2012 - ) – in collaboration with CBS
  o Consider implementation of Focus Group recommendations regarding operational implementation of prototype GIFS products;
  o Continue GIFS product development and scientific evaluation to widen range of potential high-impact GIFS applications;
  o Generalize procedures developed for prototype GIFS products to enable generation of a wider range of GIFS products;
  o Engage with downstream user groups such as HEPEX for hydrologic forecasting in support of developments toward an end-to-end GIFS system; and
  o To the extent scientific justification has been established, specific benefits have been demonstrated and resources permit, start to implement adaptive techniques in an end-to-end GIFS system.

THORPEX DAOS WG

For the T-PARC the group will:

• Review data impact results for the summer phase;
• Extend the observation impact inter-comparison for the winter phase;
• Support the testing of the impact of enhanced Russian radiosonde network on operational data assimilation systems to determine the value of maintaining the extended network;
• Evaluate the use of alternative satellite data sets that are not available operationally; and
• Review the results of centres (NRL, Environment Canada, and GMAO) that will evaluate the impact of observations.

In support of future campaigns, such as T-NAWDEX (see section 4.1.3.8), the group will engage in:

• A review of the results from the NOAA Winter Storm Reconnaissance 2001 – 2008.

The additional in situ data deployed during AMMA are now used operationally by operational centres; the group will:

• Lend support to organisations that are working to keep the additional AMMA in-situ data available; and
• Encourage the investigation of the impact of radiosonde and AMDAR data over Africa.

In the context of the International Polar Year, the group will:

• Coordinate the work on satellite data assimilation over the polar regions; and
• Investigate the impact of the improved use of satellite data and of in situ observations.

General studies will be sponsored to:

• Optimise the deployment and usage of existing operational in situ observing systems;
• Support the use of well-calibrated OSSEs to evaluate the impact of new instruments;
• Assess model error using ensembles; and
• Investigate fundamental issues such as the use of flow-dependent structure functions, the evaluation of the downscale impact of global scale improvements on the meso-scale and issues on coupled data assimilation and new data sets associated with it.

THORPEX PDP WG

The PDP WG has identified a number of tasks with which the group will be involved over the next few years.
i) Prepare and publish a comprehensive review of predictability issues in the THORPEX WMO publication series; publish a summary in the BAMS;

ii) Organize a summer school on “Atmospheric Predictability” in 2010;

iii) Contribute to the organisation of sessions at the following meetings:
  o High-impact weather at IAMAS 2009;
  o Ensemble prediction at IAMAS 2009;
  o Seamless approach to modelling at EGU 2009; and
  o 3rd THORPEX Science Symposium in Monterey 2009;

iv) Participate in the design, execution and analysis of field experiments including:
  o Summer and Winter T-PARC (2008/09); and
  o NAWDEX / HYMEX (2011);

v) Encourage submission of specific YOTC research proposals to funding agencies;

vi) Encourage the dynamical meteorology community (in particular academia) to study the relationship between dynamical processes and forecast accuracy (for example, diagnosis of forecast errors and predictability);

vii) Promote the use of data sets produced by THORPEX through TIGGE, YOTC, T-PARC to both the academic and operational communities;

viii) Encourage testing dynamical hypotheses using the TIGGE data set (e.g., regarding how the large-scale influences smaller-scale development);

ix) Encourage further research on the following problems of ensemble prediction:
  o Further development and understanding of multi-model ensemble post-processing techniques, in particular estimates of the relative weights to be given to the various members;
  o Assess the value of an ensemble of high-resolution deterministic forecasts compared with the value of a single- or multi-model ensemble at coarser resolution; and
  o Continue investigation on how to best combine high-resolution deterministic control forecasts with lower-resolution ensemble members;

x) Sponsor and encourage studies (in conjunction with the AfRC) of model diagnostics, predictability, ensemble forecasting and dynamical processes in Africa; in particular it is recommended that:
  o A catalogue of high-impact African weather events is compiled and the quality of operational predictions for these events is assessed;
  o The utility of Ensemble Prediction Systems for Africa is assessed; and
  o Model diagnostic studies of African weather systems are carried out; and

xi) Establish closer links with the WGSERA and undertake collaborative work on issues such as:
  o User-relevant evaluation of deterministic and probabilistic forecasts;
  o Predictability of persistent flow regimes (e.g. blocking onset and duration); and
  o Quantitative precipitation forecasts for large catchments on long time scales.

THORPEX ARC

- The T-PARC data will be fully analyzed, to understand
  o The feasibility of targeted observation/sensitivity analysis for Tropical Cyclones;
  o The characteristics of high-sensitivity area; and
  o The major controlling factors to determine Tropical Cyclone tracks.

- The ARC will explore the future collaboration on international/regional/domestic programmes and field experiments including the
  o Korea Enhanced Observation Period (KEOP) for heavy rainfall studies;
  o Implementation of Chinese THORPEX Research Plan;
  o Joint India-US Forecast Demonstration Project on Land-falling Tropical Cyclones (2009 - 2012);
  o Optimal Design Studies on Siberian RA0B network;
  o YOTC collaboration on the MJO; and
  o Application studies of the TIGGE database.
The ARC meeting will be held at least annually, in order to
- Exchange the status reports in operational and scientific sides, including model
development, from all members;
- Discuss coordination of the regional activities; and
- Prepare documents for WWRP and/or ICSC;

The THORPEX-Asia Science Workshop will be held regularly to discuss advancements in
THORPEX related scientific studies in the region; and

More members will be encouraged to join the ARC, by closely working with the
ESCAP/WMO Typhoon Committee, WMO RA II and individual domestic weather
services/academic societies in the region.

**THORPEX NARC**

- The North American Regional Committee is participating in the IPY-THORPEX project
  cluster and the T-PARC;
- The North American region will have a significant focus on ensemble prediction and
  research with the operational North American Ensemble Forecast System (NAEFS) and
  through participation in TIGGE;
- A long-term priority of this regional effort is tropical-extratropical interactions with a focus on
  the improved representation of organized tropical convection and its effect on middle
  latitude weather; and
- Other long-term efforts include capacity building and developing specific projects for the
  socioeconomic research and application area of THORPEX.

**THORPEX SHRC**

- Societal and Economic Research and Applications - the initial focus is on three key user
groups: emergency management, agriculture, and health. Three projects will be carried out:-
  - Inventory of high-impact weather forecast opportunities in the Southern Hemisphere;
  - Facilitate transfer of THORPEX advances to operational forecast offices in support of
    end user requirements, including involvement in Severe Weather Forecast
    Demonstration projects and use of TIGGE and GIFS data; and
  - Research on User Requirements and Potential Benefits;
- Data Assimilation and Observing Strategies (DAOS) - three projects will be carried out
  - Assessment and improvement of observing system impact on regional NWP in the
    Southern Hemisphere;
  - Assessment of 3DVAR versus 4DVAR in Southern Hemisphere regional numerical
    weather prediction; and
  - Convective and Tropical Data Assimilation;
- Predictability and Dynamical Processes - future activities will include cooperation on
  research and simulation of the Madden Julian Oscillation, which is an important part of the
  THORPEX objective to improve forecasts in the second week. Planned activities cover:
  - Publish review papers on the predictability of SH high-impact weather systems;
  - Major rainfall producing systems;
  - Impact of high latitude processes on hemispheric predictability;
  - High resolution analysis and forecasting of high-impact weather; and
  - Web forum real-time discussion on dynamics and predictability.

Members of the SHRC will also be collaborating with other THORPEX activities including, for
example the evaluation of T-PARC and the IPY (particularly ConcordIASI).
**THORPEX AfRC**

Key topics and major expected deliverables include:

- Development of a high-impact weather information system for Africa (including economic and societal impacts);
- User forecast verification, cost and benefit assessments of improved forecasts;
- Assessment of the performance of the current observing network, the impacts of field campaigns on predictive skill and the design of an “optimal” observational network for Africa;
- Enhancing the use of available observing technologies;
- Improvement of telecommunication facilities (WIS-Africa) to assist towards improved forecasts of high-impact weather events;
- Evaluating the predictive skill of high-impact weather events in Africa;
- Development of a seamless forecasting system;
- Capacity building and infrastructure development;
- Selected Forecasts Demonstrations Projects (FDPs); and
- Monitoring and evaluation of THORPEX-Africa activities.

**THORPEX ERC**

Key topics and major expected deliverables include:

- Organized convection (tropical and extratropical) dynamics and predictability;
- Role of Rossby wave dynamics in predictability;
- Ensemble prediction;
- Atmospheric blocking and low-frequency variability;
- Idealised model experiments;
- Impact of diabatic processes on dynamics and predictability;
- Monsoons and aspects of tropical-extratropical interactions;
- Air quality issues;
- The E-TReC 2007 campaign took place over five weeks in July 2007, in conjunction with the mesoscale experiment COPS and the MAP D-PHASE forecast demonstration project (www.pa.op.dlr.de/cops/etrec_docs.html). Sensitive regions were calculated daily at Météo-France, ECMWF and the Universitat de les Illes Balears (Spain). Special observations were made for seven events, using combinations of the DLR Falcon with wind and water vapour lidars and dropsondes, and additional radiosonde and AMDAR measurements provided by EUCOS. Further evaluation of the E-TReC data sets will be carried; and
- It is also proposed to carry out an international field experiment (the THORPEX North Atlantic Waveguide and Downstream impact Experiment - T NAWDEX) in autumn 2010 or 2011 (at the same time as HYMEX) to study disturbances on the North Atlantic waveguide and their downstream impacts over Europe.

**THORPEX T-PARC**

Investigators from the research and operational communities within Canada, China, France, Germany, Japan, Korea, Mexico, Russia, and the United States are now leading the evaluation of the T-PARC field data. The general strategies for accomplishing the T-PARC goals span observational, theoretical and modelling disciplines and, of course, long-term research efforts that span years beyond the field phase. The specific research tasks include:

- Providing recommendations on the design of the global observing system through forecast impact studies that utilize operational and experimental data from T-PARC and the collaborative experiments;
• Testing the degree to which skill for short and medium range prediction can be improved by future assimilation and modelling strategies including the use of global non-hydrostatic models at very high resolution;
• Further investigating the utility of ensemble models;
• Advancing our understanding of the predictability of high-impact weather events both over East Asia and the western North Pacific region and at “downstream” locations; and
• Carrying out capacity building and establishing societal and economic research and application projects.

**THORPEX IPY**

Specific tasks include the following:

• The Greenland Flow Distortion Experiment - The focus is upon investigating Greenland tip jets, air-sea interactions, barrier winds and mesoscale cyclones;
• Storm Studies of the Arctic - Includes enhanced observations in the eastern Canadian Arctic to study gap flow, air-sea interactions, precipitation, interaction of cyclones with topography;
• ConcordIASI - Infrared Atmospheric Sounding Interferometer (IASI) assimilation in the Antarctic and the use of IASI data for climate monitoring, assimilation of dropsondes launched from driftsondes; studies of polar processes including the circumpolar vortex, stable boundary layers, polar clouds and ozone;
• Norwegian IPY-THORPEX - Optimization of new satellite data, improved modelling of the latent heat cycle, improved operational NWP, ensemble simulations and studies of extreme weather;
• THORPEX Arctic Weather and Environmental Prediction Initiative (TAWEPI) - Study of various aspects of Arctic weather and the Arctic climate system (snow processes, polar clouds, sea-ice and ozone layer); develop and validate a regional weather prediction model and the use of satellite observations over the Arctic;
• Greenland jets - Will study mesoscale flows, including orographic disturbances, mesocyclones and surface fluxes;
• GREENEX - Considers forecasting of small-scale weather phenomena, including extremes. Meso- and fine-scale flows in the vicinity of orography and sea ice and downstream weather development as well as scale interactions;
• Arctic Regional Climate Model Inter-comparison Project - Targeted observations from the North Pole station over the Arctic Ocean; studies of the feedback between the planetary boundary layer and meso-cyclones; climate processes and feedbacks within the coupled Arctic climate system; and
• Impacts of surface fluxes on severe Arctic storms, climate change and Arctic coastal orographic processes - Includes studies of storm activity in the western Arctic in the context of surface fluxes from changing ice, ocean and land-surface conditions. Studies of coastal ocean processes and assessment of severe weather and climate factors that can impact human communities.

**THORPEX YOTC**

Take the initial steps to develop global data-bases to enable YOTC studies in particular:

• Establishing a high-resolution (T799/25km grid) ECMWF analysis and deterministic forecast data complete with all relevant YOTC quantities (2008/9);
• Obtaining an analogous data set from NCEP (2009);
• Implementing a modest enhancement of the routine TIGGE archive for YOTC use; and
• Obtaining selected quantities and products from the satellite operator community (based on multi-sensor satellite platforms) for model evaluation and assessment (2009/10).
Mesoscale Weather Forecasting Research Implementation tasks

Task MWFR.1:
COPS RDP: Following the recent field experiment, studies of the process chain leading to convective precipitation in low mountain regions; research on the description of convection in mesoscale models, and on mesoscale data assimilation and observation impact studies.

Task MWFR.2:
MAP D-PHASE FDP: demonstration of end-to-end forecast and warning chain involving mesoscale atmospheric and hydrological deterministic models and ensembles over the Alps, with emphasis on assessment of severe precipitation.

Task MWFR.3:
Beijing 2008 RDP: mesoscale forecast models and ensemble forecast systems.

Task MWFR.4:
Contribution to Vancouver 2010 FDP: mesoscale ensemble forecasting under steep topography, winter conditions.

Task MWFR.5:
Contribution to Shanghai 2010 RDP: mesoscale ensemble forecast capabilities within an integrated warning system for high-impact weather.

Task MWFR.6:
Organization of regional IMRE activities on mesoscale data assimilation, convection parameterization, surface and mesoscale ensemble forecasting.

Task MWFR.7:
Organization of international surface physiography workshop and follow-up.

Task MWFR.8:
Organization of international workshop on data assimilation for nowcasting.

Task MWFR.9:

Task MWFR.10:
Organization of QPF symposium 2010 or 2011.

Task MWFR.11:
Contribution to London 2012 RDP: mesoscale ensemble data assimilation and forecast capabilities for summer rainfall probability prediction in urban environments.

Nowcasting Research Implementation tasks

Project Activities including RDP/FDP and Testbeds

Task NR.1:
Beijing 2008 FDP was conducted successfully during the Beijing 2008 Olympics to demonstrate how operationally tested state-of-the-art nowcast systems can provide an improved (value-added) nowcast service in the Beijing area. Agreed WWRP products were made available to end users for evaluation. The 3rd B08 FDP Workshop during 2009 will be a significant event highlighting advances in research undertaken as a result of the FDP. It is expected that this workshop will be coupled with a B08 Mesoscale Ensemble Prediction (MEP) RDP workshop. MAP D-PHASE will also host symposia summarizing advances in hydrological nowcasting.
Task NR.2:  
Testbeds have significant potential to provide an avenue for technology transfer, prototyping, long term demonstration and the integration of research and development into forecasting applications and processes in a quasi-operational framework meeting end-user requirements. The international Helsinki Mesoscale Testbed (Dabberdt et al. 2006) will be a focus for such activities.

Task NR.3:  
For winter nowcasting research the SNOW 2010 FDP is proposed in Vancouver with a focus on such issues as nowcasting fog, visibility, and precipitation in various phases in an orographically forced winter maritime regime.

The execution of RQQI.

Task NR.4:  
Through 2010 the WENS activity is to provide science demonstration and service delivery of very short term forecasting of multi-hazard, high-impact weather, including flash flooding.

Symposia

Task NR.5:  
The second WWRP Symposium on Nowcasting and Very Short Range Weather Forecasting (WSN09) will be conducted in Canada during 2009.

NWG Workshops

Task NR.6:  
Unified Frameworks for Probabilistic Approaches to Nowcasting and Very Short Range Forecasting. This can be viewed as part of tackling the seamless forecast system.

Task NR.7:  
Current research (e.g., as undertaken through EUMETSAT employing the Meteosat Second Generation (MSG)) shows significant applications relevant to nowcasting. A workshop on Advancing the Utilization of Satellite Techniques in Nowcasting will be employed as way to promote satellite-based nowcasting important for developing countries.

Task NR.8:  
Nowcasting for Hydrological Purposes. The purpose of this workshop will be to bring together invited specialists in precipitation nowcasting with counterpart hydrologists to address flash flooding in an urban environment.

Task NR.9:  
Nowcasting Verification. Verification of nowcasting requires new and sophisticated techniques that enable meaningful evaluation of mesoscale forecasts (with the JWGVR).

Task NR.10:  
Role of the Human in the Nowcast Process.

Capacity building workshops

Task NR.11:  
Asian Training Workshop 2009-10 will be conducted at the conclusion of the B08 FDP with a focus on Asian region involvement. Activities will attempt to include real-time training on B08 FDP systems.
Task NR.12:
East European Training Workshop 2010 is proposed to be conducted in Romania as part of proposed Testbed activities associated with JONAS.

*Tropical Meteorology Research Implementation tasks*

Task TMR-TC.1:
Organize with WWW/TCP and Chinese hosts the second International Workshop on Tropical Cyclone Landfall Processes in October 2009.

Task TMR-TC.2:
Organize with WWW/TCP the seventh IWTC in 2010 under the direction of the International Organizing Committee, including preparation of the Workbook by WGTMR Tropical Cyclone Panel Expert Teams and invitations to forecasters and researchers.

Task TMR-TC.3:
Organize the post-TCS08 experiment workshop in 2009 for coordinating research analyses, joint publication preparation, and satellite intensity technique validation.

Task TMR-TC.4:
Organize in conjunction with Météo France a workshop in mid-2009 for the preparation of the science and implementation plan for the Southwest Indian Ocean Experiment.

Task TMR-TC.5:
Develop an affiliation with the Hurricane Forecast Intensity Programme to include other Region IV countries participation (2009-2012).

Task TMR-TC.6:
Explore affiliations with three 2010 tropical cyclone field experiments as appropriate (2009-2010).

Task TMR-TC.7:
Organize in cooperation with WGNE the International Mesoscale Model Intercomparison of Typhoon Sinlaku with the preliminary organization via electronic conferencing and then a final Workshop (2009-2011).

Task TMR-TC.8:
The Expert Team on Climatic Effects on Tropical Cyclones will issue an updated statement on Tropical Cyclones and Climate Change, submit a review article for journal publication, and prepare the Team agenda for the next two years.

Task TMR-TC.9:
The Expert Team on Seasonal Forecasts of Tropical Cyclone Activity will continue the preparation of material for the WMO website according to list of Tasks agreed at the April 2008 workshop.

Task TMR-TC.10:
Co-editors J. Chan and J. Kepert will submit in 2009 the updated book *Global Perspectives on Tropical Cyclones* that originated from IWTC-VI.

Task TMR-TC.11:
Editor C. Guard will submit in 2009 a website version of the updated *Global Guide on Tropical Cyclone Forecasting*. 
Task TMR-M.1:
Monsoon Panel members will collect manuscripts from IWM-IV and prepare updated WMO Technical Document 1266 for publication in 2009.

Task TMR-M.2:
Lecture materials from the International Training Workshop on Monsoons to be made available by the Monsoon Panel in 2009.

Task TMR-M.3:

Task TMR-M.4:
The Monsoon Panel Expert Team on Severe Monsoon Weather will in 2009 identify national and regional field experiments/observing projects on heavy monsoon rainfall/high-impact weather; identification of collaborative research projects will continue as appropriate.

Task TMR-M.5:
The Monsoon Panel will formulate plans in 2009 to establish a monsoon field campaign legacy data centre to archive past field project data sets and to facilitate exchange of data for monsoon research.

Task TMR-M.6:
The Monsoon Panel will formulate plans by Fall 2009 to establish a data centre for the monitoring and assessment of extreme weather and climate events, in order to develop a unified database and monitoring platform to help organize and disseminate real-time and archived monitoring and assessment information on these events.

Task TMR-M.7:
The Monsoon Panel will formulate plans in 2009 to establish a monsoon radar meteorology data information centre to consolidate and categorize information on available radar observations in the Asian monsoon region, to facilitate severe monsoon weather research.

Task TMR-M.8:
The Monsoon Panel and Expert Teams will advise NMHSs on projects to improve monsoon forecasts on a continuing basis as requested.

Task TMR-M.9:
The Monsoon Panel will review the overall results of IWM-IV in early 2010 and begin long-range planning for IWM-V in 2012.

Task TMR-M.10:
The Monsoon Panel and the Tropical Cyclone Panel in conjunction with NCAR, NOAA and host China will organize in June 2010 the third International Conference on QPE and QPF with sessions emphasizing monsoon and tropical cyclone rainfall.

Verification Research Implementation tasks
Facilitate research on verification methodologies and approaches

Through workshops, intercomparison projects, and other projects, the JWGVR will encourage, undertake, and publicize research on verification methodologies and approaches.

Task VR.1:
Organize periodic international workshops on verification methods, to facilitate the sharing of research results and the development of collaborative relationships among verification
researchers. Workshops should take place approximately every two years, with the next one occurring in 2011 or 2012.

Task VR.2:
Co-develop, coordinate, and participate in specialized workshops with other working groups and programmes on topics of mutual interest (e.g., nowcast verification approaches, user-relevant verification methods).

Task VR.3:
Promote and coordinate intercomparison projects as part of a virtual Verification Testbed (VTB) to encourage new method development and to facilitate understanding of the capabilities of new methodologies and their advantages over other approaches. These intercomparison projects will be organized in a similar way to the ongoing spatial verification method intercomparison project.

Task VR.4:
Encourage the sharing of verification methods and codes through the JWGVR website as well as the VTB and intercomparison projects. Coordinate publication of special issues and collections in scientific journals to present results and methodologies from method intercomparison studies and other special verification activities (e.g., FDPs).

Provide outreach and training on verification methods and applications

Through a variety of tasks, the JWGVR will encourage the development of knowledge of modern verification methodologies and the use of best practices in the application of verification approaches.

Task VR.5:
Maintain and enhance a web page with comprehensive information about forecast verification methods and links to other resources on forecast evaluation.

Task VR.6:
Coordinate an internet discussion group which will provide a forum for posting questions and sharing knowledge and information.

Task VR.7:
Provide periodic tutorials on forecast evaluation methods and practice. Typically a tutorial will take place in conjunction with a scientific workshop; additional tutorials will be organized in conjunction with other WWRP events or projects (e.g., FDPs).

Task VR.8:
Develop training modules and materials that can be made widely available to anyone with an interest in forecast verification methods and practices. An example is the Eumetcal module on verification, already developed by members of the JWGVR. These types of materials will be expanded through use of materials developed for the tutorials.

Task VR.9:
Develop written recommendations on verification approaches and methods to be applied for specific research and operational forecast evaluation problems. Publish each document as a WMO technical report. The first document is on verification of precipitation forecasts, published in 2009. A document on verification of cloud forecasts will be completed and published in 2010, and will be followed in subsequent years with documents on other topics of interest to the verification, research, and operational communities.
Transfer research results to operations and to developing organizations

Task VR.10:
The JWGVR will work with the Commission for Basic Systems (CBS) and the WMO Public Weather Services (PWS) division to promote the use of new forecast evaluation methodologies in operational settings. Members of the JWGVR will participate on the new CBS Coordination Group on Forecast Verification.

Task VR.11:
Develop recommendations based on VTB activities; identify attributes of new methods to help users (including operational groups) to understand their capabilities.

Task VR.12:
Coordinate with WGNE to define approaches for the operational centres to apply in WGNE’s annual forecast comparisons.

Task VR.13:
Participate in FDPs and RDPs, as well as other forecasting activities that aim to provide methods and capabilities to developing organizations.

Social and Economic Research and Applications Implementation tasks

Task SERA.1:
Finalize the initial WGSERA membership and establish a three-year WG meeting schedule with the WWRP Secretariat.

Task SERA.2:
Clearly define mutual and complementary roles with the ICSU Planning Group on Natural and Human induced Hazards and Disasters (ICSU IRDR).

Task SERA.3:
Establish a basic inventory of related projects, capacity, contacts, and interest in SERA through consultation with WG members, NMHSs, WWRP WGs, THORPEX Regional Committees, other WMO programmes, professional societies, and academic institutions.

Task SERA.4:
Develop the architecture and content for an international SERAwx web resource for social scientists and users (either on the WMO-WWRP site or an external server).

Task SERA.5:
Convene a joint meeting/session with the JWGVR to define and scope a series of regional and sector based case applications that cut across nowcasting, meso-, and sub-seasonal scales of prediction/decision-making.

Task SERA.6:
Develop, test and evaluate a SERA-friendly TIGGE dataset from multiple user-perspectives in conjunction with the THORPEX-TIGGE WG.

Task SERA.7:
Prepare an outline scoping out a multi-year project to assess the global societal and economic benefits (and costs) of weather information.
Weather Modification Research Implementation tasks

Task WMR.1:
To lead a rolling review by the scientific community every three years of the “WMO Statement on Weather Modification (including an Executive Summary)” and the “WMO Guidelines for the Planning of Weather Modification Activities” and present it to WMO through the Commission for Atmospheric Science in 2011 and 2014.

Task WMR.2:
To organize, with the support of WMO Members, the WMO Research Department and the WMO Trust Fund on Weather Modification, the 10th Scientific Conference on Weather Modification in 2011.

Task WMR.3:
To represent the science of weather modification at international scientific fora such as the Quadrennial meeting of the International Commission on Clouds and Precipitation in 2012.

Task WMR.4:
To prepare a paper by 2011 on “Lessons Learned In Weather Modification Relevant To The Climate Change Geo-Engineering Debate”.

Evaluation and improvement of weather forecasting systems implementation tasks

Task WFS.1:
Establish with CBS the support to be provided by WWRP for the development and evaluation of forecast systems.

Task WFS.2:
Promote research on forecast systems and on the full integration of NWP within forecast systems.

Task WFS.3:
Organize international forums to exchange views and promote international research collaboration on forecast systems.

Task WFS.4:
Conduct studies to compare alternative solutions to problems in the design and implementation of forecast systems.

Task WFS.5:
Develop international consensus on scientifically rigorous approaches to the evaluation of the performance of forecast systems.

Task WFS.6:
Develop demonstration projects to properly intercompare forecast systems.

Task WFS.7:
Work with the TIGGE and GIFS projects of the THORPEX Programme to promote and evaluate the full integration of multi-model ensemble predictions within forecast systems.

Atmospheric chemistry and weather implementation tasks

Task ACW.1:
Promote the recognition of aerosols, ozone and greenhouse gases as essential weather variables.
Task ACW.2:
Promote the real-time availability of satellite data related to aerosols, ozone and greenhouse gases.

Task ACW.3:
Provide support for global coordination of projects needed to incorporate aerosols and ozone as radiatively and cloud/precipitation active constituents in next generation operational weather analysis and forecasting systems.

Task ACW.4:
Develop standardized verification techniques to evaluate the quality improvements resulting from the inclusion of aerosols and chemical variables in weather models.

Task ACW.5:
Promote the development of new products and services that become possible with the inclusion of aerosols and chemical variables within weather models, such as air quality predictions and SDS-WAS.

**WWRP/WCRP unified approach for sub-seasonal to seasonal predictions implementation tasks**

*Weather/Climate Ensemble Prediction Systems (EPSs)*

Task Sea.1:
Extend the TIGGE approach to cover sub-seasonal to seasonal predictions.

Task Sea.2:
Establish terms of reference for collaboration between the CHFP and TIGGE activities, to develop MEPS on time scale from weeks to seasons.

Task Sea.3:
Develop a common framework for comparison and diagnostic activities between the CHFP and TIGGE communities.

Task Sea.4:
Coordinate the sharing of predictions, both from retrospective forecasts and near real-time forecasts, and the assessment of MEPS biases and forecast skills through hindcast experiments.

Task Sea.5:
Identify a few data archive centres for the very large databases of retrospective and near real-time forecasts, to support the scientific and user community.

Task Sea.6:
Intensify research on the development and use of ensemble-based modelling in order to improve probabilistic estimates of the likelihood of high-impact events, including rare extreme events.

*Tropical convection and its two-way interaction with the global circulation*

Task Sea.7:
Develop metrics of the daily, sub-seasonal and seasonal characteristics of the MJO, organized convection and their interactions, to assess model performance.
Task Sea.8:
Promote NWP-type experiments exploring error growth in simulations of the MJO and other modes of organized convection and of two-way interactions between the tropics and extratropics.

Task Sea.9:
Promote forecast demonstration experiments coupling prediction systems based on statistical techniques with those based on dynamical models to assess the value of improved MJO-organized convection simulations for deterministic and ensemble prediction on timescales up to 4 weeks.

Task Sea.10:
Integrate process studies of observed organized convection based on satellite and ground-based remote sensing with in situ measurements to provide validation of high-resolution models of tropical convection, as proposed in THORPEX-YOTC.

Task Sea.11:
Promote field campaigns on organized tropical convection guided by high-resolution modelling studies.

Task Sea.12:
Promote international collaboration on CSRM studies for exploring the upscale energy cascade associated with organized convection in order to optimize convective parameterizations.

Data assimilation for coupled models as a prediction and validation tool for weather and climate research

Task Sea.13:
Promote the need to test climate models in a deterministic prediction mode, as started within the WCRP SPARC Programme. The seasonal prediction time frame provides a valuable opportunity to do this.

Task Sea.14:
Promote the use of advanced data assimilation methodologies for parameter estimation, both in weather and climate models, through close collaboration with model developers to interpret assimilation results.

Task Sea.15:
Promote research towards the development of a composite data assimilation system, applying different assimilation steps to different scales (weather to climate time-scales) and components (atmosphere, land, ocean, atmospheric composition) of the total Earth system model.

Task Sea.16:
Promote research on the development of coupled data assimilation, accompanied by a much better characterization of the errors and biases in each component of the coupled model.

Task Sea.17:
Promote interdisciplinary research on data assimilation methods appropriate for the next generation of re-analysis projects aimed at developing historical records for climate studies.
Socio-economic applications of sub-seasonal to seasonal predictions

Task Sea.18: Promote a seamless approach to the application of sub-seasonal and seasonal predictions, through the active involvement of physical and social science researchers, service providers and users.

Task Sea.19: Liaise with various groups to develop a pool of interdisciplinary scientists and representatives of decision-makers in key sectors.

Task Sea.20: Identify areas that have the greatest potential societal contribution, then help articulate requirements and develop specific projects.

Task Sea.21: Leverage existing programmes such as MERIT, HEPEX, ClimDev Africa, the Disaster Risk Reduction Programme and the Global Environmental Change and Human Health Initiative.

Task Sea.22: Provide sub-seasonal and seasonal predictions in a form easily accessible to non-atmospheric scientists, user groups and intermediaries who understand both the scientific and socio-economic issues.

WWRP resources implementation tasks

Task Res.1: To review annually WWRP's costs, for the implementation of the WWRP Strategic Plan (Secretariat - beginning of each calendar year)

Task Res.2: To continually review the funding needs of the WWRP and THORPEX programmes and identify:
- How much is needed to achieve specific goals
- How WMO Member countries can help meet these needs. (Secretariat - ongoing)

Task Res.3: To publicize a list of programme needs for which resources are required and to use all avenues to recruit sponsors. (Secretariat and JSC-WWRP - annually)
Terms of Reference of the WWRP Joint Scientific Committee (JSC)

Membership
The Chair of the JSC is selected by CAS. The members of the JSC are appointed by the CAS Management Group upon recommendation by the JSC Chair. The membership currently consists of the Chair and/or Co-chair of the WWRP WGs and Programme, and additional members to meet the need for scientific and geographical representation. The term of JSC members is four years and can be renewed.

Functions
a) To provide scientific guidance for the WWRP including making appropriate comments on major THORPEX activities to be considered by the THORPEX International Core Steering Committee;

b) To develop a strategic science and implementation plan for the WWRP and a work programme aligned with the WMO Strategic Planning Process;

c) To review and assess the development of all elements of the WWRP, including FDPs, RDPs and forecast evaluation methods, to formulate recommendations to guide further actions and to report on the progress of the programme to the president of the Commission for Atmospheric Sciences (CAS);

d) To facilitate, coordinate and prioritize weather research and development activities, which are planned and implemented through the project committees and working groups, to meet the objectives of CAS;

e) To facilitate the exchange of information among scientists participating in the programme and relevant scientific institutions and agencies, at the national and international levels;

f) To collaborate, as appropriate, with OPAG-EPAC, the Commission for Basic Systems (CBS) and other technical commissions, relevant groups of the JSC/ World Climate Research Programme (WCRP) and the WCRP projects committees, academia, users of forecast products and other partners; and

g) To delegate to each working group and expert team, as required, the responsibility to promote the timely exchange of information, data and new knowledge through publications, workshops and meetings.
General Terms of Reference of WWRP Working Groups (WG)

Membership
Chairs and co-chairs of WWRP WGs are appointed by the CAS Management Group upon recommendation of the JSC Chair, the CAS President and the WMO Secretariat after seeking advice from the members of JSC and the Working Group. WG members are appointed by the CAS Management Group upon recommendation from the WG Chair, the JSC Chair and the WMO Secretariat. The THORPEX WGs are governed by the ICSC. The term of WG members is four years and can be renewed.

Functions
a) To advise the WWRP JSC, CAS and the WMO Secretariat on the current research status in their area of expertise and to recommend priorities and strategies for future research that are well suited to advancement through international collaboration. These recommendations should factor in both scientific knowledge and the potential implications of advances in research to meet the needs of Members of the WMO to improve their prediction of and response to high-impact weather;

b) To work toward advancing the science in their area of expertise and to work, often in partnership with others, to foster the utilization of research knowledge and techniques for societal and economic benefit including the transition of research into operational practice within NMHSs;

c) To act as an international focal point and resource for research in their area of expertise by bringing together scientists from the academic, research institution and operational communities with users of weather products;

d) To endorse, guide, develop, and/or implement RDPs, FDPs, Societal and Economic Demonstration Projects, (SEDPs), Testbeds, and other research projects that advance the underlying science and the utilization of weather information;

e) To publish findings on WWRP activities in refereed journal articles, WMO Technical Documents and other appropriate venues and to publicize their results through the web and other means;

f) To convene symposia, conferences, workshops and other meetings as necessary to advance these goals;

g) To establish panels and expert teams and other subgroups as needed to support these activities. If these panels function on a continuous basis, they need to obtain JSC approval;

h) To undertake these goals in conjunction with partnerships with WMO Members and other programmes, projects, and organizations both internal and external to the WMO and the UN System; and

i) To assist, when appropriate, in the resource mobilization necessary to undertake these activities. Appropriate activities include seeking co-sponsorship of conferences, symposia and large workshops of the WWRP or submitting proposals to regional and national funding sources for projects and activities initiated by the WWRP WGs.
Terms of Reference of Regional Rapporteurs on the WWRP

Designation
Regional rapporteurs on the WWRP are designated by the JSC Chair after consultation with the THORPEX ICSC, from the members of the JSC, the WWRP WGs or the THORPEX WGs and Committees. The term of a regional rapporteur on the WWRP is four years and can be renewed.

Functions
a) To promote and facilitate the participation of NMHSs, academia and related organizations and agencies of the Region in weather research and development projects and activities, in particular through the CAS working structure;

b) To keep the regional associations and CAS informed on relevant WWRP plans and activities in the area, specifically those requiring the support and engagement of the Region; and

c) To assist the Secretariat and WWRP including THORPEX in the exchange of information and support of cooperative research and monitoring projects in the field of weather prediction research in the Region.
ANNEX 5

Terms of Reference of the Expert Team on Weather Modification Research (ET-WMR)

Membership
The Chair of the ET-WMR is appointed by the CAS Management Group upon recommendation of the JSC Chair, the CAS President and the WMO Secretariat, after seeking advice from the members of the JSC and the ET-WMR. The members of the ET-WMR are appointed by the CAS Management Group upon recommendation from the Chair of the ET-WMR, the JSC Chair and the WMO Secretariat. The term of the ET-WMR members is four years and can be renewed.

Functions
a) To keep under review, on behalf of OPAG-WWRP and OPAG-EPAC, relevant research, advise CAS on issues requiring attention related to weather modification and suggest mechanisms for addressing such issues;

b) To review the criteria for conducting weather modification research to ensure the quality of the science, from the initial design to the final evaluation of field experiments, taking into account advances in supporting fields, including cloud physics, atmospheric chemistry, numerical modelling and SEAs;

c) To serve as a focal point and provide advice and assistance to Members on the manner and means of transferring competence for planning scientific experiments; and

d) To assist in the drafting of WMO documents on the status of weather modification and guidelines for providing advice to Members and to propose revisions to these documents where necessary.
This Annex presents the Guidelines for Developing and Submitting a Research and Development Project (RDP), a Forecast Demonstration Project (FDP) as well as a Developing Country Forecast Demonstration Project (DC-FDP).

1. **Guidelines for Developing and Submitting a Research and Development Project (RDP)**

RDPs can be field campaigns, model or assimilation based, or geared to social science research. The RDP focus is on advancing knowledge in research topics relevant to improving the prediction of high-impact weather and/or the development of improved tools, techniques, and models. RDPs can address any component of weather forecasting (e.g., observations, data assimilation, modelling, forecast, dissemination and the utilization of weather products). Thus RDPs should be based on the priorities of the Working Groups and Programme(s) of the WWRP including those of the WGSERA. In addition, the RDPs are encouraged to contain a SERA type component.

The following text presents guidelines for submission of RDP proposals to the WWRP Joint Scientific Committee (JSC). In many cases, RDPs have specific science plans. Thus another option for the proposal process is to submit the full science plan with a short document that covers any topic not well represented in the science plan such as a SERA component, explaining how this project will meet the priority needs of the WWRP and/or facilitate the operational transition.

The JSC will define, prioritize, and where appropriate endorse candidate projects within the WWRP. The JSC is under no obligation to endorse or otherwise participate in any project brought to its attention. By its very nature, the WWRP can be most effective by focusing on a relatively few project areas, to create a critical mass of research effort associated with forecast problems of highest priority determined, in part, by their broad societal impact and technical achievability.

**Proforma for a Research and Development Project Proposal to the WWRP**

**TITLE**

*Proposer(s) Name(s) and Institution(s)*

**CONTENTS**

- Project Summary
- Background
- RDP Proposal
- RDP Management
- Societal Impacts
- Forecast Demonstration Projects
- Acknowledgements
- References
- Supporting Documentation

**Project Summary**

The project summary will provide a concise summary of the proposal. It should start with the specific aim or goal of the programme, including a list of any specific recommendations and expected outcomes.
The entire document should be kept to a reasonable length, generally not more than 15 pages, not including supporting documentation.

**Background**

A brief discussion of events that have lead to the proposal should be included here. Examples include workshop recommendations, background events, etc. Also included here should be a discussion of the WWRP recommendations arising from the preliminary proposal. The proposal must specifically address weather system research that fits with the WWRP Goals to undertake the necessary R&D leading to the development and demonstration of improved and cost effective forecasting techniques, with emphasis on high-impact weather, and to promote their application among Member States.

High Impact weather is defined as weather that affects quality of life, is economically disruptive, or is life threatening and is prominent among the concerns of the International Decade for Natural Disaster Reduction (IDNDR). High-Impact Weather can occur in forecast ranges from the very short-range to the long-range, up to a season.

**RDP Proposal**

This section should address the full programme of research that is being proposed and will form the bulk of the proposal. The contents are up to the individual, but should be in the form of an expansion of the preliminary proposal, addressing any recommendations from the JSC. The following WWRP R&D requirements must be addressed:

- Specification of the problem to be addressed and especially its scientific basis;
- A review of current knowledge in the area, together with a highlight of where knowledge is deficient; and
- A comprehensive discussion of how the programme will undertake the research and development, including methodology to be adopted, envisaged field programmes (and their justification), and time scale. If desired, several sections and subsections can be devoted to the RDP Proposal.

**RDP Management**

This section should address the management structure of the programme. As a minimum requirement the WWRP requires that two groups be formed:

A Scientific Steering Committee comprised of 6-8 scientists in the relevant disciplines. This committee will be responsible for producing the science proposal and the scientific implementation of the programme, should it be approved by the JSC. Complex programmes may choose to include additional specialist subcommittees working under the Scientific Steering Committee.

A Community Advisory Group comprised of representatives from end users, community groups, industry, forecast offices, etc. This group will be utilized to provide an impacts perspective on the programme and a review of the plans that are produced. The WWRP JSC is happy to help with recommendations on the membership of these two groups. This section should also indicate the organizations and institutions that are supporting, or are expected to support the programme. Please note that the WWRP will only support programmes that are international in nature.

**Societal Impacts**

This section must discuss:

- How end users have been involved in the development of the research proposal;
- The manner in which the research is expected to impact on society; and
- The proposed method whereby societal impacts are to be incorporated into the RDP.
Prospects for operational transition including Forecast Demonstration Projects

This section must address potential FDPs or related programmes arising out of the RDP. Future FDPs may be highly developed in some cases, or presented as a planned approach in cases of more strategic RDPs. All FDPs must follow the WWRP requirements.

Acknowledgements

Acknowledge any funding sources, contributors, etc.

References

Please use the format of either the AMS Journals, or the QJRMS for referencing. Reports that are not readily available should have copies of the relevant pages included in the supporting documentation.

Supporting Documentation

Supporting documentation in the form of resolutions from workshops, etc, should be attached here. Also include a short CV for each of the main proposers.

2. Guidelines for Developing and Submitting a Forecast Demonstration Project (FDP)

The Joint Scientific Committee (JSC) will define, prioritize, and where appropriate endorse candidate projects within the WWRP. The JSC is under no obligation to endorse or otherwise participate in any project brought to its attention. By its very nature, the WWRP can be most effective by focusing on a relatively few project areas, to create a critical mass of research effort associated with forecast problems of highest priority determined, in part, by their broad societal impact and technical achievability. The proposal should meet the scientific mission of the WWRP and include a societal component.

Forecast Demonstration Projects should be submitted for review to the Chair of the JSC and the WMO Secretariat for the WWRP. The proposal will then be sent for comments to members of the relevant Working Groups and/or members of the JSC. Proposals for FDPs, along with the comments of reviewers, are typically presented at the annual meeting of the JSC of the WWRP. The role of the JSC is to review these FDPs in order to determine if the proposal sufficiently meets the guidelines below, suggest improvements in the proposed project and determine if the project should be endorsed as a WWRP activity. Note that THORPEX has its own management structure and final decisions on projects are made by the THORPEX International Core Steering Committee after considering the recommendations of the WWRP JSC and THORPEX bodies.

Proforma for a Forecast Demonstration Project Proposal to the WWRP

TITLE

Proposer(s) Names and Institutions

Contents

Project Summary
Background and Motivation
FDP Proposal
FDP Management
Acknowledgements
References
Supporting Documentation
Attachment 1: Societal Impacts
Project Summary
The project summary will be a maximum of one page and provide a concise summary of the proposal. It should start with the specific aim or goal of the programme, including a list of any specific recommendations and expected outcomes.

The entire document should be concise and generally not more than 10-15 pages in length, not including supporting documentation.

Background and motivation
A brief discussion of events that have lead to the proposal should be included here. Examples include workshop recommendations, background events, etc. FDP proposals must follow the WWRP requirements:

FDPs will serve to exhibit and formally quantify the benefits to be derived from improved understanding and enabling technologies. The improved understanding and technological advances, the benefits of which are to be demonstrated, may or may not be a direct consequence of other WWRP activities. FDPs will involve the dissemination of forecast information to real users in real-time. Candidate FDPs will be selected by the JSC on the basis of readiness of the science, timeliness of the demonstration, and feasibility of technology transfer and training.

FDP Proposal
This section should contain an outline of the proposed FDP in sufficient detail for the WWRP committee to arrive at a conclusion on its merits. The contents are up to the individual, but address as a minimum the WWRP FDP requirements noted above. The proposal should specifically address the following issues:

- Basis of the proposal (e.g. what new research outcome or forecast technique is to be demonstrated);
- Forecast procedure, hosting organization and method of disseminating forecasts;
- Expected impact of the proposed programme on society; and
- Validation and verification methodology to be adopted including a means for measuring impacts of the forecast improvement on users.

FDP Management
This section should address the management structure of the programme. As a minimum requirement the WWRP requires that two groups be formed:

An FDP Steering Committee comprised of 6-8 people in the relevant disciplines. This committee will be responsible for producing the FDP proposal and the implementation of the programme, should it be approved by the JSC. Complex programmes may choose to include additional specialist subcommittees working under the FDP Steering Committee.

A Community Advisory Group comprised of representatives from end users, community groups, industry, forecast offices, etc. This group will be utilized to provide an impact perspective on the programme and a review of the plans that are produced. The WWRP JSC is happy to help with recommendations on the membership of these two groups.

Acknowledgements
Acknowledge any funding sources, contributors, etc.

References
Please use the format of either the AMS Journals, or the QJRMS for referencing. Reports that are not readily available should have copies of the relevant pages included in the supporting documentation.
Supporting Documentation

Supporting documentation in the form of resolutions from workshops, etc, should be attached here. Also include a short CV for each of the main proposers.

Attachment 1: Societal impacts

Research and Development Projects and Forecast Demonstration Projects will lead to societal benefits if and only if that research is successfully turned into products that are used by decision makers. Thus, the societal aspects of weather are an essential area of complementary research. Four areas of investigation are identified:

- **Obtaining an improved understanding of the nature of the problem and the opportunity:** These include the costs of weather related events and who incurs those costs. Results obtained from this research, in conjunction with knowledge of predictability, etc., can help scientists to more effectively prioritize research objectives. More broadly, such research can provide information to help policy makers focus national priorities.

- **Use of forecasts by decision makers:** Even the most accurate forecast is of little value if it is not well used. To this end, it is important to understand what information decision makers could effectively use and also effective ways to communicate that information. Research in this area can help to identify those conditions necessary and sufficient for forecasts to contribute to the needs of decision makers.

- **The process of transitioning research to the operational community:** This process focuses on the needs of forecasters seeking to provide information of use to decision makers. Both the structure of the process and the content of the information being transferred should be evaluated from the standpoint of the penultimate goal of producing useful products. Thus in addition to research on the use of forecasts, appropriate research might include the institutional structures through which the transfer process takes place.

- **Evaluation of forecasts:** There are many measures of forecast "goodness." Such evaluations are an important component of the programme’s ability to assess progress with respect to its goals. Evaluation from a user perspective is an important component of these projects.

3. **Guidelines for the Development and Submission of a Developing Country Forecast Demonstration Project (DC- FDP)**

DC-FDPS will serve to demonstrate the benefits derived from improved understanding and enabling technologies, and improved prediction capacity in developing countries. It involves a partnership between a developing country (or countries), a relevant Regional Specialised Meteorological Centre (RSMC) and a developed country (or countries), with the aim of:

- Developing the research capacity in the developing countries and relevant RSMC; and

- Operational application of improved and cost effective forecasting techniques in developing countries for the benefit of societies.

DC-FDPS will involve the development or implementation of new or enhanced technologies in an operational environment in developing countries, and the dissemination of forecast information to real users in real-time.

The following attributes, which must be addressed in proposals, will be considered as a basis for the endorsement of DC-FDPS within the overall WWRP:

- The project addresses forecasts of weather of international or regional applicability, with the emphasis on high-impact weather;
• The strength and nature of the partnership between a developing country, a relevant RSMC and a developed country;

• The existence of clear evaluation protocols;

• The expectation of success and level of support available;

• The suitability of the techniques, systems or skills and prospect of clear advance on current operational practice within developing countries; and

• The forecasts will be provided in real-time and forecast information will be communicated for user utilisation and subsequent impact evaluation.

Editor: Mr P. Dubreuil, Environment Canada

Executive Summary: Mr P. Dubreuil, Environment Canada

Introduction: Dr D. Parsons, WMO

Organization: Dr D. Parsons, WMO

Challenges: Dr G. Brunet, Environment Canada

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SDS-WAS: Dr L. Barrie, WMO

Shanghai MHEWS: Dr N. Lomarda, WMO

Sub-seasonal to seasonal predictions: Dr G. Brunet, Environment Canada

Outcomes: Dr D. Parsons, WMO

Resources: Dr L. Barrie, WMO
Acronyms

AfRC   THORPEX Africa Regional Committee
AMDAR  Aircraft Meteorological Data Relay
AMIP   Atmospheric Model Intercomparison Project
AMMA   African Monsoon Multidisciplinary Analyses
AMS    American Meteorological Society
AMY    Asian Monsoon Year 2008-2011
AOD    Aerosol Optical Depth
ARC    THORPEX Asia Regional Committee
ARE    WMO Atmospheric Research and Environment Branch
ARM    Atmospheric Research Monitoring
A-TReC  Atlantic THORPEX Regional field Campaign
BAMS   Bulletin of the American Meteorological Society
BMB    Beijing Meteorological Bureau
BOM    Bureau of Meteorology, Australia
B08    Beijing Olympics 2008 RDP and FDP projects
CAS    Commission for Atmospheric Sciences of WMO
CBS    Commission for Basic Systems of WMO
CHFP   CLIVAR Climate-system Historical Forecast Project
CHy    Commission for Hydrology
CIMO   Commission for Instruments and Methods of Observation
CLIVAR Climate Variability
CMA    China Meteorological Agency
CMC    Canadian Meteorological Centre
COPS   Convective and Orographically-induced Precipitation Study
COST   Co-Operation in Science and Technology (European Programme)
CPM    Convection-Permitting Model
CPTEC  Centre for Weather Forecasting and Climate Studies (Brazil)
CSRM   Cloud System Resolving Model
CXML   Cyclone eXtended Markup Language
DA     Data Assimilation
DAOS WG THORPEX Data Assimilation and Observing Systems WG
DATC   Data Assimilation Testbed Center
DC-FDP  Developing Country Forecast Demonstration Project
DLR    Deutsches Zentrum Fuer Luft- Und Raumfahrt, Germany
D-PHASE MAP Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region
EC     Executive Committee or Executive Council
EC – AG DPM Executive Council Advisory Group on Disaster Prevention and Mitigation
ECMWF  European Centre for Medium Range Weather Forecasting
EGU    European Geophysical Union
ENSO   El Nino/Southern Oscillation
EOS    Earth Observing Systems
EPAC   Environmental Pollution and Atmospheric Chemistry (a CAS OPAG)
EPS    Ensemble Prediction System
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<tr>
<th>Acronym</th>
<th>Description</th>
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<tr>
<td>IGBP</td>
<td>International Global Biosphere Project</td>
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<tr>
<td>ILEAPS</td>
<td>Integrated Land Ecosystem-Atmosphere Processes Study (IGBP)</td>
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<td>IMRE</td>
<td>Integrated Mesoscale Research Environment</td>
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<td>IOP</td>
<td>Intense Observing Period</td>
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<td>IOS</td>
<td>Integrated Observing Systems, a component of the CBS</td>
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<td>IPCC</td>
<td>International Panel on Climate Change</td>
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<td>IPO</td>
<td>THORPEX International Project Office</td>
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<td>IPY</td>
<td>International Polar Year</td>
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<tr>
<td>IRDR</td>
<td>ICSU’s programme on Integrated Research on Disaster Risk</td>
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<td>ITCZ</td>
<td>Inter Tropical Convergence Zone</td>
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<td>IUGG</td>
<td>International Union of Geodesy and Geophysics</td>
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<td>IWM</td>
<td>International Workshop on Monsoons</td>
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<td>International Workshop on Tropical Cyclone Landfall Processes</td>
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<td>Japan Meteorological Agency</td>
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<td>JONAS</td>
<td>PWS-WWRP Joint Steering Committee on Nowcasting Applications</td>
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<td>JSC</td>
<td>WWRP Joint Scientific Committee</td>
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<td>JWGVR</td>
<td>Joint Working Group on Verification Research</td>
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<tr>
<td>KEOP</td>
<td>Korea Enhanced Observation Period</td>
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<td>KMA</td>
<td>Korean Meteorological Agency</td>
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<tr>
<td>LAM</td>
<td>Local Area Model</td>
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<tr>
<td>MACC</td>
<td>ECMWF modelling system</td>
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<td>MAP</td>
<td>Mesoscale Alpine Project</td>
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<tr>
<td>MAP D-PHASE</td>
<td>MAP Demonstration of Probabilistic Hydrological and Atmospheric Simulation of flood Events in the Alpine region</td>
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<tr>
<td>MEP</td>
<td>Mesoscale Ensemble Prediction</td>
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<tr>
<td>MEPS</td>
<td>Multi-model Ensemble Prediction System</td>
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<tr>
<td>MERIT</td>
<td>Meningitis Environmental Risk Information Technologies</td>
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<td>MF</td>
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<td>MHEWS</td>
<td>Shanghai Integrated Multi-Hazard Early Warning System Project</td>
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<td>MJO</td>
<td>Madden Julian Oscillation</td>
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<td>MOS</td>
<td>Model Output Statistics</td>
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<td>MPI</td>
<td>Max Plank Institute</td>
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<td>MSG</td>
<td>Meteosat Second Generation</td>
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<td>MWFR</td>
<td>WWRP WG on Mesoscale Weather Forecasting Research</td>
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<td>NAEFS</td>
<td>North American Ensemble Forecasting System</td>
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<td>NARC</td>
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<td>NASA</td>
<td>National Aeronautics and Space Administration</td>
</tr>
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<td>NCAR</td>
<td>National Centre for Atmospheric Research</td>
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<tr>
<td>NCEP</td>
<td>National Centres for Environmental Prediction, USA</td>
</tr>
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<td>NMHS</td>
<td>National Meteorological and Hydrological Service</td>
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<td>NOAA</td>
<td>National Oceanic and Atmospheric Administration (USA)</td>
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<td>NR</td>
<td>WWRP Working Group on Nowcasting Research</td>
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<td>NRL</td>
<td>Navy Research Laboratory (USA)</td>
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<tr>
<td>NWP</td>
<td>Numerical Weather Prediction</td>
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<td>Abbreviation</td>
<td>Description</td>
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<td>OFDA/CRED</td>
<td>Office of Foreign Disaster Assistance/Center for Research on the Epidemiology of Disasters (USA)</td>
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<tr>
<td>OPAG</td>
<td>Open Programme Area Group (WWRP is an OPAG of CAS)</td>
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<td>OPERA</td>
<td>European Operational Project for the Exchange of Weather Radar Information</td>
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<tr>
<td>OSE</td>
<td>Observing System Experiment</td>
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<tr>
<td>OSSE</td>
<td>Observing System Simulation Experiment</td>
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<tr>
<td>PDF</td>
<td>Probability Density Function</td>
</tr>
<tr>
<td>PDP WG</td>
<td>THORPEX Predictability and Dynamical Processes WG</td>
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<td>PHONE</td>
<td>Pukyong University – HyARC/Nagoya University Observation Network over East China Sea</td>
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<tr>
<td>PM</td>
<td>Particulate Matter</td>
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<tr>
<td>PQPF</td>
<td>Probabilistic Quantitative Precipitation Forecast</td>
</tr>
<tr>
<td>PWS</td>
<td>Public Weather Services, a component of CBS</td>
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<tr>
<td>QJRMS</td>
<td>Quarterly Journal of the Royal Meteorological Society</td>
</tr>
<tr>
<td>QPE</td>
<td>Radar Quantitative Precipitation Estimate</td>
</tr>
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<td>QPE/QC</td>
<td>Radar Quantitative Precipitation Estimate/Quality Control</td>
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<td>QPF</td>
<td>Quantitative Precipitation Forecasting</td>
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<td>RA</td>
<td>WMO Regional Association</td>
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<td>RAOB</td>
<td>Radiosonde Observation</td>
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<tr>
<td>RC</td>
<td>THORPEX Regional Committee or Regional Centre</td>
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<tr>
<td>RDP</td>
<td>Research Demonstration Project</td>
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<tr>
<td>RES</td>
<td>WMO Research Department</td>
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<tr>
<td>ROQI</td>
<td>Radar Quality control Quantitative Intercomparison</td>
</tr>
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<td>RSG</td>
<td>Regional Steering Group</td>
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<tr>
<td>RSMC</td>
<td>Regional Specialized Meteorological Centre (a CBS designation)</td>
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<td>SDS</td>
<td>Sand and Dust Storm</td>
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<td>SDS-WAS</td>
<td>WMO Sand and Dust Storm Warning Advisory and Assessment System</td>
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<td>SEA</td>
<td>Socio-Economic Application</td>
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<td>SEDP</td>
<td>Societal and Economic Demonstration Project</td>
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<td>SERA</td>
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<tr>
<td>SH</td>
<td>Southern Hemisphere</td>
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<tr>
<td>SHRC</td>
<td>THORPEX Southern Hemisphere Regional Committee</td>
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<td>SMB</td>
<td>Shanghai Meteorological Bureau</td>
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<td>SOLAS</td>
<td>International Convention for the Safety of Life at Sea</td>
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<td>SPARC</td>
<td>Stratospheric Processes and their Role in Climate</td>
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<td>SPECTRUM</td>
<td>Special Experiment Concerning Typhoon Recurvature and Unusual Movement</td>
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<tr>
<td>SWFDP</td>
<td>Severe Weather Field Demonstration Project</td>
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<td>SWICE</td>
<td>Southwest Indian Ocean Experiment</td>
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<td>TAWEPI</td>
<td>THORPEX Arctic Weather and Environmental Prediction Initiative</td>
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<tr>
<td>TC</td>
<td>Tropical Cyclone</td>
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<td>TCM</td>
<td>Tropical Cyclone Motion experiment</td>
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<td>TCP</td>
<td>Tropical Cyclone Programme</td>
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<td>TCS08</td>
<td>Tropical Cyclone Structure 2008 Experiment</td>
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<tr>
<td>THORPEX</td>
<td>THE Observing Research and Predictability EXperiment</td>
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<td>TIGGE</td>
<td>THORPEX Interactive Grand Global Ensemble</td>
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<td>Acronym</td>
<td>Description</td>
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<td>TiMREX-SOWMEX</td>
<td>Terrain-induced Monsoon Rainfall Experiment-Southwest Monsoon Experiment</td>
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<td>TMR</td>
<td>WWRP WG on Tropical Meteorology Research</td>
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<tr>
<td>T-NAWDEX</td>
<td>THORPEX North Atlantic Waveguide and Downstream impact Experiment</td>
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<td>TOPEX</td>
<td>Typhoon Operational Experiment</td>
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<td>TOST</td>
<td>THORPEX Observing System Tests</td>
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<td>T-PARC</td>
<td>THORPEX Pacific Asian Regional Campaign</td>
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<td>TReC</td>
<td>THORPEX Regional field Campaign</td>
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<td>UKMO</td>
<td>United Kingdom Meteorological Office</td>
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<td>UN</td>
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<td>United Nations Convention to Combat Desertification</td>
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<td>UNDP</td>
<td>United Nations Development Programme</td>
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<td>VTB</td>
<td>Verification Test Bed</td>
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<td>VR</td>
<td>WWRP Joint WG on Verification Research</td>
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<td>World Climate Research Programme</td>
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<td>Working Group</td>
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<td>Joint Working Group on Numerical Experimentation</td>
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<td>WGNR</td>
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<td>WGSERA</td>
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<td>WGTMR</td>
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<td>World Health Organization</td>
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<td>WMO Integrated Global Observing System</td>
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<td>WMO Information System</td>
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<td>WWRP Expert Team on Weather Modification Research</td>
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<td>WTO</td>
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<td>World Weather Research Programme</td>
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<td>WWW</td>
<td>World Weather Watch</td>
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<td>YOTC</td>
<td>Year of the Tropical Convection</td>
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<tr>
<td>3DVAR</td>
<td>Three Dimensional VARIational data assimilation</td>
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<tr>
<td>4DVAR</td>
<td>Four Dimensional VARIational data assimilation</td>
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</table>
Sixth WMO International Workshop on Tropical Cyclones (IWTC-VI), San Jose, Costa Rica, 21-30 November 2006 (WMO TD No. 1383) (WWRP 2007 - 1).


WMO International Training Workshop on Tropical Cyclone Disaster Reduction (Guangzhou, China, 26 - 31 March 2007) (WMO TD No. 1392) (WWRP 2007 - 3).


Recommendations for the Verification and Intercomparison of QPFS and PQPFS from Operational NWP Models – Revision 2 - October 2008 (WMO TD No. 1485) (WWRP 2009 -1)