A WORKSHOP TO ASSIST IN:
SUSTAINING NATIONAL METEOROLOGICAL SERVICES – STRENGTHENING WMO REGIONAL AND GLOBAL CENTRES

FINAL REPORT

Washington DC, U.S.A., 18-20 June 2013

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Executive Summary

The Workshop, convened by the World Bank/GFDRR, World Meteorological Organization and the US National Weather Service, was attended by Heads of Meteorological Services and Permanent Representatives of Countries with the World Meteorological Organization (WMO), or their appointed representatives, representatives of the World Bank, GFDRR Secretariat and other Donor Agencies, and the WMO Secretariat (list of attendees at Annex I), and was held in Washington DC, U.S.A., 18 to 20 June 2013:

1. Context

The provision of reliable, timely and accurate severe weather forecasts and warnings for the range of hydro-meteorological hazards is a global endeavour. It is an end-to-end process that involves the world-wide, realtime collection and exchange of weather observations, the processing of these observations to produce forecast projections and the conversion of the resulting data into products that can be used by trained meteorologists and hydrologists to prepare and disseminate forecasts and warnings. These forecasts and warnings must be prepared and then delivered so as to reach their intended audience in good time to enable effective decision-making, and to prompt those actions necessary to minimise loss of life, livelihoods, property and environmental assets that might otherwise result from the impending hazard.

While a number of National Meteorological and Hydrological Services (NMHSs) have very advanced capabilities to provide such services, there are a large number which have little or no such capability, mostly in developing or least developed countries. The aim of the Workshop was to consider efficient (cost-effective and sustainable) ways in which investment can build capacity in the NMHSs to enable them to provide a basic service giving effective warnings of severe weather and thus protecting life and property in their countries.

In essence the SWFDP is a process whereby scientists from global and regional centres work with severe weather forecasters at the national level to identify services that would assist the national disaster risk reduction efforts, and that can be implemented almost immediately by tailoring numerical weather prediction model outputs that exist in the most advanced centres, by making them routinely available at the national level. The SWFDP employs a '*Cascading Forecasting Process'* whereby outputs from forecast systems existing in advanced global centres are cascaded to NMHSs through a designated regional centre which provides interpretation and guidance on severe weather. This allows forecasters at the NMHSs to focus limited resources on considering the impact of this weather in their country and on service delivery and communicating the message to users in their countries to ensure effective protective responses. An SWFDP project includes building capacity of national meteorologists in the application of the cascaded information and in the development of services to meet the disaster management communities needs, and opportunities are taken to involve disaster managers in preparation of the user requirements.

Outcomes of the SWFDP include:

- improved quality of national forecast and warning services;
- the development of operational partnerships between meteorologists, hydrologists and disaster managers,
- the development of operational partnerships between global, regional and national centres,
- enhanced visibility and reputation of the NMHSs involved; and,
- increased forecaster confidence and capability.

These positive outcomes have been delivered at relatively low cost and appear to be sustainable provided that:

- global centres remain able to support the provision of relevant products on a long-term operational basis;
- regional centres are able to maintain an interpretation and guidance service on a similar long-

term operational basis; and,

- regular capacity building and training can be maintained for new forecasters along with refresher training for experienced forecasters.

The Workshop did not seek to address all aspects of this end-to-end forecasting and warning process, but rather it was focused on the Severe Weather Forecasting Demonstration Project (SWFDP) which has already proven to provide a cost effective and practical method of strengthening NMHSs capacity and capability and is scalable.

2. Relevant considerations

Participants of the Workshop recognized that:

2.1 Hydro-meteorological hazards have major implications for countries and affected individuals in terms of loss of life and livelihoods, and damage to property and ecosystems;

2.2 There are important inter-relationships between hydro-meteorological hazards, high risk levels and substantial societal impacts in many countries, most notably (but not only) the developing and least developed countries. There is a body of evidence that these effects are being exacerbated by a number of factors such as increasing population and environmental degradation in high risk areas and as a result of climate change;

2.3 There is a crucial role to be played in improving severe weather forecasts and warnings by all stakeholders, including the UN agencies, and in particular the WMO and its Members, the World Bank, GFDRR and other donor agencies;

2.4 Many NMHSs in developing and least developed countries lack infrastructural, technical, human and institutional capacities to provide provide high-quality meteorological services;

2.5 There is a significant and growing donor interest in assisting least developed and developing countries in increasing their capability to manage the risks associated with hydro-meteorological hazards, but it is becoming apparent that investments in modernizing NMHSs often lack the necessary long-term sustainability strategies and coordinated approach at global, regional and national levels, to build from.

3. Opportunities for improving the forecasting of hydro-meteorological hazards

The Workshop participants noted that:

3.1 There has been a great deal of scientific progress, such as, ever-increasing precision, reliability and lead-time in forecasting hydro-meteorological hazardous phenomena using numerical weather prediction and related systems, and in developing and implementing improved early warning systems using modern communications and improved service delivery practices;

3.2 While the accuracy of computer-based systems has increased, the role of the forecaster has evolved to include, as a critical function, interpretation of computer output in terms of the impact of the forecast weather on their community, and communicating these forecasts and warnings in a way that will support decision makers at all levels of their society;

3.3 Forecasters in developing and least developed countries often do not have access to or benefit from the recent progress made in forecasting techniques, or from suitable training targeted to enable them to efficiently access and use the products available from the WMO operational centres. Nowcasting is particularly important and gaps in infrastructure and training limit capabilities;

3.4 The WMO's Severe Weather Forecasting Demonstration Project (SWFDP) has successfully demonstrated the application of the '*Cascading Forecasting Process'* in which products and new technical capabilities are moved from global to regional and then national centres so as to strengthen the capacity of NMHSs in developing and least developed countries. As a result, this Project has improved the lead-time and reliability for alerts of high-impact hydro-meteorological events leading to demonstrable protection of life.

4. The Workshop participants acknowledged:

4.1 The need for effective strategies for building climate resilience and mitigating extreme hydro-meteorological hazards;

4.2 That in response to the growing risk of meteorological and hydrological hazards, the World Bank, GFDRR and other donor agencies have recognized the importance of improving NMHSs in developing countries, including support for the modernization of NMHSs within the wider regional and global context;

4.3 That in many instances building climate resilience and mitigating some weather events and extremes is through capacity development and investment in the modernization of NMHSs so as to enable them to provide more timely and useful early warnings;

4.4 That capacity development is a high-priority for WMO, and its key planning documents call for strengthening global, regional and sub-regional mechanisms through effective partnerships, such as those established through the '*Cascading Forecasting Process*' and managed by regional frameworks (consisting of boards with representatives from global, regional and national centres);

4.5 That strengthening and sustaining the '*Cascading Forecasting Process'*, especially the regional centres, and their linkages to national centres in their respective regions, would sustain and increase the benefits of other investments in the NMHSs of developing and least developed countries.

5. Recommendations to increase NMHSs' capacity

The Workshop participants:

5.1 *Urged* the WMO to consolidate the Demonstration Projects into sustainable operational services and transition the SWFDP activities to become a fully supported global programme whose task would be to coordinate, lead and help further develop the '*Cascading Forecasting Process*' world-wide, thereby providing access to high quality analysis and forecasts for least developed and developing countries. This programme would include support for a Programme Office, as part of the Data-processing and Forecasting System (DPFS) unit, with adequate resourcing.

5.2 *Urged,* that as part of the SWFDP, consideration be given by the WMO to collecting and conveying the requirements for the Basic Systems at national level, but within a regional framework, to address those aspects related to increasing Members' capacity to manage the risks associated with hydro-meteorological hazards. Continued investment in and strengthening of the national observation and data networks is critical to the success of the programme.

5.3 *Encouraged* a coordinated approach for donor investment targetting a group of like-countries (i.e. a five year strategy for implementation of the '*Cascading Forecasting Process*' within a sub-region), including funding to sustain regional frameworks (that improves regional monitoring, regional exchange of hydro-meteorological data and information, training, regional operations through a regional centre and support by advanced centres, all for the common benefit of individual participating countries), which improves on sustainability and sharing of related scientific and technological investments and outcomes, and the harmonizing of warnings across national borders.

5.4 *Encouraged* further and more intensive engagement of the donor community in mobilization of long-term financial resources to support sustainable operations of the '*Cascading Forecasting Process'*, especially NMHSs and regional centres, and the Programme Office functions, that would contribute to mitigation of risks of natural hazards, help adaptation to climate change and facilitate further economic development.

5.5 *Suggested* that the '*Cascading Forecast Process*' exploited in the SWFDP establish synergy with the Flash Flood Guidance System, and with the RCOFs for long-range forecasting.

The Workshop further recommended:

5.6 That a meeting of potential donors with representatives of the global, regional and national centres involved in the SWFDP be convened to further develop the details of an initiative that builds on the lessons learnt and identifies the optimum way to "scale up" the concept.

5.7 That from early stages of implementation, strategic coordinating frameworks, such as AMCOMET in Africa, and relevant groups within regional economic communities are engaged to ensure effective project oversight and sustainability.

5.8 That under the guidance -of the Steering Group and management by the regional project teams, and overall coordination by the Programme Office, the development of pilot(s) to be financed by donor agencies, would include:

a. Sustaining and strengthening existing Regional Specialized Meteorological Centres (RSMCs) to create a fully functional regional centres aimed at regional integration of hydro-meteorological forecasting guidance;

b. Expanding the role of relevant RSMCs with activity specialization in Tropical Cyclones involved in the pilot(s) into RSMCs with activity specialization in forecasting hazardous hydro-meteorological phenomena;

c. Ensuring RSMC support for the '*Cascading Forecasting Process*' in all areas, consistent with the evolution of the GDPFS.

These pilots would also incorporate the support provided by global centres and the establishment of warning systems at the national level, as well as Programme Office functions and management.

5.9 Development of pilot(s) will also include a cost-benefit assessment of the *'Cascading Forecasting Process'* in support of a group of like-countries versus single-country investment, including sustainability issues.

5.10 That as a part of the each project development plan there would be the project risk assessment, and establishment of metrics to measure success of the projects' implementation.

6. References

Workshop documents are available at:
http://www.wmo.int/pages/prog/www/swfdp/Meetings/WK-SNMS-RGC.html

Workshop presentations are available at:
ftp://ftp.wmo.int/Documents/PublicWeb/www/swfdp/WK-SNMS-RGC/Presentations/

A Workshop to Assist in: Sustaining National Meteorological Services – Strengthening WMO Regional and Global Centres

Workshop Report

1. INTRODUCTION

1.1 The Workshop to assist in Sustaining National Meteorological Services – Strengthening WMO Regional and Global Centres, convened by the World Bank/GFDRR, World Meteorological Organization (WMO) and the US National Weather Service, was attended by Heads of Meteorological Services and Permanent Representatives of Countries with the World Meteorological Organization (WMO), or their appointed representatives, representatives of the World Bank, GFDRR Secretariat and other Donor Agencies, and the WMO Secretariat, and was held in Washington DC, U.S.A., 18 to 20 June 2013. List of participants is given in Annex I.

2. PROCESS AND ACTIVITIES

2.1 Workshop Steering Committee

2.1.1 Based on interest at side meeting of the sixty-fourth session of the WMO Executive Council, which took place on 26 June 2012, and subsequent discussions with participants, the following countries and institutions expressed interest in participating in a Workshop Steering Committee: Australia, Canada, China, European Centre for Medium range Weather Forecasts (ECMWF), Germany, India, Mexico, Russia, South Africa, United Kingdom, and United States. Others were invited to provide geographical and institutional balance.

2.1.2 Terms of Reference (ToR) of the Workshop Steering Committee include:

- Solicit reaction to a concept note that was prepared in end 2012 by the organizers;
- Develop discussion papers that form the working basis of the Workshop;
- Prepare a provisional list of participants; and,
- Prepare the Workshop Programme.

2.1.3 Following the formal invitation by the organizers (the World Bank/GFDRR, WMO and the US/NWS) in November 2012, the Workshop Steering Committee membership is as follows:

- Jerry Lengoasa (WMO)
- Vladimir Tsirkunov (World Bank)
- Andrew Tupper (Australia)
- Jianjie Wang (China)
- Yea Raj (India)
- Yuki Honda (Japan)
- Linda Makuleni (South Africa)
- Ken Milne (UK, WMO Commission for Basic Systems (CBS))
- Mikhail Kovtunenko (Russia)
- Jordan Alpert (US)

2.1.4 Noting that the Steering Committee chairperson should represent one of the organizations involved, it was proposed and agreed that WMO should chair the Steering Committee. The Workshop facilitator should be an independent person (i.e. someone without any vested interest), and therefore it was proposed and agreed that Geoff Love would serve as Workshop facilitator.

2.1.5 The Steering Committee met virtually via email and three conference calls (on 7 February, 21 May, and 5 June 2013), and a physical meeting at the end of the Workshop, on 20 June 2013. Participants in the conference calls and physical meeting (on behalf of the Steering Committee members) include: Andrew Tupper (Australia), Jianjie Wang and Qingliang Zhou (China), Yea Raj (India), Yuki Honda (Japan), Eugene Poolman (South Africa), Ken Mylne (UK, CBS), Dmitriy Kiktev (Russia), Jordan Alpert (US), Dan Beardsley (US), Martin Steinson (US), Alice Soares (WMO), Peter Chen (WMO), and David Rogers (World Bank).

2.2 Workshop structure

2.2.1 The first conference call (on 7 February 2013) agreed on the overall goal of the Workshop as follows: "*The ultimate objective of the workshop is to develop a compelling plan for investment in the cascading forecasting process demonstrated by WMO through the Severe Weather Forecasting Demonstration Project (SWFDP), i.e. in strengthening/sustaining WMO's operational centres (especially regional centres – the Regional Specialized Meteorological Centres (RSMCs) and the Regional Climate Centres (RCCs), and their linkages to global as well as to national centres in their respective geographical regions) to sustain and increase the capacity of NMHSs to deliver weather, climate and hydrological forecasting and warning services. Target audience of the outcomes of the workshop is the entire WMO community, and the workshop paper (main product) would be used to make contact with donor agencies.*" It also agreed that four working papers would be prepared as inputs to the Workshop, addressing the following aspects:

(a) Detailed description and future directions of the SWFDP towards strengthening/sustaining WMO's operational centres;

(b) Anticipated advances in NWP, and the growing technology gap in weather forecasting;

(c) Role of Regional Specialized Meteorological Centres (RSMCs) and service benefits to National Meteorological and Hydrological Services (NMHSs) in developing and least developed countries;

(d) Investing in the "*Cascading Forecasting Process*" in modernizing NMHSs.

2.2.2 The second conference call (on 21 May 2013) reviewed the above-mentioned papers and initiated the development of the Workshop Programme. The third conference call (on 5 June 2013) finalized the Workshop Programme, including key speakers and the panellists (detailed programme provided in Annex II). The Workshop Programme includes four sessions, as follows:

(a) <u>Overview of global system and impact of advances in NWP on NMHSs' operations</u>
- Workshop Paper 1 – Anticipated advances in NWP, and the growing technology gap in weather forecasting, by Ken Mylne (WMO/CBS Data-processing and Forecasting Systems (DPFS) chairperson);
- Leverage the scientific developments in NWP on what can result in significant impacts on safety (life, livelihoods and properties), health, environment and economy, by William Lapenta (NOAA National Centers for Environmental Prediction (NCEP));
- Needs and requirements by NMHSs in developing countries in fulfilling their mandate of providing weather forecasts, warnings and other information for public welfare, and for the protection of life and property; and their interactions with regional centres, by Amit Avikash Singh (Fiji);
- Panel Discussion 1 – aim is to understand how the GDPFS could better mitigate the growing technology gap in weather forecasting; how do we bridge the gap between those

who have the capacity and knowledge and those who don't? Panellists: Jerry Lengoasa (WMO), Ken Mylne (CBS/DPFS), William Lapenta (WMO Working Group on Numerical Experimentation (WGNE)), and Amit Singh (Fiji).

(b) Strengthening and sustaining WMO operational centres

- Workshop Paper 2 – SWFDP and its future directions towards strengthening/sustaining WMO's operational centres, Alice Soares (WMO);
- Panel Discussion 2, followed by General Discussion – this focused on some of the challenges facing global and regional centres, and allowed short presentations from panellists on specific aspects related to SWFDP implementation. Panellists: Alice Soares (WMO), Rob Varley (UK global centre), Mark Majodina (RSMC Pretoria), Peter Kreft (RSMC Wellington).

(c) What NMHSs need from regional and global centres to serve better their national needs

- Invited presentations from developing countries' NMHSs on needs, by D.J.A. Weerawardena (Sri Lanka), Moisés Vicente Benessene (Meteorological Association of Southern Africa (MASA) and Mozambique), Michael Nkalubo (East African Community (EAC) and Uganda);
- Panel Discussion 3 – This focused on some of the issues presented in the previous sessions from developing countries NMHSs perspective. This touched on some of the broader issues of modernization needs, training and national financing of operations. Panellists: Hamza Kabelwa (Regional Forecast Support Centre (RFSC) Dar), D.J.A. Weerawardena (Sri Lanka), Moisés Vicente Benessene (MASA and Mozambique), Michael Nkalubo (EAC and Uganda);
- Workshop Paper 3 – SWFDP regional frameworks and their impact in Developing and Least Developed Countries, by Eugene Poolman (RSMC Pretoria);
- Panel Discussion 4 – Presentations and discussion from RSMCs of challenges and opportunities. Panellists: Eugene Poolman (RSMC Pretoria), Hamza Kabelwa (RFSC Dar), Peter Kreft (RSMC Wellington), YEA Raj (RSMC New Delhi), Pham Van Tan (RFSC Hanoi).

(d) Financing NMHSs and RSMCs

- Workshop Paper 4 – Financial implications and investment options to support regional frameworks, by David Rogers;
- Panel Discussion 5 – on way forward; panel discussed from different perspectives and from the current realities of RSMCs and support for developing countries, including actual costs. Panellists: Vladimir Tsirkunov (WB), Wayne Elliott (WMO), Tyrone Sutherland (Caribbean Meteorological Organization (CMO)), Dan Beardsley (NOAA National Weather Services (NWS)), Erik Hagemark (Norway).

3. OUTPUTS

3.1 Context

3.1.1 The provision of reliable, timely and accurate severe weather forecasts and warnings for the range of hydro-meteorological hazards is a global endeavour. It is an end-to-end process that involves the world-wide, realtime collection and exchange of weather observations, the processing of these observations to produce forecast projections and the conversion of the resulting data into products that can be used by trained meteorologists and hydrologists to prepare and disseminate forecasts and warnings. These forecasts and warnings must be prepared and then delivered so as to reach their intended audience in good time to enable effective decision-making, and to prompt those actions necessary to minimise loss of life, livelihoods, property and environmental assets that might otherwise result from the impending hazard.

3.1.2 While a number of National Meteorological and Hydrological Services (NMHSs) have very advanced capabilities to provide such services, there are a large number which have little or no such capability, mostly in developing or least developed countries. The aim of the Workshop was to consider efficient (cost-effective and sustainable) ways in which investment can build capacity in the NMHSs to enable them to provide a basic service giving effective warnings of severe weather and thus protecting life and property in their countries.

3.1.3 The Workshop did not seek to address all aspects of this end-to-end forecasting and warning process, but rather it was focused on the Severe Weather Forecasting Demonstration Project (SWFDP) which has already proven to provide a cost effective and practical method of strengthening NMHSs capacity and capability and is scalable.

3.2 Summary of the papers and panel discussions

3.2.1 The physical meeting of the Steering Committee held at the end of the Workshop, on 20 June 2013, agreed that the four workshop papers should be reviewed and revised to include relevant information from the presentations. The WMO and World Bank representatives were tasked to finalize the documents, and final versions are presented in Annexes III to VI to this report.

Workshop paper 1 – Anticipated advances in NWP, and the growing technology gap in weather forecasting

3.2.2 The advances in Numerical Weather Prediction (NWP) in the last decades have been tremendous: higher accuracy, higher resolution, longer lead-time, wider range of relevant applications. Consequently the emphasis in operational meteorology, hydrology, oceanography and climatology has shifted towards the implementation of increasingly sophisticated and diverse numerical models and applications, for an ever-increasing variety of users.

3.2.3 Foremost, the ever-increasing precision, reliability and lead-time provided by NWP systems have led to increasingly skilful weather forecasting over the recent decades and will become even more relevant in the future. NWP systems generally provide an accurate indication of developing extreme weather events, thereby being a very relevant component of routine and severe weather forecasting and warning programmes at NMHSs.

3.2.4 The capability among NMHSs in weather forecasting varies enormously. Advanced NMHSs are making best use of the dramatic development/progress being made in NWP (i.e. high refresh and high resolution modelling, use of Ensemble Prediction Systems (EPS) in early detection of severe weather events, convective-scale NWP, and severe weather impact modelling), and within the next 10-15 years, they will: (a) have non-hydrostatic global deterministic NWP at <5km resolutions; (b) global ensembles at sub-20km resolutions; and (c) embedded convective scale ensembles. All supported by sophisticated data assimilation systems which optimally utilise a large set of observing systems; both global and convective scale models/ensembles coupled to appropriate representations of relevant land and ocean processes; and driving (and increasingly coupled with) downstream impact models.

3.2.5 NMHSs of developing countries saw little progress due to limited budgets, failing infrastructure, inadequate guidance and expertise. A typical, small developing country (including Least Developed Countries (LDCs)) NMHS might have no or little NWP capability (i.e. usually experimental, low resolution – similar to today's global NWP, the NWP units are remote from the weather forecasting office, and no ingestion in the operational forecasting process). Thereby, there has been an increasing gap in the application of advanced technology (NWP, including EPS) in early warning systems (EWS) of NMHSs of developed and developing countries, including LDCs.

3.3 Panel discussion 1

3.3.1 Points raised in the panel discussion included:

- Developing countries need access to hourly data;
- Even the most advance global models do not handle tropical convection well;
- The public in developing countries generally does not have a good appreciation of the capabilities its national meteorological service;
- Governments of developing countries believe that outside forecast guidance is essential
- Man cannot be replaced by a machine in the forecast process;
- Developing countries need guidance on how to ingest local data (such as from a Doppler radar) into local models;
- Training is a key aspect for building the capacity at NMHSs;
- How do the WMO's technical commissions fit into this – do they need a review of re-invigoration?
- Can we share the regional responsibility among different centres?
- How do we keep weather and climate forecasts synchronised?
- The meteorological community cannot afford parallel systems (e.g. RCCs competing with RSMCs) – so these need to be co-located wherever possible;
- Seamless forecasting and warning systems would have advantages
- Synergies of the SWFDP with the Flash Flood Guidance System (FFGS);
- How do we coordinate sustainable donor investment; and,
- Effective severe weather forecasting and warning services builds resilience to climate change.

3.4 Workshop paper 2 – SWFDP and its future directions

3.4.1 In essence the Severe Weather Forecasting Demonstration Project (SWFDP) is a process whereby scientists from global and regional centres work with severe weather forecasters at the national level to identify services that would assist the national disaster risk reduction efforts, and that can be implemented almost immediately by tailoring numerical weather prediction model outputs that exist in the most advanced centres, by making them routinely available at the national level. The SWFDP employs a '*Cascading Forecasting Process'* whereby outputs from forecast systems existing in advanced global centres are cascaded to NMHSs through a designated regional centre which provides regular operational interpretation and guidance on severe weather. This allows forecasters at the NMHSs to focus limited resources on considering the impact of this weather in their country and on service delivery and communicating the message to users in their countries to ensure effective protective responses. An SWFDP project includes building capacity of national meteorologists in the application of the cascaded information and in the development of services to meet the disaster management communities needs, and opportunities are taken to involve disaster managers in preparation of the user requirements.

3.4.2 Outcomes of the SWFDP include:

- improved quality of national forecast and warning services;
- the development of operational partnerships between meteorologists, hydrologists and disaster managers,
- the development of operational partnerships between global, regional and national centres,
- enhanced visibility and reputation of the NMHSs involved; and,
- increased forecaster confidence and capability.

3.4.3 These positive outcomes have been delivered at relatively low cost and appear to be sustainable provided that:

- global centres remain able to support the provision of relevant products on a long-term operational basis;
- regional centres are able to maintain an interpretation and guidance service on a similar

long-term operational basis; and,

- regular capacity building and training can be maintained for new forecasters along with refresher training for experienced forecasters in the participating NMHSs.

3.4.4 Future directions include the development of the '*Cascading Forecasting Process*' world-wide, thereby providing access to high quality analysis and forecasts of hydro-meteorological and sector specific (e.g. agriculture, marine, etc.) hazardous events beyond day-5, by more than 100 least developed and developing countries, in all WMO regions.

3.4.5 Each SWFDP regional project development activities include: (a) implementing regional guidance and national warning systems; (b) implementing tools and verification methodologies; (c) training (approximately 50% of total costs); (d) web development; (e) regional expert consultancy; and (d) WMO Secretariat functions (Programme Office). Depending of the region, the resources required for regional SWFDP projects (i.e. establishment of regional frameworks) would be:

(a) USD 2.7M (3 years to sustain and strengthen an existing RSMC to create a fully functional regional centres aimed at regional integration of hydro-meteorological forecasting guidance. This also includes the support provided by global centres and the establishment of warning systems at the national level);

(b) USD 3.5M (4 years to expand the role of relevant RSMCs with activity specialization in Tropical Cyclones involved in the pilot(s) into RSMCs with activity specialization in forecasting hazardous hydro-meteorological phenomena. This also includes the support provided by global centres and the establishment of warning systems at the national level);

(c) USD 4.2M (5 years to ensure RSMC support for the '*Cascading Forecasting Process*' in all areas, consistent with the evolution of the WMO Global Data-processing and Forecasting System (GDPFS). This also includes the support provided by global centres and the establishment of warning systems at the national level).

3.4.6 In addition, Programme Office functions and management require ~USD 500 k annually for the period of a regional SWFDP project. Early engagement of strategic coordinating frameworks, such as relevant groups within regional economic communities (e.g. MASA, EAC), has contributed to effective project oversight and sustainability.

3.5 Panel discussion 2

3.5.1 Points raised in the discussion included:

- The cost effectiveness of SWFDP was emphasized and the strategy for improving severe weather services in a group of African countries (Kenya, Tanzania, Rwanda, Burundi, South Sudan, Uganda and Ethiopia) based upon it, was outlined;
- SWFDP is in some ways an unfortunate acronym – it needs a better name;
- Meteorologists' and forecasters' communication skills need enhancing in many countries to be able to use the language of key users rather than in traditional more 'technical' terms;
- Establishing working relationships between centres (within the region and between those in the region and in developed country global centres) is crucial;
- The key is to deliver benefits to users of severe weather services;
- Making effective use of the rapidly improving global models is a challenge for countries not operating the models;
- The availability of free weather services via the Internet sets a standard that must be beaten by national meteorological services if they are to be seen to "add value";
- SWFDP must show societal benefits if it is to be sustainable;
- SWFDP has led to improved forecasts;

- SWFDP has assisted in reducing the gap between developed and developing country capability;
- SWFDP has led to better linkages between the national meteorological service and disaster management community;
- Not all countries have been fully successful in applying the SWFDP, and therefore national plans to strengthen their capabilities have been developed and implemented, resources permitting;
- Training is a key element of the SWFDP;
- The cascading process of moving products from a global centre to a regional centre and then on to a range of national centres is an effective one and should be maintained and reinforced;
- The ability of small RSMCs to support SWFDP is very limited, and therefore a plan to strengthen or support these would be a useful activity;
- Need a regional planning framework that is consistent across countries so that donors don't promote "ad hoc" developments;
- Proper implementation of the "cascading process" means that every national meteorological service does not need to run a numerical model. The alternative is excessive investment on many regional models whose output is, at best, far inferior to products from the high resolution global models; and,
- There needs to be in place a communication strategy between donors and developed and developing countries that explains the costs and benefits of an expanded SWFDP and its implementation process.

3.6 National presentation by Sri Lanka

3.6.1 A review of the capabilities of the Sri Lankan Meteorological Department (SLMD) and the weather challenges it faces. This was followed by a review of some of the more pressing requirements of the SLMD that could be met through a process such as the SWFDP, which included:

- Collaborative research with developed world global centres and the sharing of their research out puts;
- Assistance with capacity building; and,
- Assistance in running the WRF model within the Department.

3.7 National presentation by SADC / MASA

3.7.1 The Meteorological Master Plan of the Southern Africa Development Community (SADC) and the MASA Strategy address challenges of demand for timely and quality meteorological services by, among other things, by:

- Facilitating regional cooperation;
- Strengthening national capacities; and,
- Ensuring compliance with international commitments.

3.7.2 With regard to climate services in the SADC area these are constrained by:

- Insufficient personnel; and,
- Inadequate infrastructure (Office &Equipment).

3.7.3 With regard to the calibration of meteorological instrumentation within the SADC area this is constrained by a Regional Instruments Calibration Centre that is not fully operational due to:

- Aged calibration tools; and
- Inadequate trained personnel.

3.7.4 Furthermore, Regional Training Centres in the SADC area do not meet demand largely due to:

- Inadequate trained personnel; and,
- Inadequate infrastructure (office & equipment).

3.7.5 In the medium- to long-term, improvements within the area will depend, among other things, on improvements in:

- The availability of resources both financial and human;
- Member States and SADC giving the sector high priority in their respective plans;
- development partners/stakeholders being supportive in relevant meteorological projects and activities;
- NMSs and regional institutions fulfilling their respective mandates; and,
- collaboration of SADC, the WMO and the MASA is considered critical for the success.

3.7.6 A summary of the financial needs of the SADC area, in US$, for the period 2012-2027 is given (below) in Table 1.

Table 1

No	Strategic goal/interventions	Amount required 2012 – 2027 US$
1	Strengthening of observational network	**85,629,000**
2	Improvement of Meteorological Telecommunications	**4,230,000**
3	Improvement of level of technical capacities (DPFS, DM , Training)	**8,440,000**
4	Improving the understanding of economic benefits and use of climate information and products	**2,155,000**
5	Strengthening institutional capacity of the NMSs	**10,770,000**
6	Enhancing capacity of regional units (CSC, MASA, and RMTCs, RICC)	**8,970,000**
7	**TOTAL**	**120,194,000**

3.8 National Presentation by Mozambique

3.8.1 The base of Mozambique's economy is agriculture (80% of population is dependent upon agriculture), which is very sensitive to floods, drought, tropical cyclones, fires, erosion, etc. Mozambique is a highly vulnerable country because of its location in the tropics, because it is downstream of nine major rivers and because it has a very long coast line. Mozambique is also vulnerable because more than 50% of its population lives below the poverty line and so do not have coping capacity to mitigate, or overcome the impacts of, natural disasters.

3.8.2 The implementation of SWFDP, from 2006, allowed the Mozambique Meteorological Service achieve improvement in its:

- Ability to forecast severe weather events;
- Five- day lead-time on warnings when needed;
- Interaction with Disaster Management and Civil Protection Authorities (DMCPAs) and Media;
- Skill level of the operational forecasters in the use of NWP products from Global Centres through training provided by regional centres and sharing of experience among forecasters;
- Ability to provide feedback on NWP, EPS, guidance

3.8.3 As a result of outreach activities and public education through the media and exhibitions, public awareness of the role, capability and important contributions of the Mozambique Meteorological Service increased substantially.

3.8.4 Challenges faced by the Mozambique Meteorological Service include:

- The capability and reliability of the observing network and telecommunication system;
- Effective use of NWP products in graphical format (Visualization tool);
- Reliable internet service;
- Training opportunity for all forecasters (roving and/or training desk);
- Nowcasting (e.g. severe thunderstorm), in order to avoid case like last rainy season where 39 of 117 deaths were caused by lightning stroke;
- Improvement of awareness campaign (drill excise) before rainy season;
- Strengthening the interaction with media:
- Achieving continuous learning and capacity building by forecasters at national level; and,
- Verification of warnings and forecasts.

3.9 National presentation by Uganda and EAC

3.9.1 Dramatic developments in weather forecasting science over the past few decades have been realized through advances in monitoring and Numerical Weather Prediction (NWP) as well as Ensemble Prediction Systems (EPS), leading to improved alerting of weather hazards at increased lead times of warnings. Unfortunately most National Meteorological and Hydrological Services (NMHSs), especially in developing and least developed countries, have seen little progress due to limited budgets and investments in weather monitoring infrastructure, low societal perception of the importance of weather forecasting to socio-economic development and the increasing gap in application of advanced technology (e.g. NWP, EPS) in early warnings, between developing countries and the developed ones.

3.9.2 Since 2010, at the commencement of the SWFDP in East Africa capacity development initiatives have:

- Enabled the annual training of core group of operational forecasters from the region on severe weather forecasting and warning services in support of disaster risk reduction, and fishing and farming communities;

- Uganda has benefited from special training of all operational forecasters in preparation for mobile weather alert pilot with funding from WMO and training experts from the UK Met Office; and,
- Forecasters from Uganda, Kenya, Tanzania, Ethiopia and Rwanda benefited from the meteorological training course on ECMWF Products. This program is supported by WMO.

3.9.3 The key challenges faced in the East Africa Region, as related to meteorological services, were identified as being:

- Sustainability and roll-out of the SWFDP project across the entire region;
- Internet speeds in the region is still low and downloads of guidance products is sometimes difficult;
- Sparse observation network limits the accuracy and reliability of forecasts; and,
- Technical capacity, in terms of human resource and computing facilities, is inadequate.

3.9.4 In order to overcome these (and other) deficiencies, the EAC Heads of Meteorological Services have made the following recommendations:

- The SWFDP should be sustained and strengthened as it moves from demonstration to operational stage. This calls for support from all partners;
- Additional resources and commitment is needed at regional and national levels to ensure EAC leadership in transforming the East African SWFDP into an integral part of the forecasting and warning services of NMHSs in the region.

4. Workshop paper 3 – SWFDP regional frameworks and their impact in developing and least development countries

4.1 It was emphasized that the outcomes from successful implementation of the SWFDP include:

- Enhanced capability for NMHSs to forecast severe weather and issue warnings at national level, including improved accuracy and longer lead times;
- Enhanced access to global and regional nowcasting products for very short period forecasting;
- Established warning processes agreed with national disaster management and civil protection authorities, along with planned responses for protection of lives and property;
- Established forecast processes and Quality Management Systems (QMS), and strengthened forecast capabilities in support of other users sectors at the national level;
- Raised awareness of the value of NMHSs with national governments and their agencies, leading to greater national support and investment, which in turn improved supply of observations and feedback into the GDPFS system; and,
- Reduced loss of life and damage to property with contributions to the Millennium Development Goals of eradicating extreme poverty and reducing child mortality.

4.2 It was noted that the SWFDP approach follows the Millennium Development Goal of a Global Partnership for Development and contributes directly to disaster risk reduction and climate change adaptation.

4.3 The focus on sustainable, active regional frameworks within SWFDP was given emphasis through noting that NMHSs in a geographical region (i.e. neighbouring countries) typically need similar (or the same) products and that there are efficiency gains in coordinating their requirements (collective needs). It was noted that a regional framework provides a forum for sharing expertise and experiences among forecasters, including on how to deal and liaise with intra-government communication, emergency services, the media, etc. A regional framework also provides a coordinated, harmonized and consistent approach to address hazards (including high impact weather situations in a geographical region), as well as a continuous learning environment. At the same time, observational data are typically more widely shared among NMHSs within a regional economic body (directed by regional data policies), which, in turn, leads to regional forecast improvements.

4.4 It was emphasized the critical role of the RSMCs within the regional frameworks of the SWFDP. The role and functions of these centres as focal point and central hub for all information exchange between the various global, regional and national partners have been essential, including the production of coordinated forecast guidance. The experience acquired with the SWFDP is actually been used to redefine the role of a regional centre with geographical specialization, to become an RSMC with activity specialization in Forecasting Hydro-Meteorological Hazardous Phenomena, which provides forecasting guidance to NMHSs in a geographical region, in support of their national severe weather warnings programmes. It was noted that NMHSs hosting RSMCs within the regional frameworks of the SWFDP would require additional investment (e.g. in the case of the South Africa Weather Service (SAWS), it requires ~USD 60K to run its RSMC Pretoria).

4.5 The success of the SWFDP is in part because it takes a holistic, regional driven approach, i.e. through improving the entire end-to-end chain from production to the delivery of warning services to the users, through the "Cascading Forecasting Process". Coordination with the Regional Programme (RP) – Regional Offices, including the Programme for LDCs, Education and Training Programme (ETR), Voluntary Cooperation Programme (VCP), and the Resource Mobilization Office (RMO), in the planning and implementation of regional projects has been (is) critical to ensure that desired, sustainable and relevant outcomes are achievable.

4.6 The SWFDP continues to experience important benefits and significant growth, with five regional projects, either underway or under development (Southern Africa, Southwest Pacific, Eastern Africa, Southeast Asia, and Bay of Bengal/South Asia). It was noted that four of the five SWFDP regional projects include NMHSs of countries that are within the footprint of Tropical Cyclone basins. Synergies (including specific collaboration and joint development work) are being established with the Tropical Cyclone Programme (TCP), and its Regional Bodies. Coordination with other WMO Technical Commissions and Programmes that address applications of meteorology is associated with the nature (i.e. the main focus) of each SWFDP regional project. SWFDP contributes to the WMO Quality Management Framework (QMF) through supporting efforts in NMHSs in their implementation of Quality Management Systems (QMS).

4.6 Panel discussion 3

4.6.1 Points raised in the discussion included:

- Concern about the reliability of the Internet given that it is vital for SWFDP, and so the need access to local observations and small scale, national numerical weather prediction capability was stressed by developing countries;
- Verification of products is important;
- WMO Information System (WIS) will be the preferred product delivery mechanism, which includes alternative methods of disseminating NWP products and the SWFDP web pages have been explored (e.g. via EumetCast in Africa, EMWIN in the South Pacific);
- Supports the strengthening of the cascading process;
- A regional strategy for modelling in Africa to make most efficient use of resources was advocated;
- Need a sub-seasonal forecast capability along with a verification system;
- For sustainability of whatever follows SWFDP there needs to be in place a continuous training program; and,
- Flash flood forecasting might be able to work in a cascading process environment but for this to have a chance of working countries need to be willing to exchange river water level data and still there may be problems with response time.

5. Workshop paper 4 – Investing in the Cascading Forecasting Process in Modernizing NMHSs

5.1 In collaboration with the World Meteorological Organization (WMO), the World Bank and development partners are focusing efforts to modernize entire NMHSs – through investments directed towards institutional strengthening, improving observation networks and forecasting, and strengthening service delivery.

5.2 Efforts in the past have focused almost exclusively on national investments; however, the WMO Severe Weather Forecasting Demonstration Project (SWFDP) has shown that the lead time and reliability of high impact weather warnings are effectively improved through a three-layer cascading forecasting process that operationally links NMHSs with WMO regional and global centres. This approach requires broader investment, particularly to support regional frameworks of weather forecasting and training.

5.3 By relying on the WMO Regional Specialized Meteorological Centres (RSMCs) for numerical weather prediction (NWP) support, NMHSs can free up resources to focus more on observations, impact forecasts and service delivery. This enables NMHSs with relatively small numbers of staff and limited resources to achieve a higher level of service delivery. Incorporating support for the cascading forecasting process evinced by the SWFDP in NMHSs modernization efforts is cost-effective and can contribute to the achievement of long-term sustainability of NMHSs.

5.4 Several pilots, building on the existing SWFDP activities were proposed. The aims of the pilots were to:

- build greater synergy between NMHSs, RSMCs and global production centres; and,
- incorporate the approach into NMHSs modernization programs financed by the development community.

5.5 It was noted that funding for the operational management of the system of regional centres is also required however such funding is beyond the mandate of donors. It was also noted that this is associated with the commitment of the NMHS who hosts the regional centre.

5.6 Panel discussion 4

5.6.1 Points raised in the discussion included:

- Hard benefit/cost evidence will help to scale up investment in the expansion of the SWFDP to a sustainable program;
- We need to collect and document “success stories” of the SWFDP so as to support further investment in the work;

- We need better coordination between donors and users and so the next step in the process should be a joint meeting between donors and stakeholders in the SWFDP;
- There needs to be more focus on quality management within the SWFDP (this would greatly assist in the acquisition of benefit/cost information);
- Should the management of SWFDP within a region adopt something along the lines of the ECMWF management model?
- The resource requirements of the cascading process for small RSMCs in SWFDP can be very onerous;
- Building "the better National Meteorological Service" is at least a five year program and maybe a ten year program with a phase 1 and a phase 2 and requires the commitment of, and engagement by, the national government and regional economic bodies;
- Are the expressions "SWFDP" and "cascading process" getting in the way of dealing with the issue of strengthening the regional and national centres of the developing world?

5.7 Panel discussion 5

5.7.1 Points raised in the discussion included:

- Often there is no plan at a national level to upgrade the national meteorological service, so this makes it hard to participate in regional planning and also leads to ad hoc acceptance of any donor offers for contributions to modernisation;
- Many national meteorological services do not have underpinning legislation that defines their mandate, particularly in the area of severe weather forecasting which, in turn, limits their ability to get national government engagement in tackling the modernisation issues;
- The World Bank is limited in its ability to support regional activities. Rather, its efforts are predominantly country focused. Still there is a scope for increasing regional activities particularly in combination with supporting national investment in NMHSs strengthening. Government of Norway has been supporting the SWFDP regional projects in Africa;
- There is a need to put in place a process that builds on the pilots that reflects a scaling up of the successes of SWFDP in a sustainable way. There must be a strategy built into the implementation plans that enables the "mainstreaming" of these pilots if they are successful;
- The funding of these pilots should be a part of the global climate change adaptation response;
- The pilots need to make the linkages between their outputs and the benefits they provide to society;
- We do not need more RSMCs, rather we need to strengthen the ones we have;
- NMHSs ideally should work with WMO and regional economic bodies;
- There is a need for a coordinated approach for donor investment;
- Sustainability of services and the building of partnerships is critical;
- If the upscaling is to be a success, we may need to have in place agreements that access to global products will be available through the RSMCs;
- The heads of national meteorological services need to be committed to the next steps along with their governments (particularly Departments of Finance) if it is to be successful.

6. AGREEMENTS REACHED

6.1 Participants of the Workshop recognized that:

(a) Hydro-meteorological hazards have major implications for countries and affected individuals in terms of loss of life and livelihoods, and damage to property and ecosystems;

(b) There are important inter-relationships between hydro-meteorological hazards, high risk levels and substantial societal impacts in many countries, most notably (but not only) the developing and least developed countries. There is a body of evidence that these effects are being exacerbated by a number of factors such as increasing population and environmental degradation in high risk areas and as a result of climate change;

(c) There is a crucial role to be played in improving severe weather forecasts and warnings by all stakeholders, including the UN agencies, and in particular the WMO and its Members, the World Bank, GFDRR and other donor agencies;

(d) Many NMHSs in developing and least developed countries lack infrastructural, technical, human and institutional capacities to provide provide high-quality meteorological services;

(e) There is a significant and growing donor interest in assisting least developed and developing countries in increasing their capability to manage the risks associated with hydro-meteorological hazards, but it is becoming apparent that investments in modernizing NMHSs often lack the necessary long-term sustainability strategies and coordinated approach at global, regional and national levels, to build from.

6.2 The Workshop participants noted that:

(a) There has been a great deal of scientific progress, such as, ever-increasing precision, reliability and lead-time in forecasting hydro-meteorological hazardous phenomena using numerical weather prediction and related systems, and in developing and implementing improved early warning systems using modern communications and improved service delivery practices;

(b) While the accuracy of computer-based systems has increased, the role of the forecaster has evolved to include, as a critical function, interpretation of computer output in terms of the impact of the forecast weather on their community, and communicating these forecasts and warnings in a way that will support decision makers at all levels of their society;

(c) Forecasters in developing and least developed countries often do not have access to or benefit from the recent progress made in forecasting techniques, or from suitable training targeted to enable them to efficiently access and use the products available from the WMO operational centres. Nowcasting is particularly important and gaps in infrastructure and training limit capabilities;

(d) The WMO's Severe Weather Forecasting Demonstration Project (SWFDP) has successfully demonstrated the application of the '*Cascading Forecasting Process'* in which products and new technical capabilities are moved from global to regional and then national centres so as to strengthen the capacity of NMHSs in developing and least developed countries. As a result, this Project has improved the lead-time and reliability for alerts of high-impact hydro-meteorological events leading to demonstrable protection of life.

6.3 The Workshop participants acknowledged:

(a) The need for effective strategies for building climate resilience and mitigating extreme hydro-meteorological hazards;

(b) That in response to the growing risk of meteorological and hydrological hazards, the World Bank, GFDRR and other donor agencies have recognized the importance of improving NMHSs in developing countries, including support for the modernization of NMHSs within the wider regional and global context;

(c) That in many instances building climate resilience and mitigating some weather events and extremes is through capacity development and investment in the modernization of NMHSs so as to enable them to provide more timely and useful early warnings;

(d) That capacity development is a high-priority for WMO, and its key planning documents call for strengthening global, regional and sub-regional mechanisms through effective partnerships, such as those established through the '*Cascading Forecasting Process*' and managed by regional frameworks (consisting of boards with representatives from global, regional and national centres);

(e) That strengthening and sustaining the '*Cascading Forecasting Process'*, especially the regional centres, and their linkages to national centres in their respective regions, would sustain and increase the benefits of other investments in the NMHSs of developing and least developed countries.

6.4 The Workshop participants:

(a) *Urged* the WMO to consolidate the Demonstration Projects into sustainable operational services and transition the SWFDP activities to become a fully supported global programme whose task would be to coordinate, lead and help further develop the '*Cascading Forecasting Process*' world-wide, thereby providing access to high quality analysis and forecasts for least developed and developing countries. This programme would include support for a Programme Office, as part of the Data-processing and Forecasting System (DPFS) unit, with adequate resourcing.

(b) *Urged,* that as part of the SWFDP, consideration be given by the WMO to collecting and conveying the requirements for the Basic Systems at national level, but within a regional framework, to address those aspects related to increasing Members' capacity to manage the risks associated with hydro-meteorological hazards. Continued investment in and strengthening of the national observation and data networks is critical to the success of the programme.

(c) *Encouraged* a coordinated approach for donor investment targetting a group of like-countries (i.e. a five year strategy for implementation of the '*Cascading Forecasting Process*' within a sub-region), including funding to sustain regional frameworks (that improves regional monitoring, regional exchange of hydro-meteorological data and information, training, regional operations through a regional centre and support by advanced centres, all for the common benefit of individual participating countries), which improves on sustainability and sharing of related scientific and technological investments and outcomes, and the harmonizing of warnings across national borders.

(d) *Encouraged* further and more intensive engagement of the donor community in mobilization of long-term financial resources to support sustainable operations of the '*Cascading Forecasting Process'*, especially NMHSs and regional centres, and the Programme Office functions, that would contribute to mitigation of risks of natural hazards, help adaptation to climate change and facilitate further economic development.

(e) *Suggested* that the '*Cascading Forecast Process*' exploited in the SWFDP establish synergy with the Flash Flood Guidance System, and with the RCOFs for long-range forecasting.

(f) *Recommended* that from early stages of implementation, strategic coordinating frameworks, such as AMCOMET in Africa, and relevant groups within regional economic communities are engaged to ensure effective project oversight and sustainability.

7. NEXT STEPS

7.1 The Workshop recommended:

(a) That a meeting of potential donors with representatives of the global, regional and national centres involved in the SWFDP be convened to further develop the details of an initiative that builds on the lessons learnt and identifies the optimum way to "scale up" the concept. This meeting is planned for first half 2014.

(b) That under the guidance of the Steering Group and management by the regional project teams, and overall coordination by the Programme Office, the development of pilot(s) to be financed by donor agencies, would include:

1. Sustaining and strengthening existing Regional Specialized Meteorological Centres (RSMCs) to create a fully functional regional centres aimed at regional integration of hydro-meteorological forecasting guidance;

2. Expanding the role of relevant RSMCs with activity specialization in Tropical Cyclones involved in the pilot(s) into RSMCs with activity specialization in forecasting hazardous hydro-meteorological phenomena;

3. Ensuring RSMC support for the '*Cascading Forecasting Process*' in all areas, consistent with the evolution of the GDPFS.

These pilots would also incorporate the support provided by global centres and the establishment of warning systems at the national level, as well as Programme Office functions and management.

(c) Development of pilot(s) will also include a cost-benefit assessment of the *'Cascading Forecasting Process'* in support of a group of like-countries versus single-country investment, including sustainability issues.

(d) That as a part of the each project development plan there would be the project risk assessment, and establishment of metrics to measure success of the projects' implementation.

7.2 A meeting of the Steering Group for the SWFDP will be held in Q4 2013 to address the outcomes of this Workshop, and identify and develop the pilot project(s) proposals. Donor agencies (primarily, the DFID, World Bank/GFDRR and regional offices, Government of Norway, USAid, AUSAid and EU) will be invited to participate in part of this meeting.

8. REFERENCES

Workshop documents are available at:
http://www.wmo.int/pages/prog/www/swfdp/Meetings/WK-SNMS-RGC.html

Workshop presentations are available at:
ftp://ftp.wmo.int/Documents/PublicWeb/www/swfdp/WK-SNMS-RGC/Presentations/

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Annex II

Programme

Tuesday, 18th June 2013			
DAY 1			
	Opening remarks		
0900-0930	On behalf of NOAA National Weather Service	Louis Uccellini, NOAA/NWS Director	30 mins
	On behalf of World Meteorological Organization	Jerry Lengoasa, WMO Deputy Secretary-General	
	On behalf of World Bank	Zoubida Allaoua, World Bank, Director of Urban and Disaster Risk Management Department	
	Introduction to Workshop		
0930-1000	Overview of the WMO's Global Data-processing and Forecasting System (GDPFS) and how it contributes to WMO's High Priorities; Objectives of workshop, expected outcomes, highlights of the agenda, participants, etc.	Jerry Lengoasa, WMO/DSG, chairperson of the Steering Committee	30 mins
1000-1030	**GROUP PHOTO; COFFEE / TEA BREAK**		**30 minutes**
	Overview of global system and impact of advances in NWP on NMHSs' operations		
1030-1100	**Workshop Paper 1** – Anticipated advance s in NWP, and the growing technology gap in weather forecasting	Ken Mylne, CBS/DPFS chairperson	30 mins
1100-1130	Leverage the scientific developments in NWP on what can result in significant impacts on safety (life, livelihoods and properties), health, environment and economy	William Lapenta, NOAA/EMC Director, representing WGNE	30 mins
1130-1200	Needs and requirements by NMHSs in developing countries in fulfilling their mandate of providing weather forecasts, warnings and other information for public welfare, and for the protection of life and property; and their interactions with regional centres	Amit Avikash Singh (Fiji)	30 mins
1200-1230	**Panel Discussion 1** – aim is to understand how the GDPFS could better mitigate the growing technology gap in weather forecasting; how do we bridge the gap between those who have the capacity and knowledge and those who don't?	Geoff Love, facilitator Panellists: Jerry Lengoasa (WMO), Ken Mylne (CBS/DPFS), William Lapenta (WGNE), and Amit Singh (Fiji)	30 mins
1230-1400	**LUNCH BREAK**		**90 minutes**
	Strengthening and sustaining WMO operational centres		
1400-1500	**Workshop Paper 2** – SWFDP and its future directions towards strengthening/sustaining WMO's operational centres	Alice Soares, WMO	60 mins

1500-1530	**Panel Discussion 2, followed by General Discussion** – this will focus on some of the challenges facing global and regional centres, and will allow short presentations from panellists on specific aspects related to SWFDP implementation (*session could end at 1730*)	Geoff Love, facilitator Panellists: Alice Soares (WMO), Rob Varley (UK global centre), Mark Majodina (RSMC Pretoria), Peter Kreft (RSMC Wellington)	30 mins
1530-1600	**COFFEE / TEA BREAK**		**30 minutes**
1600-1700	**Panel Discussion, followed by General Discussion** *(Cont.)*	Geoff Love, facilitator Panellists: Alice Soares (WMO), Rob Varley (UK global centre), Mark Majodina (RSMC Pretoria), Peter Kreft (RSMC Wellington)	60 mins
1700	**END OF DAY 1**		
1800-2100	**Reception ("Networking and Informal Discussions")**		
Wednesday, 19 June 2013			
DAY 2			
	What NMHSs need from regional and global centres to serve better their national needs		
0900-1000	Invited presentations from developing countries' NMHSs on needs (representing: SIDS, coastal country, land-lock country) *(other presentations may be considered, time permitting)*	D.J.A. Weerawardena (Sri Lanka), Moisés Vicente Benessene (MASA and Mozambique), Michael Nkalubo (EAC and Uganda)	60 mins
1000-1030	**COFFEE / TEA BREAK**		**30 minutes**
1030-1100	**Panel Discussion 3** – This will focus on some of the issues presented in the previous sessions from developing countries NMHSs perspective. This will touch on the some of the broader issues of modernization needs, training and national financing of operations.	Geoff Love, facilitator Panellists: Hamza Kabelwa (RFSC Dar), D.J.A. Weerawardena (Sri Lanka), Moisés Vicente Benessene (MASA and Mozambique), Michael Nkalubo (EAC and Uganda)	30 mins
1100-1230	**VISIT TO NOAA/NCEP**		**90 minutes**
1230-1400	**LUNCH BREAK**		**90 minutes**
	What NMHSs need from regional and global centers to serve better their national needs – continued		
1400-1430	**Workshop Paper 3** - SWFDP regional frameworks and their impact in Developing and Least Developed Countries	Eugene Poolman (RSMC Pretoria)	30 mins

1430-1530	**Panel Discussion 4** – Presentations and discussion from RSMCs of challenges and opportunities	Geoff Love, facilitator Panellists: Eugene Poolman (RSMC Pretoria), Hamza Kabelwa (RFSC Dar), Peter Kreft (RSMC Wellington), YEA Raj (RSMC New Delhi), Pham Van Tan (RFSC Hanoi)	60 mins
1530-1600	**COFFEE / TEA BREAK**		**30 minutes**
1600-1700	Continuation of **Panel Discussion**	Geoff Love, facilitator	60 mins
1700	**END OF DAY 2**		
	Thursday, 20 June 2013		
	DAY 3		
	Financing NMHSs and RSMCs		
0900-0930	**Workshop Paper 4** – Financial implications and investment options to support regional frameworks	David Rogers, WB	30 mins
0930-1000	**General Discussion**	Geoff Love, facilitator	30 mins
1000-1030	**COFFEE / TEA BREAK**		**30 minutes**
	Towards a plan of action		
1030-1200	**Panel Discussion 5** – on way forward. Panel should discuss from different perspectives and from the current realities of RSMCs and support for developing countries, including actual costs	Geoff Love, facilitator Panellists: Vladimir Tsirkunov (WB), Wayne Elliott (WMO), Tyrone Sutherland (CMO), Dan Beardsley (NOAA/NWS), Erik Hagemark (Norway)	90 mins
1200-1230	Wrap-up session (report back to conference participants on next steps)	Geoff Love (facilitator)	30 mins
1230-1400	**LUNCH BREAK and End of Formal Workshop**		**90 minutes**
	Steering Committee Meeting		
1400-1530	Steering Committee Meeting	Steering committee	90 mins
1530-1600	**COFFEE / TEA BREAK**		**30 minutes**
1600-1700	Steering Committee Meeting	Steering committee	60 mins
1700	**END OF DAY 3**		

Workshop Paper 1

ANTICIPATED ADVANCES IN NUMERICAL WEATHER PREDICTION (NWP), AND THE GROWING TECHNOLOGY GAP IN WEATHER FORECASTING

Submitted by WMO, with contributions from the CBS/DPFS chairperson

1. INTRODUCTION

The advances in Numerical Weather Prediction (NWP) in the last decades have been tremendous: higher accuracy, higher resolution, longer lead-time, wider range of relevant applications. Consequently the emphasis in operational meteorology, hydrology, oceanography and climatology has shifted towards the implementation of increasingly sophisticated and diverse numerical models and applications, for an ever-increasing variety of users.

Foremost, the ever-increasing precision, reliability and lead-time provided by NWP systems have led to increasingly skillful weather forecasting over the recent decades and will become even more relevant in the future. NWP systems generally provide an accurate indication of developing extreme weather events, thereby being a very relevant component of routine and severe weather forecasting and warning programmes at National Meteorological and Hydrological Services (NMHSs).

The capability among NMHSs in weather forecasting varies enormously. While noting that advanced NMHSs are making best use of the dramatic development/progress being made in NWP, NMHSs of developing countries (including Least Developed Countries, LDCs) saw little progress due to limited budgets, failing infrastructure, inadequate guidance and expertise. Thereby, there has been an increasing gap in the application of advanced technology (NWP, including EPS) in early warning systems (EWS) of NMHSs of developed and developing countries, including LDCs.

The Global Data Processing and Forecasting System (GDPFS) enables WMO Members to make use of these advances by providing a framework for the sharing of data related to operational meteorology, hydrology, oceanography and climatology. The main support for the exchange and delivery of these data – that is, GDPFS products – is the WMO Information System (WIS). One of the key features of the WIS compared to the GTS is the expansion of the range of centres that can connect to the system; this supports growth in the range of GDPFS applications.

However, the challenge is: *how do we mitigate the growing technological gap in weather forecasting? How do we bridge the gap between those who have the knowledge and those who don't, those who have the capacity to run, maintain, develop and support such complex systems and those who don't have the capacity, and the capability?* The WMO's Severe Weather Forecasting Demonstration Project (SWFDP) has been attempting to close this gap by increasing availability, and developing capacity to use existing NWP, including EPS, in countries where it is not effectively used (see *Workshop Papers entitled: "SWFDP and its Future Directions towards Strengthening/Sustaining WMO's Operational Centres", and "SWFDP Regional Frameworks and their Impacts in Developing and Least Developed Countries"*).

2. GDPFS: A WORLD-WIDE NETWORK OF OPERATIONAL CENTRES OPERATED BY WMO MEMBERS

The GDPFS is the world-wide network of operational centres operated by WMO Members. Its purpose is, in operational conditions (i.e. 365 days per year, 24 hours per day, 7 days a week), to make available among WMO Members, agreed products and services for applications related to weather, climate, water and environment. The GDPFS therefore enables scientific and technological advances made in meteorology and related fields to be shared as efficiently and effectively as possible among, and for the benefit of, WMO Members (including the building of capacity in developing and least developed countries).

The activities, organizational structure and operations of the GDPFS are designed in accordance with Members' needs and their ability to contribute to, and benefit from, the system. A key objective is to facilitate cooperation and the exchange of information, thereby also contributing to building capacity amongst developing and least developed countries. These are described in the *Manual on the GDPFS* [1] (WMO-No. 485, http://www.wmo.int/pages/prog/www/DPFS/Manual/GDPFS-Manual.html), which is the single source of technical regulations for all operational data-processing and forecasting systems of WMO Members, including their designated operational centres.

The agreed products and services for applications related to weather, climate, water and environment are:

- Numerical weather, oceanographic and climate prediction products (analysis and forecast, including probabilistic information produced from Ensemble Prediction Systems (EPS));
- Specialized products tailored for specific applications.

GDPFS Centres shall ensure that their agreed products and services are made available through the WMO Information System (*Manual on WIS*, WMO-No. 1060 – see Annex I for a brief description of RSMCs and WIS) in a timely manner for operational use.

The accuracy of forecast products provided by advanced GDPFS Centres is monitored by objective verification procedures. The goal is to provide consistent standardized verification of the forecast products of GDPFS Centres so that users can make best use of products and so that opportunities for improvement are identified. GDPFS centres prepare verification data according to the standard procedures, as defined in the *Manual on the GDPFS* (WMO-No. 485). Verification results are collected by the Lead Centres (LC) for Deterministic NWP Verification (the European Centre for Medium-range Weather Forecasts, ECMWF), and for EPS Verification Website (the Japan Meteorological Agency, JMA), and displayed on their Websites (http://apps.ecmwf.int/wmolcdnv/ and http://epsv.kishou.go.jp/EPSv/, respectively).

The non-real-time functions of the GDPFS include long-term storage of observations, products and verification results for operational and research use. GDPFS Centres shall operate an archiving and retrieval system to serve the needs of their continual improvement process; this process should include, inter alia, the non-real-time assessment of their products and the ability to perform re-runs of

[1] The *Manual on the Global Data-Processing and Forecasting System* (GDPFS) (WMO-No. 485) is currently under a comprehensive revision, following the adoption of the revised Manual's outline by the World Meteorological Congress, at its sixteenth session (Cg-XVI, May 2011) in Resolution 6 (WMO, 2011). This new Manual will incorporate aspects related to all WMO data-processing and forecasting systems operated by WMO Members. The new Manual is being developed in accordance to quality management principles and will facilitate the review of compliance of GDPFS Centres against the designation criteria, which include, amongst others, forecast verification activities. This is critical to quality assurance and management of the outputs of the GDPFS, as the verification of numerical and other forecasts is an activity that supports continuous improvement of the forecasting and warning systems. The new Manual introduces a number of changes to the current procedures, and therefore some GDPFS centres may report temporary non-compliance with regard to some of the requirements, mainly because of resource constraints during system development or adaptation. In this context, and noting that the new Manual would most likely be in force by 2015, the Commission for Basic Systems, at its fifteenth session (CBS-XV, Jakarta, September 2012) requested the WMO Secretariat to clearly indicate the comprehensive summary of changes of functions and procedures well in advance to ensure the smooth transition, and also recommended that a transition plan for the implementation of the new Manual (which will replace the current version) be developed to manage the technical changes and the initial designation of the GDPFS centres as defined in the new Manual, including WMCs and RSMCs (WMO, 2012a).

their operational production. WMO Members should ensure that their NMCs archive and retrieve appropriate data originating from their national observing networks and facilities.

GDPFS centres provide annually detailed information on their NWP system configurations in their *WMO Technical Progress Reports on the Global Data-Processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research*, which are available on the WMO Website at http://www.wmo.int/pages/prog/www/DPFS/ProgressReports/2012/2011_GDPFS-NWP.html.

Activities supported by the GDPFS

Through the GDPFS, WMO Members provide and have access to meteorological, hydrological, oceanographic and climatological information supporting a range of operational activities. Many of these activities are conducted in real time; however, non-real-time operational coordination activities (often referred to as Lead Centre activities) are also part of the GDPFS.

The list of GDPFS activities is given in this paragraph; associated commitments and other appropriate details are specified in Part II of the *Manual on the GDPFS* (WMO-No. 485).

General Purpose Activities:

- Nowcasting
- Global deterministic numerical weather prediction
- Limited area deterministic numerical weather prediction
- Global ensemble numerical weather prediction
- Limited area ensemble numerical weather prediction
- Seasonal and climate numerical prediction
- Numerical ocean wave and storm surge prediction

Specialized Activities:

- Forecasting hazardous hydro-meteorological phenomena (currently named RSMCs with geographical specialization)
- Seasonal to sub-seasonal Climate prediction and information
- Multi model ensemble prediction for long range forecasts
- Tropical cyclone forecasting
- Volcanic ash advisory services for aviation
- Response to marine environmental emergencies
- Response to nuclear environmental emergencies
- Response to non-nuclear environmental emergencies
- Atmospheric sand and dust storm forecasting

Non real time coordination activities:

- Coordination of deterministic NWP verification
- Coordination of EPS verification
- Coordination of LRF verification
- Coordination of wave forecast verification
- Coordination of GOS observation monitoring results (surface, upper-air, etc.)
- Coordination of GCOS observation monitoring results (GSN and GUAN)
- Coordination and testing of emergency response activities and procedures
- Coordination of the SWFDP (Severe Weather Forecasting Demonstration Project) which supports NMHSs in developing and least-developed countries with access to GDPFS products.

GDPFS Centres

World Meteorological Centres (WMCs), and Regional (or) Specialized Meteorological Centres (RSMCs) with activity specialization in Global NWP/EPS (general purpose activities)

A GDPFS Centre which carries out at least the following activities to the specified standards described in Part II of the *Manual on the GDPFS*:

- Global deterministic numerical weather prediction, and
- Global ensemble numerical weather prediction, and
- Seasonal and climate numerical prediction

shall be designated as a World Meteorological Centre (WMC).

A GDPFS Centre which carries out at least one of the General Purpose or Specialized activities listed above to the specified standards described in Part II of the *Manual on the GDPFS* shall be designated as a Regional (or) Specialized Meteorological Centre (RSMC).

WMO has currently three designated WMCs (Melbourne – Australia, Moscow – Russian Federation and Washington – USA) – Figure 1. Other centres with operational global NWP capability may obtain this designation in a near future, with the introduction of the new *Manual on the GDPFS*, most likely in 2015. Currently there are thirteen centres with operational global NWP capability – typically named global NWP centres (BoM – Australia, CMA – China, CMC – Canada, CPTEC – Brazil, DWD – Germany, ECMWF – Europe, IMD/NCMRWF – India, JMA – Japan, KMA – Republic of Korea, MF – France, NOAA/NCEP – USA, ROSHIDROMET – Russian Federation, and UKMO – UK), twelve of them also with the formal designation of Global Producing Centres (GPCs) for Long-Range Forecasts (LRF) – monthly and seasonal forecasting. A summary of the NWP system configurations (as of June 2013) for the thirteen advanced GDPFS centres is provided in Annex II. These global NWP centres operate supercomputer systems, high speed communication networks, extensive data assimilation and storage facilities, and major front-end computing systems to do pre- and post-processing of atmosphere and ocean modelling system inputs and outputs. An important feature of these centres is that they continually invest in research to improve their data assimilation and Earth-system forecasting capabilities as well as constantly updating their computing and communications infrastructures so as to keep it “state-of-the-art”.

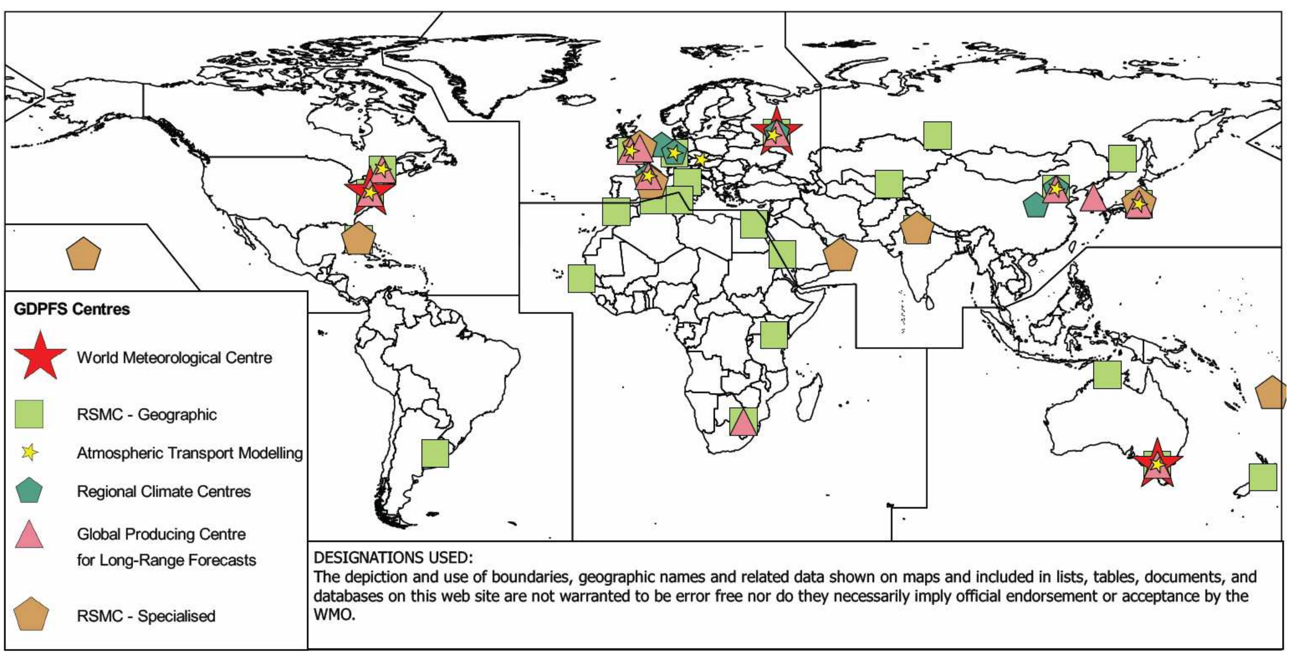


Figure 1 – Currently designated WMCs and RSMCs, including RCCs.

Leading global NWP centres are typically now running a combination of global models at grid resolutions of around 16-45km (most <30km) and high resolution regional models with grid resolutions between 1.5 and 12km (most 1-7km) (see Annex II, Table II-2.1 with the configuration of the NWP systems for the advanced global NWP centres (as of June 2013), base on the information provided by WMO Members in the *Annual WMO Technical Progress Reports on the Global Data-Processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research*). Regional models are generally run for national domains or regional domains centred around the immediate area of the NWP centre. However, there are a few cases of global centres also running high resolution regional models for other regions of the globe, for example the United Kingdom runs a regional model at 4km grid resolution for the Lake Victoria region of Africa supported by external development funding. More details on current status of NWP at advanced global NWP centres are given in item 4 below.

Other Regional or Specialized Meteorological Centres (RSMCs)

There are currently forty-eight Regional or Specialized Meteorological Centres (RSMCs) – Figure 1. These include:

- Twenty-five RSMCs with geographical specialization;
- One RSMC with activity specialization in the provision of ultraviolet-index forecasts for RA VI (Europe);
- Six RSMC with activity specialization in tropical cyclones;
- One RSMC with activity specialization in medium-range weather forecasts;
- Ten RSMCs with activity specialization in atmospheric transport modelling for environmental emergency response and / or backtracking;
- One RSMC with activity specialization in atmospheric sand and dust storm forecasts; and,
- Three Regional Climate Centres (RCCs), and one RCC-Network, providing regional long-range forecasts and other regional climate services.

With the implementation of the new *Manual on the GDPFS*, in 2015, these centres will be designated in accordance with their activities (see section on *"Activities supported by the GDPFS"* above). This will be particularly the case for the RSMCs with geographical specialization. The experience acquired with the Severe Weather Forecasting Demonstration Project (SWFDP) is actually being used to redefine the role of a regional centre with geographical specialization, to become an RSMC with activity specialization in Forecasting Hazardous Hydro-Meteorological Phenomena, which provides forecasting guidance to NMHSs in a geographical region, in support of their national severe weather warnings programmes.

RSMCs with activity specialization are mostly in developed countries, some of them being co-located with global NWP centres – Figure 1. On the other hand, capability amongst RSMCs with geographical specialization is not universally uniform, with those in developed countries at times co-located with centres with highly advanced global capabilities[2] (see section on *"WMCs and RSMCs with activity specialization in Global NWP/EPS"* above), while some RSMCs in developing countries can have quite modest computing and communication resources, with limited scientific and technical support levels.

There are a number of RSMCs in developing countries that still run limited area deterministic NWP models at grid resolutions of <45km over their regions (similar to those of global NWP), with little additional value (i.e. without regional data assimilation, limited verification, etc.). With the initiation of the SWFDP and its regional frameworks (projects), WMO is assisting a number of RSMCs implementing high resolution regional models with grid resolutions between 2.8 and 12km over the project footprint and/or its sub-regions (e.g. SWFDP – Eastern Africa, over Lake Victoria) for operational forecasting in their geographical regions. Within some of the SWFDP regional frameworks, this activity is supported by global NWP centres, which provide training to staff at RSMCs, and scientific and technical assistance throughout the implementation and model upgrades, for sustainable use. It is in this context that the SWFDP has been effective in building the capacity of

[2] RSMCs with geographical specialization in developed countries which are co-located with centres with highly advanced global capabilities, will be designated RSMCs with activity specialization in Global NWP/EPS, with the introduction of the new *Manual on the GDPFS*, in 2015.

RSMCs, who play a critical role and functions as focal point and central hub for all information exchange between the various global, regional and national partners, including the production of coordinated forecast guidance to NMHSs of neighbouring countries (in a geographical region), in support of their national severe weather warnings programmes, and harmonization of warnings across borders (see *Workshop Papers entitled: "SWFDP and its Future Directions towards Strengthening/Sustaining WMO's Operational Centres", and "SWFDP Regional Frameworks and their Impacts in Developing and Least Developed Countries"*).

Networks

A GDPFS network, that is, an association of GDPFS Centres constituted to undertake an identified GDPFS activity, shall follow the same specifications and adhere to the same criteria and commitments as individual GDPFS Centres carrying out the same activity. Appropriate documentation shall be produced and made available to distribute the tasks and responsibilities among the participating Centres; a unique focal point shall be designated to answer requests from users of the network's products.

National Meteorological Centres (NMCs)

WMO Members' National Meteorological Centres (NMCs) carry out functions to meet the national and international requirements of the WMO Member. Each WMO Member shall ensure that it has a National Meteorological Centre adequately staffed and equipped to enable it to play its part in the GDPFS.

The functions of a NMC, shall include the preparation of forecasts and warnings at all ranges necessary to meet the requirements of the WMO Member, especially supporting their national severe weather warnings programmes for protection of lives and property. In addition, depending on the context, NMCs may also be responsible for other activities such as production of:
(a) Special user-application products, including climate and environmental quality monitoring and prediction products;
(b) Non-real-time climate-related products;
(c) Specific products and their delivery in support of United Nations humanitarian missions.

NMCs should have the capacity to make best use of GDPFS products in order to reap the benefits of the WWW system. NMCs should be linked to the WIS to ensure suitable connection with other GDPFS Centres in order to carry out interactive-processing activities between Centres.

Currently, the capability amongst NMCs in weather forecasting varies enormously. While noting that advanced NMHSs are making best use of GDPFS products, many NMHSs of developing countries (including Least Developed Countries, LDCs) have seen little progress due to limited budgets, failing infrastructure, inadequate guidance and expertise. Thereby, there has been an increasing gap in the application of advanced technology (GDPFS, including NWP and EPS) in early warning systems (EWS) between NMHSs of developed and developing countries, including LDCs.

In developed countries and many developing countries, global NWP centres and some RSMCs are co-located and well connected with their NMCs/Forecasting Offices, where forecasters are well trained and make best use of all NWP products. Many advanced NMHSs, especially those hosting global NWP centres and some RSMCs, are now introducing a new methodology for operational forecasting. Specifically, automation of "routine weather" forecasts is increasing to allow forecasters in their

Forecasting Offices to concentrate their efforts on "high-impact weather" ("HIW"[3]). In this case, the question is: *how best to optimize the human–machine mix?* There will be greater emphasis on science in operations, including improved forecaster knowledge (including on decision-making processes), tools incorporating the latest research, and a more scientific forecasting process, providing a good process of "scientific forecasting", continuously supported by adequate training. Such centres will also have well-established procedures for issue of severe weather warnings, and established communication chains with national civil protection and disaster risk reduction agencies to ensure that warnings are acted upon for the protection of lives and property.

By contrast, a typical, small developing country (including LDCs) NMHS might have a very small NWP Unit which may not be co-located with the NMC/Forecasting Office, and typically outputs from their "NWP systems" are not ingested in the operational forecasting process. Their NWP Units run limited area deterministic NWP models, mostly on experimental basis, at grid resolutions of 45km or longer over their countries on a cluster of PCs, without regional data assimilation, limited verification, etc. Such systems have usually been generously supplied by a donor, but often without a long-term sustainability strategy. Such systems rapidly become out-dated, and typically add little or nothing to what may be obtained from modern global NWP systems which have comparable or better resolution and advanced data assimilation.

Many of these NMHSs do not have an adequate programme for severe weather warnings, and make insufficient use of modern NWP forecasts to increase the lead-time for anticipating the development of severe weather situations, several days in advance. Their NMCs/Forecasting Offices might only have two or three forecasters (possibly one of them being a senior or chief forecaster/supervisor) on duty during daylight hours, reducing in number to one or two overnight where it works 24/7 – typically Forecasting Offices at airports work 24/7, whereas there are still a number of NMCs/Forecasting Offices that work daytime hours only. Typical activities include: hand analysis of national charts, reviewing NWP products from major centres (mostly deterministic NWP), monitoring of satellite imagery, and preparation of national forecasts (typically for major cities, out to day-1 or day-2). Many NMCs also prepare warnings, which are disseminated through national and local systems, including the media, telephone-based services and some degree of facsimile distribution to emergency services; however there is still a significant number of NMHSs that do not have defined warning criteria. These NMCs/Forecasting Offices, in general, do not have a well-established day-to-day forecasting process implemented, including an integrated screen-based display of data; lack standard operational procedures in case of emergency, including internal prioritization of tasks and external liaison with stakeholders; and lack a recruitment/succession plan for training new staff to move into the NMC/Forecasting Office. In addition, the Aviation Forecasting Offices at times are separate of the NMHS.

3. Technical requirements for running of operational numerical weather prediction

Global models require the resources of a major operational centre to support a full data assimilation system and the telecommunications infrastructure to import the required volumes of observational data, particularly satellite data. Large supercomputers are required to support models of competitive resolution, and a large and expert staff of scientists and computer scientists is required to develop and maintain such a system 24 hours per day, 365 days per year in an operational environment. There are a number of such centres around the world already, including some groupings which share model code and its development. While there is likely to be a small increase in the number of global modelling centres over the coming decades, there is little benefit to be gained from any significant increase as outputs, including boundary conditions for limited area models, can be provided from the existing centres much more cheaply and efficiently.

[3] Here, HIW is any meteorological related event or combine events that occurs within a time period from nowcasting to seasonal that can result in significant impacts (real or perceived) on safety, health, environment or economy.

Effective running of regional (limited-area) models requires a similar level of scientific and technical expertise. While off-the-shelf model codes can be sourced and run relatively easily, running them in an effective operational system to provide forecasts which improve on those available from the global models requires high quality processing and assimilation of local observations. Lateral boundary conditions can be sourced from global centres, but the inherent errors introduced in passing data through a model boundary mean that significant benefit is only achieved when the regional model can be run at substantially higher resolution than the global model. Initial conditions can also be sourced from global centres for a pure downscaling approach, but the benefits will be limited without assimilation of high quality local observations at high resolution. To maintain and update such systems requires a long-term commitment to maintaining scientific and technical expertise and a complex infrastructure of high-level computing and telecommunications. Retention of the highly skilled scientists and computer scientists required to run such systems can also be a major challenge as such skills are highly sought-after by alternative employers. Efficient provision of such NWP services is therefore best concentrated into a limited number of regional specialist centres, with the support where appropriate from expert global NWP centres, allowing the NMHSs to focus their limited resources on interpretation and the issue and communication of warnings.

4. Current status of numerical weather prediction (NWP)

As mentioned in item 2, leading global NWP centres are typically now running a combination of global models at grid resolutions of around 16-45km (most <30km) and high resolution regional models with grid resolutions between 1.5 and 12km (most 1-7km) (see Annex II, Table II-2.1 with the configuration of the NWP systems for the advanced global NWP centres (as of June 2013), based on the information provided by WMO Members in the *Annual WMO Technical Progress Reports on the Global Data-Processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research*). Models with grid resolutions of 4km or less are capable of partially resolving convective storms such as thunderstorms and offer a new level of predictive capability which has only become available in the last 5 years or less. Such models are typically available only over relatively small national or sub-national domains, although some global centres now have the capacity to support a small number of regional model domains at around 4km resolution at a very modest cost. For those countries with very large domains of responsibility regional model resolutions may still be somewhat less.

The global models are now reaching the resolutions served by previous-generation regional LAMs. As an example of an advanced global NWP centre, the UK Met Office strategy for achieving improved forecasts for hourly to seasonal range is built on moving towards the use of twin configurations of the Met Office Unified Model system: a global mesoscale coupled ensemble for short range to seasonal forecasting and a UK convective-scale coupled ensemble for very short range forecasting to two days ahead. Each configuration will include coupled representations of relevant land and ocean processes and appropriate aspects of the chemical composition of the air. Where possible, the two configurations will be kept consistent with each other. A combination of dynamical downscaling and statistical adjustment will be used to generate forecasts from the output of these models. A 12km UK configuration is run to five days ahead with chemistry and aerosol for air quality forecasting.

The next stage of upgrading currently being implemented during 2013-14 following the mid-life supercomputer upgrade in 2012 includes:

- Global modelling system for UK & Global short range forecasting:
  - 12-hourly deterministic forecast to 5 days ahead on a 17km / 70 level grid
  - 6-hourly deterministic forecast to 2 days ahead on a 17km / 70 level grid
  - 6-hourly ensemble forecast to 3 days ahead on a 33km / 70 level grid
- Coupled global modelling system for UK & Global medium-range and seasonal forecasting
  - Daily ensemble forecast to 15 days ahead on 60km / 85 level grid
  - Daily lagged ensemble forecast to 6 months ahead on 60km / 85 level grid
- Regional modelling system for UK short range forecasting

- 6-hourly 2.2km UK ensemble forecast to 36 hours ahead
- 3-hourly 1.5km UK deterministic forecast to 36 hours ahead
- 6-hourly 4km European deterministic forecast to 5 days ahead
- 12-hourly 12km UK air quality forecast to 5 days ahead

Rapid refresh and high resolution modelling

Nowcasting, providing very short-period forecasts up to 6 hours ahead, has for a long time been achieved by extrapolation of observations for the first hours, blending with numerical weather prediction for the later hours. Nowcasting systems are typically based on remote-sensed observations from radar or satellite, providing rapid refresh with detailed spatial coverage. However, in recent years, the development of high resolution models and the ability to assimilate such remote-sensed data has renewed the interest in the implementation of rapid refresh suites of NWP models for nowcasting, while bringing new challenges on assimilation, spin-up and cycling issues.

An example of such a rapid refresh system is given by NOAA's High Resolution Rapid Refresh system – Figure 2. HRRR provides dynamic adaptation forecasts from the Rapid Refresh model -previously known as the Rapid Update Cycle- at a 3-km resolution every hour, to a 12-hour forecast range.

JMA also started operating a new high-resolution hourly-updated forecast model named the Local Forecast Model (LFM) in August 2012. The non-hydrostatic model, JMA-NHM, with grid spacing of 2km provides 9 hour forecasts every hour over Eastern part of Japan. In addition to most observation, including Radar data, used in operational regional analysis, automated surface station (AMeDAS) data are assimilated using 3D-Var data assimilation system, LA, ahead of other operational data assimilation systems in lower resolutions, in order to appropriately reflect effects from local-scale environments near the surface.

Another example, Météo-France plans to implement an hourly rapid refresh version of its non-hydrostatic AROME model. First experiments have demonstrated an improvement over the operational version of AROME at a 2.5-km resolution, except for surface pressure in the first hours. Very-high resolution versions of AROME (0.5 km) will be developed and coupled with the rapid refresh system as a nowcasting downscaling process for certain areas of interest, like airports or cities, and will make use of high-level local observation systems (band X radars, lidars, ground fluxes measurements, etc.) – Figure 3.

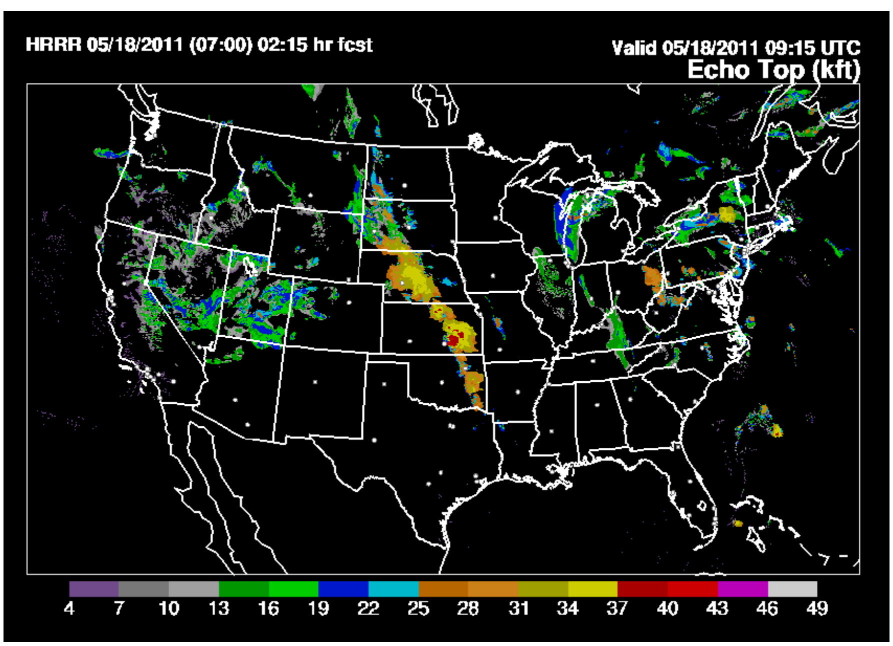
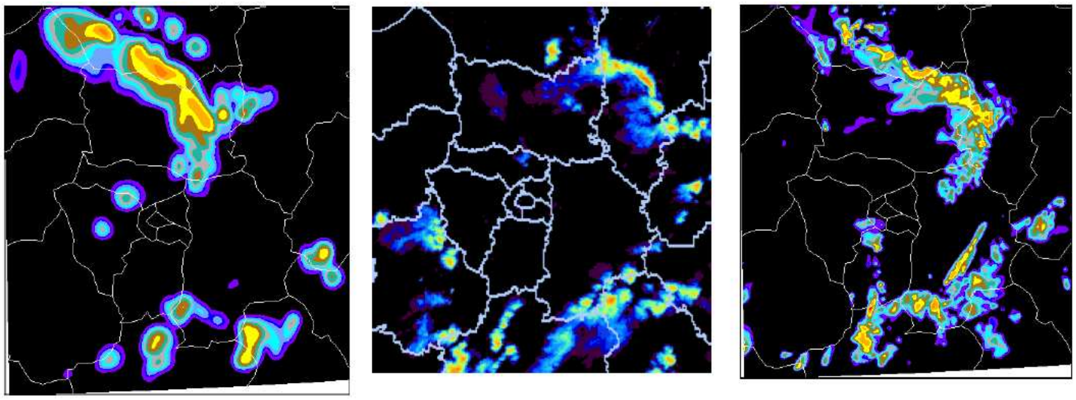


Figure 2 – NOAA's High Resolution Rapid Refresh system.



2.5-km model reflectivities **Radar reflectivities** **0.5-km model reflectivities**

Figure 3 – Meteo-France's rapid refresh and high resolution modelling.

Early detection of severe weather events

An important and continuing development for operational weather forecasting is the use of Ensemble Prediction System (EPS), which is capable of providing uncertainty information, associated with NWP results. EPS are a powerful tool in predicting (and early detection of) severe weather events. For impact-based warnings systems the EPS may be used to help estimate the probability of weather hazards for use in the estimate of Risk = Probability x Impact. The combined use of deterministic and probabilistic forecast guidance helps NMHSs in their risk assessment at an early stage in severe weather forecasting and improving decision-making processes. This contributes towards the national social and economic development goals.

A wide range of ensemble products are currently being generated operationally through the advanced post-processing systems, for example: probabilities of reaching or exceeding given thresholds (e.g. rain amounts), Extreme Forecast Index (EFI), EPSgrams and EPS-plumes which provide graphical summary of confidence in point forecasts and tropical cyclone tracking. Detailed information is provided in the *WMO Guidelines on Ensemble Prediction Systems (EPS) and Forecasting* (WMO, 2012b), which was prepared in the context of the SWFDP.

As an example, the Extreme Forecast Index developed by ECMWF allows identification of forecasts which are extreme relative to the model climate, providing an alert to a risk of severe weather – Figure 4. The EFI does not provide explicit probabilities of severe events, but a useful alert to where extreme events are more likely than usual.

Figure 5 shows two examples: (1) probability chart generated from JMA's global fields for accumulated precipitation exceeding 25mm in the Southeast Asia, and (2) CMA's EPSgram for a city in Thailand in support of the SWFDP regional project.

MRI/JMA has developed a Web site (http://tparc.mri-jma.go.jp/TIGGE/tigge_SWFDP.html) which displays experimental risks of high-impact weather (e.g. heavy rainfall, extremely high/low temperature, and strong wind) using data from the TIGGE research database from four global NWP centres (ECMWF, JMA, NCEP and UKMO) and a brief description about these products and guidelines on how to use them. The genesis potential of high-impact weather is calculated by comparing ensemble members with climatological PDFs calculated from each of the four TIGGE models. The Web site is automatically updated every day and includes forecast up to 15 days ahead. These experimental products are currently run in non-real time with a 2-day delay. SWFDP RSMCs have been evaluating the prototype products available on the Web site and assess requirements for near-real-time products. The UK Met Office is currently working in collaboration with JMA to implement the products in real-time. Figure 6 shows an example of the ensemble-based occurrence probability of extreme the SWFDP regions.

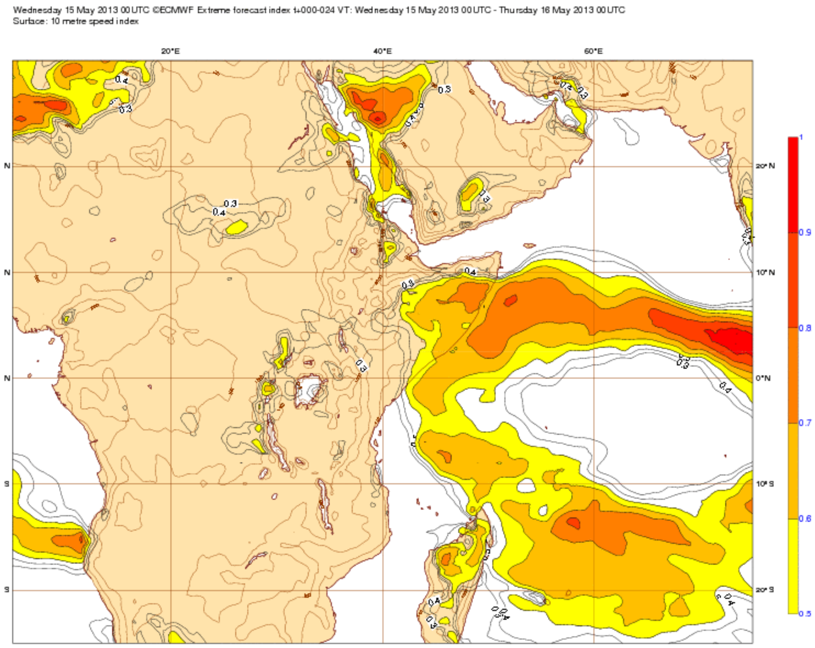


Figure 4 – ECMWF Extreme Forecast Index (EFI) 10m wind speed. Product made available to NMHSs in Eastern Africa, through the SWFDP – Eastern Africa.

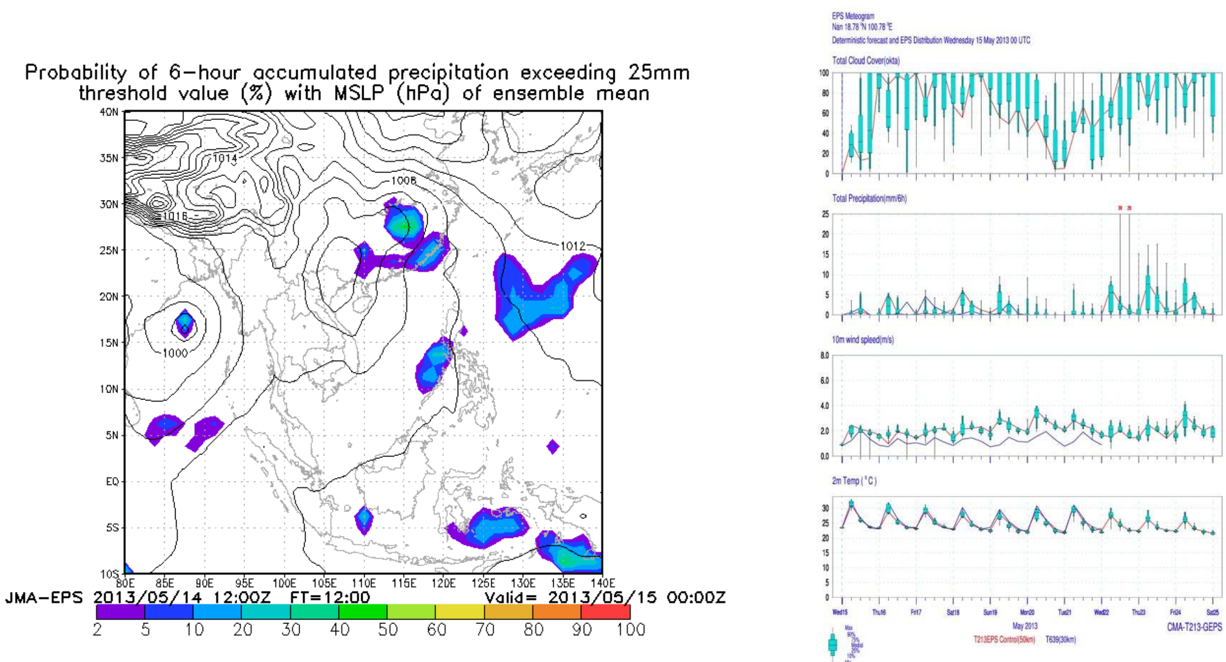


Figure 5 – Two examples: probability chart generated from JMA's global fields for accumulated precipitation exceeding 25mm in the Southeast Asia (left), and EPSgram from the CMA global ensemble for a city in Thailand (right) in support of the SWFDP regional project.

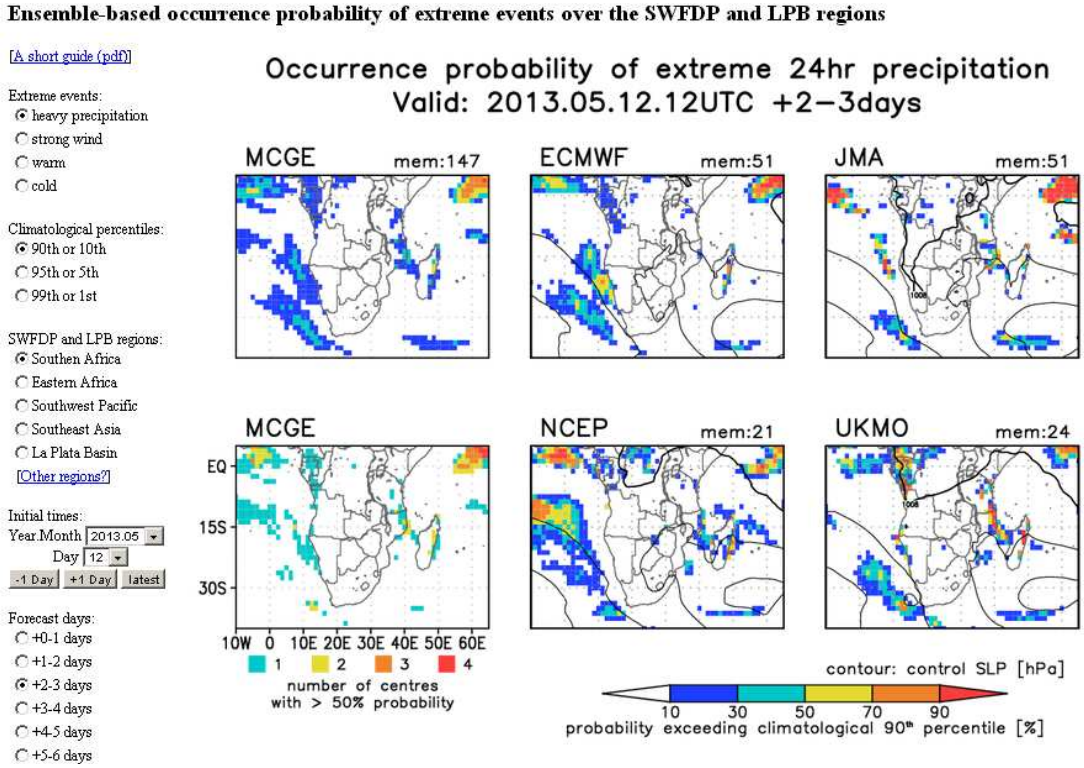


Figure 6 – Example of occurrence probability of extreme 24 hours precipitation, in support of the SWFDP regional projects.

Convective-scale NWP

At many advanced centres and consortia, NWP development to support high-impact weather prediction is now focused on high-resolution global models and convection-permitting (or convective-scale) models (grid spacing: 1-4 km). EPS is highly relevant to convective-scale NWP because convective instability adds a new scale of forecast uncertainty not resolved by the lower resolution models, and with much shorter timescales. In addition to convection itself, models on this resolution have greatly enhanced capability for forecasting other aspects of local weather, such as low cloud and visibility of interest to aviation. Many of these phenomena are significantly affected by topographic forcing which may give enhanced predictability when that forcing can be resolved by the models (e.g. convective initiation or valley fog). Convective scale EPS has the potential to provide information on the predictability of all these weather elements.

Physical processes leading to convection are highly non-linear, so that the explicit modelling of convective cells over one or a few hours should already be seen as medium-range forecasting, with very limited deterministic predictability for the individual cells. Thus, convection-permitting ensembles already focus on the shortest-range (0-24 hours), as opposed to the short-range (0-3 days). Furthermore, error growth in convection-permitting models does not necessarily behave in a similar way as in convection-parameterization models. Different error growth may arise from the strong non-linearities and the different role of physical processes.

A few centres (e.g. Météo-France, UKMO, and COSMO Consortium – Figure 7) have been experimenting with convection-permitting ensembles with horizontal resolutions of around 2.5km, with an emphasis on the prediction of heavy precipitation events.

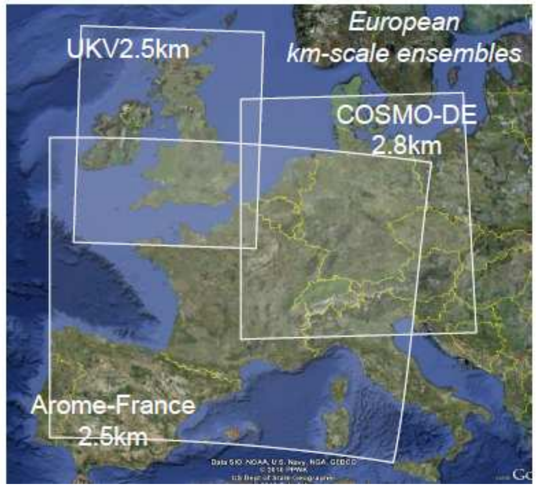
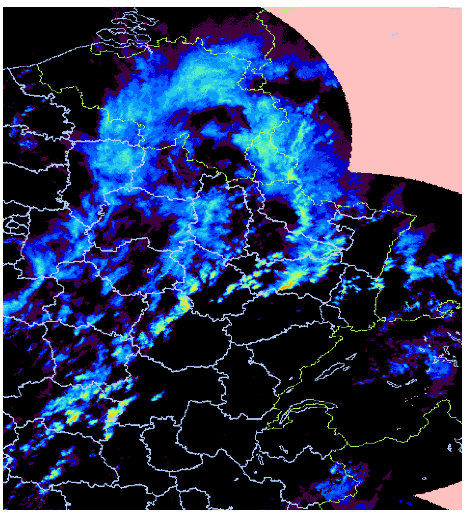
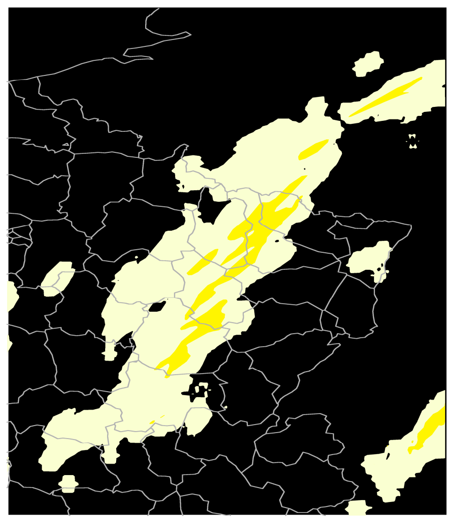


Figure 7 – European *km*-scale ensembles.

A case study is shown below where instantaneous rains are compared with ensemble forecasts obtained with Météo-France's AROME ensemble prediction system at a 2.5-km resolution using stochastic physics – Figure 8.



Instantaneous radar precipitations



Ensemble non-hydrostatic prediction
Dark yellow : deterministic forecast > 20 mm
Light yellow : P(precips > 20 mm) > 10%

Figure 8 – Instantaneous rains (i.e. radar data) compared with ensemble forecasts obtained with Météo-France's AROME ensemble prediction system at a 2.5-km resolution using stochastic physics.

Uncertainty on the convective scale has a very large dimensionality, and a very large ensemble would be required to fully sample this. Therefore, these systems have been addressing uncertainty in the location of convective precipitation by neighbourhood processing techniques whereby the probability of heavy precipitation at a location can be estimated by considering whether the model has precipitation within a neighbourhood around that location. Use of this technique in combination with the ensemble has the effect of greatly increasing the effective ensemble sampling (figure 9).

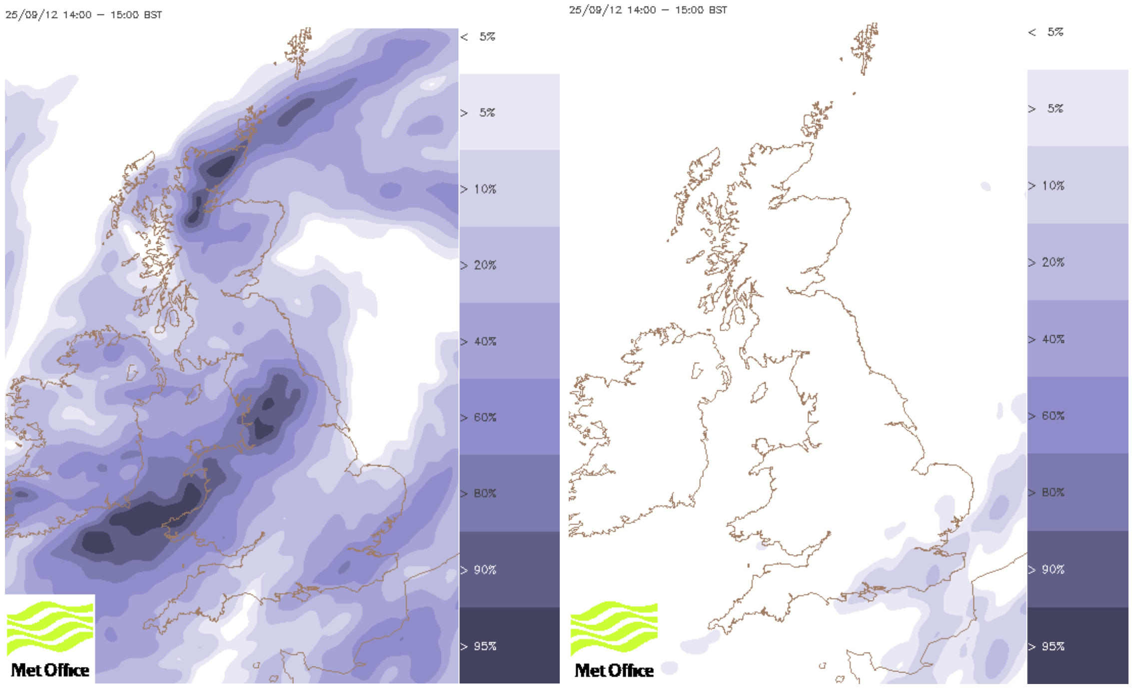


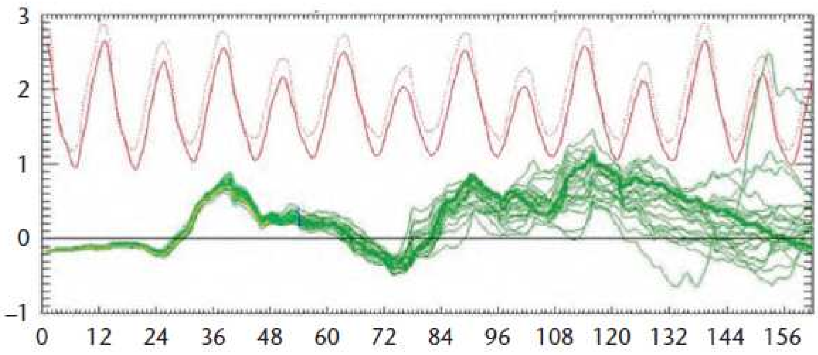
Figure 9 – Ensemble forecasts of heavy rain from the UK Met Office MOGREPS-UK 2.2km ensemble post-processed with neighbourhood processing showing probabilities of rain (>1mm/h, left) and torrential rain (>16mm/h, right).

Benefits of km-scale or non-hydrostatic ensemble systems is expected in the case of severe convective events where deterministic models often fail to adequately represent local extreme precipitations events.

Severe weather impact modelling

Both global and regional EPS have been operated in the prediction of high-impact weather events (specialist EPS). As an example, JMA has improved its Typhoon EPS, by implementing a stochastic physics scheme and by setting the initial perturbation (IP) target area around the central position of TC forecasts as a circular region (in contrast to the previous rectangular-area settings) and reducing the IP amplitude. These revisions have improved the spread-skill relationship of TC track forecasting. JMA operates the Typhoon EPS four times a day (00, 06, 12, and 18 UTC) with a forecast range of 132 hours. This has been merged with the JMA global EPS.

The uncertainty in the weather forecast can be propagated through to uncertainty in impact by coupling ensemble members to impact models and generating a distribution of impact predictions. Examples include hydrological models for probabilistic flood forecasting, coastal storm surge models and heat health models. This is an advanced application, which is being increasingly applied in the more advanced centres. Figure 10 shows an ensemble forecast of storm surge at a coastal port, where the weather forecasting EPS has been used to force an ensemble with a storm surge model. The red lines at the top of the graph show the flood danger level oscillating up and down with the tide, and a flood risk is indicated where the ensemble forecast surge lines cross above the red lines. This is an interesting example as one member of the ensemble produces an extreme surge at day 7, indicating a low probability of severe coastal flooding. In this situation the user needs to be able to take some early preparedness action but without overreacting because the probability of the flooding occurring is low.



Source: UK Met Office, © British Crown Copyright

Figure 10 – Ensemble forecast of storm surge at a coastal port.

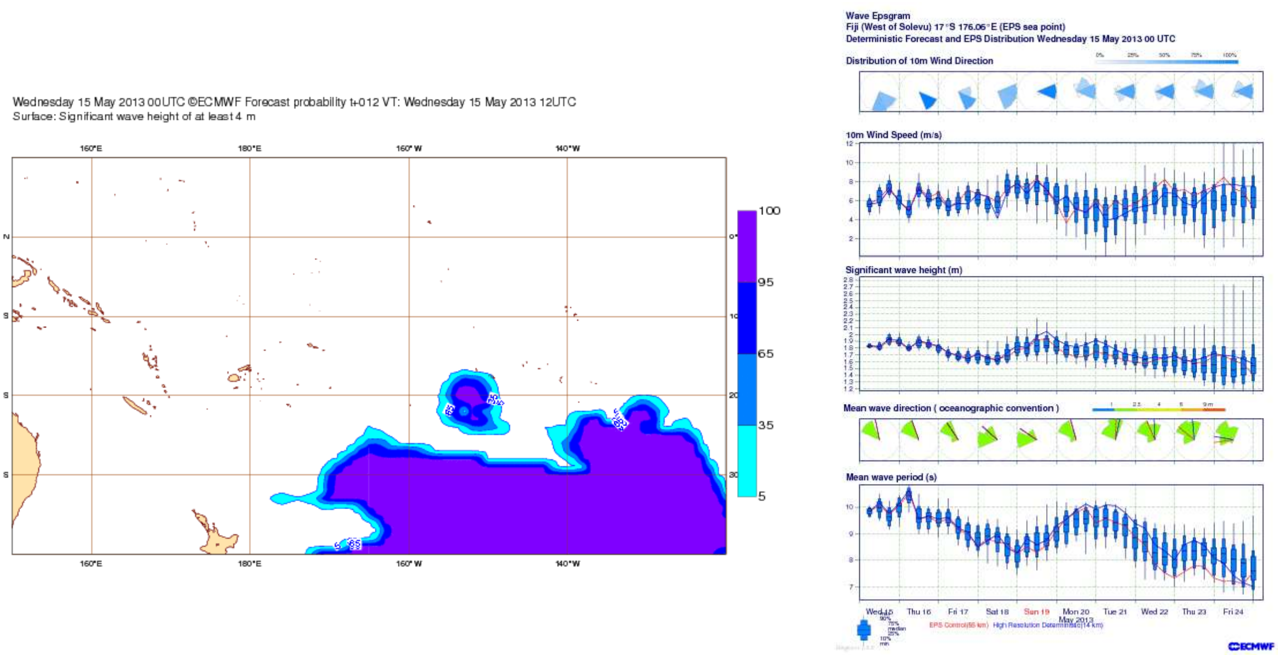


Figure 11 – Probability chart for significant wave height of at least 4m in the South Pacific (left) and Wave EPSgram in a sea location nearby Fiji (right), generated from the ECMWF EPS and which are available to SIDSs in the South Pacific, through the SWFDP regional project.

Figure 11 shows examples of a probability chart for significant wave height of at least 4m in the South Pacific and Wave EPSgram in a sea location nearby Fiji, which are available to SIDSs in the South Pacific, through the SWFDP regional project.

5. Future plans and anticipated advances in numerical weather prediction (NWP)

The atmospheric water cycle is the driving force of weather and climate, and the spatial and temporal characteristics of precipitation have profound effects on all aspects of life. A significant focus of research over the coming years is likely to be on improving the closure of the water cycle in both global and high resolution models, with the incorporation of improved hydrological and soil system models within the NWP models.

In the Tropics, rainfall is dominated by cumulus convection, which itself is organised on a vast range of different space and time scales, from the diurnal cycle of individual clouds to the planetary monsoon systems of Southeast Asia and Africa. The challenge of representing the multi-scale nature of tropical convection in global models is widely recognized. This limits our ability to forecast beyond a few days in the Tropics and potentially compromises our global extended range and longer term predictions. A concerted effort to use cloud system resolving models, combined with new satellite observations of cloud structures, to develop new understanding of organized convection is a central part of our strategy for tackling this key problem. Experimental convection-permitting models are now being implemented in some small regions of the Tropics (e.g. at 4km resolution over Lake Victoria in support of the East Africa SWFDP) supported by development funding. Such systems are computationally demanding, but with increasing computing power may be extended to larger domains and at higher resolutions, with increasingly sophisticated data assimilation and ultimately as EPS, over the coming decades. Such studies will also provide information on the multi-scale interactions between physics and dynamics and guide the design of stochastic-based parametrizations for global models. These are likely to gain in importance as the multi-scale nature of ocean and atmospheric flows is increasingly understood.

Despite decades of research, quantitative precipitation forecasting (QPF) remains an enormous challenge. Significant advances have been achieved recently with the development of convection-permitting models. These have the potential to provide better guidance on the intensity of precipitation, especially in situations with strong synoptic forcing. However, considerable research is still required on the initiation of convective storms and on how to include the stochastic nature using EPS to assess the probabilities associated with small-scale uncertainties.

Within the next 10-15 years, major NWP centres will have:
- non-hydrostatic global deterministic NWP at <5km resolutions
- global ensembles at sub-20km resolutions
- embedded convective scale ensembles
- supported by sophisticated data assimilation systems which optimally utilise a large set of observing systems
- both global and convective scale models/ensembles coupled to appropriate representations of relevant land and ocean processes
- all driving (and increasingly coupled with) downstream impact models

All of the above increase the accuracy/reliability of the product but there are still inherent errors growing with lead time at some scale-dependent rate, and the use of probabilistic products will continue to become more widespread.

Research plans for improving NWP systems are typically focussed on addressing identified deficiencies in the existing capabilities – which may be in the accuracy, resolution, or range of the forecasts. Diagnostic studies are used to identify the causes of large or persistent forecast errors, including inadequacies in observational data, deficiencies in the use of that data, and the models themselves. As well as improving the underlying forecast performance, plans aim to meet the detailed requirements of customers through targeted post-processing with supplementary models, and through application of statistical and physical diagnostic relationships. Typical examples of key research topics might be:

- Very short range thunderstorm forecasting, especially the need for improved data assimilation, including the use of new data sources such as Doppler radar and quantifying the benefits of 4D-Var and ensemble approaches to data assimilation
- Forecasting the nocturnal boundary layer structure, especially the evolution of cloud and the response to topographic variability
- Improved methods of using ensemble forecasts to predict forecast uncertainty and improve the use of observations via ensemble-based data assimilation techniques.
- Model and data assimilation codes that run efficiently on massively parallel computer architectures
- Improved post-processing systems providing a seamless forecast production capability from hours to months ahead

- Improved techniques for diagnostic adjustment of forecasts
- More sophisticated post-processing to support warnings of the expected impact of the forecast weather.
- Coupling of atmosphere, land surface hydrology, ocean waves & ocean dynamics in global and regional configurations at all timescales
- Improved representation of atmospheric composition to improve radiation and cloud physics processes and to predict visibility and air quality

Addressing these many areas of research and implementing them into operational models is a highly complex task, and is increasingly undertaken in a collaborative framework. Many NWP model systems, such as the Met Office's Unified Model and the DWD's COSMO, are now developed by consortia of global NWP centres and also in collaboration with multiple academic partners in universities and other research institutes.

One of the greatest challenges of the coming years will be effectively exploiting the vast numbers of processors in the next generations of supercomputers. This will require a major restructuring of model codes.

6. The Challenge: mitigating the growing technological gap in weather forecasting

The Global Data Processing and Forecasting System (GDPFS) enables WMO Members to make use of these advances by providing a framework for the sharing of data related to operational meteorology, hydrology, oceanography and climatology. As noted in the introduction, the challenge is: *how do we mitigate the growing technological gap in weather forecasting? How do we bridge the gap between those who have the knowledge and those who don't, those who have the capacity to run, maintain, develop and support such complex systems and those who don't have the capacity, and the capability?* The WMO's Severe Weather Forecasting Demonstration Project (SWFDP) has been attempting to close this gap by increasing availability of existing NWP, and developing capacity to exploit it, including EPS, in countries where it has not previously been used effectively. Ongoing sustainable training, both in the interpretation of GDPFS products, and in the use of these to issue effective warnings systems which lead to effective action to protect lives and property, is a critical component of the project (see *Workshop Papers entitled: "SWFDP and its Future Directions towards Strengthening/Sustaining WMO's Operational Centres", and "SWFDP Regional Frameworks and their Impacts in Developing and Least Developed Countries"*).

Reliance just on the global products and nowcasting systems would be a sub-optimal solution, but given where we are at present, probably still a very good solution for many NMHSs. A more optimal solution would include implementation of:

- "convection-permitting" models with grid-lengths of ~km, which are particularly suitable for severe weather forecasting in tropical and sub-tropical regions;
- high resolution rapid refresh systems (e.g. hourly) for very short-range forecasting.

This would be possible in the future at well-established Regional Centres, but requires the support by advanced global centres in the transfer of knowledge of such proven techniques. For some regions these advances may be best provided, at least in the shorter term, directly from a global NWP centre (acting as Regional Centre), allowing NMHSs to focus their limited resources on interpretation and the issue and communication of warnings. Best solution for very short range prediction might require boost of in situ observations in area of interest.

Propagating NWP outputs (important meteorological and other weather-related parameters) into high-impact models (e.g. flash floods and coastal flood forecasting) offers further opportunities to enhance the information in support of improved warnings. This would also be possible in the future at well-established Regional Centres, and again would need the support of advanced global centres in the transfer of knowledge of such proven techniques.

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RSMCs AND THE WMO INFORMATION SYSTEM (WIS)

Regional Specialized Meteorological Centres (RSMCs) have been designated by the Commission for Basic Systems (CBS) to provide information that has to be shared regionally or globally. In many cases this information is time critical. RSMCs therefore need to be able to collect and distribute information reliably.

WMO Information System (WIS)

The WMO Information System (WIS) builds on the Global Telecommunications System (GTS), seeking to retain the strengths of the GTS while overcoming some of its weaknesses. Particular drivers for developing the WIS are to:

- Increase information visibility, so that greater benefits can be achieved from the investment in creating the information;
- Broaden information access, so that a wider range of users can benefit from the information; and
- Simplify information use, so that the technical challenges in obtaining the information are reduced.

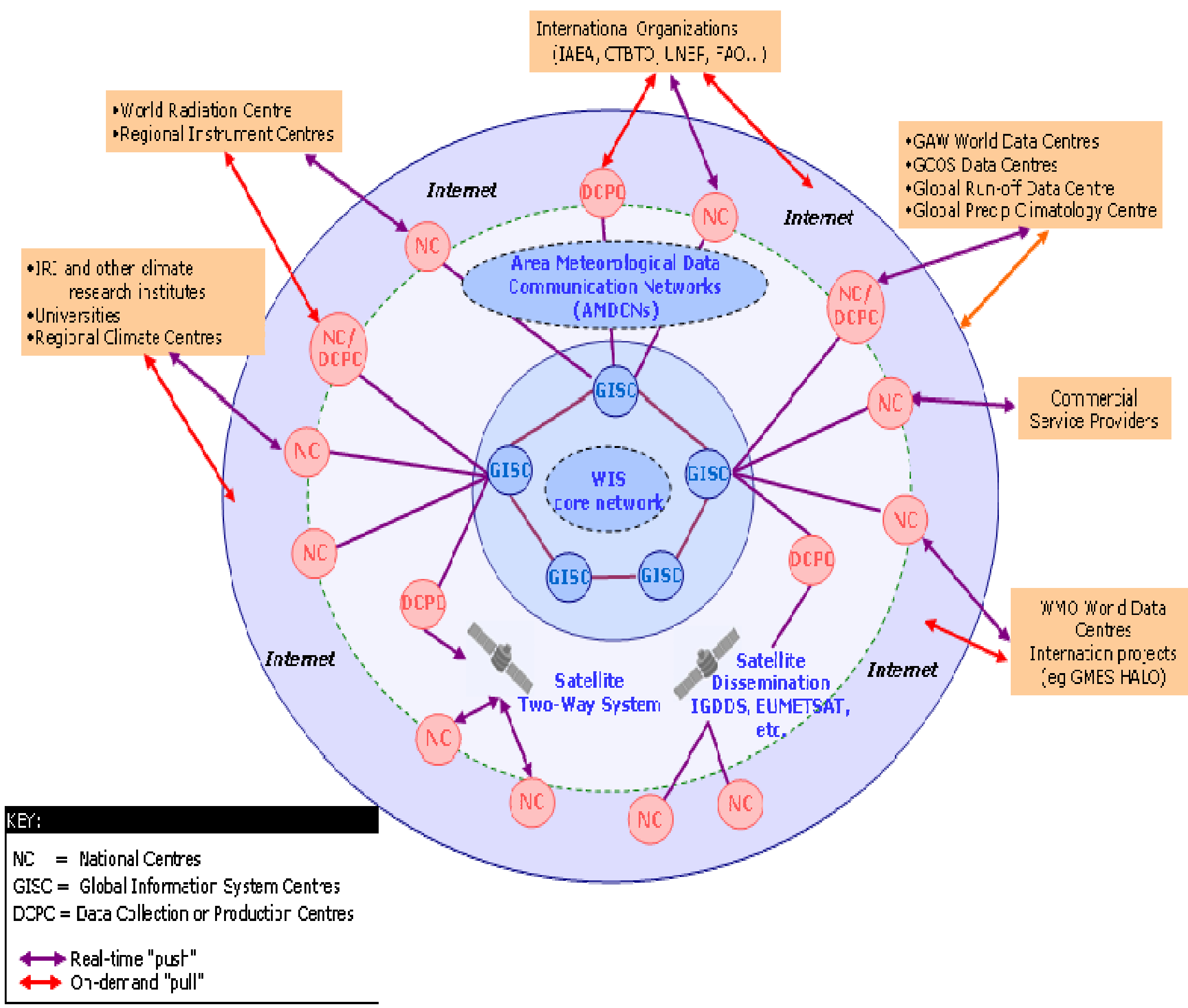

Figure I-1 – Structure of the WMO Information System (WIS).

Figure I-1 shows the structure of WIS. **National Centres (NCs)** are organizations within a country that are responsible for some aspect of weather, water or climate information. A NC collects information nationally and passes it to a WIS centre responsible for international exchange. A NC also receives information through the WIS and passes it to national users. Most users of information distributed through the WIS will receive the information through their country's NCs. The National Meteorological or Hydrological Service (NMHS) will be a NC, and some countries may wish to nominate other centres as well.

Data Collection or Production Centres (DCPCs) are centres that have a clear international role. That role can either be one of data aggregation and transmission (such as the Regional Telecommunications Hubs of the GTS), generation of information (such as ECMWF), or storage of information (such as the Global Run-off Data Centre). CBS expects that RSMCs will seek to be designated as DCPCs and use WIS for sharing the information they create.

Global Information System Centres (GISCs) have two roles. The first is to ensure reliable flow of information around the globe, and in doing so they store and can distribute at least one day of information that has been designated for routine global exchange. Their second role is to publish the catalogue of all the information that is available through the WIS.

Although the responsibilities of NCs, DCPCs and GISCs differ, many organizations are providing more than one role. For example RosHydromet that operates GISC Moscow acts as a GISC, is a DCPC as a result of its World Meteorological Centre responsibility, and is also a NC for the Russian Federation.

Submitting data to or receiving data from the GTS requires a dedicated connection with specialized equipment. This limits the number of organizations that are able to exploit data exchanged through the GTS. The WIS expands on this by allowing a wider range of telecommunications options, including the public internet. It also makes receiving information more flexible; information discovered in the GISC catalogue can be downloaded, or can be delivered routinely using standard techniques such as email or ftp as it becomes available.

Preparing a RMSC to be a DCPC

RSMCs are already able to deliver information to their users, so the main additional requirement of becoming a DCPC is to publish metadata about the information supplied by the RSMC. WIS Discovery Metadata is intended to help end users discover the information that is available, assess whether a particular information source is relevant to their needs, and to find out how to obtain the information. WIS Discovery Metadata records produced by DCPCs and other WIS centres are uploaded to the GISC responsible for that DCPC so that they can be shared by all the GISCs.

Before a DCPC is fully endorsed, its WIS functionality has to be assessed by CBS. This is normally done by the GISC to which the DCPC is associated (i.e. the GISC to which the candidate sends its WIS discovery metadata records), and concentrates on whether the DCPC is able to deliver the information required with appropriate reliability (from an information exchange perspective).

One of the objectives of WIS is to simplify information use, including giving users access to information sources that they can trust. As part of the quality management associated with the WIS, DCPCs have to be supported by a technical commission or regional association before they can be endorsed by CBS. All RSMCs are recorded as having been supported by CBS.

Table II-2.1 – NWP system configuration for the Advanced Global Centres, as of June 2013 (base on the information provided by WMO Members in the *Annual WMO Technical Progress Reports on the Global Data-Processing and Forecasting System (GDPFS) and Numerical Weather Prediction (NWP) Research*)

Centre, Country	NWP System	Domain	Horizontal Resolution	Maximum Lead-Time	Vertical Levels
BoM, Australia	ACCESS-G (UM)	Global	~40km N320	10 days	70
	ACCESS-R (UM)	Regional	~12 km (0.11°)	3 days	70
	ACCESS-C (UM)	Brisbane, Perth, Adelaide, VICTAS, Sydney	~4 km (0.038°)	36 hours	70
	ACCESS-TC (UM)	Tropical Cyclone - relocatable	~12 km (0.11°)	3 days	50
	ACCESS-Coupled Climate Model	Global	Atmos: ~250km T47 (2.5°x2.5°) Ocean: ~200km (1° x 2°), enhanced Tropics	1 to 9 months	38 50
CMA, China	GFS	Global	~30km T_L639	10 days	60
	GEPS	Global	~60km T213	10 days	31
	GRAPES	Regional	15km	3 days	31
	REPS	Regional	15km	60 hours	31
	Typhoon Det & EPS	Global - relocatable	~60km T213	5 days	31
	AGCM	Global	Atmos: ~200km T63 (1.875° x 1.875°) Ocean: ~200km (1.875° x 1.875°)	1 to 6 months	16 30
CMC, Canada	GDPS	Global	~25km	10 days (15 days on Sundays)	80
	GEPS	Global	~66km (0.6°)	16 days	74
	RDPS	Regional	10km	54 hours	80
	REPS	Regional	~33km	3 days	28
	HRDPS	North America Canada regions	10km 2.5km	24 hours	80 58
	CanSIPS	Global	Fully coupled with Ocean (2 model configs GCM3 and GCM4 T63/L31 and T63/L35	1 month to 1 year	40
	GEM-MACH15 (air qual.)	Regional	10km	2 days	58
CPTEC, Brazil	AGCM	Global	~45km	7 days	64
	AGCM-EPS	Global	~100km	15 days	28
	AGCM-MRF	Global	~200km	6 months	28
	BRAMS	Regional	5km	84 hours	50
	BRAMS-CCATT	Regional	25km	3 days	38
	ETA	Regional Southeast Brazil Northeast Brazil	15km 5km 10km	7 days 3 days 3 days	50 50 50

Centre, Country	NWP System	Domain	Horizontal Resolution	Maximum Lead-Time	Vertical Levels
	ETA-EPS	South America Southeast Brazil	40km 5km	11 days 3 days	38 50
	OA-GCM	Global	2-tier ~200km	6 months	28
	ETA-LRF	Regional	40km	6 months	38
DWD, Germany	GME	Global	20km	174 hours	60
	COSMO-EU	Regional	7km	78 hours	40
	COSMO-DE	Germany	2.8km	21 hours	50
	COSMO-DE-EPS	Germany	2.8km	21 hours	50
ECMWF, Europe	IFS-HRES	Global (coupled to ocean wave model)	Atmos: ~16 km T1279 Ocean waves: ~28km (~10km European waters)	10 days (5 days)	91
	IFS-ENS	Global (coupled to ocean wave model); 51 members	~32km T639 Ocean waves: ~55km	10 days	62
		Global (coupled to ocean wave model and ocean model); 51 members	Atmos: ~64km T319 Ocean: 0.3 to 1° Ocean waves: ~55km	10 to 32 days	62 42
	IFS-SEAS	Global (coupled to ocean wave model and ocean model); 51 members	Atmos: ~80km T255 Ocean: 0.3 to 1° Ocean waves: ~111km	7 months 13 months (4 times/year)	62 42
IMD/NCMRWF, India	GFS	Global	~23km T574	10 days	64
	GEPS	Global	~75km T190	10 days	28
	UM (non-hydrostatic)	Regional – 2 domains: 30ºE-125ºE; 9ºS-50ºN; 76ºE-79ºE; 26ºN-29ºN	12km 4km	10 days	70
	WRF	North Indian Ocean India Indian regions	27km 9km 3km	3 days	38
	GFS-monsoon	Global	~40km T62	4 months	38
JMA, Japan	GSM	Global	~20km T_L959	9 days (12UTC init.)	60
	One-week EPS (WEPS)	Global	~55km T_L319	9 days (12 UTC init.)	60
	One-month EPS	Global	~110km T_L159	34 days (Once a week)	60
	MSM	Japan and its surrounding (East Asia)	5km	15 hours (00061218UTC Init. 33 hours (03,09,15,21UTC Init.)	50
	LFM	Eastern part of Japan	2km	9 hours (8 times a day)	60
	Typhoon EPS (TEPS)	Global	~55km T_L319	5.5 hours	60
	Seasonal EPS	Global - Coupled	Atmos: ~180km T_L95 Ocean: 0.3-1.0 x 1.0 deg	7 months(Once a month)	40 50
KMA, Republic of Korea	GDAPS (UM)	Global	~25km N512	252 hours	70
	UM-EPS	Global	~40km N320	10 days	70
	RDAPS (UM)	Regional	12km (0.11°x 0.11°)	3 days	70

Centre, Country	NWP System	Domain	Horizontal Resolution	Maximum Lead-Time	Vertical Levels
	WRF	Regional	10km	3 days	40
	UM-Korea	Korea	1.5km	12 hours	70
	DBAR (Typhoon model)	Relocatable	35km	3 days	42
	GDAPS-LRF	Global	T106	6 months	21
MF, France	ARPEGE-IFS	Global	T798C2.4 (10.5 to 60 km)	102 hours	70
	PEARP	Global	T538 var mesh 2.4 (15 to 90 km)	108 hours	65
	ALADIN	France Tropics	7.5km 8km	54 hours	70
	AROME – non-hydrostatic	France	2.5km	30 hours	60
	ARPEGE - Climat	Global	Atmos: T127 Ocean: 0.5 – 1°	6 months	31 31
	MOCAGE 3D (air qual.)				
NOAA/NCEP, USA	GFS	Global	~27km T574 (0-8days) ~70km T190 (8-16days)	16 days	64
	GEFS	Global	~55km T254 (0-8days) ~70km T190 (8-16days)	16 days	42
	NAM	Regional USA regions	12km 4km	84 hours 2 days	60 35
	SREF (NAMB/WRF)	Regional	~16km	87 hours	35
	Hurricane	Pacific, Atlantic	~3km	5 days	42
	CFS	Global	Atmos: ~100km T126 Ocean: 1/4°	9 months	64 40
ROSHIDROMET, Russia Federation	SLAV-2008	Global	~75 km (0.72° x 0.9°)	10 days	28
	GSM	Global	~75 km (T169)	10 days	31
	BGM-EPS	Global	T169 T85	10 days 30 days	31
	REG	Regional, 2 Domains : Europe + Western Siberia Eastern Siberia +Far East of Russia	~40 km ~40 km	48 hours	30
	COSMO-Ru	Regional, 4 Domains: European (incl. Ural + West Siberia) part of Russia Central Russia West Caucasia Ural and Siberia	7 km 2.2 km 2.2 km 14 km	78 hours 24 hours 42 hours 78 hours	40 50 50 40
	BGM-LRF	Global	~75 km (0.72°x0.9°)	Season	28
UKMO, UK	GM (UM)	Global	~25km N512 (0.35° x 0.24°)	6 days	70
	MOGREPS-G - EPS (UM)	Global	~33km N400 (0.45° x 0.30°)	3 days	70
	MOGREPS-15 - EPS (UM)	Global	~60km N216 (0.84° x 0.56°)	15 days	70

Centre, Country	NWP System	Domain	Horizontal Resolution	Maximum Lead-Time	Vertical Levels
	UKV (UM)	UK	1.5km (inner domain)	36 hours	70
	Euro4	Europe	4km	5 days	70
	MOGREPS-UK-EPS (UM)	UK	2.2km (inner domain)	36 hours	70
	AQUM (Air quality)	UK	12km	5 days	38
	HADGEM3-EPS (GloSea4)	Global	Atmos: ~140km N96 (1.87^{o} x 1.25^{o}) Ocean: ~110km (1^{o} x 1^{o})	6 months	85 75

Workshop Paper 2

SWFDP AND ITS FUTURE DIRECTIONS TOWARDS STRENGTHENING/SUSTAINING WMO'S OPERATIONAL CENTRES

Submitted by WMO, with contributions from the CBS/DPFS and the SWFDP-Southern Africa Regional Management Team chairpersons

1. INTRODUCTION

The Severe Weather Forecasting Demonstration Project (SWFDP) was originally designed in 2004. The SWFDP is a project carried out by the WMO's Commission for Basic Systems (CBS), under the general guidance of its Steering Group (SG-SWFDP). The two main ideas driving the project are still valid today:

- Ensure that valuable forecast information readily available in the Global Data-processing and Forecasting System (GDPFS) regarding severe weather occurrence was effectively used in operations by developing countries, and,

- Further develop the three-layer structure of the GDPFS, applying the *Cascading Forecasting Process*.

The main goals set for the SWFDP were to:

- Improve severe weather forecasting,
- Improve lead-time and reliability of warnings,
- Improve interaction of NMHSs with media and with disaster management and civil protection authorities,

and also:

- Improve the skill of products from GDPFS Centres through the provision of feedback.

2. SWFDP – EXPLOITING THE *GDPFS* FOR ENHANCED BENEFITS

2.1 Why a project on severe weather forecasting?

The World Meteorological Congress, at its fifteenth session (Cg-XV, May 2007), approved a *Vision for Improving Severe Weather Forecasting in Developing Countries* (ftp://ftp.wmo.int/Documents/PublicWeb/mainweb/meetings/cbodies/governance/congress_reports/english/pdf/1026_E.pdf, paragraph 3.1.3.11):

> *"NMHSs in developing countries are able to implement and maintain reliable and effective routine forecasting and severe weather warning programmes through enhanced use of NWP products and delivery of timely and authoritative forecasts and early warnings, thereby contributing to reducing the risk of disasters from natural hazards."*

The World Meteorological Congress, at its sixteenth session (Cg-XVI, May 2011), recognized that this Vision was being implemented through the SWFDP. That through the implementation of the "*Cascading Forecasting Process, an approach that provides improved access to, and effective use by forecasters of existing and newly developed NWP/EPS products made available by advanced GDPFS Centres, national forecasting and warning services have improved significantly, with increased lead-*

times and greater reliability" (ftp://ftp.wmo.int/Documents/PublicWeb/mainweb/meetings/cbodies/governance/congress_reports/english/pdf/1077_en.pdf, paragraph 3.1.3.7).

Following the Recommendation by CBS, Cg-XVI endorsed a *Strategy for the SWFDP* (ftp://ftp.wmo.int/Documents/PublicWeb/mainweb/meetings/cbodies/governance/tc_reports/english/pdf/1070_en.pdf, Annex XII, page 193), and approved a vision for the SWFDP as an end-to-end, cross-programme collaborative activity led by the GDPFS, in which the participants in the Projects (ftp://ftp.wmo.int/Documents/PublicWeb/mainweb/meetings/cbodies/governance/congress_reports/english/pdf/1077_en.pdf, paragraph 3.1.3.8):

(a) Make best possible use of all existing and newly developed products and facilities at the global, regional and national levels, including high-resolution NWP and ensemble prediction products, and very-short-range forecasting, including nowcasting, tools;

(b) Establish sustainable services of reliable and effective early warnings tailored to the needs of the general public and a wide range of socio-economic sectors in LDCs, SIDSs and developing countries;

(c) Ensure a continuous improvement cycle and quality assurance of services, including efficient and responsive feedback loops between the NMHSs and the end users at the national level.

The SWFDP contributes to many of the WMO's high priorities:

(i) Through the use of NWP/EPS from the GDPFS centres for predicting severe and high-impact weather, contributing to disaster risk reduction (DRR) and capacity development (as per objective 5 of the *WMO Capacity Development Strategy*);

(ii) Through evermore skilful and useful prediction services with increasing resolution across all scales of modelling. This includes for climate, increasing forecast lead-times in the medium-range, and beyond, and increasing accuracy to widen the scope of applications, that contributes to climate change adaptation (with a high likelihood of the globe experiencing changing climatology of extreme weather events), and thereby to the Global Framework for Climate Services;

(iii) By benefiting other socio-economic sectors, including aviation, agriculture, and marine safety;

(iv) As a starting point for developing and establishing national severe weather warning programmes for WMO Members, and a vehicle to assess the gaps in the Basic Systems, including WIGOS and WIS, for effective weather warnings' services

2.2 Strategies

Cooperation through the Cascading Forecasting Process

The initial aim of the SWFDP was to demonstrate how cooperative work among operational meteorological centres could be further implemented. This would enhance the forecasting process of several types of severe weather phenomena, which in turn would improve the warning services provided by the NMHSs.

The SWFDP's organization is a three-level system (*Cascading Forecasting Process*) which carries out various functions at the global, regional and national levels. The GDPFS is an underpinning capability for weather forecasts and warning services in all WMO Members. In addition to this organization, several GDPFS Centres are officially entrusted with the responsibility of providing NMHSs with specialized products (e.g. for medium-range forecasting, tracking and forecasting tropical cyclones, long-range forecasting, and transport of radiological pollutants in emergency response). Nevertheless, for severe weather events which can cause many casualties and widespread damage, some NMHSs have had very little access to advanced GDPFS capabilities. Enhancing the exchange and use of existing products or readily adaptable products among GDPFS centres and with these NHMSs was therefore highly desirable.

Continuous learning and modernization

Since their inception the skill of Numerical Weather Prediction (NWP) models (see *Workshop Paper entitled: "Anticipated Advances in NWP, including Strengths and Weaknesses"*) has continuously improved for all forecast ranges, and the models have become increasingly powerful tools for the prediction of hazardous weather worldwide. Notably, the technique used in the Ensemble Prediction System (EPS) stands out as an efficient way to provide the forecaster with alternative scenarios or probabilistic forecasts. Initially designed for medium-range global forecasting, this technique is an efficient way to take into account the various sources of forecast errors (initial state, boundary conditions, model) even for short-range and for limited area forecasting, and to understand the risks associated with severe weather.

Owing to the high computational cost of limited-area NWP and of the the EPS technique using multiple model runs, only a limited number of GDPFS centres have been able to operationally implement such systems. Many of the latest advances in NWP systems, such as so-called "convection-permitting" models with grid-lengths of 4km or less, are particularly suitable for severe weather forecasting in tropical and sub-tropical regions, but are extremely computationally intensive and can be supported only by the most advanced and resourced centres (most likely the global and regional centres). Moreover, to make effective use of NWP and ensemble systems also requires the application of complex model-output post-processing systems to generate forecast products to support severe weather forecasting, and several GDPFS centres provide the forecaster with sophisticated products such as maps of potential vorticity, convection indices, etc. The SWFDP provides the opportunity to encourage operational forecasters to utilize such standard or newly developed products and procedures, which have already been introduced in many GDPFS centres and which could be relevant to a number of NMHSs that have not yet used or applied them.

In addition to NWP systems, GDPFS centres also provide nowcasting systems for very-short-range forecasting of severe weather based on extrapolation of observational data. Appropriate for the SWFDP with near-global coverage are nowcasts based on satellite imagery.

Despite the increasing number of GDPFS centres that run global and limited-area NWP models and nowcast systems, not all forecasters benefit from the recent progress of the NWP techniques or from the training necessary to efficiently use the large numbers of products available from GDPFS centres. This is particularly the case in Least Developed Countries.

The SWFDP framework represents a systematic approach for building capacity and for transferring knowledge and skills to operational weather forecasting teams across the NMHS community. Its approach has been used to implement a series of proven, modernizing enhancements to the forecasting process, as well as providing a channel for the testing of relevant promising S&T research and development outputs. An example is the WWRP/TIGGE project "Global Interactive Forecast System" (GIFS).

The evaluation of the first regional project in Southern Africa showed that the SWFDP was a successful demonstration of how developing countries could be assisted to reduce the technology gap and increase their capacity in operational severe weather forecasting and further enhance national weather warning services for the protection of life and property. The Commission for Basic Systems (CBS) therefore recommended transitioning matured regional projects into a fully operational activity, ensuring the long-term sustainability of the benefits gained with the project. This takes into account sustainability and development of SWFDP activities, including the exploring of synergies with other WMO programmes in order to respond to the needs of other user sectors (e.g. aviation, marine, hydrology, agriculture, etc). To ensure long-term sustainability of the benefits of the SWFDP, ongoing training is a major requirement, which should take place on an annual basis and should become sustainable within the regions.

Regional project management and implementation

SWFDP implementation has four phases (see Annex I). These are a series of specific regional projects dedicated to severe weather forecasting, each exchanging relevant products and experience among selected GDPFS and national centres at the three levels of responsibility – global, regional, and national.

Planning, partnerships and accountability

One of the reasons for the success of the SWFDP is that an efficient management framework has been put in place. Each regional project has been managed within the regional, with appropriate guidance from the Project Steering Group (that provides a linkage to CBS mechanisms), and with considerable support from the WMO Secretariat. Good project management practices have been encouraged, including the setting up of a continuous improvement cycle, with regular reporting and evaluation of progress and objective identification of technical gaps.

The SWFDP management framework consists of individual regional project-specific implementation plans for which management teams are accountable. Following the SWFDP guidance materials (i.e. the Overall SWFDP Project Plan and the Guidebook for Planning New SWFDP Regional Projects), each regional project-specific implementation plan describes key aspects. These include team members' responsibilities, project activities and milestones (typically for 12-18 months) such as training and reporting. These actions build and sustain partnerships of WMO global to regional operational centres with less capable national centres in a geographical region. Country-specific/national implementation plans have also been developed within the SWFDP (resources permitting), addressing gaps and weaknesses, and including a review of current levels of services, training requirements and outputs. Stakeholder engagement is very important and is also included. This should assist in ensuring long term sustainability of projects. For example the SWFDP engages with the meteorological-related groups within the regional economical bodies (i.e. comprising Heads of Meteorological Services and Ministries in charge of meteorology) encouraging regional ownership and sustainability of the benefits gained with the project.

Implementation

The SWFPD implements a *Cascading Forecasting Process* implying the participation of selected countries/centres chosen within a geographical area affected by agreed types of severe weather event. The cascading process aims to ensure the real-time distribution of the relevant available information produced by both Global Centres and a Regional Centre to selected NMHSs. Moreover, it is necessary to continue the cascade by making the final authoritative products of hazardous conditions (advisories or warnings) produced by the NMHSs available to the final users, such as local bodies or teams in charge of hydrology and/or local Disaster Management and Civil Protection Agencies (DMCPA).

Global-scale products, as well as data and information provided by other Regional Centres, are integrated and synthesized by a Regional Centre (typically a designated Regional Specialized Meteorological Centre (RSMC)), which, in turn, provides daily guidance for short-range (days 1 and 2) and medium-range (out to day-5) on specified hazardous phenomena (e.g. heavy rain, strong winds, damaging waves, etc.) to participating NMHSs of the region. This is the "Cascading" concept of the forecasting process (from global centres through regional centres, to a small group of NMHSs), including their PWS structures – Figure 1). Regional Centres interpret information received from Global Centres, prepare daily guidance products for NMHSs, maintain a RSMC Web site and Portal, and liaise with the participating NMHSs, especially in case of predicted severe weather event(s).

Regional centres may also run additional limited-area models to provide detailed local forecast information for the region.

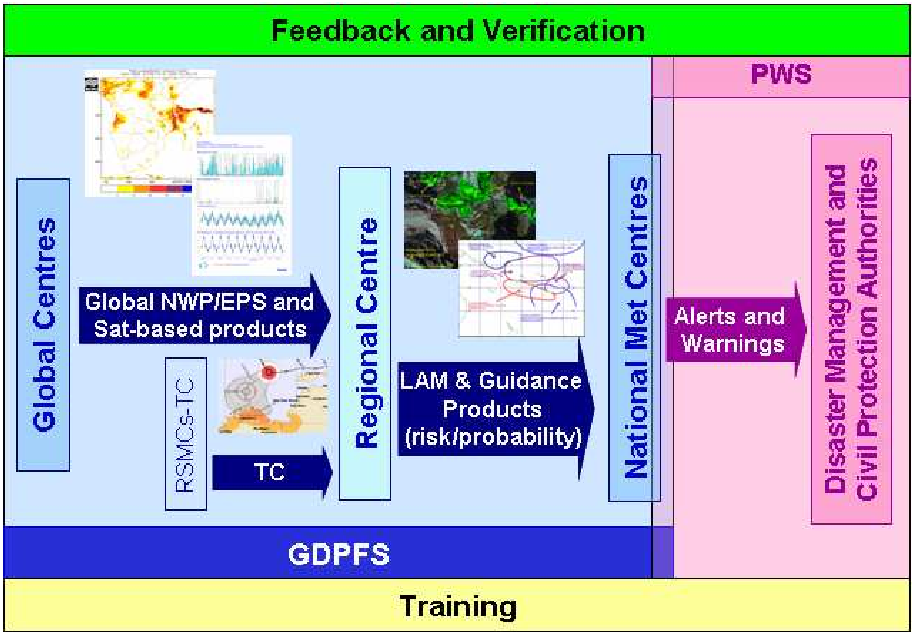

Figure 1 – The *Cascading Forecasting Process* of the SWFDP.

Near real-time verification and evaluation is conducted, based on observations of the meteorological parameters collected at local meteorological stations as well as information gathered on the impacts of the severe weather phenomena, such as those reported by DMCPA services, or news services. This evaluation of the performance of the cascading process, including the quality of the NWP/EPS and guidance products, will then be provided as feedback to the participating centres to further fine tune the process and products.

Training is a critical component of the SWFDP, which is carried out on an annual basis. The forecasters of the NMHSs need to know how to optimally utilize the various products coming from the Global Centre(s) and the Regional Centre(s) in the framework of severe weather forecasting (e.g. interpretation and presentation of NWP and EPS products and probabilistic forecasts, special guidance for selected severe weather events, synthesized satellite images, etc.). Similarly, training is required in service delivery principles and practices including user focus, communication skills and user satisfaction assessment.

Practically speaking there is no need to provide in-depth information on the way the products are produced, but it is essential to emphasize how the products should be used by the forecaster when facing a potentially dangerous weather situation. The presentation of case studies is also indispensable. Annual training is essential both to provide updates on new and evolving products and to provide training opportunities for new staff entering the system.

It would be expected that the staff assigned to the SWFDP project at the centres involved would maintain close working relationships, whereby "training" and consultations are an ongoing aspect of the routines of the project.

Resources for implementation and sustainability

A study was carried out to review the development of the SWFDP since its inception, and to scope out the resource requirements for ensuring effective implementation and long-term sustainability of the benefits gained with the SWFDP (available at ftp://ftp.wmo.int/Documents/PublicWeb/www/swfdp/SWFDP-study-29Aug2012.doc). Figure 2 shows the funding requirements for the implementation and sustainability of a SWFDP regional project (based on 6 NMHSs, 1 regional centres and 3 global centres; and no costs for infrastructure).

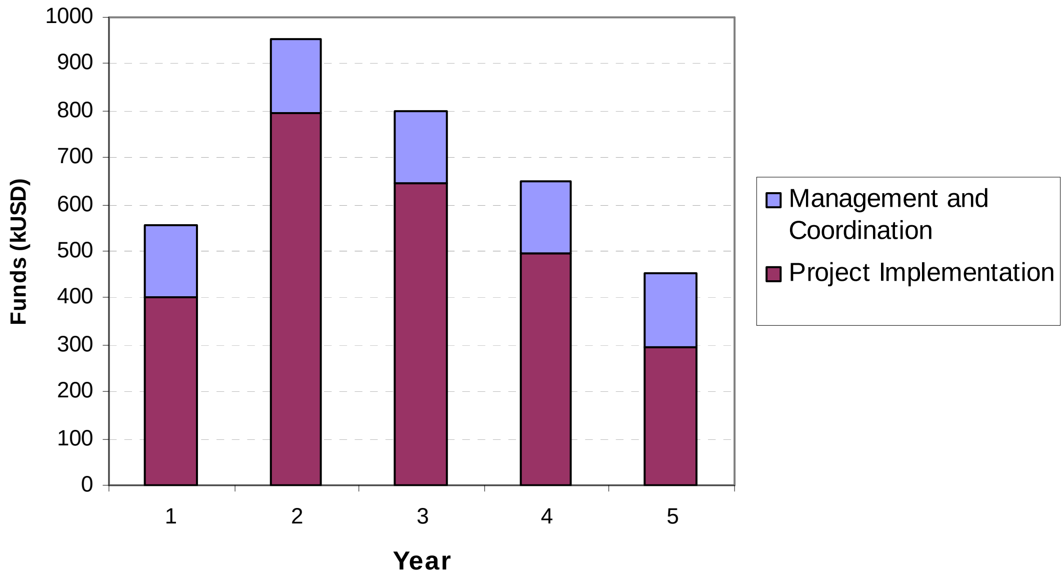

Figure 2 – Funding for implementation and sustainability of a SWFDP regional project (based on 6 NMHSs, 1 regional centres and 3 global centres; and no costs for infrastructure).

The support from advanced global centres that provide NWP/EPS and satellite-based products, and the roles played by the regional centres are critical components for the implementation of the SWFDP regional projects, and has been provided by in-kind contributions by WMO Members. This does not include the special global guidance service (financial resources permitting) provided by advanced global centres (for specific and limited periods, typically 1 or 2 rainy season period(s)) to assist regional centres in fulfilling their regional responsibilities in providing daily regional forecasting guidance to NMHSs in their geographical region. Such additional support can greatly accelerate the uptake of global NWP model outputs and satellite-based products by regional centres, and lead rapidly to more effective exploitation of such resources. This service also includes visits of trained regional forecasters to national centres of countries in a geographical region for hands-on training, to further improve the entire end-to-end chain from production to the delivery of warning services to the users.

The GDPFS programme's regular budget (through savings and re-apportionment from other activities) has financially supported many of the SWFDP-related events, including training and planning activities, while a number of WMO Programmes (e.g. ETR, PWS, TCP, AgM and SAT) have collaboratively provided limited funds to support expert participation at some of the SWFDP-related meetings. Collaboration with these programmes has also included opportunistic use of other organized events to share resources and expertise.

No specific WMO Regular Budget has been allocated to GDPFS for the coordination, management and implementation of the Project; however WMO surplus funds allocated for the 2009-2011 period allowed the expansion of the first SWFDP in Southeast Africa (5 countries) to include all 16 countries in Southern Africa, and to initiate a second project in 2009. The initiation of the 3 other SWFDP regional projects was only realized with extrabudgetary funds that have been provided either by WMO Members through the VCP programme or by external organizations (such as the Word Bank, UNESCAP, Government of Norway, AusAid, and NZAid).

WMO staff responsible for the GDPFS, in collaboration with PWS, have been involved with the coordination, management, tracking and implementation of the SWFDP and its 5 regional projects. In view of the limited resources available, to sustain provision of the support to the existing and new projects requires a dedicated Office, which is estimated to require annually an equivalent of 2 person-years of staff.

2.3 Regional projects

The SWFDP continues to experience important benefits and significant growth, with 5 regional projects (Figure 3), either underway or under development (Southern Africa, South-west Pacific, Eastern Africa, Southeast Asia, and Bay of Bengal/South Asia). These projects presently involve several WMO global and regional operational centres (e.g. RSMCs), 41 NMHSs of developing countries (29 of which are LDCs/SIDSs) (Annex II, Table A-II.1), and engage several WMO programmes (i.e. GDPFS, PWS, TCP, DRR, MMO, AgM, SP, ETR, CD, LDC, RP, and WWRP) and technical commissions (i.e. CBS, CAgM, CHy, JCOMM, and CAS). Status information is provided in Annex II. Others regional projects are in consideration, resources permitting.

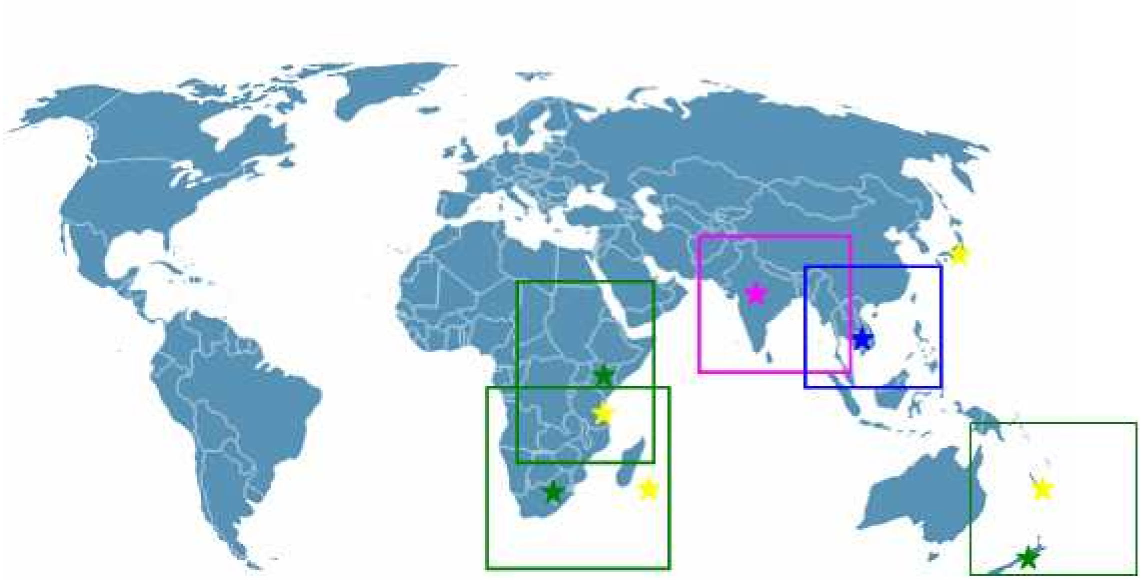

Figure 3 – SWFDP regional projects, either underway (Southern Africa, South Pacific and Eastern Africa – in green) or under development – in different stages: Southeast Asia – in blue (in development since 2010), and Bay of Bengal/South Asia – in pink (early stages of development). Regional Specialized Meteorological Centres (RSMCs), carrying out the central regional role for the project, are RSMC Pretoria, RSMC Wellington and RSMC Nairobi, respectively for the SWFDP regional projects: Southern Africa, South-west Pacific, and Eastern Africa identified (in green). New regional centres – Regional Forecast Support Centre (RFSC) are being established: RFSC Ha Noi for the SWFDP – Southeast Asia (in blue), and RFSC Dar (in yellow) for the Lake Victoria Basin. The RSMC with activity specialization in Tropical Cyclones (RSMC-TC) New Delhi is expanding its role to address other hazards and take the central regional role for the SWFDP – Bay of Bengal/South Asia. Other supporting centres, including RSMCs-TC in yellow.

2.4 Lessons Learnt, so far

The principles applied to the regional project development and implementation, including an efficient management framework at regional level, with appropriate oversight from the SWFDP project steering group and considerable support from the WMO Secretariat has made it a success. The programme has improved NMHS capacity to provide short to medium-range forecasting and warning services of weather-related hazards (thereby increasing their visibility, credibility and value of meteorological services). It has also provided strong evidence of real benefits at the level of the NMHSs' delivery services to their users, and in the value placed on weather forecasting services and improving the 'return on investment' in their overall modernization efforts, particularly where there is strong national interest and leadership.

Another important aspect explaining the positive outcome of the SWFDP is that it is highly cost-effective. The project budget has been building, but is still modest compared with the benefits. Even taking into account the substantial in-kind contributions of the global and regional centres involved, the overall total cost is much less than what might generally be expected for projects resulting in this level of outcome. It is also certainly very much less than it might cost to implement similar NWP and nowcast capabilities locally in individual NMHSs, and much more likely to be sustainable on a long-term basis. In the early stages and still the case in some senses, funding for project activities has been ad-hoc and not adequately secured for ensuring a long lasting legacy of benefits.

The primary approach to building climate resilience and mitigating extreme weather hazards is through capacity development and investment in NMHSs to provide more timely and useful early warnings. Specifically, this requires institutional strengthening of NMHSs, reinvestment in national observing networks, improved forecasting, and placing a greater focus on delivering information and prediction services that meet the needs of governments, industry and communities, particularly in developing and least developed countries. Sustaining this investment requires technical training, a favourable continuous learning environment, and access to technical expertise and reliable and quality assured products that can help NMHSs attain increasingly higher level of forecasting and service delivery skills. This would largely rely on effective partnerships, as those established through the *Cascading Forecasting Process* that provides improved access to and effective use by forecasters of existing and newly developed products and tools made available by advanced operational global and regional centres, where a tremendous contribution to transfer from proven R&D to Operations can be achieved. The initial choice to develop and build upon a 3-layer cascading process has proven to be a good one, perfectly well in line with today's operational meteorology. In addition, the engagement of the meteorological-related groups within the regional economical bodies (i.e. comprising Heads of Meteorological Services and Ministries in charge of meteorology) is critical to ensure regional motivation and ownership, addressing collective needs, and sustainability of the benefits gained with the project, in a continuous learning environment.

Likely the most important weaknesses identified are that many of the NMHSs of developing and least developed countries do not have an adequate programme for severe weather warnings, and insufficient use of modern NWP forecasts to increase the lead-time for anticipating the development of severe weather situations, several days in advance. Further implementation and development is required in order to establish and formalize national severe weather warnings programmes within national disaster management and civil protection frameworks, with possibly a regional coordination of national programmes across national boundaries. The SWFDP regional projects represent the regional infrastructure to support national warnings programmes.

At this point it should be strongly underlined that the most critical condition for success has been the engagement of high quality and efficient leading centres at the regional level (see *Workshop Paper entitled: "SWFDP Regional Centres and their Impact in Developing and Least Developed Countries"*). The role and functions of these centres as focal point and central hub for all information exchange between the various global, regional and national partners have been essential, including the production of coordinated forecast guidance.

The global NWP products centres have well met the requirements of the SWFDP. It is recognized that these centres carry out their functions reliably, and largely in an automated fashion, with infrequent problems that required technical repair and support from these centres.

Noting that many NMHSs with low capacity would not be able to handle numerical (digital) files, so far, within the SWFDP there have been limited infrastructure requirements as products being available from advanced global centres have been provided in graphical form (Web pages) via Internet for rapid display and dissemination, but may also be made available by other methods (e.g. EumetCast in Africa).

Suitable training is required to trigger a fundamental change in thinking by both weather forecasters and users (e.g. disaster management organizations) whereby alerts of severe weather would become more probabilistic in nature to represent the risks associated with severe and high-impact weather.

Among the main challenges for the SWFDP, has been the need for very short-range forecasting (including the first 12 hours) tools, especially to address the rapid onset of localized severe thunderstorms that produce heavy precipitation and strong winds, in the absence of adequate real-time observational networks, especially in absence of weather radar coverage. In this context, following the outcome of the first phase of the SWFDP in Southeast Africa (in 2008), the RSMC Pretoria Web site has incorporated Eumetsat/MSG derived products for nowcasting purposes. In addition, the project steering group has been coordinating with the WMO Space Programme, to explore collaboration related to training, satellite information (data and products) and dissemination mechanisms to support the SWFDP; which are now a core component of the SWFDP.

Cross-programme synergy has been very positive, and has strengthened the connection between the S&T that underpin the production of forecasts and warnings, with the delivery of timely and authoritative warning services to the public, the news media, and to those responsible for public safety. In addition, in the SWFDP implemented in the Eastern African region, an Agrometeorological component is included in the project, to benefit from the effective relationships that the NMHSs have with their respective socio-economically important Agricultural sector.

3. FUTURE DIRECTIONS TOWARDS STRENGTHENING/SUSTAINING WMO'S OPERATIONAL CENTRES

The SWFDP has reached a stage where a broader view should be taken of its future development. Strengthening the mechanisms established through the SWFDP, and transitioning the SWFDP to become a properly supported activity in the medium to longer-term would be an important strategic investment in WMO's plans to more fully address its priorities, for more of its Members. Therefore, there is a need to consolidate the SWFDP into a sustainable and ongoing programme to strengthen operational centres, to provide guidance of hazardous meteorological conditions and meteorological-related hazards to sustain and increase the capacity of NMHSs in developing and least developed countries to deliver relevant services. This is aligned with the WMO Capacity Development Strategy (Objective 5), and would assist in sustaining the linkages between regional and national centres in their geographical regions; as well as global to regional relationships.

Future plans and anticipated advances include the establishment of the SWFDP service in further geographical areas, providing wider access to existing and expected NWP products and forecast guidance wherever required globally. The ultimate goal is a core set of high-quality NWP including EPS and VSRF systems be used by all NMHSs, thereby building their capability to provide hydro-meteorological forecasting and warning services in support of disaster risk reduction and a range of targeted applications to broaden the benefits of SWFDP to other user sectors in society. It is expected that in the next few years, more countries in new regions (over 100 countries: developing and least developed countries; supported by a network of ~12 regional centres with activity specialization in forecasting hazardous hydro-meteorological phenomena, with contributions by ~6 other regional centres, including those for Tropical Cyclone, and ~13 global centres – Figure 4), be considered, addressing hydro-meteorological and sector-specific hazards (e.g. agriculture, marine, hydrology, aviation, etc.), beyond day-5.

Substantial in-kind contributions from a network of global and regional centres are expected to continue, however this global framework requires the engagement of sustainable high-quality and efficient leading centres at the regional level. For that, there will be a need for:

(1) Sustaining and strengthening existing Regional Specialized Meteorological Centres (RSMCs) to create fully functional regional centres aimed at regional integration of hydro-meteorological forecasting guidance;

(2) Expanding the role of relevant RSMCs with activity specialization in Tropical Cyclones involved in the pilot(s) into RSMCs with activity specialization in forecasting hazardous hydro-meteorological phenomena;

(3) Ensuring RSMC support for the '*Cascading Forecasting Process*' in all areas, consistent with the evolution of the GDPFS.

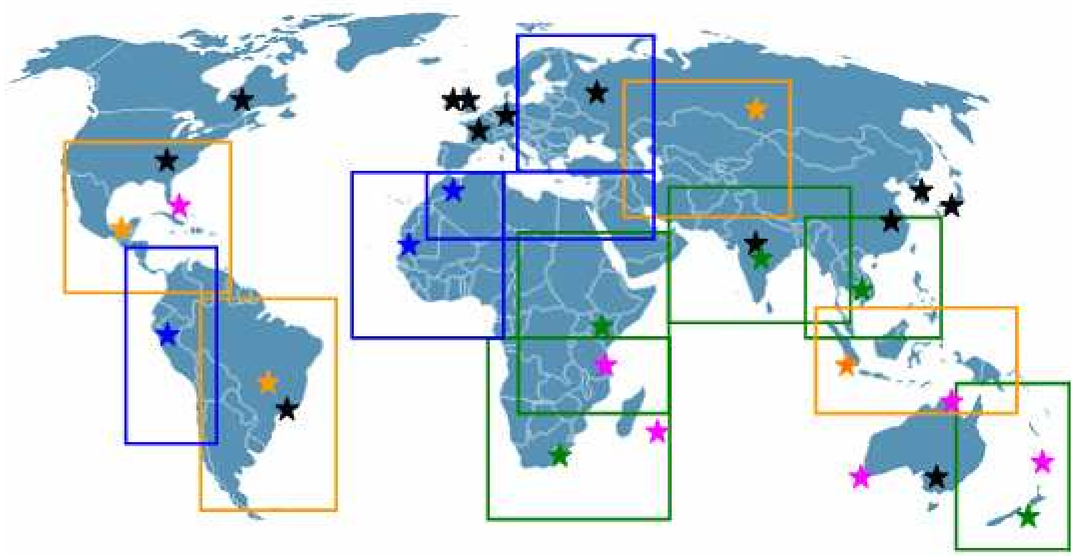

Figure 4 – Existing and anticipated geographical areas for the implementation of SWFDP regional projects, supported by a network of ~12 regional centres with activity specialization in forecasting hazardous hydro-meteorological phenomena – currently the lead regional SWFDP centres (existing SWFDP regional projects in green, early developments being planned for in 2013/2014 in orange, and future geographical regions to consider in blue), with contributions by ~6 other regional centres, including those for Tropical Cyclone (in pink); and ~13 global centres (in black).

With the addition of several more regional frameworks (including RSMCs/RFSCs) and many more NMHSs being engaged in the system, it is no longer sustainable to rely on in-kind contributions of regional and global centres, including to support the annual training activities. Sustainable SWFDP activities will require dedicated funded resources. In addition, country-specific training and development activities to implement effective warning systems and services in NMHSs, especially in LDCs, can greatly accelerate the delivery of benefits and the establishment of sustainable services, but such activities also require short-term funding for the implementation period. Some of the global and advanced regional centres are well-qualified to provide such training and development, particularly where they can provide opportunities for training within their own operational forecasting facilities, and this can provide very cost-effective training while also establishing long-term support networks between operational staff throughout the cascading forecasting process of global centres, regional centres and NMHSs.

Sustainability (including the coordination and implementation of numerous ongoing activities in the SWFDP, and with a continuous cycle of technical and "engineering" enhancements (modernization) to the forecasting process, different for each of the regional projects) has placed a highly excessive demand on the limited resources in the WMO Secretariat that has the overall responsibility for the SWFDP. The necessary conditions to sustain the services under development and allow for the planned expansions to a global service include:

(a) Funding to sustain 5 years implementation of each SWFDP regional project;

(b) An expert from each Region, who would act as regional focal point (project manager) for the implementation of the project and liaise with the WMO Secretariat. This also includes support for the recruitment (including liaison with local universities), training and development of national leaders to be "deployed" at the regional and national centres. They will be working with the regional project manager in developing country-specific implementation plans, in order to address their gaps and weaknesses, which also include audits of current levels of services, training requirements and outputs, and stakeholders' engagement;

(c) The establishment and maintenance of a Project Office (in support of the programme to strengthen operational centres, especially regional centres), which would need to be properly staffed in order to facilitate the further implementation, expansion and mainstreaming of the SWFDP into all WMO Regions and other programmes of WMO;

(d) Throughout the implementation of each SWFDP regional project, the organization of meetings of the regional project management team to (1) prepare regional project-specific implementation plans describing the team members' responsibilities, and project activities and milestones (typically for 12-18 months), such as training and reporting; (2) identify gaps and deficiencies, and areas for improvement; (3) define/refine detailed specifications in terms of data and products to be exchanged, and performance measurements; and (4) explore synergies with other WMO programmes in order to respond to the needs of other user sectors (e.g. aviation, marine, hydrology, agriculture, etc).

(e) From early stages of implementation, engagement with groupings of directors of NMHSs within the regional economical bodies (i.e. comprising Heads of Meteorological Services and Ministries in charge of meteorology) to garner their support and to ensure regional ownership and sustainability (i.e. recognition of SWFDP as a contributing mechanism for the implementation of their regional meteorological development plans and investment strategies).

At the regional forecast support level (i.e. regional frameworks that could address situations (1) – (3) above):

(a) Establishment and maintenance of regional forecasting desks at RSMCs and national warning desks at NMHSs (24/7);

(b) Maintenance and/or establishment (as part of WIS) of the RSMC Web site and Portal (password protected to allow only NMHSs to have access to products), where products from global centres are consolidated. This development should follow the concept of a "dashboard" (design and definition of a forecast process which mirrored forecast office workflow), as an aid to better decision-making. Recognizing the potential for information overload in many forecast offices, including in LDCs, a formalized forecast checklist would help to focus forecasters' attention on the most important weather issues of the day. This "dashboard" would need to be tailored to the needs of each specific NMHS, and therefore includes their participation (this links to activity (c)-(2) below);

(c) Sustaining the necessary enhancement to the mentoring and training effort to empower forecasters (as a major ongoing investment needed, a key to sustainability, and way of introducing new products from advanced centres), by:

 (1) Combining a face-to-face training (including for sharing experiences) with e-learning approaches, by involving WMO's Regional Training Centres (RTCs) for ongoing regional and national training support;
 (2) Establishing and maintaining RSMC Training Desks, as a vehicle for professional development and training of forecasters from NMHSs of countries in their geographical regions and support for attendance of forecasters at such desks. This also includes participation of these NMHSs in the technical and "engineering" enhancements (modernization) to the forecasting process (this links to activity (d) below);
 (3) Training of trainers (i.e. regional forecasters) at or with the support of global centres. This includes training at global centres' desks and global guidance service provided by advanced global centres (for specific and limited periods, typically 1 or 2 rainy season period(s)) to assist regional centres (e.g. accelerate the uptake of global NWP model outputs and satellite-based products by regional centres) in fulfilling their regional responsibilities in providing daily regional forecasting guidance to NMHSs in their geographical region;
 (4) Hands-on training of national forecasters by deploying a regional forecaster to national centres (for specific and limited periods, typically 4 weeks total per year);
 (5) Utilization and creation of regular/daily weather briefings by the regional centres (focused on potential for severe and high impact weather) in support of NMHSs in their geographical regions, with the participation of global centres (as appropriate);
 (6) Establishing a "Training Week(s)" (e.g. webinars) focusing on specific topics to address challenges that forecasters at NMHSs have to face in forecasting (especially severe and high impact weather) that support weather, climate and hydrological services. These "Training Week(s)" will be supported by global and regional centres;

(d) Tailoring the products (including for very short-range forecasting) for severe weather forecasting (focused on high impact weather) in their geographical region that would sustain, and increase, the capacity of NMHSs in developing and least developing countries to deliver relevant services, including for use in a range of application/user sectors in society (e.g. aviation, marine, hydrology, agriculture, etc.). These tailored products (including "blending" and diagnosis products) would use digital NWP data from advanced centres, and observational data both in situ from NMHSs in the region and remote-sensed. This activity is to be supported by advanced global centres in assisting regional centres to implement new proven techniques, and will have the involvement of NMHSs in the geographical region (this links to activity (c)-(2) above);

(e) Carrying out near real-time verification and evaluation, based on observations of the meteorological parameters collected at local meteorological stations as well as information gathered on the impacts of the severe weather phenomena, such as those reported by DMCPA services, or news services. This evaluation of the performance of the cascading process, including the quality of the NWP/EPS and guidance products, will then be provided as feedback to the global and regional centres to further fine tune the process and products. This activity is to be performed by national centres with the support of regional and global centres (this links to activity (c)-(2) above);

(f) Coordinating and harmonizing of warnings across geographical regions by deploying a "Meteoalert" system (a common harmonized platform for coordinating warnings). This will be able to build strong synergies as response and feedback mechanisms, and strengthen interactive methodologies between regional and national centre and so enhance both the evaluation process and the on-line discussions on topical issues, or on severe weather event and its adverse impacts. It will also be able to strengthen the relationship between NMHSs and users, as NMHSs can provide simple and clear forecast information and warning/advisory messages, giving clear statements on what is happening, forecasts of what may happen, and the expected impact. E.g. “skype” accounts will be established for improving communication between regional and national forecasting desks.

Additional activities that well-established Regional Centres may aspire to develop to further enhance the regional support they can provide, and which will require additional funding for infrastructure (improved computational resources and training staff), include:

(1) Implementing high resolution rapid refresh systems (e.g. hourly) and “convection-permitting” models with grid-lengths of ~km, which are particularly suitable for severe weather forecasting in tropical and sub-tropical regions. This activity is to be supported by advanced global centres in assisting regional centres to implement such proven techniques, and will have the involvement of NMHSs in the geographical region (this links to activity (c)-(2) above);

(2) Propagating NWP (important meteorological and other weather-related parameters) into high-impact models (e.g. flash floods and coastal flood forecasting). As an example, the Flash Flood Guidance System (FFGS, currently being implemented at RSMC Pretoria) is primarily a nowcasting tool for estimating the immediate flash flood potential (using satellite-based diagnostic estimates for rainfall amounts as input into a separate model for surface water budget estimates) that could benefit from incorporating other NWP prediction parameters to refine the water budget model (e.g., evaporation) and NWP based predictions of accumulated rainfall amounts out to 48 hours. This activity is to be supported by advanced global centres in assisting regional centres to implement such proven techniques, and will have the involvement of NMHSs in the geographical region (this links to activity (c)-(2) above).

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THE FOUR PHASES OF THE *SWFDP* REGIONAL PROJECTS

As described in the *SWFDP – The Overall Project Plan* (http://www.wmo.int/pages/prog/www/DPFS/Meetings/SG-SWFDP_Geneva2012/documents/INF4-SWFDP_OverallPP_Updated_22-04-2010.pdf) and in the *SWFDP – Guidebook on Planning Regional Subprojects* (http://www.wmo.int/pages/prog/www/DPFS/Meetings/SG-SWFDP_Geneva2012/documents/INF5-SWFDP_Guidebook_Updated_22-04-2010.pdf), the each SWFDP regional project consists of four phases, as follows:

> Phase I: Overall Project Planning. This phase includes the preparatory work necessary to prepare the project specifications, the list of types of products to be exchanged and the work of the Steering Group (SG-SWFDP) to identify the possible participating centres and to select suitable regional subprojects according to the geographical area, the type of severe weather and the chosen period for the experimentation.
>
> Phase II: Regional Project Implementation Planning and Execution. This phase begins with the preparation of the detailed specifications (data and products to be exchanged, performance measurements, reviewing and reporting) allowing the participants (representatives of the participating GDPFS and national centres) to develop the specific project implementation plan, including a training programme, and to manage its implementation and then to carry out the experimentation itself which is likely to last about one year or 18 months.
>
> Phase III: Regional Project Evaluation. This phase includes the analysis and the evaluation of the entire project as well as contributing to the evaluation of the overall SWFDP with respect to the goals proposed initially. This phase gives the opportunity to identify gaps and deficiencies, and areas for improvement in order to ensure a sustainability of the organization tested during the regional subproject and to provide improved specifications for other similar regional projects.
>
> Phase IV: Regional Project Long-term Sustainability and Future Developments. This phase includes long-term sustainability of the benefits gained and a process of continual improvement. This phase gives the opportunity to continuously take advantage of future capability and technology developments, and to foster broadening of activities in synergy with other WMO programmes. In this phase, the responsibility for management, including seeking funding, lies with the Regional Association, while the SG-SWFDP continues to be informed of developments and to provide advice as appropriate.

It has to be noted that the Phase II, III and IV are specific to each regional project and will be repeated for each of the selected project. From the point of view of the project management, it is clear that the overall SWFDP project begins with the first step of the Phase I and after completion of Phase III of the selected regional projects, the responsibility becomes that of the Regional Associations. It is clear also that each selected regional project of the SWFDP will have its own date of beginning and date of completion of Phase III and transitioning to Phase IV.

STATUS OF *SWFDP* REGIONAL PROJECTS AS OF APRIL 2013

- The SWFDP in Southern Africa has been implemented successfully and is now in Phase 4, which means it has turned from the roll-out phase to 16 countries, to the phase of continuous development and sustainable activities. The SWFDP – Southern Africa project is to be maintained relative to the implemented routine forecasting framework of the project, i.e. the cascading forecasting process. RSMC Pretoria carries out the lead centre role for the Project. A new project implementation plan (entitled "Regional Phase 4 Implementation Plan ("RP4IP") has been developed and is available at http://www.wmo.int/pages/prog/www/CBS-Reports/documents/Regional-Phase4Impl-Plan_2011draft.doc.

- A second project, in implementation for the South Pacific, commenced its full demonstration phase in November 2010. The SWFDP – South Pacific is focused on heavy rains, strong winds, and damaging waves for nine Island States, with the central RSMC role for the project undertaken by RSMC Wellington, while RSMC Nadi (Fiji) and RSMC Darwin (Australia) enhanced their existing regional forecasting functions. In addition to PWS and DRR, collaboration was established with TCP, MMO and WWRP programmes to properly address the technical aspects of tropical cyclones and marine-related hazards, such as damaging waves and storm surges. The Regional Project Implementation Plan (RPIP) is available at http://www.wmo.int/pages/prog/www/CBS-Reports/documents/ImpPlan_SWFDDP_Nov2010.pdf.

- A third project is in implementation in Eastern Africa, focused on forecasting and warning services for the general public, agriculture and fishery communities. KMD and TMA are hosting, respectively, the RSMC Nairobi for the entire project footprint, and the Regional Forecast Support Centre (RFSC) Dar for the Lake Victoria Basin. The RPIP for the initial demonstration of the project, which commenced in September 2011, is available at http://www.wmo.int/ pages/prog/www/CBS-Reports/documents/RSIP-SWFDP-EA.pdf.

- Developments for the implementation of an SWFDP in Southeast Asia have been made, focusing on heavy rain and strong winds. The Regional Forecast Support Centre (RFSC) Hanoi will take the role as the lead regional centre. A RPIP has been drafted and is available at http://www.wmo.int/pages/prog/www/CBS-Reports/documents/RSIP_v4.4.pdf, and the project would likely commence its implementation in late 2013.

- Plans have initiated in Region Association II to consider a SWFDP regional project for the Bay of Bengal region (South Asia). The RSMC with activity specialization in Tropical Cyclones New Delhi will expand its role to become the lead regional centre for the project. A RSIP is being drafted and the project would likely commence its implementation in late 2013.

Table A-II.1 – SWFDP Participating Countries

Regional project	Participating Developing Countries	Status/Notes
Southern Africa	Botswana, Madagascar, Mozambique, South Africa, Tanzania, Zimbabwe Angola, Comoros, DR-Congo, Lesotho, Malawi, Mauritius, Namibia, Seychelles, Swaziland, Zambia	In implementation since 2006 Expanded in 2008

Eastern Africa	Burundi, Ethiopia, Kenya, Rwanda, Tanzania, Uganda	In implementation since 2011
South Pacific Islands	Samoa, Solomon Is., Vanuatu, Fiji, Cook Is., Kiribati, Niue, Tonga, Tuvalu	In implementation since 2009 Expanded in 2010
Southeast Asia	Cambodia, Lao PDR, Philippines, Thailand, Vietnam	In development since 2008
Bay of Bengal	Bangladesh, India, Maldives, Myanmar, Sri Lanka, Thailand	In development since 2011

Workshop Paper 3

SWFDP REGIONAL FRAMEWORKS AND THEIR IMPACT IN DEVELOPING AND LEAST DEVELOPED COUNTRIES

Submitted by WMO, with contributions from the CBS/DPFS and SWFDP-Southern Africa Regional Management Team chairpersons

1. INTRODUCTION

The Severe Weather Forecasting Demonstration Project (SWFDP) is a project carried out by WMO/CBS to further explore and enhance the use of outputs of existing numerical weather prediction (NWP) systems, including ensemble prediction systems (EPS). It aims to contribute to capacity building by helping developing countries to access and make use of existing NWP products for improving warnings of hazardous weather conditions and weather-related hazards. The SWFDP is primarily built on the Global Data Processing and Forecasting System (GDPFS) programme, in collaboration with the Public Weather Services (PWS) to improve severe weather forecasting and warning services. It coordinates, as appropriate, with other WMO Technical Commissions and Programmes to extend the range of targeted applications to broaden the benefits of the SWFDP to other user sectors in society.

The SWFDP follows a “Cascading” concept of the forecasting process (see *Workshop Paper entitled: “SWFDP and its Future Directions towards Strengthening/Sustaining WMO’s Operational Centres”*) whereby global-scale products (made available by advanced GDPFS centres, i.e. Global NWP Centres), are integrated and synthesized by a regional centre (typically a designated Regional Specialized Meteorological Centre (RSMC)) to provide daily guidance for short-range and medium-range forecasts of hazardous weather phenomena such as heavy rain, strong winds and damaging waves to NMHSs in its geographical region, enabling those centres to issue effective severe weather warnings in their regions. Regional Centres also supplement the global products with locally produced data and information.

The expected outcomes include:

- Enhanced capability for NMHSs to forecast severe weather and issue warnings at national level, including improved accuracy and longer lead-times;
- Enhanced access to global and regional nowcasting products for very short-period forecasting;
- Established warning processes agreed with national disaster management and civil protection authorities, along with planned responses for protection of lives and property;
- Established forecast processes and Quality Management Systems (QMS), and strengthened forecast capabilities in support of other users sectors at the national level;
- Raised awareness of the value of NMHSs with national governments and their agencies, leading long-term to greater national support and investment, leading in turn to improved supply of observations and feedback into the GDPFS system;
- Reduced loss of life and damage to property with contributions to the Millennium Development Goals of eradicating extreme poverty and reducing child mortality.

The approach follows the Millennium Development Goal of a Global Partnership for Development and contributes directly to disaster risk reduction and climate change adaptation.

Advances being made in numerical weather and climate prediction by advanced GDPFS centres that run global systems (see *Workshop Paper entitled: “Anticipated Advances in NWP, including Strengthens and Weaknesses”*) would require downscaling and tailoring their products (e.g. by a Regional Centre) for practical use by NMHSs. While acknowledging the importance of the continued support from global centres that provide NWP/EPS and satellite-based products, it is recognized that Regional Centres play the backbone role in the implementation of the SWFDP. Strengthening and sustaining WMO operational centres within the SWFDP regional frameworks (especially Regional Centres and their linkages to NMHSs in their respective geographical regions, and with Global NWP Centres for continuous learning) would sustain and increase the beneficial impacts of the development of much needed capabilities at NMHSs of developing and least developed countries (which typically lack the basic human and financial capacity) for delivering weather, climate and hydrological forecasting and warning services.

2. *SWFDP* – EXPLOITING THE *GDPFS* FOR ENHANCING AND SUSTAINING OPERATIONAL SERVICES

2.1 SWFDP regional frameworks

The principles applied to SWFDP planning and implementation (through regional projects) is built on efficient management frameworks at regional level, with appropriate guidance from the project Steering Group (that provides a linkage to CBS mechanisms), and with considerable support from the WMO Secretariat. Good project management practices have been encouraged, including the setting up of a continuous improvement cycle, with regular reporting and evaluation of progress and objective identification of technical gaps.

Why a regional framework? NMHSs in a geographical region (i.e. neighbouring countries) typically need similar (or the same) products and there would be efficiency gains in coordinating their requirements (collective needs). Similar views to the user requirements, therefore a regional framework would provide a forum for sharing expertise and experiences among forecasters, including on how to deal and liaise with with intra-government communication, emergency services, the media, etc. A regional framework also provides a coordinated, harmonized and consistent approach to address hazards (including high impact weather situations in a geographical region), as well as a continuous learning environment. At the same time, observational data are typically more widely shared among NMHSs within a regional economical body (directed by regional data policies), which could lead to regional forecast improvements.

The SWFDP management frameworks consist of individual regional project-specific implementation plans for which management teams (comprised of representative of global, regional and national centres) are accountable. Following the SWFDP guidance materials (i.e. the Overall SWFDP Project Plan and the Guidebook for Planning New SWFDP Regional Projects), each regional project-specific implementation plan describes key aspects. These include team members' responsibilities, and project activities and milestones (typically for 12-18 months) such as training and reporting. These actions build and sustain partnerships of WMO global to regional operational centres with less capable national centres in a geographical region. Country-specific/national implementation plans have been developed within the SWFDP (resources permitting), addressing gaps and weaknesses, and including a review of current levels of services, training requirements and outputs. Stakeholder engagement is very important and is also included. This should assist in ensuring long term sustainability of projects. For example the SWFDP engages with the meteorological-related groups within the regional economical bodies (i.e. comprising Heads of Meteorological Services and Ministries in charge of meteorology) encouraging regional ownership and sustainability of the benefits gained with the project.

SWFDP: a cross-cutting activity involving multiple WMO Technical Commissions and Programmes, led by the GDPFS

The World Meteorological Congress, at its sixteenth session (Cg-XVI, May 2011) agree that SWFDP should be an end-to-end cross-programme collaborative activity led by the GDPFS, that engages all WMO programmes that concern the real-time prediction of hydro-meteorological hazards, through their respective technical commissions: from observations, to information exchange, to delivery of services to the public and a range of targeted applications/user sectors, education and training, capacity development and support to LDCs, and to the transfer of relevant promising research outputs into operations.

Standards and guidance established by WMO are effectively implemented by WMO Members through projects like the SWFDP, in particular in developing new capacities, benefiting from new technologies, managing change and developing appropriate mentoring schemes. The success of the SWFDP is in part because it takes a holistic, regional-driven approach, i.e. through improving the entire end-to-end chain from production to the delivery of warning services to the users, through the "Cascading Forecasting Process". Coordination with the Regional Programme (RP) – Regional Offices, including the Programme for LDCs, Education and Training Programme (ETR), Voluntary Cooperation Programme (VCP), and the Resource Mobilization Office (RMO), in the planning and implementation of regional projects has been (is) critical to ensure that desired, sustainable and relevant outcomes are achievable.

Many of the NMHSs of developing and least developed countries do not have an adequate programme for severe weather warnings, and insufficient use of modern NWP forecasts to increase the lead-time of anticipating the development of severe weather situations, several days in advance. Further implementation and development of the "Basic Systems" is required in order to establish and formalize national severe weather warnings programmes (coordinated by GDPFS in coordination with PWS) within their respective national disaster management and civil protection frameworks, with possibly a regional coordination of national programmes across national boundaries.

The SWFDP regional projects represent the regional infrastructure to support national warnings programmes, including in collecting and conveying the requirements for the "Basic Systems" (including coordination with WIGOS and WIS), while addressing aspects related to severe weather forecasting and warning services (e.g. this is the case for the SWFDP – Eastern Africa, where issues related to observational and telecommunication aspects are being considered/addressed). The SWFDP regional projects also represents a systematic approach for building capacity and for transferring knowledge and skills to NMHSs, especially to weather forecasters. Their framework has been used to implement a series of proven or modernizing enhancements to the forecasting process, as well as to provide a channel for the transfer of relevant promising S&T research and development outputs through trials, such as from the WWRP/THORPEX TIGGE project "Global Interactive Forecast System" (GIFS), and involves the WWRP/SERA to support effective propagation of benefits to society.

Among the main challenges for the SWFDP, has been the need for very short-range forecasting (including nowcasting) tools, especially to address the rapid onset of localized severe thunderstorms that produce heavy precipitation and strong winds, in the absence of adequate real-time observational networks, especially in absence of weather radar coverage. In this context, following the outcome of the first phase of the SWFDP in Southeast Africa (in 2008), coordination has been established with the WMO Space Programme (SAT) to ensure that satellite-based products are available through each SWFDP regional project. Satellite-related training, satellite information (data and products) and dissemination mechanisms to support the SWFDP are now core component of the SWFDP. These products made available through the SWFDP also contribute to aeronautical meteorology (AeM).

Presently, four of the five SWFDP regional projects include NMHSs of countries that are within the footprint of Tropical Cyclone basins. Synergies (including specific collaboration and joint development work) are being established with the Tropical Cyclone Programme (TCP), and its Regional Bodies. Coordination with other WMO Technical Commissions and Programmes that address applications of meteorology is associated with the nature (i.e. the main focus) of each SWFDP regional project (see section below). SWFDP contributes to the WMO Quality Management Framework (QMF) through supporting efforts in NMHSs in their implementation of Quality Management Systems (QMS).

SWFDP regional projects

The SWFDP continues to experience important benefits and significant growth, with 5 regional projects (Figure 1), either underway or under development (Southern Africa, South-west Pacific, Eastern Africa, Southeast Asia, and Bay of Bengal/South Asia).

SWFDP – Southern Africa

The SWFDP in Southern Africa currently involves the participation of RSMC Pretoria (responsible for the basic guidance forecasts out to day-5; dissemination of NWP/EPS products; and preparation and dissemination of satellite-based and “blending” products), and RSMC La Réunion (responsible for tropical cyclone forecasting); NMHSs of the fifteen SADC (Southern African Development Community) countries (namely Angola, Botswana, Democratic Republic of the Congo, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Lesotho, Seychelles, South Africa, Swaziland, Tanzania, Zambia, and Zimbabwe), as well as the Comoros; and three global NWP centres (i.e. ECMWF, NOAA/NCEP and the UK Met Office) that provide NWP/EPS products to the regional project. The project is currently in Phase 4, under regional responsibility. In addition to heavy rain and strong winds (the two main hazards addressed by the SWFDP) associated or not with tropical cyclones, the regional project also include winter weather as well as high swell and waves, particularly important to South Africa and the small island developing states (SIDSs). The project is also establishing synergies with the Southern African Regional Flash Flood Guidance (SARFFG) project. Therefore, within the framework of the SWFDP – Southern Africa there has been coordination with TCP, MMO, and HWR programmes.

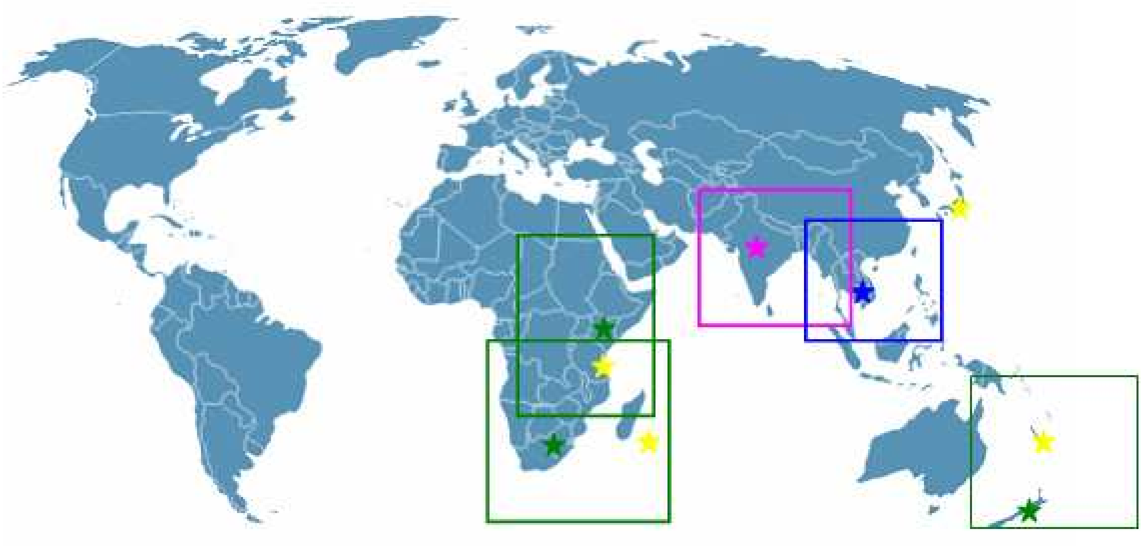

Figure 1 – SWFDP regional projects, either underway (Southern Africa, South Pacific and Eastern Africa – in green) or under development – in different stages: Southeast Asia – in blue (in development since 2010), and Bay of Bengal/South Asia – in pink (early stages of development). Regional Specialized Meteorological Centres (RSMCs), carrying out the central regional role for the project, are RSMC Pretoria, RSMC Wellington and RSMC Nairobi, respectively for the SWFDP regional projects: Southern Africa, South-west Pacific, and Eastern Africa identified (in green). New regional centres – Regional Forecast Support Centre (RFSC) are being established: RFSC Ha Noi for the SWFDP – Southeast Asia (in blue), and RFSC Dar (in yellow) for the Lake Victoria Basin. The RSMC with activity specialization in Tropical Cyclones (RSMC-TC) New Delhi is expanding its role to address other hazards and take the central regional role for the SWFDP – Bay of Bengal/South Asia. Other supporting centres, including RSMCs-TC in yellow.

SWFDP – South Pacific

The SWFDP in South Pacific currently involves the participation of RSMC Wellington (responsible for the basic guidance forecasts out to day-5 and dissemination of NWP/EPS products – a special forecaster's tool has been constructed to help generate the regional forecast guidance), RSMC Darwin (with geographical specialization) and RSMC Nadi (responsible for tropical cyclone forecasting); NMHSs of nine SIDSs (Cook Islands, Fiji, Kiribati, Niue, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu); Fiji Meteorological Service provides daily routine forecasting for four SIDSs; four global NWP centres (i.e. ECMWF, JMA, NOAA/NCEP, and the UK Met Office) that provide NWP/EPS products to the regional project; and one global centre providing satellite-based products (JMA). In addition to heavy rain and strong winds associated or not with tropical cyclones, the regional project also addresses damaging waves, particularly important to South Pacific SIDSs. The project is also establishing synergies with the Coastal Inundation Forecasting Demonstration project (CIFDP) in Fiji. Therefore, within the framework of the SWFDP – South Pacific there has been coordination with TCP, MMO, and HWR programmes.

SWFDP – Eastern Africa

The SWFDP in Eastern Africa currently involves the participation of RSMC Nairobi (responsible for the basic guidance forecasts out to day-5 and an outlook up to day-10, and dissemination of NWP/EPS products), and RFSC Dar (which coordinates and provides specialized products from high-resolution NWP over Lake Victoria, together with daily forecast guidance products); NMHSs of Burundi, Ethiopia, Kenya, Rwanda, Tanzania and Uganda; four global NWP centres (i.e. ECMWF, DWD (for providing the GME data needed for nesting COSMO), NOAA/NCEP, and the UK Met Office (also provides high-resolution NWP over Lake Victoria)) that provide NWP/EPS products to the regional project. In addition to heavy rain and strong winds, the regional project also addresses hazardous waves (South-west Indian Ocean and Lake Victoria) and dry spells, which are particularly important to this region for agriculture and food security. An Agrometeorological component is included in the project, to benefit from the well-working relationships that the NMHSs have with their respective socio-economically important Agricultural sector. In addition to severe weather forecasting and warning services for the benefit of the general public and socio-economic sectors, in particular agriculture, for the entire project footprint, the SWFDP – Eastern Africa includes a specific component addressing severe weather forecasting and warning services over the Lake Victoria, addressing marine meteorological aspects for the safety and protection of fishers, living in nearshore communities and operating daily in small vessels. Plans include extending the forecast guidance to longer timescales (monthly and seasonal), in support of RCOFs and agricultural communities. Therefore, within the framework of the SWFDP – Eastern Africa there has been coordination with AgM, MMO and WCP programmes.

SWFDP – Southeast Asia

The SWFDP in Southeast Asia, which is in development, currently involves the participation of RSFC Ha Noi (which is a newly established regional centre, responsible for the basic guidance forecasts out to day-5 and dissemination of NWP/EPS products), Hong Kong Observatory (for training and technical support), and RSMC Tokyo and RSMC New Delhi (for Typhoon / Tropical Cyclone forecasting support); NMHSs of Cambodia, Lao PDR, Philippines, Thailand and Socialist Republic of Viet Nam; six potential global NWP centres (i.e. CMA, DWD (for providing the GME data needed for nesting COSMO), ECMWF, JMA, NOAA/NCEP, and KMA) that provide NWP/EPS products to the regional project; and one global centre providing satellite-based products, and TC track forecast and TC strike probability maps, using the TIGGE CXML data under the THORPEX North Western Pacific Tropical Cyclone Track Ensemble Forecast (NWP-TCTEF) research project (JMA). Target severe weather are heavy rain and strong winds associated or not with typhoon/tropical cyclones. The project is also establishing synergies with the Flash Flood Guidance System of the Mekong River Commission. Therefore, within the framework of the SWFDP – Southeast Asia there has been coordination with TCP, WWRP and HRW programmes.

SWFDP – Bay of Bengal (South Asia)

The SWFDP in Bay of Bengal (South Asia), which is in development, currently involves the participation of RSMC-TC New Delhi (which is expanding its role as RSMC for Tropical Cyclone Forecasting to carry out the role of the regional centre for the project, responsible for the basic guidance forecasts out to day-5 and dissemination of NWP/EPS products); NMHSs of Bangladesh, India, Maldives, Myanmar, Sri Lanka and Thailand; five potential global NWP centres (i.e. ECMWF, IMD supported by NCMRWF, JMA, NOAA/NCEP, and UK Met Office) that provide NWP/EPS products to the regional project; and two global centres providing satellite-based products (IMD and JMA). Target severe weather are heavy rain and strong winds associated or not with tropical cyclones, and marine-related hazards (i.e. damaging waves and storm surges). The project is focused on the safety of coastal communities, and therefore is also establishing synergies with the CIFDP in Bangladesh and in India. I.e., within the framework of the SWFDP – Bay of Bengal (South Asia), there has been coordination with TCP, MMO and HRW programmes.

2.2 Role of Regional Centres

Based on the lessons learnt, so far, with the implementation of the SWFDP regional projects, it should be strongly underlined that the most critical condition for success has been the engagement of high quality and efficient leading centres at the regional level. The role and functions of these centres as focal point and central hub for all information exchange between the various global, regional and national partners have been essential, including the production of coordinated forecast guidance. Several important lessons have been identified relative to the functions of the SWFDP regional forecasting support centre (e.g. existing designated Regional Specialized Meteorological Centre, "RSMC", expanded RSMC for Tropical Cyclone Forecasting, or a new established Regional Centre "RSFC" – see *Workshop Paper entitled: "SWFDP and its Future Directions towards Strengthening/Sustaining WMO's Operational Centres"*):

- The Regional Centre is an unarguable project critical component of the SWFDP, in processing, downscaling and tailoring products from advanced global centres (including forecast guidance, especially for high impact weather) for practical use by NMHSs;

- The Regional Centres provides an appropriate environment to trial new proven S&T research products, in preparing the daily severe weather forecasting guidance, and provide feedback;

- The Regional Centre should be the central source for severe weather forecasting guidance, and operational coordination of the SWFDP region;

- The Regional Centre functions are largely daily and real-time, and include labour-intensive components;

- The Regional Centres could act as Training hub for forecasters in severe and high-impact weather;

- Regional forecasters need training and experience in forecasting weather hazards of their geographical region;

- Observational data, collected at the national level, relevant to monitoring of severe weather development need to be shared in real-time with the Regional Centre;

- The Regional Centre could assist NMHSs to implement post-processing methods that objectively adapt NWP forecasts with in-situ observations;

- The Regional Centres could coordinate warnings across their geographical region.

The experience acquired with the SWFDP is actually been used to redefine the role of a regional centre with geographical specialization, to become an RSMC with activity specialization in Forecasting Hydro-Meteorological Hazardous Phenomena, which provides forecasting guidance to NMHSs in a geographical region, in support of their national severe weather warnings programmes.

Annex I provides an example of an SWFDP Regional Framework, including the roles and responsibilities of a lead regional centre for the project (in this case, RSMC Pretoria) and its relationship with NMHSs in its geographical region, with showcases.

2.3 Service Benefits to NMHSs and to society in Developing and Least Developed Countries

Although no detailed socio-economical study and cost-benefit assessment have been made up to now, there are a number of evidences, including the article *"Public benefits of the SWFDP in south-eastern Africa"* (WMO, 2008; http://www.wmo.int/pages/publications/meteoworld/archive/dec08/swfdp_en.html) – in Annex II, that clearly indicate the service benefits of the SWFDP to NMHSs and to society in developing and least developed countries.

Quoting from a message from Sacrasta Nchengwa, the representative from Botswana's Department of Meteorological Services (DMS) to the SWFDP (WMO, 2009; http://www.wmo.int/pages/publications/meteoworld/archive/aug09/swfdp_en.html):

> *"… I would like to report to you that your (with your partners) dedication and tireless efforts in helping developing countries' NMHSs to improve their capability to forecasts severe weather has not gone unnoticed. Recently, the DMS through its Weather forecast issued two press releases to the public through the media and the Disaster Management Office and true to the forecasts the expected conditions did occur. The press releases were first read over all the radios as part of the news bulletins. Though we have already entered into the winter season in Botswana, our confidence in the forecasts as issued by the modes was so high that we did not even hesitate to issue a press release (which contained advisories) at least 72 hours before the onset of the expected events. The feedback was massively positive and for the first time in a long time, DMS got commendations from a lot of customers including high profile figures in the society. Most feedback we got was through the telephone and during the week following the issue of the first press release our telephone lines were busy with more requests for warnings and forecasts from a more appreciative public. What took us by surprise was the huge interest and publicity generated by those press releases … I can confidently and categorically state that the public's view about DMS has changed for the better and the DMS visibility has been enhanced as a result. Our participation in the SWFDP project surely played a huge part in this recent achievement." (2 July 2009).*

These statements recognizably noted that SWFDP led to an increase in lead-time for alerting users, up to 3 to 5 days, and a definite positive impact on NMHS' ability to forecast severe weather events, and reinforces forecasters' confidence in issuing their warnings, which is an important element in communication to users, including government stakeholders and the public. It has therefore improved interactions of NMHSs with disaster management and civil protection agencies, and contributed to welcome improvements in public image and profile, as well as improved status and enhanced visibility of the NMHSs in the country, thereby encouraging national investment in Early Warning Systems. It's through its public weather services' (PWS) component that SWFDP assists NMHSs in building effective relationships with users, including stakeholders in the context of emergency preparedness and response.

The SWFDP engages with groupings of directors of NMHSs within the regional economical bodies (i.e. comprising Heads of Meteorological Services and Ministries in charge of meteorology), who agree that SWFDP is relevant to regional socio-economic benefits and development, and support the implementation of the SWFDP at regional and national levels (i.e. within the SWFDP regional frameworks). As examples,

(a) At the meeting of the Regional Technical Implementation Team of the SWFDP for Southern Africa (WMO, 2011; [http://www.wmo.int/pages/prog/www/CBS-Reports/ documents/Report-RTIT-SWFDP-SA-Mauritius-July2011.pdf](http://www.wmo.int/pages/prog/www/CBS-Reports/documents/Report-RTIT-SWFDP-SA-Mauritius-July2011.pdf)):

"The meeting noted that NMHS members of the Meteorological Association of Southern Africa (MASA) had requested WMO to continue to support the SWFDP, including all countries of the southern Africa region. The WMO Executive Council, at its sixtieth session (2008), responded positively to this request. The meeting further noted the commitment made by the Meeting of SADC Ministers Responsible for Transport and Meteorology (Pemba, Mozambique, May 2010) to support the SWFDP in Southern Africa. The Chair invited Mr Mark Majodina, representing MASA to make a statement in this regard.

Mr Majodina, expressed the view of the Meteorological Association of Southern Africa, that the SWFDP has been enormously beneficial to its members, and represented a genuine partnership between the developed and the developing world in meteorology. The demonstration has been important for this region, from the initial project that involved five NMHSs, and at the request of MASA in 2008, expanded to all sixteen countries of the southern African region with additional support from WMO. At the annual meeting of the Ministers of SADC, it was recognized that 1) the SWFDP was a contribution to climate change adaptation in improving the prediction of severe weather; 2) NMHSs were requested to secure the future of the project by allocating sufficient budget to ensure its continuation; and 3) SWFDP is relevant to regional socio-economic benefits and development. It was recognized that LDCs were not likely in a position to allocate adequate budget to permit their full participation, and therefore resource mobilization efforts are needed.
(…)
The meeting concluded that the support of MASA was important to ensure governments of the region will favour and further develop this project into the future, including providing overarching direction on its goals and priorities, as well as ensuring adequate resources are mobilized to support its activities, especially for regular technical training and developmental activities, and project coordination. At the same time MASA requested that the participation of the global and regional centres, and that coordination with WMO, continue."

(b) *"The East African Community (EAC) Heads of National Meteorological Services participated in the second meeting of the Regional Subproject Management Team (RSMT) for the Severe Weather Forecasting Demonstration Project (SWFDP) in Eastern Africa to be informed of achievements and challenges, and provide direction on its future implementation and possible expansion. The outcome of the meeting will inform the EAC five-year Meteorological Development Plan and Investment Strategy.*

The Heads welcomed the significant contributions of the SWFDP to disaster risk reduction, sustainable development and climate change resilience, as well as to vital socio-economic sectors as agriculture and fisheries. They agreed that the Project has enhanced the authority and visibility of National Meteorological Services (NMSs), and built public and government confidence in the accuracy and reliability of forecasts and warnings of severe weather events.

The Heads acknowledged that the SWFDP represents a systematic and practical approach for strengthening capacity in and for transferring new knowledge and skills to NMSs in developing and least developed countries, to deliver improved forecasts and warnings of severe weather to save lives, livelihoods and property.

The Heads therefore recommended that the Project should be sustained and strengthened as it moves from demonstration to operational stage. This will necessitate additional resources and commitment at regional and national levels to ensure EAC leadership in transforming the Project into an integral part of the forecasting and warning services of NMSs in the region." (EAC, 2013)

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South African Weather Service
ISO 9001 Certified Organisation

Report: RSMC Pretoria

RSMC PRETORIA

South African Weather Service

BACKGROUND

On request of RA1, the South African Weather Service (SAWS) was mandated by WMO in the mid 1990's to be a Regional Specialized Meteorological Centre (RSMC Pretoria) with geographical specialization (Southern Africa). Under this mandate RSMC Pretoria have the following functions (from the WMO *Manual on the Global Data-Processing and Forecasting System*):

- Providing the interface between WMCs and NMCs by formatting and distributing global products to meet the needs in a particular Region;
- Providing regional analysis and forecasting products for 12–48 hours, for designated areas;
- Providing meteorological assistance to United Nations humanitarian missions, in the event the relevant associated NMC is facing an emergency or is in catastrophic distress and out of service;
- Coordinating with other RSMCs as appropriate.
- RSMCs shall also carry out verification and intercomparison of products and arrange regional workshops and seminars on centres' products and their use in national weather forecasting.

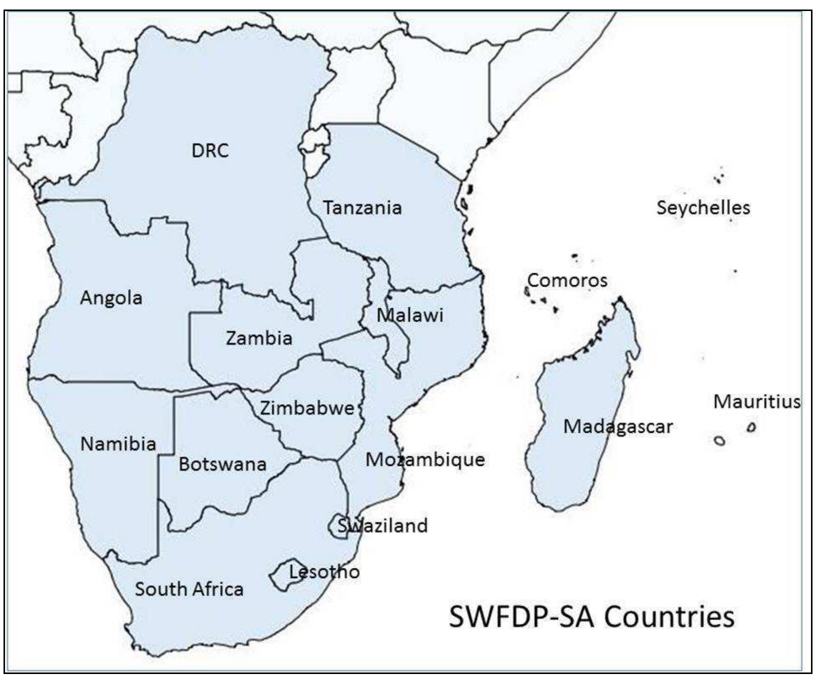

Figure 1: Countries within the responsibility region of RSMC Pretoria.

OVERVIEW OF RSMC PRETORIA AND ITS ACTIVITIES

Introduction

The daily forecasting activities of RSMC Pretoria are performed by the National Forecasting Centre (NFC) of the SAWS Forecasting Department in Pretoria, with support from the other departments in SAWS, specifically ICT, Research and International Relations. RSMC Pretoria has developed a dedicated RSMC Pretoria website (Figure 2) through which NMCs in the region can access various kinds of information, including products from the UM SA12 running in SAWS over the SADC region, and satellite-based nowcasting products developed in SAWS for the region. It is password protected to allow only NMCs to have access to the products. RSMC Pretoria is supporting NMCs in their countries and thus do not provide products to other users within other counties. This webpage is due to undergo a revision to comply with standards, make provision for additional products and cater for the needs of the NMCs.

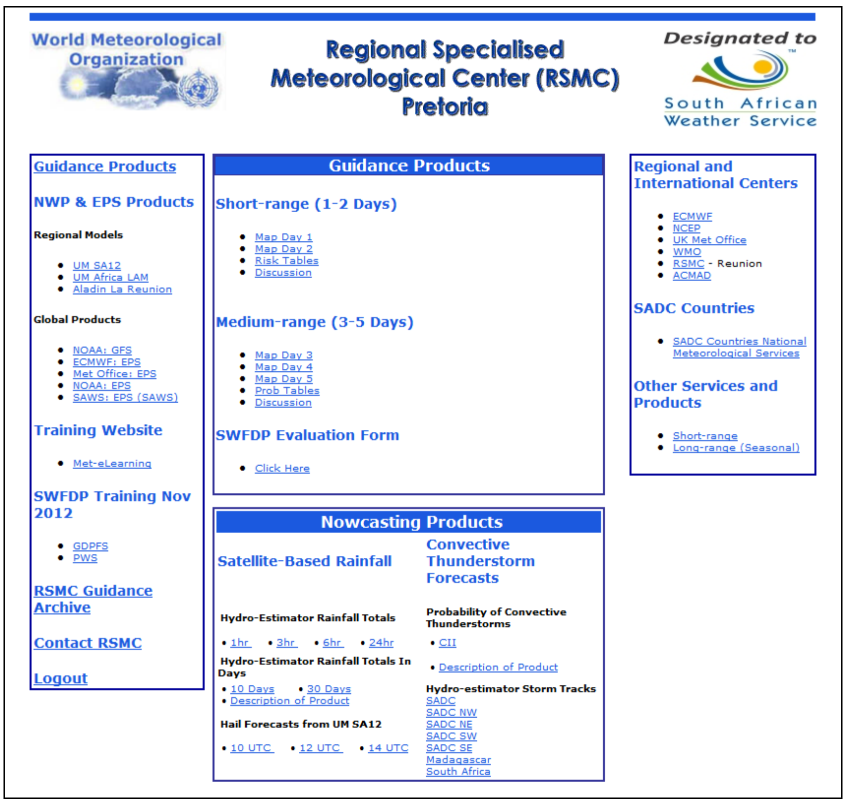

Figure 2. RSMC Pretoria website, dedicate for use by NMCs within its responsibility region.

In 2006 WMO approached RSMC Pretoria with the request to be the first RSMC that will test the concept of the Severe Weather Forecasting Demonstration Project (SWFDP). Since 2007 RSMC Pretoria has dedicated significant effort and contribution to the success of the SWFDP project in Southern Africa. This included providing guidance products every day for the following five days on potential severe weather over the entire RSMC Pretoria domain. In support of its SWFDP activities, the RSMC Pretoria webpage was modified to include relevant SWFDP products, including the guidance forecasts. Other regular activities include hosting the annual training events, and since January 2012 acting as the regional secretariat for the operational SWFDP activities as the project entered the final Phase 4 of the SWFDP program.

In 2009 RSMC Pretoria was requested by WMO's Hydrological Department to also be the regional centre for the Southern African Regional Flash Flood Guidance system (SARFFG) sub-regional project. This required RSMC Pretoria to coordinate regional input in terms of data provision during the development of the regional flash flood warning system. The system is anticipated to be operational from October 2013 whereupon RSMC Pretoria will host and manage the SARFFG modelling system on a dedicated computer, and provide guidance and support activities similar to SWFDP for the seven participating SARFFG countries. This will add additional responsibilities to the activities of RSMC Pretoria.

With time, it is anticipated that the Regional Early Warning System (REWS) of SADC will develop additional components to the current SWFDP and SARFFG activities. Through these projects and activities RSMC Pretoria is fulfilling its role as RSMC regarding how it should perform its functions mentioned above.

Impact of RSMC activities on SAWS

The RSMC activities are provided currently as an in-kind service by SAWS. In a nutshell these include about 50% of a senior forecaster shift per day (approximately 4 to 5 hours), focussing on preparing the guidance products every day, seven days a week. When the SARFFG system becomes operational, this activity is likely to become even more time-consuming (by a matter of a few additional hours per day to ensure that an effective service is still delivered. Other core operational activities unrelated to SWFDP already put undue pressure on the forecaster to maintain situational awareness during episodes of severe weather, whilst simultaneously devoting extended periods of time to the creation of SWFDP products. Naturally, in extreme circumstances, this type of scenario is likely to compromise the quality of the SWFDP guidance products. Consequently SAWS will in future be forced to consider devoting a dedicated shift, manned by a senior forecaster for RSMC activities.

Other staff impacts are:

- The requirement of variable senior staff time to perform the secretariat functions, specifically preparing reports,
- Arranging of training workshops,
- Attending relevant meetings in the SADC region and abroad,
- Lecturers at the training sessions including the time spent on preparation of lectures,

System development relates to:

- *Ad hoc* time of research staff to develop products specifically for the RSMC region related typically to the UM SA12 model and MSG satellite nowcasting, and
- RSMC webpage maintenance and development.

SPECIFIC ACTIVITIES OF RSMC PRETORIA

SWFDP (Severe Weather Forecasting Demonstration Project)

Introduction

The SWFDP project aims at supporting NMCs of developing and least developing countries to have access to modern forecasting technology (such as NWP and Ensemble Prediction System products) that they never before had access to in order to improve their forecasting services . It thus tested the concept of cascading of specialized forecasting information from World Meteorological Centres (WMCs) via RSMC Pretoria to the National Meteorological Centres (NMCs). RSMC Pretoria also had to provide regional guidance every day for the next five days on potential severe weather based on an analysis of the global and other products, provides higher resolution regional model products from its own NWP suite to the NMCs and developed nowcasting products based on the MSG satellite for the region. A major component of SWFDP is to develop the in-country coordination between NMCs and their local disaster management authorities and media. Another coordination component developed through SWFDP is coordination on a daily, and more intensively on a severe weather event basis, between the forecasters of the various NMCs and also with RSMC Pretoria's forecasters.

SWFDP in Southern Africa (SWFDP-SA) has progressed by December 2011 to the final Phase 4 of the WMO's SWFDP Programme. Phase 1 was the planning phase that started in 2006. Phase 2 was the 1-year demonstration phase that lasted from Nov 2006 to Nov 2007 and during which the concept of SWFDP was successfully demonstrated in Southern Africa using three global WMCs, RSMC Pretoria, and five NMCs. From there SWFDP-SA moved to Phase 3 during which the activities of the demonstration phase was rolled out to all 15 countries in SADC plus the Comoros, including SAWS as an NMC. This phase took four years beyond which SWFDP-SA progressed to the final phase 4.

SWFDP-SA Phase 4

Phase 4 is the Continuous Development Phase of SWFDP aimed at sustainability of the SWFDP concepts within the regional early warning system. It focuses on transferring oversight to the region, broadening the activities of the SWFDP to other areas and ensures sustainability of the SWFDP concept to avoid a fall-back to the previous status where NMCs do not have access to advanced forecasting technologies. During Phase 4 WMO has already withdrawn itself from managing the regional project in Southern Africa in favour of spending their available time and funds on the other four SWFDP regional projects elsewhere in the world that were recently established based on the success in Southern Africa. The management of SWFDP-SA transferred to the region, and specifically to MASA. This includes the basic financing of activities of SWFDP-SA, although WMO supported financially the recent training workshop with additional funds from extra–budgetary funds. WMO, however, will still monitor the progress of SWFDP-SA in case it needs to provide specific assistance to aid the sustainability of the system.

Operations

RSMC Pretoria is providing daily guidance forecasts as prepared by their forecasters for the next five days to the SWFDP activities. The supervisor shift in the NFC spends a few hours per day to prepare the five relevant maps and four documents every day, totalling 9 separate products. NWP products from the UM SA12 are also provided to the RSMC Pretoria webpage, and regional satellite-based nowcasting products developed by researchers of the SAWS research department are available on the webpage.

By nature the secretariat functions (previously provided by WMO) are now performed by RSMC Pretoria, including collecting semi-annual country reports and preparing the regional reports to MASA and the WMO, and the relevant training activities. RSMC Pretoria chairs the Regional Technical Implementation Team and liaises with international activities such as THORPEX TIGGE who have an interest in supporting the SWFDP projects.

Training activities

RSMC Pretoria is now responsible for arranging and conducting the SWFDP two-week regional training workshop for the SADC NMCs. During phase 4 the first major training activity was the 2-week SWFDP 2012 Training Workshop conducted from 12-23 November 2012 in Pretoria. This was the first major workshop entirely planned by the region, and funded by MASA with significant financial support also from the WMO. The organizing committee included the RSMC Pretoria SWFDP secretariat, NFC staff involved with the RSMC, the Regional Training Centre in SAWS, International Relations, and the MASA secretariat. This training session followed more or less the proven concept of previous SWFDP training workshops in Pretoria and elsewhere in the world. The successful workshop involved a forecaster per country for two weeks, and a PWS focal point per country for one week.

The 2-week training workshop is anticipated to continue annually for the foreseeable future. Another anticipated training activity related to SWFDP will include testing a RSMC Training Desk (with initial support from WMO) hosted at the RSMC Pretoria forecasting centre where a forecaster from a relevant NMC can be attached for two weeks to learn from the RSMC Pretoria forecasters.

Examples of Successful Coordination

There are various examples of the successful coordination between NMCs and RSMC Pretoria using the SWFDP principles. This is illustrated by the following two examples.

Tropical Cyclone Favio – February 2007

In the aftermaths of earlier flooding Mozambique had to deal with tropical cyclone Favio as it tore into the country on 22 February 2007 near the town of Vilanculos in the Southern Province of Inhambane. Favio developed as a tropical depression on 12 February far north-east of Mauritius. It was classified as an intense tropical cyclone by RSMC La Reunion on 20 February as it rounded the southern tip of Madagascar on its way towards Mozambique. It weakened marginally before making its landfall near Vilanculos. Moving inland in a north-westerly direction towards Zimbabwe, it weakened further though wide spread heavy rain and flooding still occurred.

Based on the information from RSMC La Reunion, ensemble tracks of ECMWF and other numerical model information, the guidance products from RSMC Pretoria (Figure 3) indicated landfall close to Vilanculos in Mozambique five days in advance, even though there were disagreement between different model products on the position of the cyclone. Forecasts for the subsequent days were quite consistent, and the movement towards eastern and northern Zimbabwe was well predicted five days in advance.

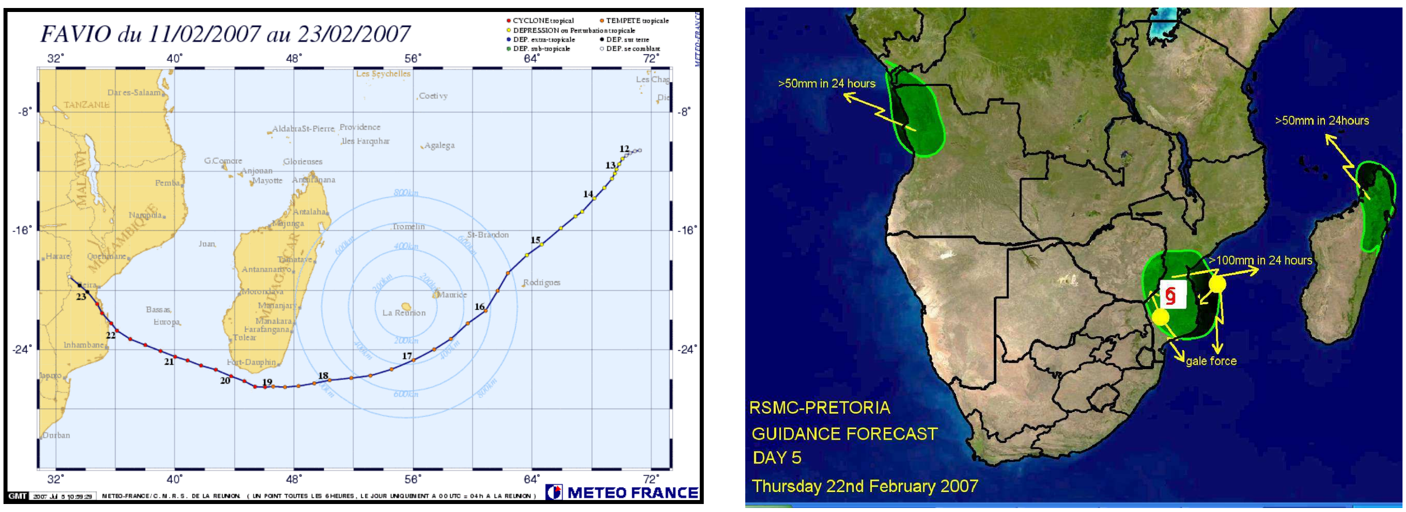

Figure 3. Track (left, and five day guidance forecast (right) of tropical cyclone Favio.

The SWFDP products were used by the National Institute of Meteorology of Mozambique (INAM) and the Meteorological Services Department of Zimbabwe (ZMSD) as guidance to warn their disaster management authorities and the public days in advance of the approaching threat.

Public warnings were initiated on the 20th when Favio was in Mozambican territorial waters. Warnings were disseminated by INAM to the media and to the Technical Emergency Committee on the status of forecasts and warnings. The response of the population, local authorities to the warnings and the measures being announced was remarkable. It prevented major loss of life given the impact of the cyclone. Scores of volunteers were ready to move people to the relative safety of schools and churches. As part of the government disaster coordinating body, the Mozambique Red Cross, supported by the international Federation of Red Cross and Red Crescent societies, were preparing for the impact of the cyclone on the Inhambane and Sofala provinces and surrounding areas a few days in advance already.

The Department of Civil Protection in Zimbabwe received the first early warnings from the ZMSD with 7 days to go. By 14 February, It was evident to ZMSD that Favio was heading towards the mainland and towards the northeast of Zimbabwe given the skill and agreement of the available guidance. Alerts were issued to Government and Civil Protection and Disaster Management Authorities by the

15th whilst early warnings were disseminated to the Public from the 16th. Despite failure by some members of the public to heed warnings, the level of disaster preparedness by Civil Protection Committees was quite high.

In South Africa the RSMC Pretoria informed South Africa's National Disaster Management Centre (NDMC) about the potential threat of tropical cyclone Favio on South Africa, as well as its likely impact on the Southern African region.

A key goal of the SWFDP was to improve the lead-time of alerting of severe weather events - and the case of Favio demonstrated success in this regard.

Tropical Cyclone Irina – March 2012

Within six weeks of the devastating impact of tropical cyclone Dando in January 2012 over southern Mozambique and South Africa, tropical cyclone Irina threatened the same region in early March. Irina was difficult to forecast as the ensemble prediction system model products from the global centres were not able to provide consistent guidance between different model runs (Figure 4). Initially the indications were that it will follow Dando into the subcontinent, but eventually it moved around just east of the sub-continent before it weakened.

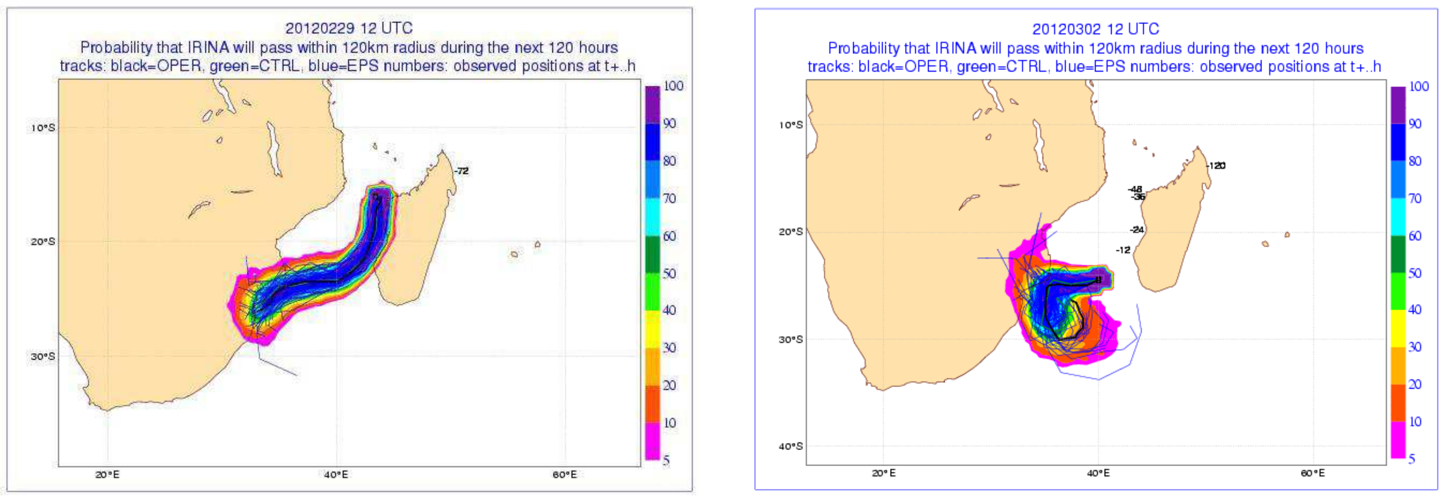

Figure 4. Conflicting products indicating the potential landfall of tropical cyclone Irina on 29 February (left) and 2 March (right).

This has lead to outstanding coordination between the RSMC Pretoria and the NMSs of Mozambique and Swaziland to predict the most likely path and impact of Irina. Frequent phone calls and email exchanges were made as the storm moved approached the sub-continent, changing its track daily. A couple of times every day during this period forecasters personally discussed the likely path based on the latest information available and the most appropriate communication to the relevant disaster management authorities. This forecasting coordination is an excellent example of what SWFDP is about, and the level of coordination achieved in the project.

The Value and Benefits of SWFDP

At its 2009 and 2010 session, the Commission of Basic Systems of WMO noted that the project continues to demonstrate the following:

- An accelerated implementation into operational use of outputs of advanced NWP/EPS systems;
- Continuous learning by forecasters as an effective way of capacity building;
- A sustainable "tight" cycle of demonstration, adapting to regional needs, evaluation, and operational implementation;
- Its contribution to adopting probabilistic forecasting methods;

- Increase in the visibility, credibility, and value of meteorological services in public and economic sectors;
- A possible new role of RSMCs of the GDPFS to synthesize and to provide forecasting guidance on severe weather forecasting to regional groups of NMCs.

Feedback from NMCs on the value of SWFDP

From the quarterly and annual reports of the SWFDP project in Southern Africa the benefits of the SWFDP project and its implementation to all Southern African countries are numerous. Among these are the following:

- Improvement of the early warning services in countries through the enhanced use of modern early warning technology such as NWP and ensemble prediction systems (EPS).
- Improve the early warning services to build resilience in support of disaster risk reduction
- Increase in the lead-time of warnings based on solid scientific information and guidance products.
- Increase in the support to national forecasters through the guidance products from RSMC forecasters, and additional NWP and EPS output, leading to enhanced confidence of forecasters in issuing forecasts, advisories and warnings.
- Capacity building of forecasters and thus NMHSs in using modern forecasting technology such as NWP and EPS.
- Increase in the access of forecasters from developing countries to modern forecasting information and improved forecasting systems.
- Increased collaboration between forecasters and their local disaster management and news media structures.
- Increased regional coordination between NMHSs, and also with the RSMC on forecasts, advisories and warnings.
- Opportunity to share, coordinates, and collates all weather warnings in the region.
- Enhanced severe weather warning services for the end-users including the general public
- Enhanced cooperation between RSMCs in the region
- Improved relationships between NMHSs, RSMCs and Global Centres
- Afford the opportunity to evaluate the performance of the global models including the usefulness of the products to forecasters

The country by country responses of the progress of SWFDP Phase 4 against the SWFDP Goals, as received in the individual country reports can be summarized as follows:

<u>SWFDP Goal 1</u>: To improve the ability of NMHSs to forecast severe weather events

From the input provided there is a unanimous conclusion that SWFDP-SA is still providing important guidance and products to improve the ability of NMHSs to forecast severe weather events. The RSMC Pretoria website remains the most important vehicle to get access to the products. The guidance products available on the website, the NWP and ensemble prediction system (EPS) products, as well as the limited area model products from UM SA12 and La Reunion Aladin is highly appreciated and has contributed to improved forecasts in most countries.

<u>SWFDP Goal 2</u>: To improve the lead-time of alerting these events

It was unanimously responded that the lead-time has increased due to the products provided through SWFPD. The role of EPS in this regard is evident.

<u>SWFDP Goal 3</u>: To improve the interaction of NMHSs with Disaster Management and Civil Protection authorities (DMCPAs), the media and the public, before, during and after severe weather events

A number of countries have significantly improved their relationships with their stakeholders during the project. There are still a few countries where NMHSs struggle to establish appropriate access to the DMCPAs where they do not exist properly, or others where new DMCPA structures recently were established. Other countries have developed excellent relationships, or report continuous improvement, with their DMCPAs. A number of countries are now also conducting, or planning to conduct, user surveys to establish user satisfaction. More need to be done in this regard, however.

SWFDP Goal 4: To identify gaps and areas of improvements (Addendum 1, table 4)
Gaps in the overall process have been identified and are addressed. These refer usually to the need for new specific products needed by the forecasters to address some specific forecasting issue. Other gaps in some countries relate to some training needs, lack of enough observation systems, internet speed challenging in some countries, and to the fact that in some countries forecasting is not a 24 hour service.

SWFDP Goal 5: To improve the skill of products from Global Centres through feedback from NMHSs
Individual comments and suggestions are made by countries as reflected in the summary report. It is evident that the products are very useful and global centres are applauded for continuing to provide them to the region.

Southern Africa Regional Flash Flood Guidance (SARFFG) System

Introduction

The WMO requested RSMC Pretoria in 2009 to be a regional centre for the implementation of their Flash Flood Guidance System (FFGS) project in a part of SADC. The FFGS (or SARFFG as the SADC regional version is called) uses satellite-based rainfall estimation as major input to the soil moisture and runoff modelling system over the 8000 river basins covering 7 countries and the model update times are 6-hourly. The main aim of the flash flood guidance systems such as SADC SARFFG is to provide guidance to weather forecasters on the potential for flash flooding in a specific basin. It is thus very similar in purpose than Numerical Weather Prediction models, but focussing on hydro-meteorological nowcasting. It is not intended to provide directly products to the public, but guidance to forecasters. It will be a significant development of the Regional Early Warning System in Southern Africa, of which the SWFDP is a principle component, and will build on the coordination framework already developed by SWFDP. This includes coordination between NMC forecasters and their disaster management authorities, and between the NMCs and RSMC Pretoria.

Progress of SADC SARFFG

The development and implementation of the SADC SARFFG system is funded by USAID. The development phase, Phase 1 of the FFGS project, was done by the Hydrologic Research Centre (HRC) in the USA. SADC SARFFG is currently running as a beta test system for more than a year at the HRC. Phase 2 implies operational implementation of the system and has commenced in January 2013. Operational implementation includes training of forecasters and the transfer of the main computer workstation to RSMC Pretoria as the operational host of the modelling system. This workstation accommodates the hydro-meteorological modelling system of SADC SARFFG. Forecasters of 7 SADC countries will then access the flash flood guidance products from this computer by internet (Figure 5). Training sessions for RSMC forecasters, ICT staff and SADC forecasters at RSMC Pretoria also forms part of Phase 2.

RSMC Pretoria will manage and maintain the SARFFG modelling system on the dedicated workstation, and its forecasters will provide guidance and support activities similar to SWFDP for the seven participating SARFFG countries on a daily basis. It is anticipated that a secretariat function, including reporting and an annual training session for the forecasters of all countries involved, will be performed by RSMC Pretoria.

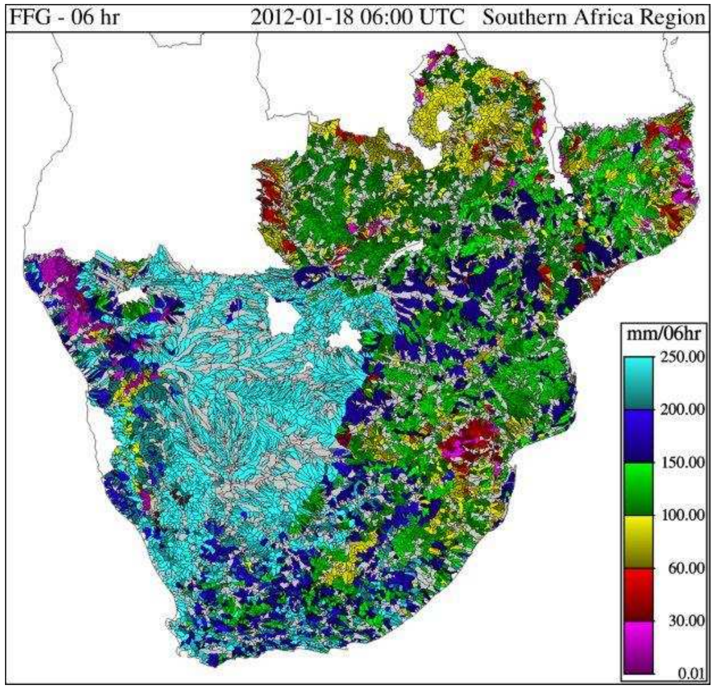

Figure 5. An example of the SARFFG flash flood guidance field after landfall of tropical cyclone Dando

CONCLUSION

RSMC Pretoria reports also to the Meteorological Association of Southern Africa (MASA), the association of SADC meteorological services. The two programme activities mentioned above, SWFDP and SARFFG, are currently the two main development activities involving RSMC Pretoria, and both are key projects for MASA. In this way RSMC Pretoria is attempting to fulfil its mandate as required by WMO, and to support the region, and specifically the SADC NMCs, with short-range forecasting activities.

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Annex II to Workshop Paper 3

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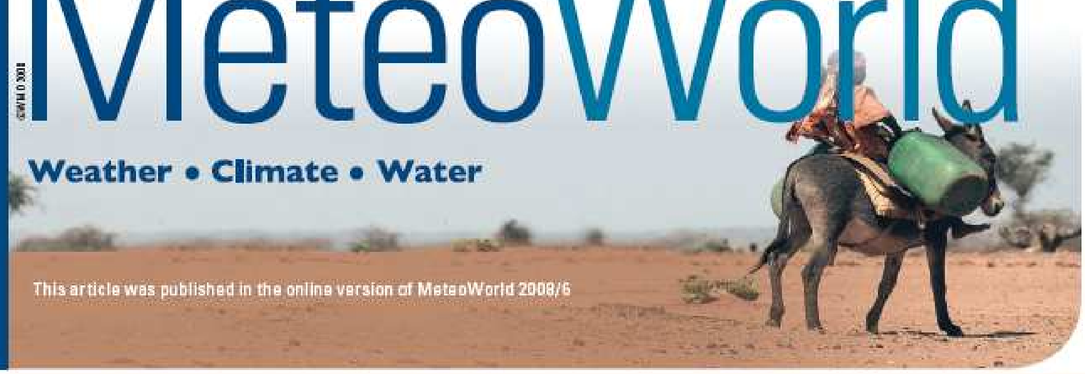

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Public benefits of the Severe Weather Forecasting Demonstration Project in south-eastern Africa

by Eugene Poolman[1], Hector Chikoore[2], Filipe Lucio[3]

Introduction

The Severe Weather Forecasting Demonstration Project (SWFDP), conducted by WMO in south-eastern Africa from November 2006 to November 2007, tested a new concept for capacity-building of National Meteorological and Hydrological Services (NMHSs) in developing and Least Developed Countries to improve warning services to communities. The project received considerable support and interest, even before conclusion of the demonstration phase. What caused this interest? Maybe the answer is that it produced positive results quickly at a relatively low cost, demonstrating a practical way of supporting NMHSs of Least Developed Countries in applying modern forecasting techniques not easily accessible to them, in order to provide real benefit to their communities.

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Background to the project

The science and practices of weather forecasting have improved around the globe at a tremendous pace over the past two decades. Major contributors to these improvements were the dramatic development in numerical weather prediction (NWP) systems, including ensemble prediction systems (EPS), giving guidance to weather forecasters many days in advance of potential hazardous weather conditions (ECMWF, 2003).

Weather services worldwide are taking advantage of these and other technological developments to improve their forecasting and severe weather warning services to the emergency management authorities and the public. The lead time of warnings of approaching severe weather has increased far beyond the traditional two days, and useful forecasts are given five days in advance with outlooks beyond that. Prospects for the future are exciting and advances in these technologies will increasingly push closer to the limits of predictability and improve services to communities (McBean, 2000).

The SWFDP Regional Subproject Management Team met in Maputo, Mozambique, from 27 February to 2 March 2007.

Against this exciting background, a different picture can be painted of the actual capabilities and services in many developing countries and Least Developed Countries in particular, where limited budgets and inadequate infrastructure hamper development and access by NMHSs to the latest technology. Very few of these NMHSs have adequate access to high-resolution NWP products, and even fewer use EPS products to extend the lead time of forecasts beyond two days.

The consequence is that a significant gap exists in the level of service that NMHSs of developing countries and Least Developed Countries can provide, compared to those in more prosperous countries. This gap is likely to increase in coming years as forecasting technology continues to advance. In an attempt to reduce this growing gap, WMO decided to explore ways to utilize existing numerical forecasting products in NMHSs where the sophisticated products are currently not used.

The Severe Weather Forecasting Demonstration Project

The Severe Weather Forecasting Demonstration Project (SWFDP) was initiated by the WMO Commission for Basic Systems to utilize the network of Global Data-processing and Forecasting System centres to provide NWP and EPS products through a cascading forecasting process from global centres via regional centres to a group of NMHSs. The first regional subproject was conducted in south-eastern Africa from November 2006 to November 2007. Its aims included the improvement of the ability of NMHSs to forecast severe weather events, improving the lead time of alerting to these events and improving the interaction of NMHSs with emergency management authorities before and during events.

Special NWP and EPS products were made available by the Global Product Centres involved, namely the European Centre for Medium-Range Weather Forecasts (ECMWF), National Centers for Environmental Prediction (NCEPs) (USA) and the United Kingdom Met Office. Regional Specialized Meteorological Centre (RSMC) Pretoria, designated to the South African Weather Service, was responsible for the distribution of NWP and EPS products through a dedicated Website to the participating NMHSs. RSMC Pretoria also provided daily guidance products of potential heavy rain or strong wind for the next five days based on an analysis of all available NWP and EPS products.

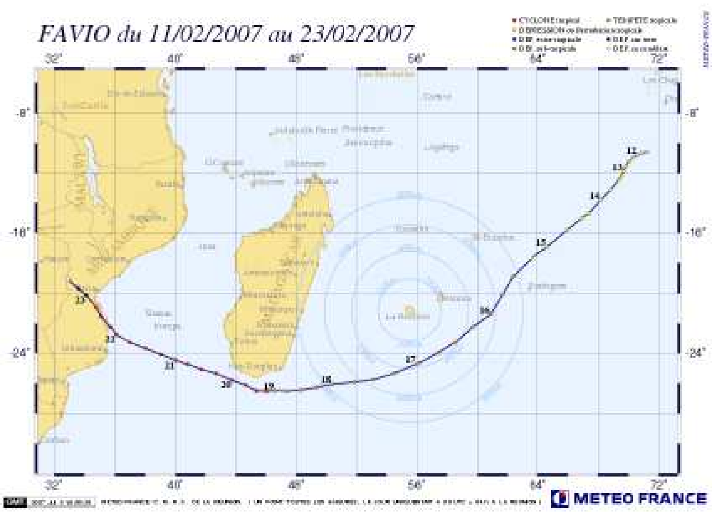
RSMC La Réunion, which is the RSMC responsible for tropical cyclone forecasts in the South Indian Ocean, maintained its normal operations and supported the project with valuable information used to prepare the guidance products. The participating NMHSs of Botswana, Madagascar, Mozambique, United Republic of Tanzania and Zimbabwe were then trained to use the guidance and model products on the RSMC Pretoria Website in deciding whether to issue warnings to their emergency management authorities of approaching hazardous weather in the next five days.

In the review of the project outcomes, it was noted that the project contributed significantly to the forecasting capabilities of the NMHSs involved (WMO Secretariat, 2008), and to the "quality and usefulness, including increased lead times of forecasts and warnings and increased confidence of forecasters". The review mentioned that the project improved significantly the lead time for alerting users to potential severe weather events, in some cases up to five days in advance. This allowed early dissemination of advisories and warnings to disaster management authorities and the media, which was appreciated by them and by the public.

In the final analysis, however, the project's success has to be determined by the impact it had on services to local communities through the warning chain. An appropriate test was the impact of the SWFDP process on potential human catastrophe before, during and after the landfall of tropical cyclone Favio on 22 February 2007 in Mozambique, and as it weakened and moved into Zimbabwe.

Forecasting *Favio*

Still struggling from the aftermath of earlier flooding in the central parts of the country that had left 120 000 people homeless (BBC report), Mozambique had to deal with *Favio* as it tore into the country on 22 February 2007 near the town of Vilanculos in the southern province of Inhambane. *Favio* developed as a tropical depression on 12 February north-east of Mauritius (see figure (*Favio* track)). By 19 February it had reached tropical cyclone status just south of Madagascar, and then started to turn to the northwest. *Favio* was classified as an intense tropical cyclone by RSMC La Réunion, with an estimated central pressure around 920 hPa (comparable to a Category 4 hurricane) on 20 February as it rounded the southern tip of Madagascar on its way towards Mozambique. It weakened marginally before making landfall with a central pressure estimated at 945 hPa. The local weather station recorded a wind speed of 195 km/h before it was blown away. Moving inland in a north-westerly direction towards Zimbabwe, it weakened though widespread heavy rain and flooding still occurred.



Track of Tropical Cyclone Favio *according to RSMC La Reunion*

Based on the information from RSMC La Réunion, ensemble tracks from ECMWF and other numerical model information, the guidance products indicated landfall close to Vilanculos in the Inhambane province of Mozambique five days in advance, despite disagreement between different model products on the position of the cyclone. Forecasts for the subsequent days were quite consistent (see fig (SWFDP guidance maps)), and movement northwards over Sofala province towards eastern and northern Zimbabwe was well predicted five days in advance.

The SWFDP products were used by the National Institute of Meteorology of Mozambique (INAM) and the Meteorological Services Department of Zimbabwe (ZMSD) as guidance to warn their disaster management authorities and the public up to five days in advance of the approaching threat. Both INAM and ZMSD used the guidance products during the subsequent days as guidance in support of their operational warning activities.

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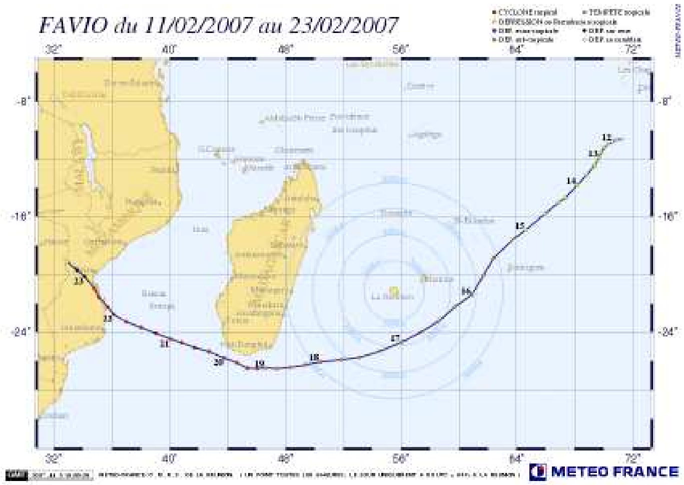

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The Department of Civil Protection in Zimbabwe received the first early warnings from ZMSD seven days ahead. A key goal of the SWFDP was to improve the lead time of alerting to severe weather events—and the case of *Favio* demonstrated success in this regard. The Department convened meetings with key stakeholders in disaster management, including ZMSD, hydrology, the police, Air Force and health, and the areas at greatest risk were mapped out. It was from these meetings that warnings were formulated and disseminated to civil protection committees in the affected areas and to the public via the different media.

Lessons for the future

The SWFDP focused attention on developing the scientific capacities of participating NMHSs in the early warning cycle. However, *Favio* gave the SWFDP an opportunity to test the application of the cascading early warning process and its impact on preparedness of disaster-management authorities and communities in an operational disaster situation early in the project's demonstration phase.

During the progress meeting of the SWFDP's Regional Subproject Management Team held coincidentally from 27 February to 2 March 2007 in Maputo, the roles of disaster management authorities in the dissemination phase of the project were discussed. As an example of input received, the Department of Civil Protection (responsible for disaster management activities in Zimbabwe) observed: "there has been a marked improvement in severe weather information and products provided by the Service (the NMHS) since the commencement of the SWFDP in November 2006" (WMO, 2007). It further stated: "there is still need for more detail and specifics with regards to the actual locations that would be hit by severe weather"—a sentiment shared by most disaster management authorities.

At the end of the demonstration phase, a number of lessons had been learned learned and gaps in the early warning process related to the public benefits identified. These gaps need to be addressed in future activities following on from the SWFDP. Although, in some instances, collaboration between NMHSs and disaster management authorities proved to be quite healthy (as shown in the case of Favio), it was not always the case with all the participating countries and this aspect needs to be addressed in more depth in the future. Prompting reaction from communities at ground level on the basis of the information provided by the NMHS is a challenge that will need special attention.

The SWFDP clearly proved its value in building the capacity of NMHSs in developing countries and Least Developed Countries to improve their early warning service and extend the lead time of warnings. The WMO review of the project (WMO, 2008), however, also emphasized that the value of the SWFDP was not only limited to severe weather forecasting in the region; it also supported day-to-day routine weather forecasting. Moreover, it played an important role in harmonizing the day-to-day forecasts of the NMHSs in the region. The SWFDP showcased a concept that worked for these five countries to such an extent that the other nine countries of the Southern African Development Community requested that it should be rolled out as an operational activity for them also. This was and will be done during 2008 and 2009. It should not end there, however. Hard work is needed in the coming years to address the gaps already identified, particularly to develop stronger links between the NMHSs and the emergency preparedness and response agencies and regional organizations. The use of the services provided by the NMHSs to these agencies for national disaster risk reduction actions must be enhanced to realize real benefit to the communities of all countries in southern Africa in the face of looming weather-related disasters.

Special recognition for the success of the project must be given to the management, forecasters and support staff of all the participating countries, the regional and global centres, and to WMO, which initiated, supported, funded and guided the project.

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Workshop Paper 4

Investing in the Cascading Forecasting Process in Modernizing National Meteorological and Hydrological Services

Authors GFDRR/WB and WMO

Summary

There is growing awareness of the high societal and economic significance of weather, climate and hydrological information and services for climate resilience and disaster reduction and of the importance of making National Meteorological and Hydrological Services (NMHSs) the center of this support.

In collaboration with the World Meteorological Organization (WMO), the World Bank and development partners are focusing efforts to modernize entire NMHSs – through institutional strengthening, improving observation networks and forecasting, and strengthening service delivery.

Efforts have focused almost exclusively on national investments; however, the WMO Severe Weather Forecasting Demonstration Project (SWFDP) has shown that the lead time and reliability of high impact weather warnings are effectively improved through a three-layer cascading forecasting process that operationally links NMHSs with WMO regional and global centers. This approach requires broader investment, particularly to support regional frameworks of weather forecasting and training. By relying on the WMO Regional Specialized Meteorological Centers (RSMCs) for numerical weather prediction (NWP) support, NMHSs can free up resources to focus more on observations, impact forecasts and service delivery. This enables NMHSs with relatively small numbers of staff and limited resources to achieve a higher level of service delivery. Incorporating support for the cascading forecasting process evinced by the SWFDP in NMHSs modernization efforts is cost-effective and can contribute to the achievement of long-term sustainability of NMHSs.

The SWFDP has identified areas where investment is needed to ensure a sustainable cascading forecasting process. At present the process relies on in-kind support of WMO Members for the global centers that provide NWP and satellite-based products, and for regional centers that provide operational guidance to NMHSs. It has operated as a proof of concept, although it is operational in several regions – in particular, southern Africa, where it is functioning routinely since November 2006. Reliance on the cascading forecasting process requires assurance that the global production centers and RSMCs will be responsive to NMHSs needs. This entails a management system that provides effective oversight from the WMO secretariat on behalf of the Members and oversight of the regional centers by the NMHSs that depend on their products.

Limited support for the cascading forecasting process was built into regional projects financed by World Bank aimed at modernizing NMHSs – for example, the Central Asia Hydromet Modernization Program. It is proposed that this effort be expanded significantly in future regional programs and national investment is aligned with the objectives of the SWFDP, which is now broadening its scope to longer-time scales in support of developing seamless early warning systems, thereby contributing to the Global Framework for Climate Services.

Several pilots, building on the existing SWFDP activities, should be proposed. The aim is to build greater synergy between NMHSs, RSMCs and global production centers and incorporate the approach into NMHSs modernization programs financed by the development community.

Funding for the operational management of the system of regional centers is also required within the WMO Secretariat to facilitate the transition from demonstration projects to operational systems within each of the WMO regions.

The outcomes from the ongoing SWFDPs and the proposed pilots should strengthen the argument for investment in regional and global centers as a cost effective, high benefit approach complementing the modernization of NMHSs through national programs and projects.

Introduction

Faced with a growing risk of weather and climate related disasters that can set back economic and social development for years, the global community needs to act quickly to strengthen National Meteorological and Hydrological Services (NMHSs). This strengthening should be done in a way that transforms weak NMHSs – especially in the developing world – into robust professional agencies capable of delivering the right information to the right people at the right time. Although the price tag of modernizing and sustaining NMHSs will be considerable, the rewards for the country and its citizens will be much higher.

The need to serve more elaborate societal needs, minimize growing economic losses from natural hazards and help countries adapt to climate change is increasing the importance of weather, climate and water information. Weather, climate and water adversely affect societies and economies through extreme events, such as tropical cyclones, floods, high winds, storm surges and prolonged droughts, and through high impact weather and climate events that affect demand for electricity and production capacity, planting and harvesting dates, managing construction, transportation networks and inventories, and human health (Rogers and Tsirkunov 2013b).

Costs of modernizing NMHSs

The key players are the NMHSs, which are the backbone of the global weather and climate enterprise. They are the authoritative source of weather, climate and water information, providing timely input to emergency managers, national and local administrations, the public and critical economic sectors.

NMHSs are small but important public sector agencies – with budgets of usually about 0.01 to 0.05 percent of national gross domestic product and total annual public funding globally of more than US$15 billion. The problem is that their capacity has become so degraded in many regions over the past 15 to 20 years – primarily owing to underfunding, low visibility, economic reforms, undervaluing of S&T investments related to the environment, and in some instances military conflict – that they are now inadequate. As a result, globally, NMHSs in more than 100 countries – over half of which are in Africa –need to be modernized.

How much will modernization cost? A conservative estimate of high-priority modernization investment needs in developing countries exceeds US$1.5 billion to US$2.0 billion. In addition, a minimum of US$400 million to US$500 million per year will be needed to support operations of the modernized systems (staff costs plus operating and maintenance costs). These recurrent costs should be covered by national governments, but few have been ready to do so. Moreover, the amount of international support for the NMHSs is significantly below what is needed just for the high-priority items (Rogers and Tsirkunov 2013c).

Complicating matters is that internationally supported NMHSs modernization efforts in the developing world have achieved only limited success so far, owing to:

- A lack of government and development agencies' understanding of the value of the NMHSs and a lack of commitment to maintain their operations;
- A preoccupation with project time-scale installation of hardware without adequate provision for training, ongoing maintenance, consumables, and other continuing technical support;
- A multiplicity of uncoordinated projects from different donors, each with its own assistance policies, objectives, and equipment suppliers, without sufficient regard to the individual NMHS's entire needs, circumstances, and priorities; and
- The technical complexity of the projects.

What can be done to improve the track record of modernization efforts and help policy makers realize the urgent need to overhaul NMHSs?

Why are NMHSs important?

Weather, Climate, and Water Hazards

In recent years – thanks largely to advances in weather forecasting and improved understanding of the societal risks through assessment of the hazards – people have been better prepared for natural disasters. Despite an increase in the number of disasters and people affected since 1980, the number of people killed has not risen significantly. However, there is a huge concern that the number of people affected and the number of disasters will continue to rise and will in turn increase the number of people killed if governments and other stakeholders do not intervene. The reasons are many:

- An increasing number of people and assets are located in areas of high risk;
- Developing countries will continue to be exposed to frequent and extreme weather events as climate change exacerbates these extremes;
- The world's population continues to explode;
- The urbanization trend continues, with more people living in cities than ever before; and
- Weather- and climate-sensitive diseases claim more than 1 million lives eachyear; most are children under five years of age in developing countries.

Between 1970 and 2010, natural hazards killed about 3.3 million people (World Bank 2010). They also took a huge financial toll on human well-being. In 2011, about 206 million people were victims of natural disasters, and the economic impact was US$366 billion (UNISDR 2011). During a longer period, between 1980 and 2011, the total estimated financial cost from floods, droughts, and storms was more than US$3.5 trillion (Munich Re 2012).

Weather, Climate, and Water Forecasts

The NMHSs make a significant contribution to safety, security and economic well-being by observing, forecasting and warning of pending weather, climate and water threats. However, this contribution is rarely quantified, which often results in an undervaluing of the vital role that NMHSs play in a country's capacity to cope with meteorological and hydrological hazards. Also severely undervalued are the economic benefits of accurate weather, climate and water information to increase productivity and avoid losses.

Accurate forecasting depends on a network of global, regional and national remote and in situ observations of the atmosphere, oceans and land that are conducted by NMHSs and their partners. These observations are assimilated by a network of global and regional forecast centers, which have differentiated responsibilities for the production of global, regional and national products. This system ensures that large-scale numerical predictions – which are needed for a good national forecast but require enormous computing power – are created cost-effectively by a few NMHSs and supporting organizations on behalf of all Members of the WMO. The efficacy of this so-called "Cascading Forecasting Process" has been demonstrated in WMO Severe Weather Demonstration Project (WMO 2013a, b).

Alone, no nation would be able to provide the meteorological and hydrological services necessary to meet the essential needs of its citizens. But as WMO Members, countries agree on data-sharing arrangements, establish operational guidelines, implement best practices, and develop and use training opportunities. This international cooperation, however, depends on the continued investment of advanced countries in developing and supporting meteorological satellites, major computing facilities, and research and development. It also depends on regional investment in adapting global products for regional and national application. And it depends on national investment in maintaining NMHSs' observation networks and tailoring services to the needs of the population and specific economic sectors.

What Are the Obstacles to Better NMHSs?

Lack of Capacity of NMHSs

Despite their importance, many NMHSs in developing countries lack the capacity to provide even a basic level of services. The massive under funding of NMHSs has led to (a) a deterioration of meteorological and hydrological observation networks and outdated technology, (b) a lack of modern equipment and forecasting methods, (c) poor quality of services, (d) insufficient support for research and development, and (e) an erosion of the workforce (resulting in a lack of trained specialists). As a result, substantial human and financial losses have occurred, which could have been avoided if weather and water agencies were more developed. Climate-resilient development requires stronger institutions and a higher level of observation, forecasting, and service delivery capacity. In addition, successful adaptation to the existing and future weather and climate variability is impossible without reliable and well-functioning NMHSs.

Lack of Investment in Regional and Global Centers

The problem is not limited to NMHSs. Despite the importance of the WMO regional, specialized and global centers in helping countries reach a high level of service (WMO 2013a), investment here is also limited, and the on-demand guidance from a WMO regional center that could be available to a country is often not. Although a national focus is primary, the benefit of international cooperation and collaboration must also be considered. Synergy between the different levels ensures that national data are available to improve model output at regional and global centers. The high value-added segment of the production chain with regard to numerical weather prediction and space-based observations is at the global level. At present, it is assumed that developed economies will continue to support this segment. But this assumption is becoming increasingly uncertain (WMO 2013a).

Key Principles for Modernizing NMHSs

In response to the growing risk of meteorological and hydrological hazards, the World Bank is following six principles for improving NMHSs in developing countries (Rogers and Tsirkunov 2013c):

Principle 1: Modernizing NMHSs in developing countries is a high-value investment

Although the challenges in modernizing NMHSs are great, so too are the potential benefits to societies coping with meteorological and hydrological hazards and the risks posed by climate change. Globally, our capabilities are the best that they have ever been. Scientific and technological advances continue to improve numerical weather and climate prediction. We now have the scientific skills to provide reliable warnings of extreme events and day-to-day weather forecasts that are more accurate, specific, and timely than ever before – and these skills continue to improve. However, they are often limited to developed countries, because NMHSs in developing countries lack the infrastructure to transfer and use these technologies.

Unfortunately, many governments fail to understand the societal value of the information and services that NMHSs should provide as a public service. This part of the so-called poverty trap – namely, the existing poor status of NMHSs – prevents the production of valuable data and information. Governments see no reason, therefore, for investing in NMHSs. But without investment, there are no new products and services, a situation that is manifest in poor or non existent meteorological and hydrological warnings. Substantial, well-targeted and long-term financial support and capacity building are needed to break this cycle, together with improved communication and advocacy campaigns.

One way to enhance government and broaden public understanding of what is at stake is to conduct socioeconomic studies that quantify the value of the public services resulting from NMHSs' strengthening. Such studies can also identify gaps in the current system and help prioritize elements of a modernization program. This process should be iterative so that stakeholders' expectations are realistic. Engaging all stakeholders, both internal and external to the NMHSs, is critical to the success of a modernization program. In Switzerland and the United States, studies show high economic returns from better NMHSs – with cost-benefit ratios of 1:4 to 1:6. And a recent World Bank study in Europe and Central Asia suggests cost-benefit ratios of 1:2 to 1:10 (Tsirkunovet al. 2007).

Principle 2: The financing and scope of modernization must be sufficient to be transformative

Financing and scope of modernization must be enough to change NMHSs with poor infrastructure, declining observation networks and weak forecasting capability into public service organizations capable of delivering timely and useful information to mitigate weather, climate and water risks to the public and sensitive economic sectors. New capabilities incur additional operating and maintenance costs, which governments must consider up front to ensure the sustainability of the modernization effort beyond the initial work program.

The appropriate operating models need to be recognized explicitly to ensure that the NMHSs meet their public service and international obligations. Governments need to recognize and support their NMHSs to protect lives, livelihoods, and property as a critical, publicly funded mission. Policies that may restrict the free and open exchange of meteorological and hydrological data should be avoided, and the public sector responsibilities of the NMHSs should be emphasized. Selecting an operating model goes hand in hand with establishing appropriate legislation to institutionalize the agreed mission.

Principle 3: Clear legal and regulatory frameworks for providing essential weather, climate and water services increase effectiveness

Broad engagement across government departments, agencies, and other institutions is essential for success. To achieve success, countries need legal and regulatory frameworks for providing meteorological and hydrological warnings, as well as for delivering other weather, climate, and water services. Such frameworks will enable all stakeholders to understand their respective roles and responsibilities and to act accordingly. Coordination across government agencies is difficult, if not impossible, without it.

Principle 4: Large-scale modernization programs should specifically include three components:

- *Institutional strengthening, capacity building and implementation support.* Strengthening NMHSs' legal and regulatory frameworks, improving their institutional performance as the main provider of weather, climate and hydrological information for the country, building the capacity of personnel and management, ensuring operability of future networks and supporting project implementation are all necessary to a large-scale modernization program.

- *Modernization of observation infrastructure and forecasting.* This component includes modernizing the NMHSs' observation networks and communication and ICT systems, improving the meteorological and hydrological forecasting systems, and refurbishing offices and facilities.

- *Enhancement of the service delivery system.* Such enhancement involves creating or strengthening the public weather services, climate services, and hydrological services and developing new information and value-added products for vulnerable communities and the main meteorological and hydrological dependent sectors. This component should include developing a national framework for climate services, considered within the context of the global framework for climate services.

Principle 5: Modernization of NMHSs should be considered within the wider regional and global context

It is important to understand which parts of the public meteorological infrastructure are best funded and operated at the local, national, regional, and global levels and to make investments accordingly. There is room for more efficient distribution and coordination of roles and responsibilities among these levels. Technological developments make it possible to generate more useful products at regional and global levels, which can underpin the services that NMHSs provide at the country level.

WMO regional centers and specialized centers are an integral part of the information system. The SWFDP has demonstrated that RSMCs can increase the capabilities of NMHSs by providing operational guidance based on the products created by the global modeling centers. There is significant potential for scaling up this effort. Strong regional and specialized centers can help sustain national modernization programs by supporting continuous technology infusion, thereby ensuring that the NMHSs are up to date (WMO 2013a, b). However, new financing mechanisms are needed to support the regional and global elements of the meteorological and hydrological system.

Principle 6: The World Bank and development partners have a vital role

The reason their role is so vital is simple: weather, climate and water services area key public good, and better resilience to climate variability and change is a key element of a broader sustainable development and green growth agenda.

Since the mid-1980s, the World Bank has prepared and implemented more than 150operations with some elements supporting NMHSs, but relatively few were aimed at modernizing the whole system. Rather, the investments were structured as small-scale activities within water resource management, agriculture, or emergency operations. The approach was often piecemeal, emphasizing efforts to patch up services by supplying individual sensors and partial systems, without a strong connection with the national meteorological services or users.

But since the mid-1990s, the focus has shifted toward development of a more holistic approach. And today, most efforts involve modernizing entire NMHSs –through institutional strengthening, improving observation networks and forecasting, and strengthening service delivery. In collaboration with the WMO, the World Bank has an advisory role in helping to inform governments of the high societal and economic significance of weather, climate and hydrological information and services and of the importance of making meteorological and hydrological agencies the center of this support. The World Bank is also helping NMHSs raise their profiles in their respective governments by using the results of economic assessments, cost-benefit analyses and analytical work, along with identifying priority investment needs and facilitating financial support. The main instruments used by the World Bank are traditional lending and technical assistance projects – and it is investigating how to use the new financial instruments of climate adaptation and climate investment funds.

The modernizing of NMHSs relies on WMO to provide scientific and technical guidance, and understanding of documented best practices for capacity development, including methods of implementation, especially in relation to the establishment of effective national meteorological warning programmes.

The Cascading Forecast Process

WMO 2013a and WMO 2013b provide the technical insight into the WMO SWFDP and the cascading forecasting process. The aim of the SWFDP is to ensure that forecast information readily available in the Global Centers is used effectively in operations by developing countries. NMHSs should be able to use this information to improve severe weather forecasts, improve the lead-time and reliability of warnings and improve the interaction of the NMHSs with the media, disaster management, civil protection and the public.

The SWFDP is organized as a three-level system (Cascading Forecasting Process). The Global Data-Processing and Forecasting System (GDPFS) is operating by the leading global centers housed in the most advanced NMHSs. These centers provide the underpinning capability for weather forecasts and warning services for all WMO Members (WMO 2013a). Many of the latest advances in NWP and ensemble prediction system techniques, which use multiple model runs can only be operationally implemented by the most advanced centers, which have the computational capacity. The latest global NWP systems, for example, are capable of resolving convection on grid-lengths of 4km, which is particularly useful for severe weather forecasting in tropical and sub-tropical regions; however, these systems can only be supported by these large centers WMO 2013c).

These GDPFS centers also provide nowcasting systems for very-short range forecasting of severe weather based on extrapolation of satellite and other data (WMO 2013a).

The global centers primarily focus on developing automated products, which must then be interpreted for specific geographical regions. This is the role of the RSMCs, which combine and synthesize global-scale products, information from other regional centers, and sometimes their own limited-area models, to provide daily guidance for short-range (1-2 days) and medium range (up to 5 days) on specific high impact meteorological hazards to NMHSs within their region of responsibility. The RSMCs also maintain websites and data portals, and liaise directly with the NMHSs providing human guidance when required.

This enables the NMHSs to focus on producing timely and accurate advisories and warnings for their users – emergency managers, civil protection and so on.

The Importance of the Cascading Forecasting Process in NMHSs Modernization Programs

The Cascading Forecasting Process Versus Stand-alone NWP

Most modernization efforts have focused on building infrastructure within the NMHSs. Built into this approach, but not sufficiently well developed, is the need to strengthen the synergy between the NMHSs and the regional and global centers.

In many instances NMHSs want to develop sophisticated in-house numerical weather prediction systems for their general forecasts and they are often encouraged to do this by the research community, or contracted parties outside of the WMO community.

Modernization of the forecasting infrastructure must explicitly consider the advantages of the cascading forecast process over a stand-alone investment in high end computing infrastructure and the staffing required for this activity. They must also consider the trade-off between investment in national NWP capacity and investment in service delivery. In many instances, NMHSs focus on trying to build technical capacity at the expense of delivering better services to their stakeholders.

The Cascading Forecasting Process—Global Products Centers, RSMCs, and NMHSs—should be the preferred approach ensuring that the global products of the major numerical prediction centers could be fully utilized by even the most capacity limited NMHSs. In turn these NMHSs would always have access to the most advanced products and could focus using this information in their alerting and warning services.

SWFDP and NMHS Modernization

Up to now the WMO SWFDP has operated largely independently of major donor- supported NMHSs modernization efforts. Relatively little support from these national efforts has been directed to the SWFDP and in some instances the SWFDP has not be considered as a component of the NMHSs modernization plans at all. At the same time, many NMHSs in modernization need to shift investments to establishing an effective meteorological warnings programme.

Limited funding has been made available as a part of the Central Asia Hydromet Modernization Program (CAHMP), which also provides national support to Kyrgyz Republic and Tajikistan. Both countries have limited forecasting capability and will continue to have limited numbers of skilled forecasters for the foreseeable future, despite investment in training and infrastructure. The cascading forecasting process offers a way to provide a higher level of services than would otherwise be possible by providing specific guidance on hazardous weather.

Efforts are underway to strengthen the NMHSs of Viet Nam, Cambodia and Lao PDR. As a part of this effort, with the support of World Bank managed East Asia and Pacific AusAID Infrastructure for Growth Trust Fund (EAAIG), the World Bank is developing a program aimed at regional integration of hydrometeorological forecasting and early warning in the lower Mekong Basin. This program would support the upgrading and enhancement of the RFSC Ha Noi to become a RSMC with the capacity to provide regional support for the SWFDP Southeast Asia (WMO 2013a). The program will also help to improve the use of forecasting products and improve warning services in Viet Nam, Cambodia and Lao PDR (Rogers and Tsirkunov 2013a).

It is also recognized that accelerating SWFDP activities in the Pacific Region may jump start modernizations where the capacity of the NMHSs is very low and human resources could be most usefully deployed on service delivery with greater reliance on forecast production through the SWFDP. Despite the large number of global centers with interests in this region, regional weaknesses also need to be addressed and the means of operating sustainably one or more regional centers must be found.

Strengthening WMO Global Products Centers and Regional Specialized Meteorological Centers

Investment Strategy

Long-term investments in the regional framework, including the RSMCs infrastructure and human resources are needed to ensure that they have the capacity to meet and sustain the needs of their users. This includes education and training, support for information technology and communication, and ongoing operations and maintenance.

Current investments in the hydro-meteorological system are through:

1. Specialized donor supported programs, such as the Pilot Program for Climate Resilience (PPCR), which is providing funding for several large scale modernization efforts of NMHSs;
2. Countries accessing credits or grants from the international financial institutions (e.g. World Bank) and UN Agencies (e.g. UNDP) to support NMHSs modernization programs;
3. Regional and bilateral donor driven initiatives that can incorporate both regional and national activities;
4. Donor support directly to SWFDP.
5. WMO supported voluntary contribution program (VCP). It provides support for training, capacity building and minor investments.

At present there are a limited number of options to sustain operational funding for this system. It is expected that NMHSs, following donor funded capital investment, will support their operations and maintenance through increments in their operating budgets. This is a challenge in most countries, which should be addressed by interactions between the donors the Ministries of Finance and Ministries of Planning. World Bank which has well established contacts with senior officials of these ministries in virtually all developing countries can play important role in this process.

The problem is even more complex for regional centers, where the stable source of operational support needs to be identified. Seen in the broader context of weather and climate resilience, they should be candidates for support from climate investment funds (World Bank 2012) or a specially created multi-donor trust; recognizing that this system would guarantee capacity and sustainability within developing countries' NMHSs through the Cascading Forecasting Process.

In the short-term investment is needed to transition the SWFDP to a fully operational program. This would provide assurance for commitments to the Cascading Forecasting Process from national and regional investment programs.

Funding for the operational management of the system of regional centers is also required through a project office housed within the WMO Secretariat. This office would facilitate the transition from demonstration projects to operational systems within each of the WMO region, the geographical expansion of the activities and extension of the Cascading Forecasting Process to climate services. Proposed pilots will help to define the scope of the future financial support for this system.

Managing the development through regional partnerships

The regional framework will necessarily include an organizational and governance structure. If new sources of financing outside of the host country area are found, RSMCs will need to operate with an appropriately representative board structure that includes all collaborating partners. This would ensure that the RSMCs properly met the needs of their users/investors, including those that invest in-kind. Since all of these centers are WMO entities, creating such a mechanism should not be too difficult and could be harmonized among WMO regions. Selection of senior staff, budget allocation and program direction would require regular review by the board to reach consensus and approval. It would also require support for the WMO to provide a Secretariat function that coordinates the activities, especially in the early stages of project development and implementation, as well as in resource mobilization, planning, prioritization, implementation, and evaluation.

Piloting RSMC/SWFDP Support

Demonstrating the benefit of investment in RSMCs and the SWFDP process can be done in 2-3 pilots. This may include cost-benefit assessment of the global/regional system versus the current business as usual and purely national option. This would be evaluated through long-term support for SWFDPs enabling them to be fully operational within client NMHSs. A clearer assessment of the investment required would be made at this pilot stage allowing donors and beneficiaries to determine the most cost effective way to deliver the level of hydro-meteorological services needed within client countries. It should be possible to demonstrate a high level of continuity of operations at the national level where the meteorological services have on-demand support from fully staffed and functional regional centers that can meet the needs of several countries simultaneously.

The proposed pilots may include (WMO, 2013a):

1. Sustaining and strengthening existing Regional Specialized Meteorological Centres (RSMCs) to create a fully functional regional centres aimed at regional integration of hydro-meteorological forecasting guidance;

2. Expanding the role of relevant RSMCs with activity specialization in Tropical Cyclones involved in the pilot(s) into RSMCs with activity specialization in forecasting hazardous hydro-meteorological phenomena;

3. Ensuring RSMC support for the '*Cascading Forecasting Process*' in all areas, consistent with the evolution of the GDPFS.

The outcomes from the ongoing SWFDPs and the proposed pilots should strengthen the argument for additional investment in regional and global centers as a cost effective, high benefit approach to modernizing NMHSs.

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