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 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

[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).

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".

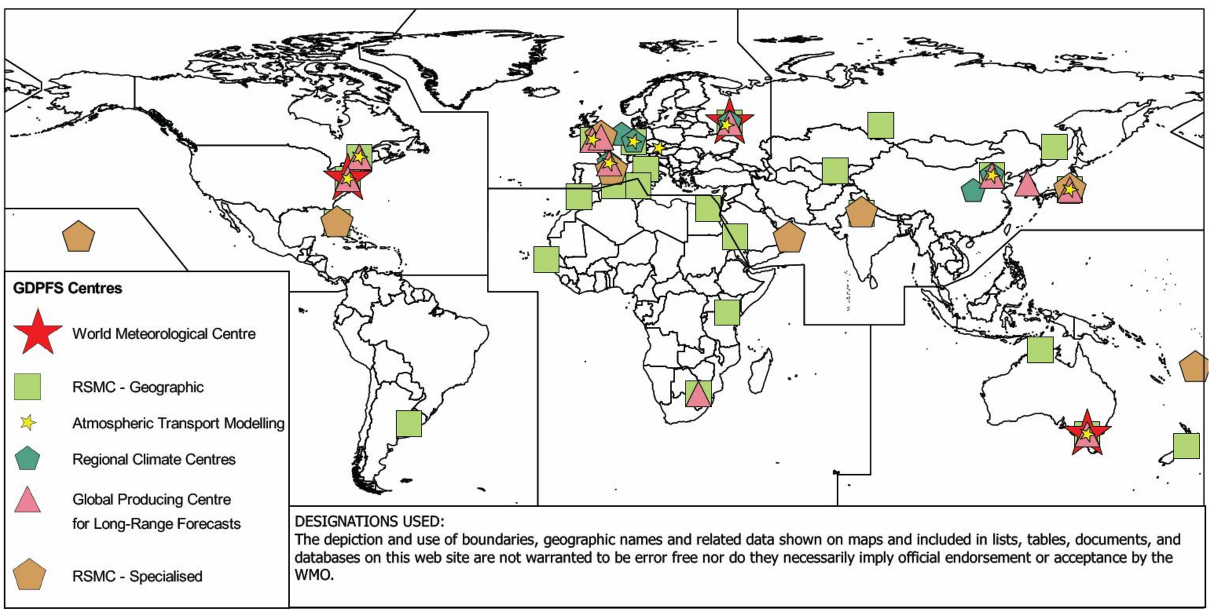


Figure 1 – Currently designated WMCs and RSMCs, including RCCs.

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 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"*).

[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.

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.

[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.

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.

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.

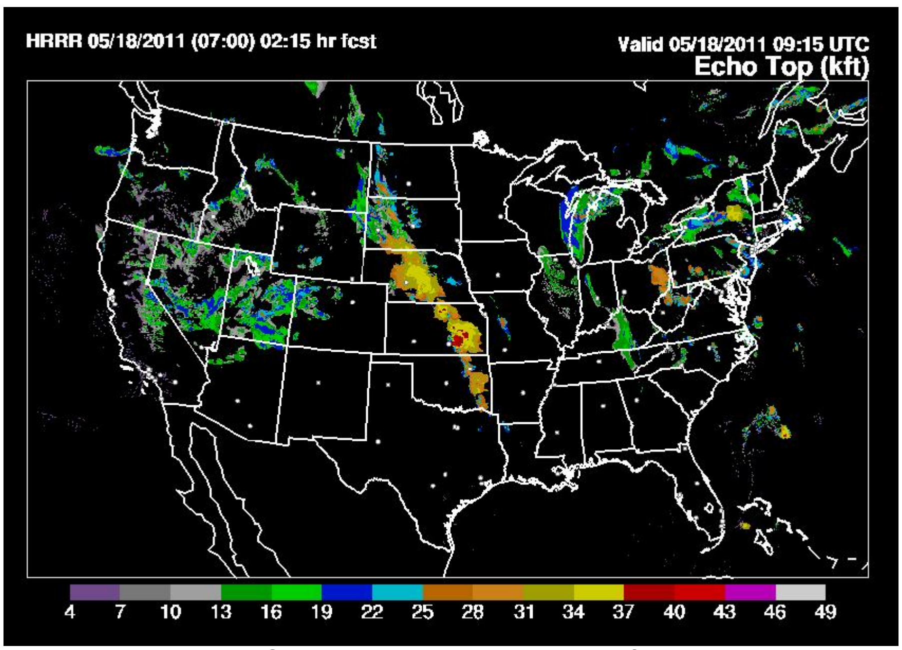
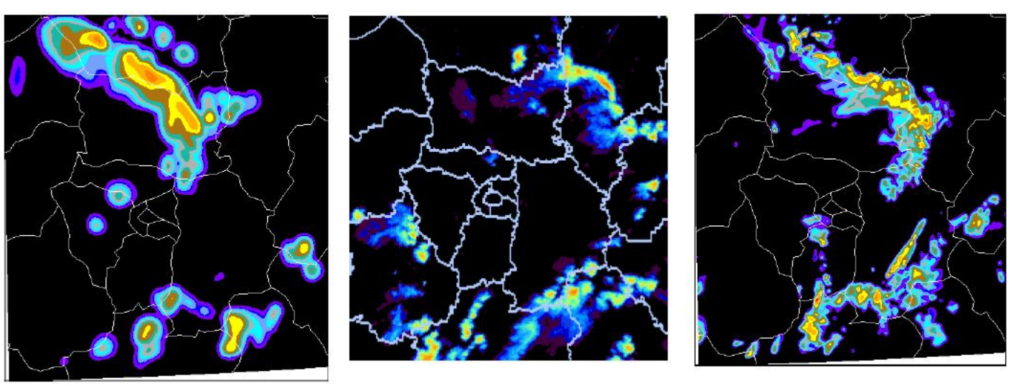


Figure 2 – NOAA's High Resolution Rapid Refresh system.



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.

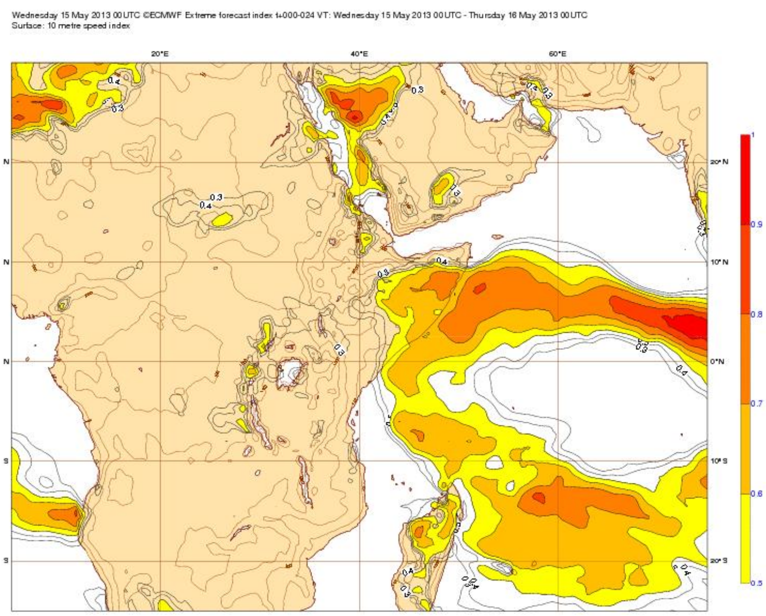


Figure 4 – ECMWF Extreme Forecast Index (EFI) 10m wind speed. Product made available to NMHSs in Eastern Africa, through the SWFDP – Eastern Africa.

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.

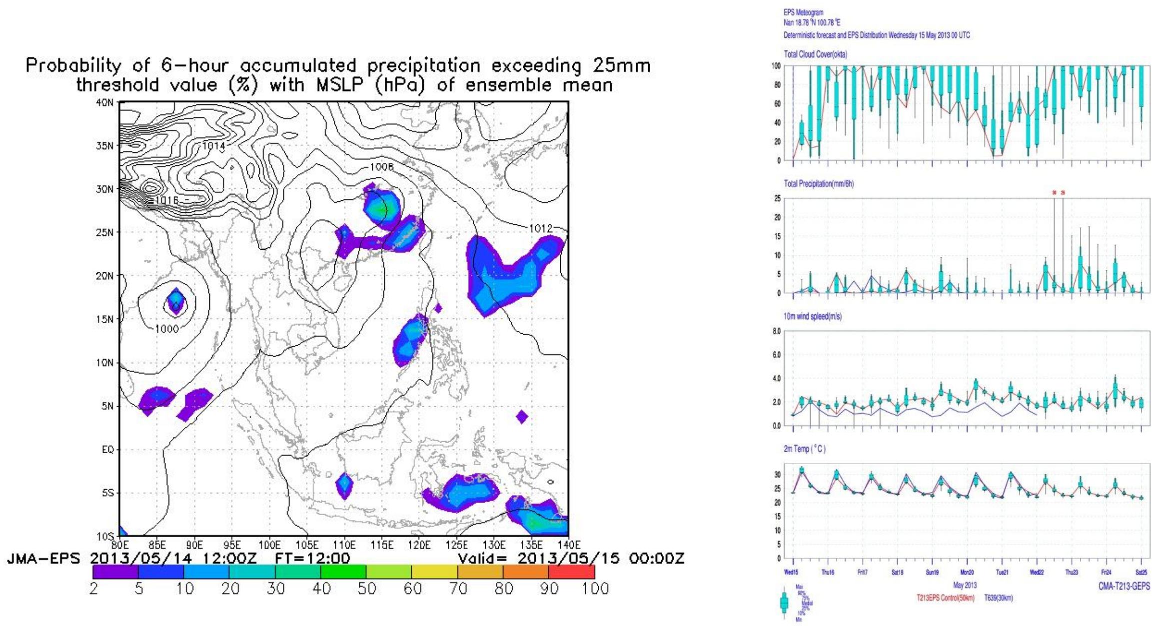


Figure 5 – Two examples: probability chart generated from JMA's global fields for accumulated precipitation exceeding 25mm in the Southeast Asia (left), and EPSgram from the CMA global ensemble for a city in Thailand (right) in support of the SWFDP regional project.

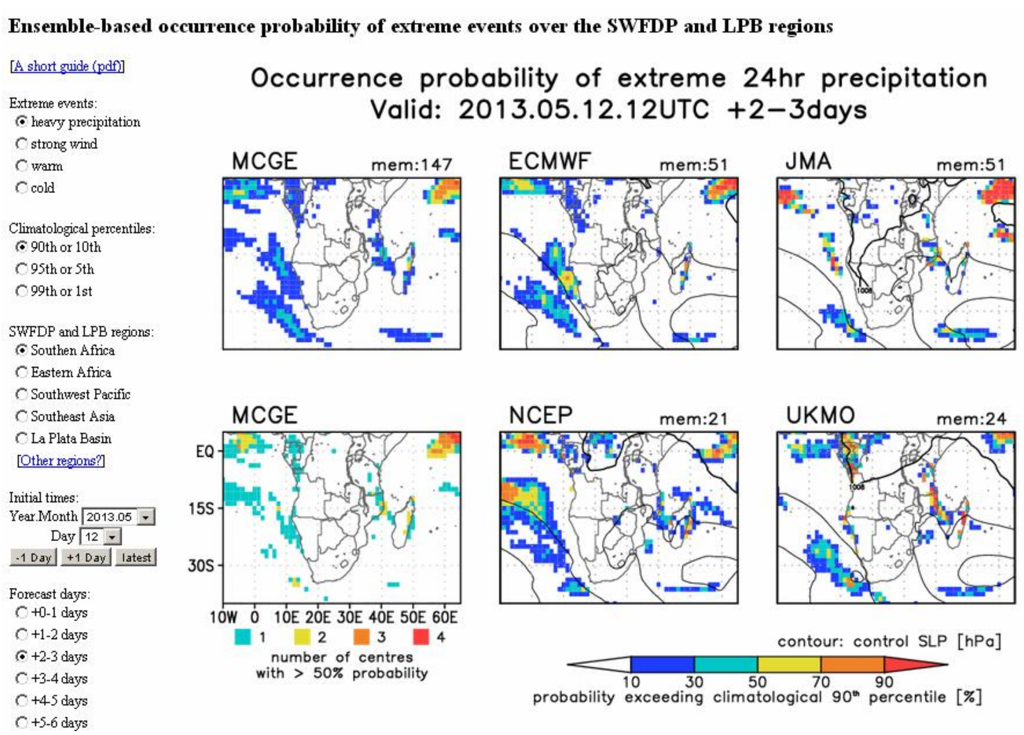


Figure 6 – Example of occurrence probability of extreme 24 hours precipitation, in support of the SWFDP regional projects.

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.

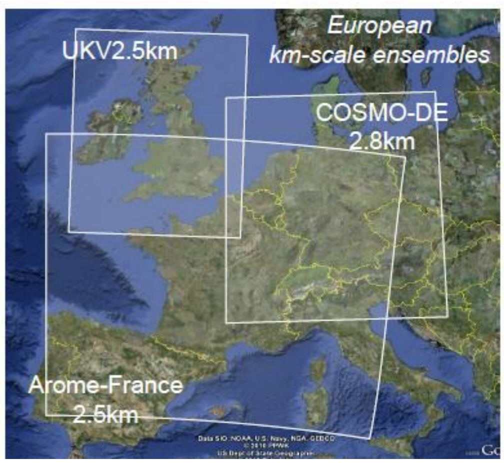
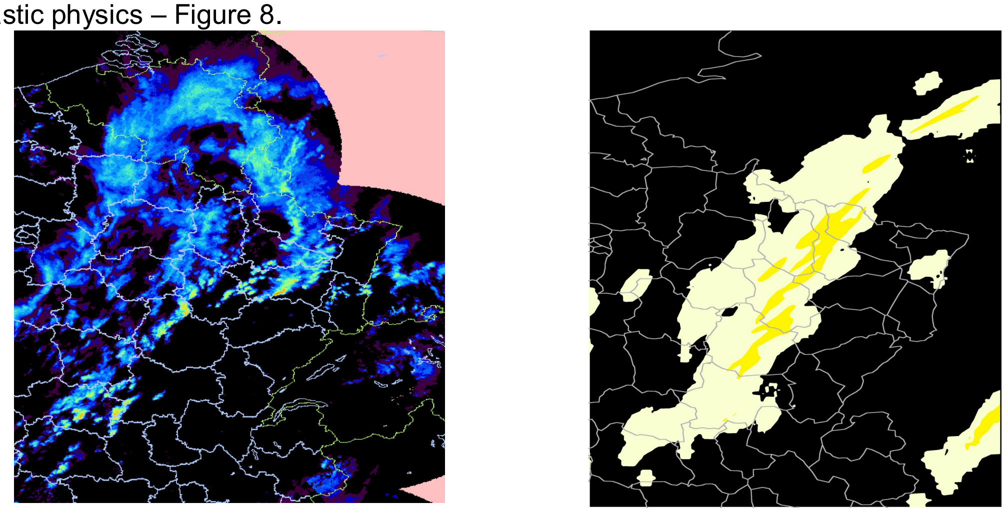


Figure 7 – European *km*-scale ensembles.

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).

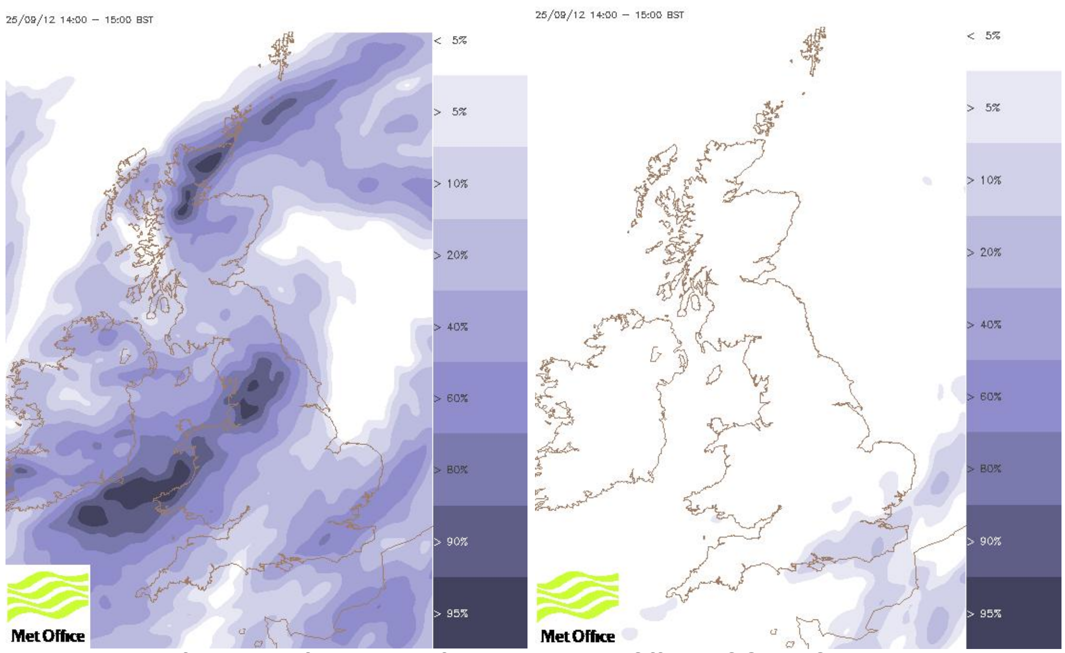


Figure 9 – Ensemble forecasts of heavy rain from the UK Met Office MOGREPS-UK 2.2km ensemble post-processed with neighbourhood processing showing probabilities of rain (>1mm/h, left) and torrential rain (>16mm/h, right).

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.

<u>*Severe weather impact modelling*</u>

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.

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

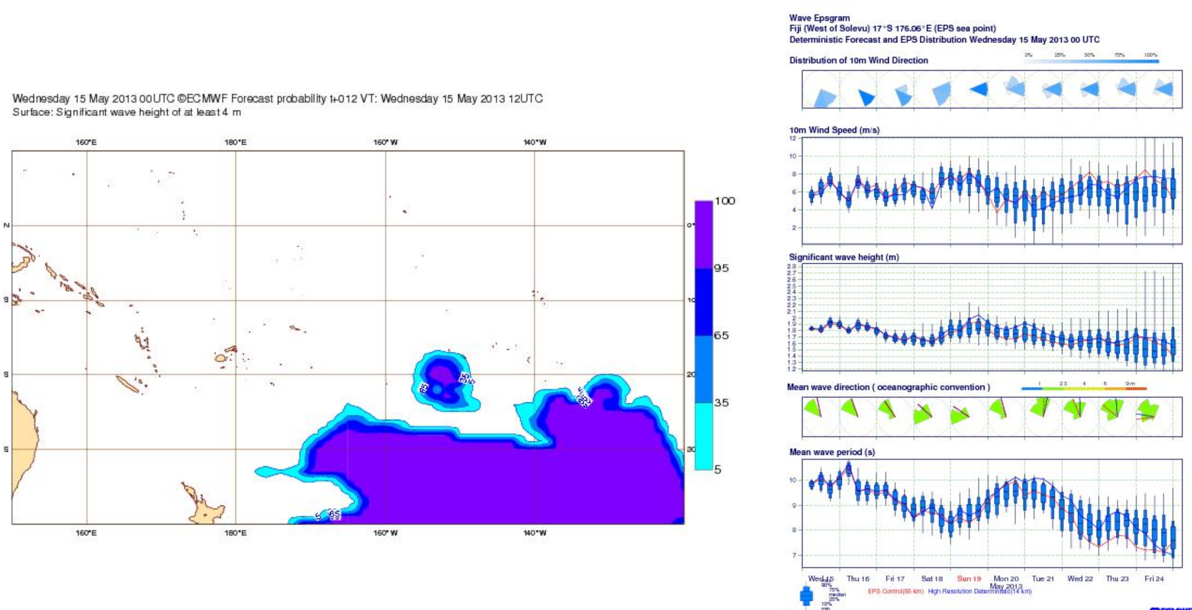


Figure 11 – Probability chart for significant wave height of at least 4m in the South Pacific (left) and Wave EPSgram in a sea location nearby Fiji (right), generated from the ECMWF EPS and which are available to SIDSs in the South Pacific, through the SWFDP regional project.

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.

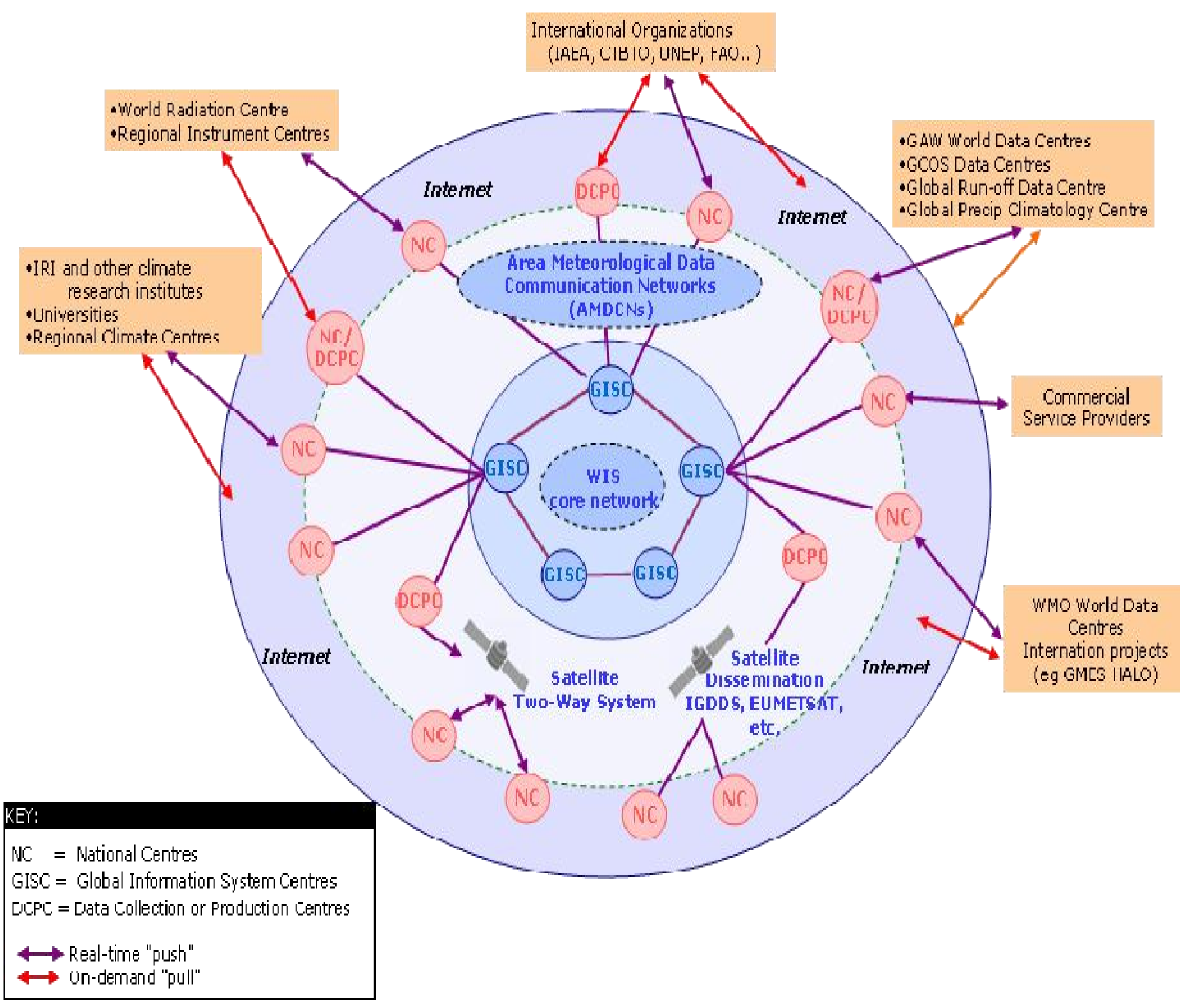

Figure I-1 – Structure of the WMO Information System (WIS).

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
	ETA-EPS	South America	40km	11 days	38

Centre, Country	NWP System	Domain	Horizontal Resolution	Maximum Lead-Time	Vertical Levels
		Southeast Brazil	5km	3 days	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
	WRF	Regional	10km	3 days	40

Centre, Country	NWP System	Domain	Horizontal Resolution	Maximum Lead-Time	Vertical Levels
	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
	UKV (UM)	UK	1.5km (inner domain)	36 hours	70

Centre, Country	NWP System	Domain	Horizontal Resolution	Maximum Lead-Time	Vertical Levels
	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