**1. Preamble.**

**1.1 The successes of the past.**

WMO, and its members have since their creation successfully met a number of major technology jumps: for example, the switch from data plotting and map drawing by hand, and more or less subjective synoptic analyses to a NWP-based system using supercomputers and automation technologies, then later on to global modeling, highly efficient and accurate numerical methods and sophisticated data analysis systems, then further on to global operational usage in data assimilation of space-based observing systems in real time, then on to ensemble methods that allowed a probabilistic estimate of the accuracy of the forecast and finally, recently, to the so-called seamless and integrated modeling approach which expands by orders of magnitude the potential applications of weather and climate modeling systems.

It is thus with a high level of confidence that we should approach the next technology transitions: correctly managed, our responses will, as in the past, result in further improvements of the excellence, relevance and impacts of our products, and thus contribute, overall, to further improvements in the security and socioeconomic progress of all our members, thus reducing further the gaps that separate some of us today.

**1.2 Challenges for the future.**

The World Meteorological Congress, at its seventeenth session (Cg-17), noted the rapidly evolving transformations in the practice of operational numerical weather prediction, particularly the integrated or seamless modeling approach, and recognized:

1. That all WMO constituent bodies and numerous subsidiary expert level groups provide a complex framework for coordination and collaboration in which a large number of decision-makers and experts from virtually all Members and partner organizations address matters related to the Data-processing and Forecasting System (DPFS),
2. That emerging requirements from the services-oriented programmes, such as aeronautical, marine, agriculture, health, and public weather services, as well as requirements from a wide range of hydro meteorological-related emergencies, or from implementing disaster mitigation strategies, require an enhanced integrated, holistic and seamless DPFSin order to be relevant to users’ decision-making,
3. That an enhanced integrated, holistic and seamless Data-processing and Forecasting System could have the potential to lead to important benefits for Members and their National Meteorological and Hydrological Services (NMHS) and the Organization as a whole,
4. That the integration of the technical support to meet the on-going and emerging requirements from different sectors of society in a single system (in a multi-dimensional/ multi-disciplinary approach) would be more cost-effective and relevant to decision-makers and users.

Cg-17 therefore decided, through Resolution 11 (Cg-17),to initiate a process for the gradual establishment of a future enhanced integrated and seamless WMO DPFS, in light of the conclusions of the first World Weather Open Science Conference (WWOSC-2014, Montreal, Canada, August 2014), and requested the Executive Council to formulate Terms of Reference for this process, and a description of the set of products the system should produce, for consideration by the eighteen session of the World Meteorological Congress (Cg-18) in 2019. This paper responds to this request by describing (a) the requirements; (b) the reason why we are doing this; (c) the vision and scope for the future Global Data-processing and Forecasting System (GDPFS); (d) linkages with observations and data exchange, applications and services, research, regional bodies, and capacity development, (e) the benefits, (f) opportunities, success factors and challenges, and (g) the mechanism for implementation and timelines.

**2. Considerations.**

**2.1 System and Service Requirements by WMO technical programs.**

The requirements associated with this exercise can be framed as follows:

* The need for a clear vision for the future of the GDPFS that would contribute significantly to the long term positioning of the WMO as a world leader in facilitating the provision of both data and forecast products encompassing not only traditional weather related products, but also increasingly a widening spectrum of environmentally related information, in the spirit of the integrated and seamless approach;
* The need to devise a system that would be flexible and easily adaptable to the many technical and expanding service needs and requirements emerging in the user and producer communities, without necessitating a complete rebuild of the system, now, or in the future (for example, standardization on model /system output formats “or” transformation scripts to achieve transformation of standardized formats).
* The need to expand collaborations with many other partners, not necessarily in the traditional family of NMHS's, and adjust the GDPFS to facilitate this openness; for example, earth system modeling, including atmosphere, oceans, land, cryosphere, chemistry interactions, etc.
* The need for a clear focus on high impact products, whilst respecting the professionalism of some users, particularly in the marine, hydrological and agro-meteorological sectors, who are well trained and aware of the impact which certain environmental conditions create and as well, the need to have all members of WMO benefit from state of the art data and products specific to their particular needs;
* The need for a system where two-way feedback between producers and users is not only facilitated but also recognized as a key to success. This could be achieved through the creation of a User Interface Platform (UIP);
* The need to enable NMHS’s and other institutions to share and leverage each other’s data resources and to identify other sources of data e.g. Crowd Sourcing, Future mobile phone systems as meteorological observation platforms, road/rail/marine vehicles as data sources through similar systems as AMDAR on aircrafts, Nano- technology, etc. ;
* The need to clearly separate policy issues (EC and CG domains of governance) from internal operational and management issues.
* The urgent need to transit the GDPFS towards a system capable of producing impact-based forecasting and risk based-warning (IBF & RBW).

The future GDPFS system will need to be designed to help deliver in the most satisfactory and efficient way the new types of services required by the users with the overarching objective to contribute to Disaster Risk Reduction. This will necessitate a close interaction between the providers and the users of the services, and the requirement for a mechanism which strongly encourages and facilitates feedback between these two parties, such as a User Information Platform (UIP), something which is seen as lacking for now and that could be enabled by social media.

Another very important aspect to consider is the move towards impact-based forecasts and risk-based warnings, e.g., not merely providing a future state of the environment to the users, but actually providing the potential impact of this future state: and for many, if not the majority of the impacts, they will be at the State level, and will depend on socio-economic type information (preparedness, local transportation, building and power infrastructure status and disaster management rules, etc.), as on the quantitative physically-based information itself. One example that was provided is that unless one has access to hydrological reservoir management rules and practices, a global attempt to provide an operational flood forecasting service runs the risk of being seriously flawed.

In defining a future state and of the GDPFS (in connection with WIGOS, WIS) one will need to make decisions on what priorities the core services provided to WMO Members shall be addressing, and what position WMO, and its services oriented programs and commissions wish to retain for themselves and their partners.

The service aspects requirement is one of the fundamental dimension and reason for the existence of the GDPFS. This will define in a significant way the structure of the GDPFS itself. We will consider six of these Services area in particular, but will also discuss briefly Earth System Environmental and Socio-Economic Services.

**2.1.1 Observations and Data Exchange**

The GDPFS, WIGOS and WIS constitute the World Weather Watch (WWW) components and as such, evolution of GDPFS is closely linked to WIGOS and WIS. If indeed one wishes to proceed with a global implementation of the seamless and integrated forecasting system, it is necessary that access to enhanced observation data through WIGOS and WIS is coordinated with non-traditional partners.

Looking for example at the data needs for hydrological, agro-meteorological and marine forecasts, this will represent a formidable challenge, for a number of reasons. An important characteristic of these three particular applications is the need for both global, regional and very fine spatial scale data requirements for informed decision-making, and this at all time scales. Another one is the fact that these three sectors have developed their own data related processes or procedures, often quite dissimilar to traditional weather or even climate related usage. They are also very often outside the traditional world of NMHS organizationally, and have developed their own dissemination and decision processes, as well as different partner and user bases.

The rapid development of data related technology (big data, crowd-sourcing, cloud computing, etc.), which has already led to the creation by the private sector of fine scale user tailored agro-meteorological services in Africa, totally outside of the WMO program structures. We can, therefore, expect many more similar initiatives for different sectors of environmental predictions.

**2.1.2 Public Weather Services (PWS):**

* While the increased resolution of the Limited Area Models (LAMs) has helped to provide good information for PWS, convective weather activities remain a challenge to predict accurately. Data suites derived from radar-based nowcasting systems, merged into model output at time ranges of 2-4hrs, can address this challenge but the technology is still out of reach for many NMHSs, even in the developed world.
* Ensemble Prediction Systems (EPS) systems consume a very significant percentage of the resources of the major centers running global models, but we are not exploiting this rich information to its full extent. Many users simply do not have decision-making systems that are sophisticated enough to incorporate this probability-based information.
* User-education is needed here, and also more social-science research into how users make decisions, and to what extent they can absorb this complexity of information or sharing. In other words, training is a major gap.
* Primarily the training of front-line forecasters in, e.g. the use of RSMC products and guidance, in the proper interpretation of EPS data, etc. If the NMHSs cannot properly organize for the adequate training of their own staff, what hope is there in providing training for users?
* New requirements: The need to incorporate weather information with data from other sources (vulnerability and exposure data, crowd-sourced observations of weather itself or its impacts etc.) means that there is a need to develop visualization platforms that allows all of this diverse data to be coherently presented and examined by forecasters (or consulting meteorologists, which is what forecasters may become). These platforms will probably be GIS-based, so the meteorological world needs to get to grips with how best to incorporate this technology.
  + 1. **Climate services, including the support to GFCS**
* Specialized centers: Their designation and monitoring processes should be improved and should evolve. It is important to have some clear criteria and metrics to assess the compliance of the labeled centers and their activities. It is also important to elaborate standards for operations, especially at the regional level (e.g., RCCs and RCOFs), including the need to label products and services (with WIS compliance). New functionalities should also be introduced (e.g., help desk function, user support, etc.). Last but not least, global monitoring centers do not presently exist, whereas this is the case for data and forecast products.
* Climate services perspective: There is a clear need to add this dimension within the GDPFS, especially with respect to CSIS and its interface with the User Interface Platform (UIP). In this respect, the involvement of organizations or entities, which are not operational (in the NMHS sense), but are nevertheless providing information routinely should be addressed. Adaptations will be necessary for tailored information for decision making (especially impact forecasts). And of course, these should be evaluated and monitored.
* Climate service Toolkit: The development of such tools should be conducted in close collaboration with CBS and have strong linkages with the GDPFS (functionalities, standards, etc.), noting that the necessary downscaling/upscaling functions should be part of the process.
* Feedback processes: Some feedback processes are missing or are not efficient, particularly with people outside our traditional climate community, and for the RCCs and GPCs.
* Verification: It should be adapted to the service provision, especially beyond the products themselves, focusing on the impact of the use of the information (e.g., demonstrated value of the services provided).
* Climate Change information and the new GDPFS: It should be integrated in the functionalities described in the GDPFS. Likewise, we should extend the described functionalities across all the time scales (making sure we preserve and ensure the consistency within the seamless provision of information).
* Additional points: Using a system approach will allow a full picture to emerge, and the possibility of assigning the necessary priorities and importance for each component of the system. There will be a need to create and monitor relevant labels for the tools used, and the provision of the information (e.g., clear identification of authoritative voices on internet, labels for candidates to the CST, etc.).

**2.1.4 Hydrological services**

The Commission for Hydrology (CHy) shapes the water related activities of the WMO and addresses issues related to the basic hydrological observation network, water resources assessment, flood forecasting and management, adaptability to climate variability and change and promotes exchange of technology and capacity building. In particular the outcomes of its deliberations provide guidance to WMO Member countries and WMO Secretariat for the implementation of the Hydrology and Water Resources Program of WMO.

* Its major activities are: 1) Quality management framework, 2) Data operations and management, 3) Water resources assessment, 4) Hydrological forecasting and prediction, and 4) Water, climate and risk management.
* The responsibilities of NHSs are: 1) Observation of surface waters (stages and discharges), 2) Data quality control and primary processing, 3) Hydrological balance and water resources management, 4) Hydrological forecasting, and 5) Water quality, ground water monitoring and assessments, etc.
* Concerning runoff or flood generation processes, one needs to consider initial conditions (soil moisture, groundwater, snow, reservoirs) are very important), the high spatial variability, and the temporal and spatial development of floods (basin-scale determines a forecast lead time).
* The forecast ranges in hydrology extend from hours to years. Whilst flood forecasting is a national responsibility, depending on the basin scale, it often requires international and regional cooperation (for example, in Europe, EFAS), and also GloFAS (GFP), and G-WADI (UNESCO-IHP).
* NHSs are users of meteorological and climatological services (data, forecasts) usually not within one NMHS. Also, levels and ways of cooperation between NMSs and NHSs differ significantly among countries and regions.

The needs of CHy and NHSs are: 1) Observations and short term forecasts (basic), 2) Service delivery as a tailored product for hydrological application (no GRIB), 3) Bias corrected and downscaled to the resolution of the hydrological model, and Verification, preferably from an authoritative source.

It is unclear at this time what form the contributions of CHy and NHSs should or would be: developed hydrological services typically provide observations in near real time, flash flood guidance, short to medium-range flood forecasting, and seasonal runoff prediction, with an aim to provide these in a seamless way to users.

**2.1.5 Marine meteorological and oceanographic services**

The long-term objectives of WMO Marine Meteorology and Oceanography Program include, as a priority, enhancing the provision of marine meteorological, oceanographic and climate services. The coordination of implementation and development is made through JCOMM, primarily in generation and analysis of observations and knowledge of the marine atmosphere and ocean in support of numerous applications, including:

* Enhanced safety of life and property at sea and coastline through improved forecasts of natural and anthropogenic hazards such as storm surge, sea level rise, harmful algal bloom, tsunami, ocean acidification, and oil spill trajectory
* Contribute to the prevention and control of marine pollution, sustainable development of the marine environment, coastal area management and recreational activities, and in support of the safety of coastal habitation and activities.
* Contribute to development of ocean-based economic and industrial activities
* Contribute to coordination and enhancement of the provision of data, information, products and services required to support atmosphere and ocean weather forecasts and detection and prediction of climate variability and change.
* Advance understanding and improve predictability of the global integrated Earth system.
* Contribute to improve marine and ocean forecasting from the global to the coastal scales by incorporating research innovation in operational systems
* In doing so, JCOMM promotes a state-of-the-art, globally distributed, and fully integrated marine observing, data management, and services system based on present and next-generation technologies and capabilities. The main challenges that the Marine Meteorology and Oceanography Program (MMOP) is facing are:
* Enhancing the coordination of global real-time, near-real time and delayed-mode (up to 1 month) data acquisition of ocean data between the “oceanographic community” and the National Meteorological and Hydrological Services, including the national navies, oceanographic institutions and centers, operational and research centers, etc.
* Moving from the "full scale global operations" to the regional and national implementation in order to meet user needs. This may be achieved through developing a marine equivalent of the WAFC concept, where a very few Global Centers are responsible for the deep water areas, with regional and national inputs being provided for near shore and coastal areas.
* Meeting the users requirements and establishing good connections between the end product users, their producers, as well as with data providers, and observational programs. Within this, the role of governance of the safety services must be considered, where ensuring connections with, for example, the International Maritime Organization (IMO), are paramount.
* Sustaining the global ocean observing system (in situ and satellite based) in order to achieve optimal sampling capabilities for analysis, reanalysis and forecasts
* Organizing training workshops and on-line learning modules for Capacity Development at the different stages of the production line.
* Ensuring that relationships with other agencies engaged in the provision of safety information, such as IMO and the International Hydrographic Organization (IHO) are robust and resourced appropriately.

Moreover, end-users will soon require new application areas, driven both by safety at sea, and socioeconomic pressures. Some examples are:

* Offshore resource exploration,
* Military and defense operations,
* Marine engineering,
* Sub-surface communications,
* Tsunami prediction and warning systems,
* Storm surges and coastal defense communities,
* Ship routing and navigation,
* Operations in the marginal ice zone,
* Pollution monitoring prevention and clean-up,
* Marine and coastal environmental management,
* Space weather impacts on safe navigation
* Synoptic, seasonal and other long-term forecasting,
* Climate prediction at different time scales,
* Sustainable management of commercial fishing.

Many of these, if not most will require crosscutting collaborations between programs of WMO and IOC but also others: a recent example is the WMO coastal inundation forecasting demonstration project (CIFDP) which was initiated jointly by JCOMM and the Commission for Hydrology.

**2.1.6 Aeronautical meteorology services**

International aviation meteorological service provision is coordinated and overseen by the International Civil Aviation Organization (ICAO) and is supported by and contributes to the GDPFS. The services, underpinned and informed by the necessary guidelines, manuals and standards, are delivered through two World Area Forecast Centers, seven Tropical Cyclone Advisory Centers, nine Volcanic Ash Advisory Centers and the numerous Meteorological Watch Offices (MWO) and Airport Meteorological Offices. In addition there are plans for the development of regional hazardous (aviation) weather advisory centers for space weather, other meteorological hazards and nuclear emergencies.

The ICAO Global Air Navigation Plan (2014-28) based on the implementation of the phased Aviation System Block Upgrades (ASBU) approach will require the increasing integration high-resolution meteorological data into 4-D Air Traffic Management (ATM) decision support systems to support and enable more efficient trajectory-based (gate-to-gate) operations. This transition from the traditional product-based 'briefing and advising' approach to one based on the application of best data by ATM decision support systems will inevitably result in significant changes to the current models of aviation meteorological service delivery with consequent impacts on and challenges for MET Services within the overarching framework of the WMO GDPFS. There is a significant opportunity to further enhance the relevance of the GDPFS given that high quality meteorological science, modeling, observations and interoperable data will be key enablers in ensuring the successful implementation of the ICAO GANP.

**2.1.7 Agricultural meteorology services**

The Commission for Agricultural Meteorology (CAgM) is proposing an AgMet Data Collection and Production Centers (DCPC) to support climate and weather services innovations for the sector of Agriculture and Food Security.

Global centers (WAMIS DCPC) would develop:

* Operational activities for downscaling NWP outputs for applications in the agriculture and food security sectors including S2S in space, time and element,
* Operational activities for Reanalysis on historical/in-situ data including non-meteorological data (i.e. crop monitoring) from remote sensing platforms,
* Operational data services for high resolution Agro Meteorological products and supplementary RS information (on a semi-real time basis),
* Operational activities for ICT sharable platforms under cloud environments with GIS-online interfaces for agricultural and food security applications.

Whilst regional centers (WAMIS Portal) would provide:

* Operational services for Agro Meteorological Bulletin archival and dissemination,
* Operational activities for Early Warning services on Agro Meteorological hazards/extremes, based on region specific needs,
* Operational data services to support regional Agro Meteorological Outlook services,
* Training in the use of operational Agro Meteorological products and services including promising tools.

This vision will clearly necessitate significant changes in the traditional GDPFS operations, and as well in WIS and by extension WIGOS. Non-traditional data, computing needs and products dissemination and visualization will need to be addressed. For example, a specialized or dedicated GISC/DCPC of WIS to support WAMIS grid/cloud portal will be a promising solution in improving resource sharing among CAgM member countries by allowing them to make better use of remotely located ICT resources for agrometeorological services at national/regional scale, especially when it provides interactive forecast-based agrometeorological services via simple Internet access.

Also the need for very high resolution climate and weather products (obtained through downscaling or other means), spanning a time interval from minutes to years, is a challenge that present seamless modeling technology (Sub-seasonal to seasonal (S2S) is an example) has not yet successfully resolved. And many countries do not yet have the capacity or the resources to run the kilometer or even meter scale models that will be needed. Nevertheless, the modernization of agrometeorological services under a WMO leadership role, and involving evolved GDPFS, WIS and WIGOS components could be an interesting option.

**2.1.8 Earth System Environmental and Socio-Economic Services**.

Clearly the ability to assimilate large volumes of data and to run ever more complex earth system models has been a major achievement of the GDPFS over the past few decades. The Sand and Dust Storm (SDS) forecasting system is a good recent example. Can these models be expanded to either: 1) incorporate all natural and man-made hazards, such as Space Weather, Air Quality issues, from urban bad air events to regional events such as forest and slash and burn smoke, vector-borne diseases, toxic algae events, etc., or: 2) provide an increasing diversity of decision-making support systems in fields like integrated ecosystem management tools, food production (fisheries, agriculture), air, land and sea transport, energy production, particularly renewable in a context of a carbon-free economy, urbanization and megacities environmental management issues, and many other products, so that science can deliver to society a truly holistic multi-hazard forecast and warnings system? If this is so, then how are the other actors and partners to be brought into the picture? The organizational and technical framework that global meteorology has developed could be expanded to encompass many other hazards or decision-making aids to civil society, but is this desirable and, if so, how does WMO go about leading or sharing this development?

**2.2 Regional requirements**

In order to expand the scope of the GDPFS stronger linkages with WMO constituent bodies (Congress, EC, RA's and Technical Commissions) and related programs will need to be established. Therefore, a close interaction of CBS with CAS, CCl, CHy, CAEM, CAgM, and JCOMM, as well as most of their main programs (GAW, WWRP, WCRP, GCOS, GOOS, WHOS, PWS, HWRP, WSP, PWSP, WIS, WIGOS, DRR, etc.) will be necessary in order to successfully evolve the present structure of the GDPFS by ensuring all facets of requirements impacted by the GDPFS are accounted for in the design of the future system. Also, given the more local aspects of some of the new services, RA's will need to become more closely involved, depending on the specific focus and scope of the new services.

To expand a bit on the links with Regional Bodies (e.g. TCP regional bodies, RAs working groups) one should note that Regional Bodies, by their very nature, represent classes of both providers and users of observational, data and forecasting products. As well, RAs provide a governance mechanism to plan and coordinate activities as well as providing a mechanism to enable supra-national discussions and decision-making. Those bodies vary immensely in their capacities and political influence, and specific products needs, this being driven by both socioeconomic, administrative and political factors, and the specific regional characteristics that weather, climate, hydrological and other environmental impacts display in the specific global areas which they cover. As the GDPFS evolves towards the provision of an expanding set of products, and focuses increasingly on forecasting impacts, close coordination with Regional Bodies will become more and more essential. Forecasting impacts at an increasing space and time resolution requires access to whole new sets of observations and data, as well as an expanding suite of numerical models, ensemble products, etc., coupled with a diverse suite of dissemination and presentation technologies: these will vary greatly between Regional Bodies. The challenge of closing the gaps between 191 NMHS's spread across the earth will require increased linkages, through better feedbacks and interactions.

**2.3 Requirements of other International Organizations**

Linkages with a number of other international organizations, including humanitarian agencies, some in the UN Family, UNEP, UNESCO, IAEA, WHO, some outside, like GEO, or ICSU are also required to ensure the GDPFS system of the future can respond to their needs.

**2.4 Research**

The value chain in meteorology is rapidly being diversified. From mainly providing weather forecasts to the general public, the NMHSs and the weather enterprise progressively develop and apply downstream models/post processing of NWP forecasts or reanalysis for a range of applications in specific societal sectors. Marine forecasts, GCM climate projections and environmental predictions are also included. Many of these have been rendered possible by adopting the seamless and integrated modeling approach.

Examples of specific applications include road traffic, aviation (civil and military), shipping, energy production and consumption (wind, solar, hydro, fossil), air quality, integrated global greenhouse gas information system, biogeochemical fluxes (ecosystem including freshwater impact), estimation of emissions of trace chemical species, agriculture, tourism, high impact weather (wind, precipitation, temperature), avalanches and mud slides, coastal erosion, storm surges, offshore weather including waves, icing on infrastructure, emergency preparedness (search and rescue), oil spill, drifting infrastructure; volcanic ash dispersion, dispersion and deposition of radioactivity, large explosions and fires, forest fires, sand and dust storms. The list can be made even longer.

The important point here is to note the foundational role of research in making this evolution possible. WMO, largely through the CAS (GAW, WWRP, GURME), CCl, JCOMM and other research programs, some of which are co-sponsored, such as the WCRP, GCOS, and others, has played a key role in making it an operational reality. It should also be noted that most of the research initiated, coordinated or facilitated through partnerships by WMO are services and policy driven, as is most of the research conducted within the NMHS's. Research activities provides an important ‘sentinel’ role in that it facilitates an over the horizon S&T watch, which allows better strategic planning for future operational programs and the GDPFS.

The future evolution of the GDPFS will require stronger links with research, and eventually the capacity to test novel operational products. Some examples that have been discussed are TIGGE and TIGGE LAM, S2S, Polar related experimental products, CHAMP, IG3IS. By making these prototypes available to WMO users, it will be possible to obtain feedbacks from the whole WMO community and, hopefully, their partners: these feedbacks will be essential to assess their accuracy, identify potential improvements, and in the end help tailor them more closely to their needs. In other words the new GDPFS will need to facilitate a smooth transfer of research results into operations.

**2.5 Capacity development, including education and training**

The evolution of the GDPFS will require a strong focus on capacity development, education, training and support to those countries facing difficulties in assessing and using the new types of products that will be made available to them. There will be a challenge in interpreting the value (accuracy, relevance and impact on decision-making processes) of specific products, as well as disseminating and presenting them to users. A key issue here will be for WMO to ensure that the progresses made in a subset of countries in providing a more diverse, probabilistic based and impact focused set of products is actually useful to those countries who presently lack the capacity to make best use of these, countries which are often those who need them most.

**2.6 Why are we doing this? Evolution, instead of revolution**

There are a number of reasons for re-examining the GDPFS. On the one hand, we are witnessing rapid advances in information and computing technologies (including such objects as smartphones, cloud computing and data storage and retrieval, big data and deep data analytics concepts, fast broadband links, extremely powerful computing technology (capacity doubling every 18 months), novel visualization and display techniques, etc.). On the other hand, we are seeing steadily increasing demands from users for highly-localized weather forecast data provided at a high temporal resolution (at least hourly for the first 12-24 hrs.), spanning a much broader level of dimensions than traditional weather products, and focusing on risk warnings and impact forecasts. In other words, both the "system” and the "services" aspects will need to evolve.

Moreover, with the successful introduction of the seamless or integrated approach in earth system modeling, and the possibility through coupled modeling techniques to touch many non-traditional weather related applications, there will also be a need to re-examine if, how and how much the GDPFS needs to evolve in order to interact or liaise with non-traditional providers of data and services (such as climate services, hydrological services, atmospheric air quality services, space-weather services, maritime or polar services, etc.).

Simultaneously, while adapting to these changes, the GDPFS will need to maintain its role as a global enterprise which enables NMHS's to fulfill their national obligations, keep on enhancing WMO's role in disaster risk reduction and mitigation, increasing its linkages with the Climate Services Information System (CSIS) of the GFCS, and ultimately contributing to the reduction of service capability gaps between developed and developing countries.

**3. The Vision.**

**The proposed vision for the Future GDPFS is:**

* The GDPFS will be an effective and adaptable monitoring and prediction system enabling Members and partners to make better-informed decisions.
* The GDPFS will facilitate the provision of impact-based forecastsand risk-based warnings through partnership and collaboration.
* The GDPFS will do so through the sharing of weather, water, climate and related environmental data, products and services in a cost effective, timely and agile way, with the effect of benefitting all WMO members, while also reducing the gaps between developed and developing Members.

A good way to crystalize this vision is to project us in 2031, that is, 16 years from now, and have a look at what the GDPFS might be.

At that time, the overall accuracy of state of the art global prediction models will have improved enough to add 1.5 days of overall predictability, if the historical rate of progress of one day per decade is maintained; we will finally have achieved the goal set by Jules Charney and others when they launched GARP in the 1970's. Global models will have resolutions below 5km, and mesoscale models significantly below 1km, down to a few tens of meters in urban areas for example. We will have achieved:

* Full predictive skill at the sub seasonal time scales and Ensemble Prediction Systems (EPSs) will routinely have hundreds of members and outputs shared between many global centers;
* Forecast products providing accurate and detailed information on such things as closed water budgets over most watersheds, wind, temperature and air quality information in urban street, canyons and outwards to the surrounding country side;
* Detailed agro met information from hourly to seasonal cycles;
* Precise storm surges and wind damage estimates from cyclone, sea state, including rogue waves, and dangerous shore currents and;
* Products on telecommunications and electricity blackouts due to solar eruptions and on toxic algae blooms, pest migrations, etc.

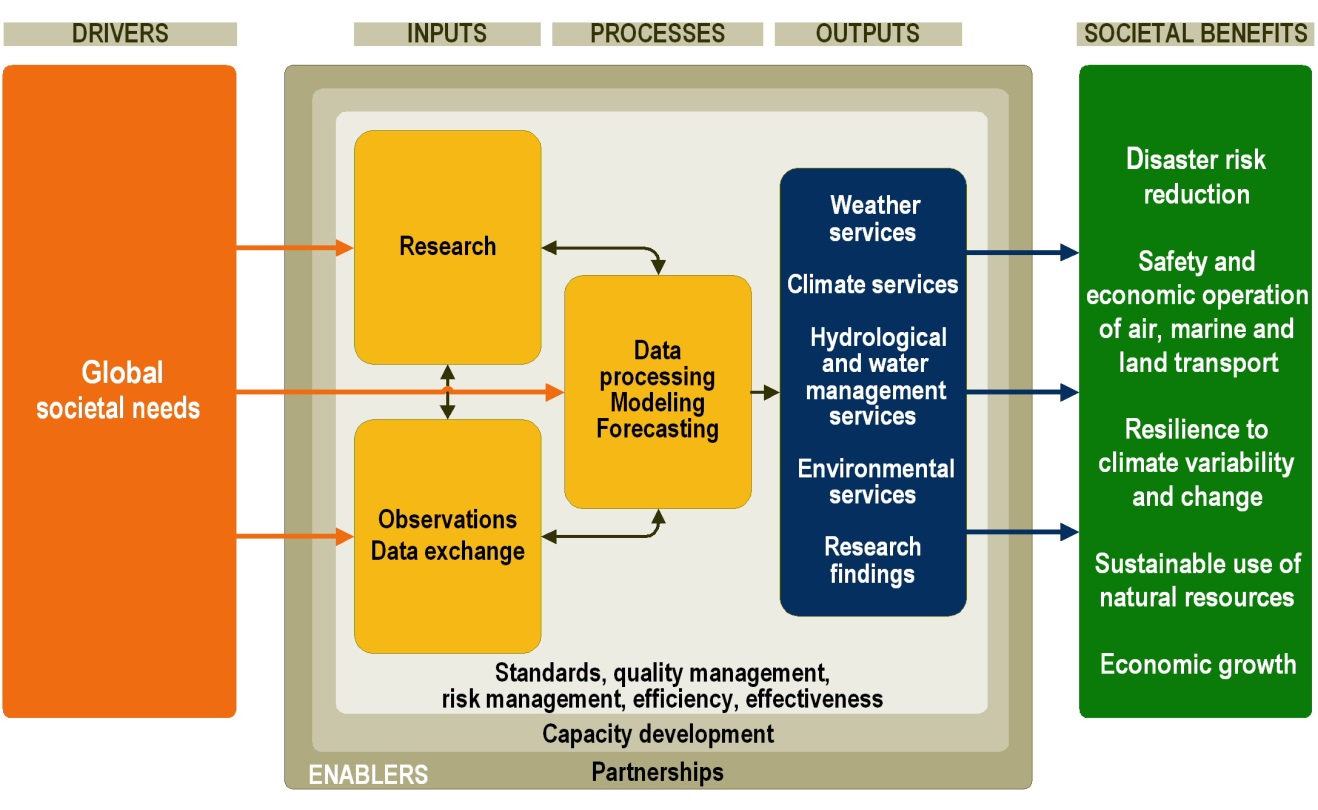
Most or even all of this information will be made accessible as a public good product to all WMO members, and their partners[[1]](#footnote-1). And most of this information will be made available either in raw format, or directly as impact information. It will be disseminated and presented in whatever medium or format the users have chosen, and use point to point or, increasingly, cloud to point communication broadband technologies. It will be quality controlled, it will be validated and will have metadata information with appropriate publications in the peer-review literature and in the case of forecast information, it will be verified. Imbedded in the design of the system will be two-way feedback and real time communication capacities between the provider and the receiver of the data.

The system will also have evolved through partnership agreements that allow it to absorb or carry information produced either by the private sector and academia, or by other closely related organizations to the traditional NMHS's. And by using alternate and less expensive technologies, such as cloud computing, crowdsourcing, smartphones, open source software, big data storage, etc., as well as potential partnerships with private sector or other non traditional information providers, gaps between WMO members in terms of ease and cost of access and positive user impacts will have decreased significantly.

In fact, these recent technology changes open up the possibility of both NWP and GCM future development strategies (both science content and operational implementation and capacity) being "community driven", relying on distributed computing and data storage capacities, thus making relatively obsolete the need for purely national facilities. By inference, it thus follows that a potential path for the future GDPFS will be the development and provision of tools giving access to pooled resources, so that NMHS's can obtain the tailored information they need to address requirements of their users of services, thus bypassing the need to implement modeling capacities at home. An extension of this approach, is for the users to directly access the information they need to link to their decision making-processes directly.

**4. Scope (integration, standardization and interoperability).**

The WMO Strategic Plan 2016-2019 will largely determine the scope of the evolution of the GDPFS. It will be driven by the need to support the role of NMHSs in their response to global societal needs facing the world population at large, focusing not only on those sectors for which they traditionally have had a leading role to play, mainly in reducing the socio-economic impacts of weather and climate related disasters in their respective countries, but more broadly on contributing to an expanding number of sustainable development issues related to weather, climate, water and related environmental factors, such as contributions to a carbon-free economy. This expansion or broadening of the role of the GDPFS will be made possible by a number of factors, a key one being the seamless and integrated modeling approach, which allows the delivery of new environmental services in support of sustainable development across all timescales and disciplines (Agriculture, hydrology etc.). Standardization and interoperability of data and products will also be important factors in providing this broadening. The figure below, extracted from the WMO Strategic Plan 2016-2019 illustrates the role of the NMHSs in responding to those needs.



The GDPFS, whilst maintaining its traditional role for standards, validation, verification and overall quality management for data processing and forecast services, will expand its linkages with other WMO constituent bodies and programs, with emphasis on regional bodies (TCP regional bodies, RA's) and programs. It will also contribute to the capacity development of its client and user base, and will strengthen its interactions with research, through participation in the design and operational testing or validation of novel products emerging from RDP's and FDP's.

**5. Benefits.**

The benefits of the future GDPFS can be articulated along three axis : contribution to the UN and WMO agendas, the quality, diversity and relevance of GDPFS information and furthering existing and developing new partnerships.

**5.1 Contribution to the UN and WMO agendas**

Quoting from the 2016-2019 WMO Strategic plan (p.10, The need for Sustainable Development), the following three Global Societal needs (GSN) are of fundamental importance in defining priorities:

* **Improved protection of life and property** by mitigating the impacts of hazardous weather, climate, water and other environmental events and addressing the need for improved safety of transport on land, at sea, and in the air;
* **Poverty eradication, sustainable livelihoods, food security, sustainable access to water and energy, and economic growth** by making available weather, climate, water and related environmental services to support the post-2015 sustainable development agenda, climate risk management, climate resilience, green economy, disaster risk reduction, food security, improved health and social well-being of citizens, water management, and tapping renewable energy resources such as hydro-, solar- and wind-power;
* **Sustainable use of natural resources and improved environmental quality** by designing weather, climate, water and related environmental services to manage atmospheric, terrestrial and water resources at all time-scales, and the development and management of other natural resources.

From the preceding sections, it is clear that the proposed evolution of the GDPFS will benefit this important and central item in the UN Agenda. It also will contribute to a number of WMO priorities for 2016-2019, in particular:

Improvement of the effectiveness of high quality impact-based forecasts and early warnings for extreme weather, climate and water events for disaster risk reduction; GFCS and Aviation

**5.2 Improving the quality, diversity and relevance of GDPFS information, data and products**

The new GDPFS will allow testing and eventual operational inclusion of many projects, all focusing on one or more of these priorities: SWFDP expanding to other regions on the globe, GLOFAS exploring the capacity to forecast flood risks on the globe, MAP providing a successful example in a mountainous area, CHAMP looking at forecasting the hydrological budget of the North American Great lakes area, CREWS, an initiative which aims to significantly increase the capacity for seamless Multi-Hazard Early Warning System (MHEWS) in the climate realm in order to generate and communicate effective impact-based early warnings, and risk information for hazardous hydro-meteorological and climate events, IG3IS which could provide at a very high spatial resolution an integrated 4D snapshot of GHG and other related atmospheric chemical constituents budget over a given area of interest, GAMOS and ChiNAMOS, a global agrometeorological outlook system, Space Weather operational forecasting system, mitigating risks of solar eruption activity to satellites, electrical and communication networks, etc. And this list is a subset of the full number of initiatives now being examined by WMO, its members and partners.

**5.3 Opening a door for new partnerships**

The common thread here is that the seamless and integrated modeling paradigm (with a high resolution core of atmospheric, oceanic and land surface modeling capacity, coupled with complex earth system modeling subsystems, and benefitting from powerful supercomputing capacity, broadband communication capacity, massive data storage capacity) will be easily accessible by an increasing number of non-traditional users. Moreover, using new dissemination technologies (cloud to point delivery of the information, smart phone access, emerging social media technologies), client focused adjusted means of product presentation or communication as opposed to traditional methodologies, will bring in new partners to the WMO world, including private sector operators and academia. It is unclear at this time how this will all evolve, but in the end, this transformation should yield direct benefits to decision makers or ordinary clients and users in optimizing either their business practices, risk mitigation of threatening environmental high impact events, or longer range adaptation and sustainable strategies.

**6. Opportunities, Success factors and Challenges.**

**6.1 The context.**

**The business of weather, water, climate and earth system observations and predictions is, first and foremost, a science-based, high technology (largely IT-related) just in time information enterprise**.

This information has global reach and relevance, and is key to countless decision-making processes, be it on: 1) global policymaking issues (UNFCC, UNCDD, Ozone, COP21, Transport of atmospheric pollutants and toxics and associated morbidity, nuclear weapons controls, etc.), 2) global weather, water and climate related disaster risk reduction, and 3) important and steadily growing socio-economic impacts.

Recently, significant scientific progresses in both observational technology (particularly space-based observing systems), as well as novel climate and weather data assimilation and modeling practices, have led us to the possibility of vastly expanding the diversity of its environmental information potential.

At the same time, it is fair to say that both the information technology and dissemination related processes are evolving at an accelerating pace (the transition of the traditional paper-based written media to a largely IT-based dissemination process (tablet, smart-phone, etc.) provides a good example of this acceleration. Given that there is a global market for the types of products NMHS's and GPC's, largely publicly funded, are on the verge of making available, it is reasonable to expect an increasing interest from the private sector with potential partnerships with the academia to take a share of the market (in fact, this has already started).

**6.2 Important issues needing consideration.**

Throughout this document, and in many of the discussions with the group of experts, it is possible to identify a number of important issues that need some consideration if the proposed evolution of the GDPFS is to be a success:

**6.2.1 Access to data and observations.**

One important consequence of moving towards a seamless and integrated modeling approach is access to new, and sometimes non-traditional observations, and at much higher spatial and temporal resolutions than has been customary. This follows from the fact that forecast products will expand to new disciplinary or thematic domains, which so far have not been part of the traditional inputs and outputs of production centers of NMHS's.

There are also other dimensions to consider: standards and formats, interoperability of the information, information storage, telecom bandwidth and downstream computing and post-processing (this may lead the GDPFS to establish globally distributed storage farms such as what CERN has done to manage the information generated by LHC; make available the basic information along with the approved piece of code to generate the post-processed information on cloud computing platform). This will require discussions on availability and data exchange protocols between WMO members and other international, national and regional organizations.

Similarly, the concept of "risk-based warnings" and "impact forecasting" requires access and sharing of novel types of data (infrastructure, emergency decision-making policies, population distribution, transportation networks, etc.), not easily amenable to present guidelines on formats, metadata, validation, etc. Moreover, some countries could be reluctant to make this data available for any number of reasons. Again, there will be a need for extensive discussions between WMO members and the other organizations controlling access to these data.

**6.2.2 Future products: optimal production, dissemination and usage**.

Many of the future warning and forecast data and information, such as those related to air quality, hydrological, marine, aviation, agro meteorological information, and more generally speaking socio-economic applications are often of use for organizations outside traditional NMHS's. These organizations have their own internal decision-making processes, data and forecast related protocols, partners and user bases. A good example was provided for hydrological forecasting. And similar issues exist for other services. Again, WMO will need to establish the necessary partnerships, in order expand the current GDPFS menu to these new products. In fact, concerning so-called "big data" related issues and applications; WMO has already started such a process.

Another key aspect, which requires further consideration, is user information and feedback. The creation by WMO of some form of user information platform (UIP), geographically or thematically structured is perhaps worth some further consideration.

**6.2.3** **Transition towards a new global, regional and national production infrastructure.**

Many of the products also depend on very high-resolution observational and modeling grids, often at he kilometer size and less. A relatively small number of countries actually have the capacity (human and technical) to operate at these resolutions. And at this time, at least, it does not seem feasible to generate these products at a small number of central locations (e.g., GPC’s) for global distribution. In order to help prevent the widening of a gap between the countries, which possess the capacity, and those that do not, some transitory and eventually permanent solutions will have to be found, perhaps involving private sector or academia-led initiatives, or use of new computing technologies, such as cloud-computing.

**6.2.4 Training and capacity building.**

The increasing complexity of many of the products will in turn increasingly require an increase in the capacity of the users (NMHS's or others) to make optimal usage of their information content. This will represent a challenge for many countries, and necessitate a strategic re-think of WMO's and its members approach to training and capacity-building initiatives.

**6.2.5 Organizational impacts (impacts on GDPFS Centers).**

Finally, as this expansion of the scope of the GDPFS happens, and numerous agreements and partnerships with new international, national and regional organizations are struck, there could be pressures from countries and partners to revisit the current membership structures. For example, it could be that some countries will wish to be represented by different types of managers or administrators along with the current Directors or CEO's of NMHS's.

**6.3 Policy considerations.**

From the preceding Sections, it becomes clear that whilst the evolution of the GDPFS proper remains an internal management and operational issue, it will also require EC and Congress to consider a number of policy issues, which will guide, clarify and facilitate this evolution.

**6.3.1 Open data policies.**

In order to fulfill WMO's vision, and a successful evolution of the GDPFS, free and open access to all necessary data, particularly observations, is critical. We are already witnessing initiatives, some led by the private sector, where new observations are either not shared openly, or if so, at reduced spatial and temporal resolutions, or against cost. At the same time, while most observations paid for by the public purse have open access some are not. There are also related issues linked with formats, validation and quality control. Eventually, some policy decisions will be required to clarify these issues and propose some solutions.

**6.3.2 Role of the private sector and the academia.**

This issue is closely linked with open data policies. However, there is also increasing evidence that some major corporations are moving towards establishing their own internal data processing and forecasting capacities, including global analyses and predictions. Given the potential value of applications derived from such capacities, mostly targeting specific socioeconomic sectors, they will in a sense potentially duplicate or compete with public good products, made available through the future GDPFS. At some point, some policy decisions might be needed to as to how the GDPFS should take these developments into account.

**6.3.3 Training and capacity building.**

We have already alluded to the linkages of this aspect to the evolution of the GDPFS. In the discussions leading to this paper, there was often mention of the high priority that should be given to this issue. As the products become even more complex, both in their content, as well as in their formats (ensemble products, impact based, etc.), and target many new and different non traditional sectors, training and capacity building will become essential to the success of the GDPFS evolution, unless one accepts the possibility of increasing gaps between members. Discussions between members and eventually policy decisions will probably be needed.

**6.3.4 GDPFS products quality assessment.**

One of the key benefits obtained by WMO members from using GDPFS products should be assurance on their quality, accuracy and reliability. Concerning weather prediction activities, for which the WMO is the UN lead agency, and which is its core business (GDPFS, WDS, etc.), there is no official external scientific assessment (produced say by an international team of experts) of these aspects. Yet, we do produce an assessment for weather modification activities, which clarifies what is scientifically validated, and what isn't.

Perhaps WMO should consider proposing to put together a core team of experts, under the leadership of its RES and WDS program, and reinstate a similar activity, which was dropped some years ago.

This would set the bar for what are good products, and those that fail to be based on good science! It would reaffirm WMO global leadership in these matters, but would also contribute very positively to the future evolution of the GDPFS, help its users in their decision-making activities, and facilitate the discussions with potential new partners.

**7. Terms of Reference (ToRs) for the Steering Group on Seamless GDPFS**

The Steering Group on Seamless GDPFS (following the request by Cg-17), will be chaired by the president of CBS and will comprise of representatives of technical Commissions and regional associations, with the following Terms of Reference:

1. Provide guidance and monitor the development of the process for the gradual establishment of a future enhanced integrated and seamless WMO Data-processing and Forecasting System;
2. Manage the integration of new components in the GDPFS, including addressing synergies with and requirements of all WMO Programmes and Regions, through active consultations with technical commissions and regional associations;
3. Develop a description of the set of products the system should produce;
4. Complete the White Paper along with the Implementation Plan for the process, for consideration by EC-69;

**8. Roadmap (phases)**

**Reference**

**List of Acronyms**

**Annex: Outline of the Implementation Plan**

**EC 68 – Present the White Paper which should include concrete actions to move us to seamless GDPFS**

**CBS nove 2016 – to consider EC-68 decision and develop the path forward for approaval by EC 69EC 69 – Approve the path forward and implementation plan**

**EC 70 -**

**CG**

1. The assumption here is that the public funding of computing facilities that NMHS's can use is maintained at a sufficient level; if not, the possible landscape described above may not be entirely funded or controlled by state-owned institutions [↑](#footnote-ref-1)