International Cooperation in Meteorology – the Example of the World Weather Watch[1]

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INTRODUCTION

In April 1963 the Fourth World Meteorological Congress approved the concept of the World Weather Watch (WWW), and set the World Meteorological Organization (WMO) on the journey that dramatically changed and enhanced the development of meteorology and the atmospheric sciences. To me this is one of the, if not the most, outstanding examples of global-scale international cooperation that we might point to.

HISTORICAL DEVELOPMENT

International cooperation in meteorology of course didn't start from scratch in 1963 – throughout history man has sought to observe and understand the atmosphere and the ocean and early on weather variations and extreme events were a major topic of the study of natural phenomena. .A concise summary of the emergence of meteorology as an international science and the gradual application of the science to practical purposes may be found in the first chapter of the volume commemorating the fortieth anniversary of WMO (Davies, 1960). For this paper I will simply highlight a few historical events that have been important in the development of what we refer to as the World Weather Watch.

The idea of organizing a world-wide network of meteorological observing sites where similar observations would be made and then collected into what we today would think of as "data sets" was proposed in 1771 and actually undertaken in 1780 by the *Societas Meteorologica Palatina* in Mannheim. Some 40 weather observing stations were organized in Europe, each station was equipped with comparable instruments and the records posted annually to Mannheim. In 1795 the siege of Mannheim ended this effort, but the archive of data provided the basis for the first systematic attempt at preparing weather maps in 1820. There followed many initiatives to organize networks of stations, to archive the data and to prepare analyses showing the characteristic patterns of pressure, wind and weather as well as empirical rules for their development and the accompanying sequence of weather changes.

The invention of the electric telegraph by Samuel Morse in 1843 opened the possibility of both organizing networks of observing ststions and transmitting the data quickly to centralized collection sites. By 1850 telegraph lines crossed the English Channel and by 1853 the Atlantic Ocean. Joseph Henry, the first Secretary of the Smithsonian Institution, for example, was instrumental in expanding the network in the US by providing meteorological instrumentation to telegraph companies if they would send daily readings by telegraph to the Institution. By 1853 there were 32 Stations, by 1860 more than 100. Similar initiatives were undertaken in Europe.

Efforts were also underway in the maritime community. Motivated by an urgent desire to improve security and efficiency of maritime transportation an International Meteorological Conference was held in Brussels in 1853 with representatives from 12 Countries. The highlighted box below is pertinent to the development of international co-operation in meteorology in that it contains the kernel of requirements that have become so basic to our understanding of how meteorology should be done; (a) all nations should co-operate, (b) observations should be standardized, (c) the enterprise should be global, and (d) the parameters measured, the data recording and exchange, and the instruments and methods of observation should follow an agreed plan.

August 1853, First International Meteorological Conference, Brussels

"… all maritime nations should co-operate and make these meteorological observations in such a manner and with such means and implements, that the system might be uniform and the observations made on board the public ship be readily referred to and compared with the observations made on board all other public ships, in whatever part of the world. And, …it becomes not only proper, but politic, that the forms of the abstract log to be used, with the description of the instruments to be employed, the things to be observed, with the manipulation of the instruments and the methods and modes of operation should be the joint work of the principal parties concerned."

Proposal of Lt. Matthew Fontaine Maury US Navy, adopted by the Conference

Over the next twenty years the concepts put forward in the maritime community were extended to the emerging national networks of observing stations and led to the First International Meteorological Congress in Vienna, September 1873, where countries with established national meteorological Services created the International Meteorological Organisation (IMO). The Congress dealt with practical matters such as calibration and checking of instruments, time of observation, scales and units, and the mutual exchange of observations by telegraph, etc. – topics that in one form or another stay with us today. It also set up permanent machinery to carry on the work. The technical work of the IMO was largely carried out by a system of Technical Commissions comprised of groups of experts who addressed issues and proposed solutions and procedures greatly influencing the direction, and accelerating the advancement, of meteorology. Technical issues dealt with included, among others, expansion of observing networks, instrumentation, standards for observations, codes and symbols, and telegraphic and eventually wireless communications. With co-ordination between IMO and the International Telegraphic Bureau international co-operation on the inter-agency level began.

Following a hiatus due to the First World War, the pace of activity within the IMO structure resumed with new forces at work such the application of meteorology to air navigation, the use of radio broadcasts and the invention of improved instruments i.e. the radiosonde. Then from 1939 to 1945 war again interrupted the orderly development of the IMO. However, the technological developments, which took place during the war years (e.g. radar, aviation, communications and advances in meteorological science) and the general level of importance that meteorology attained in the emerging world order, re-energised the IMO. The World Meteorological Convention was drafted and passed establishing the intergovernmental World Meteorological Organisation in March 1950. The WMO assumed the basic technical structure and function of the IMO and based its continuing effort on the traditions and procedures handed down from the earlier less formal non-governmental body. The purposes of the WMO, as laid down in the Convention, are a natural extension of the statement adopted almost a century before in Brussels [see box].

Purposes of the World Meteorological Organisation would be to:

a) Facilitate world-wide co-operation in the establishment of networks of meteorological observing stations and the establishment of appropriate centres charged with the provision of meteorological services,

b) Promote the establishment of systems for the rapid exchange of meteorological information,

c) Promote the standardisation of meteorological observations and to ensure the uniform publication of observations and statistics,

d) Further the application of meteorology to aviation, shipping, agriculture and other human activities, and

e) Encourage research and training.

The First Congress of WMO initiated a proposal that, after consideration by the United Nations General Assembly, made WMO a Specialised Agency of the United Nations allowing it to participate in the UN expanded program of technical assistance to developing countries. It also brought the WMO into partnership with the United Nations and allowed for the UN to call on the WMO to assume responsibility for programs and activities that fell within its terms of reference. Events within the next decade attest to the wisdom and foresight of the delegates to this First Congress. They defined the role and responsibility that WMO should have on the world stage.

THE WORLD WEATHER WATCH

The advent of the space age sparked the nations of the world to take the actions that ultimately led to the World Weather Watch. The launch by the USSR of Sputnik I in October 1957, and Sputnik II in November 1957, followed by the launch by the USA of Explorer I in January 1958, initiated tremendous interest and concern throughout the world, with an intense desire to ensure that this new technology would be used for peaceful purposes leading the Third WMO Congress in 1959 to pass a resolution (Res. 28

Cg-III) that acted to set policy regarding meteorological satellites, namely a) to encourage the development of meteorological satellites as a means of providing data, and b) to collaborate on the subject with the UN, other specialized agencies, and the scientific community

Almost immediately, the first meteorological satellite, Explorer VII, was launched in October 1959, and the first of the TIROS series of satellites was launched in April 1960.

Scientists throughout the world, realizing that the emerging technologies (satellites, digital computers, numerical prediction and communications) offered great opportunity for advancement in atmospheric science, set out to articulate just what might be possible in the coming years. For example, the National Academy of Sciences (USA) undertook an evaluation and planning process during the late 1950s that culminated in a report entitled "the Atmospheric Sciences 1961-1971". Here, apparently, the title "World Weather Watch" appeared for the first time. It included a world-wide coverage of traditional observations, meteorological satellites, automatic land stations and ocean buoys, balloon systems, soundings from merchant ships and commercial aircraft, a world-wide system of telecommunications, and a network of regional weather service centers (Petterssen, 1966).

This planning activity, while still underway, fed into the address given by the President United John F. Kennedy (USA) to the UN General Assembly on 25 September 1961 in which he urged the UN to embark on major new initiatives in weather prediction and satellite based communications [see box]. The details of the circumstances that lead to President Kennedy's speech are related in a speech presented by Harlan Cleveland to the 2001 National GeoData Forum (Cleveland. 2001).

> Excerpt from Pres. J.F. Kennedy's address to the UN General Assembly, 25 September 1961
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> "…Scientists have studied the atmosphere for many decades but its problems continue to defy us. … Here, new scientific tools have become available. With modern computers, rockets and satellites, the time is ripe to harness a variety of disciplines for a concerted attack … the atmospheric sciences require world-wide observations and hence, international co-operation … we shall propose further co-operative efforts between all nations in weather prediction and eventually in weather control. We shall propose, finally, a global system of satellites linking the whole world in telegraph, telephone, radio and television."

The General Assembly responded, passing Resolution No.1721 (XVI) on December 20, 1961. The Resolution called upon WMO to undertake a comprehensive study of measures:

(a) To advance the state of atmospheric science and technology so as to provide greater knowledge of basic physical forces affecting climate and the possibility of large-scale weather modification:

(b) To develop existing weather forecasting capabilities and to help Member countries make effective use of such capabilities through regional meteorological centers.

The Secretary General of WMO, Dr. D.A. Davies, immediately enlisted Prof. V. Bugaev (USSR) and Dr. H Wexler (USA) to undertake the requested study. Supported by Dr M. A. Alaka (USA) and the staff of the WMO Secretariat, the *First Report on the Advancement of Atmospheric Sciences and Their Application in the Light of Developments in Outer Space* (WMO, 1962) was prepared for submission to the United Nations in June 1962. This *First Report* discussed in broad outline the concept, structure and function of the World Weather Watch [see box].

Extract from the *First Report …..*
"The World Weather Watch is intended as a co-operative global meteorological observing and prediction system designed to assist meteorological services of the world to discharge their responsibilities without each service having to perform all the steps needed for this purpose. The inauguration and co-ordination of this system would be a natural extension of the role that the World Meteorological Organization already plays in the taking and standardization of meteorological observations, the scheduling of meteorological communications etc. The new activity would be with regard to the orderly creation and dissemination of processed meteorological information, from both conventional and satellite sources and would be based on a system of World Centers and Regional Centers designed to avoid duplication in preparing analyses and prognoses, but still making available to each meteorological service the data and background information it requires for carrying out it's responsibilities."

The *First Report* called for a very marked improvement in global coverage of conventional as well as satellite observations and suggested specific network improvements; it called for a dramatic improvement in telecommunications through a world-wide coordinated system; and it suggested that the data processing system, anchored in the proposed World and Regional Centers, would provide the information required by every nation for its meteorological service. Technical assistance to developing services, including expanded opportunities for education and training, would be required. The report further suggested that the global data and analyses generated by the WWW should be provided to the World Data Centers for climatological and research uses; thus anticipating the important role that the World Weather Watch would ultimately play in climate related matters.

The report also listed preliminary research topics that should be addressed through international co-operative efforts to attain the goals laid out in Resolution 1721, and proposed the creation of a WMO Advisory Committee. This committee, with membership from the broad scientific community through organizations such as UNESCO and ICSU as well as WMO, would further address and refine the needs and priorities for research. The preliminary list of research topics included:

- Problems on the general circulation and heat balance;
- Problems on numerical weather prediction;
- Medium and long-range forecasting;
- Problems in connection with solar and other external influences on the Earth's atmosphere and the interaction between upper and lower atmosphere

At its Seventeenth Session in December 1962 the UN General Assembly, in Resolution 1802 (XVII), recommended that the WMO "…should develop in greater detail its plan for an expanded program to strengthen meteorological services and research, placing particular emphasis on the use of meteorological satellites and on the expansion of training and educational opportunities in these fields…". Resolution 1802 also "…invited the International Council of Scientific Unions … to develop an expanded program of atmospheric science research which will complement the programs fostered by the World Meteorological Organization.

IMPLEMENTATION AND EVOLUTION OF THE WORLD WEATHER WATCH

The Fourth Meteorological Congress, meeting in April 1963, took up the charge contained in the U.N Resolutions 1721 (XVI) and 1802 (XVII) and set in motion the necessary program and administrative structures to ensure the organization could undertake the challenges presented. These included: approval of the World Weather Watch concept as presented in the *First Report*; set up the WMO Advisory Committee on Atmospheric Research; established a WMO Development Fund in support of the WWW; and established a WWW planning unit in the WMO Secretariat.

The years 1963-1967 were a period of intense planning on both the national and international levels. Technological breakthroughs and the initial Resolutions of the UN provided the impetus, but the political, financial and administrative fabric for the budding enterprise needed the constant attention, commitment and energy of the whole meteorological community. Some countries organized national committees or working groups to develop national programs and to decide what their national contributions to the international effort might be. These national efforts complemented and contributed directly to the work of the Secretariat. Reading the reports of each annual session of the WMO Executive Council during this period gives one the sense of the excitement and plain hard work that permeated the Organization. In addition, the WMO submitted annual sequels to the *First Report* to the UN which helped to keep the development of the WWW visible on the larger international stage. The General Assembly responded again in 1963 through Resolution 1963 (XVIII) reinforcing the earlier Resolutions and asking Member States to "co-operate in the establishment of the World Weather Watch". Such pointed interest from the highest intergovernmental body provided tremendous support and assistance to the Permanent Representatives to the WMO in their efforts to generate national support for the program. The Planning Unit of the Secretariat, working with experts from around the world and the WMO Technical Commissions organized planning meetings that prepared elements of the plan which were submitted to the Executive Committee. In addition, the World Weather Watch Planning Report Series of publications, more than 25 of which were published in 1967 alone, provided detail, definition and justification for specific components of the emerging Plan.

Two streams of activity were at work concerning the research aspects of the program. One was the work of the WMO Advisory Committee set up by Fourth Congress and the other was the creation by ICSU/IUGG of the Committee on Atmospheric Research. During the period 1963-1967 a general convergence of both streams was realized with the emergence of the concept of a Global Atmospheric Research Program conducted by an ICSU/WMO Joint Organizing Committee (JOC) made up of twelve scientists with high international standing. Thus the WMO could concentrate on the formulation of plans and implementation strategies for the operational WWW program while the joint research pursuit could enlist the broad range of governmental and non-governmental bodies, i.e. the national academies of science, in the effort to devise a focused research program. With regard to the WWW, GARP was to:

- Recommend to the WMO those techniques and procedures developed in GARP programs that may be applied in the operation of WWW;
- To recommend to the WMO the manner in which the scientific requirements of GARP can best be supported by the WWW.

The adoption of the World Weather Watch Plan and Implementation Program for 1968 –1971 by the Fifth WMO Congress (Annex to Resolution 16 (Cg-V)) in 1967 was a milestone in the long and rich history of international co-operation in meteorology and in atmospheric science in general. This first plan was intended as the initial step in a process of developing meteorological science and services globally, taking advantage of scientific progress and technological change. The WWW, and the planning process itself, were perceived as dynamic - flexible enough to adapt to changing conditions - and open to technological and scientific advances.

It focused on the following basic concepts:

- The primary purpose of the WWW was to ensure that all Member States of WMO obtain the meteorological information they require for both operational work and for research.
- The WWW was to be a worldwide system composed of the national facilities and services provided by individual Members, coordinated and in some cases supported by WMO and other international organizations.
- The WWW was to be used only for peaceful purposes...
- The WWW was be used to stimulate and facilitate research
- The WWW would require an adequate program of education and training.
- The information required by Members would include both observations and processed data exchanged in a timely and coordinated fashion and accessible in convenient forms.
- Maximum use was to be made of existing facilities and arrangements in all fields of activity.

The essential elements of the WWW as described in the Plan were:

a) Observational networks and other facilities, The Global Observing System (GOS).
b) The meteorological centers and the arrangements for processing observational data, The Global Data Processing System (GDPS).
c) The telecommunications facilities and arrangements for the rapid exchange of information. The Global Telecommunication System (GTS).
d) The research program.
e) Education and training

The Proceedings of the Fifth Congress provide insight into the magnitude of the programmatic and financial commitments that the Member States were undertaking both in their national programs and in support to the WMO and its Secretariat. The leadership of Dr. Robert White, Permanent Representative of the USA, is especially noteworthy – a quote from his intervention after the Secretary-General presented the budget proposals for the fifth financial period illustrates his strong position and forcefulness [see box].

Excerpt from the intervention of Dr. Robert White during the Fifth World Meteorological Congress

"The World Meteorological Organization is at a cross-roads. The action that we take on the financial matters before us will, in large measure, determine which direction we take. Down one road lies the realization of the promise that our modern technology opens up. Down the other lies a continuation of the past. …. At this Congress the time for action has come. …"

The machinery for governance and orderly development of the WWW rested with the WMO Technical Regulations including its Annexes, the Manuals for the GOS, GDPS and GTS. The organizational entity that would undertake the bulk of the work to develop the technical details of the program and implement the internationally agreed elements was the WMO Technical Commission for Basic Systems (CBS), which prior to 1971 was named The Commission for Synoptic Meteorology (CSM). CBS accomplished its task through Working Groups that focused on each of the three main components and an Advisory Working Group that coordinated the complex and interrelated activities and responded to requirements from other Technical Commissions and Programs. The WMO Regional Associations dealt with the regional implementation of the WWW program.

In the years and decades since 1963 significant developments have occurred in the atmospheric and oceanic sciences, and in the technologies related to these disciplines, that have had an impact on the WWW and, at least to some degree, the WWW has in turn contributed to the developments themselves. Progress in implementing the original Plan and the constantly emerging technological opportunities required that an updated Plan and Implementation Program be agreed at each succeeding Congress.

In a very real sense the WWW will always be incomplete and unfinished. Considering that the WWW is comprised of the facilities and operations of the national meteorological services of all the 185 Members of WMO, each with its own unique requirements for meteorological services, and each with different levels of technical and financial capability, it is not surprising that there have been frustrations and short falls in reaching the goals as laid down in the various editions of the Plan. From 1967 onward the reports of Congress, the Executive Council, the Regional Associations and the Technical Commissions, especially CBS, attest to these "growing pains". Opportunities arising from technological progress (e.g. global communications, and computer capacity and speed) often cannot be implemented quickly enough throughout the global system so that all Members benefit. The technical co-operation programs, while tremendously beneficial to many developing services, simply have not been able to satisfy all needs. The requirements for education and training of staff in the meteorological services of the developing countries are consistently only partially met – and the rate of turn-over of technically trained staff is a persistent problem for many Meteorological Services. In the early 1980s CBS undertook the Integrated Systems Study in order to assess the overall development of the WWW and to prioritize its implementation in such a way that the impact on the overall integrated system was optimized. The WWW Data Management component of the Basic System was developed to bring to bear modern ideas such as distributed databases and the exchange of software among Members. These steps, among others, have helped make progress in fulfilling the plan in recent years.

ROLE OF RESEARCH

The role played by research institutions and programs in the development of the WWW is a topic that deserves much more emphasis than I can summarize briefly here. The GARP had the greatest influence through the focused effort to develop the science and technology for application to numerical weather prediction, and for designing and mounting field experiments, focusing on specific meteorological problems, often using new and innovative observing systems. The GARP Atlantic Tropical Experiment (GATE) was fielded in 1974 with the objectives of providing the data resources to understand the effect of smaller tropical weather systems on the larger-scale circulation. Five years later in 1979 the Global Weather Experiment (FGGE) succeeded in the deployment of special observing capabilities that, in the aggregate, approached the global coverage dreamed of by the planners of the WWW back in the early and mid-1960s. The integrated observing program included:

- An augmented WWW network of surface and upper-air stations both on land and from ships.
- A constellation of five geostationary satellites and four polar-orbiting satellites providing truly global coverage of the wind field derived from cloud motion observations and vertical profiles of temperature.
- A system of super-pressure balloons circulating at high altitude in the tropical belt and providing real-time data through a satellite based communications and location finding system (ARGOS).
- Aircraft observations from specially equipped airliners and a dedicated fleet of reconnaissance aircraft deploying drop-sondes.
- The deployment of drifting buoys over the vast reaches of the Southern Ocean using the AGOS system for communications and location.
- A flotilla of research vessels equipped to take

high resolution vertical profiles of the wind field in the tropics.

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In addition, regional programs to study the monsoon circulation systems in Asia (MONEX) and in West Africa (WAMEX) were fielded during the same time as FGGE in order to take advantage of the intense global observational resource and, in turn, to contribute to the global effort with enhanced observations from their respective regions.

These research programs were possible because of the worldwide infrastructure provided by the WWW system of observations, communications and data processing. Many of the systems and technologies developed and deployed during the experiments have become integral parts of the operational WWW itself. The vision of the early planners for a complementary partnership between the atmospheric science community and the operational meteorology community has been one of the outstanding results of the program. It continues today.

IMPACT OF COMMERCIAL ACTIVITY

Over the last two decades there has been an upsurge in commercial activity in the provision of meteorological services. This commercial sector includes both non-governmental firms, with potentially a global reach, and components of some national meteorological services. Issues threatening the WWW tradition of free and unrestricted international exchange of data and products arose in the context of this commercial activity. After careful study, Twelfth Congress passed Resolution 40 (Cg XII) that laid down WMO policy and practice for the exchange of data and products and set up guidelines on relationships between national services and the commercial sector. The future development of the WWW depends on the effective implementation of the data exchange policy.

SYSTEM OVERVIEW

It is impossible in a short article to adequately cover the important milestones, accomplishments and challenges that the WWW has experienced over the last forty years. A brief summary follows of what, in the author’s personal opinion, are the most significant in the context of the three WWW components.

The Global Observing System (GOS)

Space Based Systems
As discussed above, the advent of meteorological satellites was one of the principal elements in the concept and implementation of the WWW. The development of the Automatic Picture Transmission (APT) system in the early 1960s provided the opportunity for all national meteorological services to have direct access to real-time satellite imagery for their forecast and analysis applications. Until high-

speed communications capabilities were available to carry a broader range of satellite data the APT system ensured that all national services could have access to information in real-time from meteorological satellites. The APT capability is an outstanding example of the application of the basic concepts of the WWW.

The progressive development of the space-based system from the rudimentary polar orbiting satellites at the beginning of the WWW to the current operational configuration of three to four polar orbiting systems and five to six satellites in geostationary orbit has been perhaps the single greatest accomplishment in our ability to observe the global atmosphere and ocean. The assessment is based not only the numbers of satellites but also on the constantly advancing technology in the sensor systems and sophistication in operational capability. The satellite operators have closely coordinated their plans with the WWW and the provision of satellite data into the WWW system has been a model of international response to user requirements. Other than in the application of visible and infrared imagery on weather analysis, the actual impact of satellite data on global, regional and local-scale numerical analyses has been slow to materialize. In the decade of the 1990s the major numerical prediction centers developed ways to assimilate satellite observed radiance values into their analysis schemes and this has begun to bring the value of satellite data up to the level that has long been anticipated.

The satellite operators are currently seeking ways to ensure that data from experimental systems are available to users following WWW protocols. As has been demonstrated in the GARP programs, the application of new data in operational settings is often the best test of its lasting value.

Surface Based Observing Systems

Upper-air Observing

A persistent problem facing the WWW has been the establishment and maintenance of the global radiosonde network. The evolution of systems from those based on radar, to those based on navigational aid radio beacons, to the current systems utilizing the Global Positioning System has resulted in continued improvement in data quality and ease of operation. However, the high cost of equipment and expendables has made it impossible to attain the global network envisaged. Some compensation has been attained through the utilization of vertically pointing radar systems (Profilers); through utilizing modern avionics systems on Commercial Airliners – providing data on assent and decent as well as at flight level; and from the improved sounding capability from satellites and the continued deployment of shipboard upper-air systems. The in-situ upper-air observing network will continue to be a major issue facing WWW in the future. Research programs employing drone aircraft and a variety of balloon-borne systems show some promise in helping to attain the density and coverage required.

Surface Networks
Two major advances have characterized the evolution of meteorological observations at the earth's surface. The first is the development of automatic weather observing technologies that have permitted the more efficient use of personnel and has allowed for the deployment of observing systems in more remote locations. The second advance has been the major improvement in observations over the ocean. The co-operative arrangements between the IOC and the WMO/WWW that led to the implementation of the IGOSS system was an early step in fulfilling the requirement for data coverage over the ocean. The development and deployment of drifting and moored buoy systems throughout the world's oceans, with data acquisition and location provided satellite based systems, has dramatically improved the data coverage.

<u>Global Telecommunications System (GTS)</u>

Historically the GTS functioned at three levels: (1) The Main Telecommunications Network - a high- speed circuit that connected the World Centres and branched to regional hubs so that the regions were effectively connected to the global system; (2) Regional Meteorological Telecommunications Networks; and (3) National Meteorological Telecommunication Networks. Over the years the plan for the GTS has progressed from the original "store-and-forward" system with its mix of automatic and manned facilities requiring an intense management effort and which was subject to outages and failures especially at the regional level; to a system which might be described as a "mixed" system with some national and regional components utilising "two-way point-to-multi-point" satellite based systems, while others operate in the traditional mode. Some particularly difficult circuits have utilised the Internet as an option. The great strength of the WWW GTS is that it allows the telecommunication connections between Members and within and between Regions to be determined by those Members concerned as long as international exchange commitments and protocols, as set down in the WMO Technical Regulations, are met. The GTS is constantly under review within CBS and planning for upgrading the global system to take advantage of the revolutionary changes in communications technology, while ensuring every Member receives the meteorological information it requires, is a high priority. A new imitative called the WMO Information System (WIS) is in the planning and initial implementation stage reflects this requirement.

<u>Global Data Processing System (GDPS)</u>

The original WWW Plan focused on the establishment of three World Meteorological Centers (WMCs) and anticipated a number of Regional Centers (RMCs) to eventually emerge. The operational concept was for the WMC to undertake the task of assembling data, information such as output fields from global numerical prediction models, and their interpretation for use by the various RMCs which in turn would add a level of more detail in order to support the National Meteorological Centers (NMCs) in their service provision responsibilities. Over the years the research contributions from major field programs like FGGE and the development of major modeling centers such as ECMWF in Europe, and GFDL and NCAR in the USA and major research programs at academic and research institutions around the world did much to expand the definition and role of the WWW GDPS. Numerical weather prediction on the continental and sub-regional to meso-scales became operational. The structure of the GDPS evolved and currently there are some twenty-five Regional Specialized Meteorological Centers (RSMCs) with geographic specialization. These centers run a suite of models and analyses particularly designed and tuned to provide forecast guidance for a particular topographical or ocean area often using data sources of a local or regional nature e.g. radar data. In addition there are six RSMCs with tropical cyclone prediction responsibility, and eight RSMCs with transport modeling responsibilities. The latter category has regional responsibility to provide atmospheric transport model products for environmental emergency response in the case of a nuclear accident, volcanic eruption or other emergency. In addition, several designated RSMCs provide medium range weather forecasts, drought monitoring and prediction and extended and long-range forecasts. More than 30 additional NMCs possess some level of numerical prediction capability, ranging from full global models to limited area models to more high-resolution meso-scale models. In recent years the GDPS has been renamed the Global Data Processing and Forecast System to more accurately define its activity.

Remarkable advances in the techniques for data assimilation into models and in the procedures for processing model output, such as ensemble prediction schemes, that allow one to objectively attain the best possible forecast outcome, continue to increase the accuracy and usefulness of numerical prediction products.

The continued improvement of both accuracy and lead time of weather forecasts attests to the progress made in implementing the WWW system as a whole as well as in the development of the atmospheric sciences in general and numerical prediction in particular. Five-day forecasts today have better accuracy than two-day forecasts did in the 1970s, the prediction of extreme events such as the occurrence, intensity and track of tropical cyclones have shown significant improvement as well.

The systematic archiving of meteorological data over the 40-year history of the WWW has allowed research-focused institutions, the World Meteorological Centers and some RSMCs to under take what is referred to as “reanalysis”. Here the latest and most sophisticated numerical analysis techniques are applied to the whole historical data record – yielding a physically consistent set of analyses covering the whole period. This powerful tool finds application in general circulation studies, research in long-term weather prediction and in climate studies.

SUMMARY

Forty-four years ago the WWW was conceived as an integrated global system of meteorological observations, telecommunications and data processing facilities and supporting activities linking all countries of the world in order to assist the National Meteorological Services in their task of providing services to their governments and populations. The WWW was to be composed of national facilities and services owned and operated by the National Meteorological Services of the individual Member States of WMO. It would be coordinated and regulated through the WMO as would the associated technical co-operation and education and training programs. The operation of the enterprise was to be based on the fundamental concept that each of the 185 or so Member States of WMO undertakes, according to its means, to meet certain responsibilities in the agreed global scheme so that all countries may benefit from the consolidated efforts.

The challenge laid down forty-four years ago has resulted in a unique success story of international co-operation and opportunity. The Basic System of the WWW has become in many ways the “core” operational facility for, not only weather forecasting, but also all WMO programs as well as many international programs of other agencies. Understanding climate and climate change, natural disaster reduction and response, and environmental protection are but three of a growing list of these broader programs. We can expect the next years to be ones of even faster technological advancement, and we can also expect new requirements to be placed on the basic systems by the more integrated earth science programs. The flexible, evolving system that was conceived originally continues to adjust and accommodate these new demands today. It is hoped that future WMO Congresses have the foresight and vision equal to that exhibited over forty years ago – enabling the WMO to provide the stimulation, leadership and co-operation that has been the hallmark of the World Weather Watch.

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