A Summary of Recommended Practices for Weather Forecasting [(1)]

(November 2004)

This document provides a first step towards the development of weather forecasting technique considered as a sequence of standard processes. The NMHSs are encouraged to use the recommended practices, evaluate their applicability and make the necessary adjustments according to their needs and capacities.

1 - Introduction

1.1 - Weather forecasting is not *a purely mechanical linear process,* for which standard practices and procedures can be directly applied. Forecaster's job is based on theoretical background and lab work which needs several years of study but mainly day-to-day practice inside a weather forecasting service having a specific technical environment. The work of the forecasters has evolved significantly over the years to take advantage of both scientific and technological improvements. The skill of numerical models has improved so much that some centres are automating routine forecasts to allow forecasters to focus on high impact weather or areas where they can add significant value. So it is not easy to determine a standard way to achieve weather forecasts.

1.2 - The way the forecaster currently works depends in fact on several factors.

- the forecast range (medium-range, short-range, very short-range, nowcasting) and the size of the domain to be covered (large portion of the globe, regional domain, small country, city);
- the geographical context and related climatology (midlatitudes, tropical or equatorial areas, isolated islands);
- the potential risk associated with the expected weather at various ranges;
- the organization of the forecast service (multipurpose forecasters or specialized forecasters for each type of applications);
- the end-user who receives the forecasts (civil defence, aviation, marine, hydrologic and water management service, road administration, medias, public)
- the technical environment (available external and/or internal NWP products, in situ observations, satellite and radar images, lightning detection network, efficient visualization workstation adapted to the forecaster, Web access);

2 – General Overview of Analysis and Forecasting at NMCs

2.1 - The *Manual on GDPS* (WMO N° 485, Volume I - Global aspects, 1991 and Volume II – Regional aspects, 1992, both of them being regularly updated) explains the organization and functions of the Global Data-Processing and Forecasting System (GDPFS) and describes the various aspects of data processing, including responsibilities of the Centres, agreed standards about analysis and forecasting practices, preparation of charts, exchange of products.

[(1)] "This document is based on a WMO consultant report entitled:"Weather Forecasting Technique Considered as a Sequence of Standard Processes from the Forecaster's Point of View" (2004), and is annexed to the report of the meeting of the Implementation Coordination Team on Data-Processing and Forecasting System (Geneva, November 2004)."

2.2 - Nevertheless, the various tasks to be performed in a Meteorological Centre, following the technical regulations described in the Manual on GDPFS greatly varies according to its level of responsibility of the Centre (WMC, RSMC, NMC or simple Forecast Office), to its specialization (medium-range, tropical cyclone forecasting, emergency response, severe weather,…) and to its internal organization with respect to the needs to elaborate products for specific meteorological activities (aviation, marine, media …) or for other end-users (civil security, transportation, …).

2.3 - From a very general point of view, it can be said that the aim of a National Meteorological Centre is to perform a clear analysis of the present weather, to provide weather forecasts, to evaluate the level of risk associated with the expected important meteorological phenomena and to issue as soon as possible pertinent warnings toward the concerned people. These general commitments have to be fulfilled for the country and for its responsibility areas and covering the forecasting ranges according to the WMO classification. Of course the forecasts should gain in detail and accuracy for geographical location when the forecast range diminishes.

2.4 - Broadly speaking, weather analysis and forecasting should be considered as the succession of the following tasks:

- to clearly understand the recent evolution and the actual situation of the atmosphere at all time scales (weather analysis);

- to obtain the pertinent information from at least one numerical model and to assess the future evolution of the atmosphere in order to determine the most likely scenario (synoptic weather forecasting); when available, automated tools provide a first guess, that forecasters may or may not follow;

- to deduce finally the consequences of the expected synoptic situation in terms of weather elements (weather elements forecasting) and to evaluate the risk of the occurrence of hazardous phenomena (risk assessment);

- to prepare the meteorological information (including possible warnings) to be directed toward the various internal or external users.

2.5 - For the more advanced Centres, extensive use of artificial intelligence, statistical methods, specialized post-processing allow the total or partial automation of several of these processes. Automation allows forecasters to concentrate more on severe or high impact weather situations. Those products or forecasts that can be automated are those for which the forecasters add little or no value.

3 - Training the Forecasters

3.1 - It is relatively simple to specify training standards in mathematics, physics and theoretical meteorology, according to the curricula proposed in TD N° 258. It can be more difficult to precisely define standard processes to achieve the various tasks associated with operational weather forecasting while still exploiting the scientific expertise of the forecaster. Several attempts have been made to define a methodology for consistent preparation of weather forecasts. (Indeed, such definition of procedures may be required where an NMHS seeks accreditation for certain quality management standards). Some attempts have been made (e.g. New Zealand Met. Service) to define “the competencies” for each element of work the forecaster has to complete (local temperature forecasting, for instance) but the generalization of such initiatives requires a huge amount of work. During recent years the methods of working of forecasters have changed dramatically thanks to the continuous progress in NWP and meteorological imagery techniques, making it difficult to keep any process definitions up to date.

3.2 - An effective way of training is to let the beginner work alongside a more experienced forecaster over several weeks until he/she feels able to do the job alone. It is also important to provide training on a regular basis to ensure skills are updated with improvement in science and technology. In addition to this “on the job training” several attempts have been made by experienced forecasters to define a methodology for consistent preparation of weather forecasts. Today’s forecaster can be overwhelmed by a huge amount of information and has to try to detect the essential characteristics of the atmosphere in order to prepare a synthesis as quickly as possible.

4 - The tasks to be performed in the context of weather forecasting

4.1 It is clearly beneficial to establish some standards to identify the basic methodology of weather forecasting and the tasks a forecaster has to perform operationally.

4.2 Weather analysis and forecasting process for short-range purpose implies the following steps.

The following outlines the steps for short-range forecasting. They may need some refinement for nowcasting or for medium range and beyond. Examples are taken mainly from the mid-latitudes – more detail on analysis and forecasting in the tropics are presented in chapter 5 of the Guide on GDPFS.

- Step 1: Evaluating the present meteorological situation

Weather analysis needs a clear understanding of the actual situation and the recent past at the synoptic scale. Animation of model analyses and satellite images during the last 24 hours is an efficient way to asses the dynamical behaviour of the atmosphere. It has been recognized that, at least for the middle latitudes, the dynamical forcings can be identified preferably in the low layers and at the tropopause level. So, fields such as Mean Sea Level Pressure (MSLP) and 850 hPa wet bulb potential temperature are very informative about the low layers while wind and geopotential height at level 1.5 PVU (the level where the Potential Vorticity reaches 1.5 PV Units, which is currently called the *dynamic tropopause level*) provide useful information to detect upper troposphere anomalies. Infrared (IR) satellite imagery allows to assess atmospheric humidity and tops of the clouds while Water vapour (WV) imagery enables to recognize some important characteristic features of the dynamic tropopause.

- Step 2: Examining the quality and relevance of the analysis

The various observations at the surface and at upper levels, especially in the sensitive regions of the atmosphere (eg. baroclinic zones) have to be scrutinized and compared with the model analysis as soon as it becomes available, as well as with satellite images, in order to evaluate the quality and relevance of the analysis. Every disagreement can reveal a failure in the analysed initial state, which is a reason to reduce the confidence in the results of the corresponding forecast. The comparison with other analyses coming from other Centres can also help to validate the confidence or not.

- Step 3: Identifying the key elements of the meteorological situation, according to the accepted conceptual models and / or guidance / tools

The inspection of the analysed fields at low levels and in the upper troposphere, jointly with satellite IR and WV images, complemented by appropriate cross-sections, allows a well trained forecaster to detect the key meteorological features associated with the conceptual models (jet streams, tropopause anomalies, frontal discontinuities, baroclinic zones… for the midlatitudes; squall lines, African easterly waves, tropical cyclones … for tropical areas). At the end of this step, it is very useful to try to synthesize the results of this analysis work on a graphic document.

- Step 4: Examining the various guidance products and choosing the most likely scenario

The assessment of numerical model output is difficult to standardize because a number of reasons can induce erroneous forecasts (eg. lack of observations in the initial state, weakness of model physics, …). When several models are available, examination of the succession of the most meaningful model fields (already mentioned for the synoptic analysis purpose) coming from the various available models has to be performed to asses the evolution of the atmospheric circulation. It is important to check whether the most recent forecast agrees with the previous one for the same model as well as to compare the various models coming from different Centres. It is also important to compare model forecasts with latest observations once the forecast enters the validity period to assess whether it is on track. Such comparison of this set of forecasts (a “poor man ensemble”) allows, when the scenarios agree, to increase the confidence in the model solution. Where Ensemble Prediction Systems are available, some tools or post-processing will provide information on probability of certain events to occur, which could provide very valuable information for decision-makers. When there is an important divergence between the various scenarios, the forecaster’s task becomes much more difficult because it is necessary to make a choice. Unfortunately it is not possible to formulate a clear rule to make this choice as rationally as possible. The rejection of an a priori valuable observation in the model analysis could be responsible for an erroneous forecast; the similarity of the model behaviour during successive forecasts could incite to increase the confidence in the model. Anyway there is no definitive rule and the choice essentially rests on the forecaster’s experience.

- Step 5: Describing the evolution of the atmosphere corresponding to the chosen scenario

By applying the knowledge about the lifecycle of the conceptual models identified during the analysis step or in the framework of the chosen forecast scenario, the forecaster determines what are the main characteristics of the evolution of the atmosphere at the synoptic scale. This mental exercise, which takes place within the forecaster’s brain, has to be carefully formalized in order to become usable by other people. This can be achieved by short written guidance describing the forecast evolution and by performing for successive forecast ranges (every 12 hours for instance) synoptic graphical products similar to the ones corresponding to the analysis. The written guidance should contain the reasons for the choice of the adopted scenario and give additional details in order to complement the graphic document. It is important to point out that, when the meteorological situation is likely to be favourable to the occurrence of severe weather, in-depth analysis of this event has to be performed with a high degree of priority.

- Step 6: Deducing the consequences for smaller scales and specific areas

An accurate description of the weather requires the forecaster to translate the synoptic scale forecast, elaborated during the preceding step, into smaller-scale phenomena. These may include effects such as diurnal variation, orographic or coastal effects. It is to be noted that as model resolution increases, some of these effects are better forecast by the model. The availability of model fields such as vertical velocities, accumulated precipitation or stability indices can be very helpful to achieve this task. Conceptual models are also useful but they can be subject to adaptations according to local conditions. The details at the scale of a country or parts of a country can be summarized in written technical bulletins or synthesized on a graphic (SIGWXs established for general aviation are good examples of documents fulfilling this purpose). In case of an expected severe weather event it becomes essential to take particular care to give a detailed account of its evolution. Modeldiagnostics and prognostics of phenomena may also be useful e.g versions of thunderstorm forecast decision trees that produce output on the possibility and severity of thunderstorms.

- Step 7: Describing of the expected weather in terms of weather elements (including automated production techniques when applicable)

With the help of the guidance and documents obtained after completion of steps 5 and 6, and local model output (eg. model's synthetic tephigrams, statistical interpretation, meteograms) the forecaster should be able to depict the expected weather at selected points by giving numerical values of the meteorological parameters characterizing the weather (temperature, wind speed and direction, precipitation) and specifying the possible occurrence of various meteors (fog, snow, thunderstorm, hail, …). A good knowledge of the characteristics and performance of objective weather guidance from dynamical/statistical interpretation tools (such as Perfect Prog. Method, Model Output Statistics, Kalman Filter …) is also needed. Such depiction of the weather elements should be done for all the important places of the area of responsibility and if possible for different times of the day in order to describe the diurnal cycle. High resolution models are able to provide detailed information/ weather elements at chosen points in time and faces. Some centres have developed tools that allow the forecasters to modify weather elements as needed.

- Step 8: Deciding on the opportunity / necessity to issue / end warnings

The risk assessment for severe weather events has to be a continuous concern for the forecaster, especially during steps 5 and 6 of the weather forecasting procedure. When severe weather is expected to threaten a region, this task has to be completed with the highest priority. The decision to issue or end a severe weather warning will result from the comparison of specific forecast weather elements (temperature, wind speed, precipitation) with agreed thresholds, adopted in cooperation with the civil security services. But it is important to note that it is not possible to define standard thresholds for each category of severe weather phenomena: the attempts to achieve such a normalization, even inside the same country, shows that the values or the thresholds depend on the level of protection against the possible damage. Moreover, the decision to issue warnings does not only depend purely on the expected value of meteorological parameters, but also on the expected impact. For example, forecasting snowfall during a period when important traffic jam is foreseeable may justify the issue of warnings even if the expected snow accumulation does not exceed the agreed threshold. For all these reasons it is not possible to establish standard rules to decide whether severe weather warnings should be issued.

- Step 9: Distributing the various products to users

This step consists of preparing forecast products for the users (eg. civil protection, hydrological service, aviation, marine). Products should be designed to meet the agreed requirements of users, and in some cases it may be appropriate to provide "raw" information such as radar imagery, satellite imagery or NWP output. Detailed inspection of the atmospheric model output as well as guidance products described in previous steps, results of other models (eg. wave model for marine forecasts) are necessary to perform these specialized forecasts. The workload necessary to elaborate special bulletins, forecasts in tabular form, graphics for the media or other clients strongly depends on the degree of involvement of the Meteorological Centre in the preparation of customized products, on their level of automation

- Step 10: Evaluating according to performance measurements / Verifying forecasts

Performance measurement is essential to ensure that products are of good quality, to identify deficiencies and facilitate continuous improvement.

5 - A cascading procedure from medium-range forecasting to nowcasting

5.1 - Normally, forecasters focus their attention on short-range forecasting. Nevertheless, medium-range forecasting can also provide users with effective products up to at least 7 days. Such forecasts may provide various possibilities for the synoptic evolution, which will be then treated in the framework of short-range forecasting.

5.2 - The number of Centres running Ensemble Prediction Systems for medium-range purpose increases regularly. They use various techniques (singular vectors, breeding, perturbed physics, …) and provide the forecaster with a set of possible evolutions of the atmosphere. This kind of forecast enables the forecaster to assess, for each meteorological parameter, a finite sample of its probability density function (PDF) instead of the single deterministic value given by a simple model. It becomes possible to obtain everywhere the mean value and standard deviation of meteorological parameters, or to compute probabilistic forecasts. Users who are able to evaluate a cost-loss ratio can take advantage of probabilistic forecasts to manage, in an optimal way, an activity that depends on weather conditions.

5.3 - A large variety of products can be generated from EPS: mean value and standard deviation, clusters resulting from an automatic classification, probability of occurrence of weather events (eg. warm or cold anomalies, rainfall accumulation, high winds and others). The products consist either of charts or the presentation of probabilistic time-series at specific locations (eg. EPSgrams are a useful tool to assess the spread of the ensemble for the main weather elements (temperature, wind speed, precipitation, cloudiness) at a given location.

5.4 - Within the framework of weather forecasting considered as a continuous process, medium-range products coming from EPS provide forecasters with different evolutions at the synoptic scale. The existence of solutions favourable to the development of severe weather within the ensemble can provide useful guidance to the possible issue of early warnings for the following days. The Extreme Forecast Index (EFI) developed at ECMWF gives an example of a specific product useful to alert forecasters to the possibility of extreme solutions.

5.5 – The forecaster’s work for very short-range and nowcasting purposes is very much dependant on observations, radar and satellite information, and model output. Nowcasting involves extrapolating the latest observations, such as radar observations of precipitation, forward in time, sometimes with the aid of wind fields from numerical models, and is often automated. In very short-range forecasting the forecaster can monitor whether the actual behaviour of the atmosphere agrees with the forecast one. This process needs to compare the model fields (or model synthetic images) with real satellite images or radar echoes. When the actual evolution differs from the model one, the forecaster should be able to adjust the forecast and to amend the products delivered toward the end-user. This task becomes particularly critical when a severe weather event is taking place.

5.6 – In some of the larger NMCs which have access to EPS, global models, limited area models and nowcasting tools such as radar networks the cascade process from medium-range forecasting to nowcasting can be performed in the same NMC. In other countries access to products required for parts of the cascade may be obtained through cooperation between the centres of the GDPFS.

5.7 - If short-range weather forecasting appears as a rather well defined process, the links with medium-range forecasting on one side, and with very short-range forecasting on the other side, are not straightforward. A good way to define the products to be exchanged in the framework of such a cooperation would be to organize a demonstration project involving several Centres. This would allow demonstration of the provision of products from producer centres to user centres, and also feedback back up to the producer centre on how the information has been applied. This feedback process should be activated every time a severe weather event is forecast in order to assess the efficiency of the cascade process.

Appendix – Further information on forecast processes and training

A.1 - Relevant information about all the knowledge and practice necessary to perform meteorological forecasting can be found in the documentation elaborated by various meteorological training schools and this subject has justified the elaboration of a very comprehensive document prepared by a panel of experts for WMO : *Guidelines for Education and Training of Personnel in Meteorology - WMO TD N° 258*.

A.2 - According to the document TD N°258, WMO classifies meteorological personnel into two categories:

- Meteorologists, who acquired at the university an appropriate knowledge on mathematics, physics and chemistry and completed a degree specialized in meteorology;

- Meteorological Technicians, who acquired scientific background at the secondary or postsecondary school and completed a specialization in meteorology;

A.3 - In many countries it is possible to acquire, at the appropriate level, the fundamentals of meteorology and to complement this scientific background by some practice of weather forecasting through lab work. Nevertheless, when a new forecaster enters a weather forecasting office, he/she has to be trained on a forecaster desk (on the job training) to apply knowledge/methodology in a real environment and to acquire the skills to perform the various tasks in due time.

A.4 - Volume I of the TD N° 258 is devoted to meteorology .Part A covers three major items: the new classification of personnel (as mentioned above), the revised core curricula in meteorology and job-specialized required competencies. It gives details of three packages: the Basic Instruction Package for Meteorologists (BIP-M), the Basic Instruction Package for Meteorological Technicians (BIP-MT) and the Continuing Education and Training (CET). Part B gives examples of BIP and job-competency requirements in the main branches of activities (in particular, weather analysis and forecasting, climate monitoring, agrometeorology, aeronautical meteorology, marine meteorology, environmental meteorology).

A.5 - Important information about the various tasks the forecaster has to carry out in a forecast office are also described with many details in the various Guides which have been prepared by specialists, edited by WMO and regularly updated.

A.6 - The Guide dealing with general weather forecasting is:

- the *Guide on the Global Data-processing System* (WMO N° 305, edited and regularly updated since 1993). It contains brief descriptions of many methods and techniques used in data processing but also interpretation techniques for weather analysis and forecasting in both middle and tropical latitudes. It includes non-real-time tasks as well as quality-control procedures.

A.7 - Other Guides dedicated to specific applications of weather forecasting describe how the products elaborated in the framework of general forecasting should be adapted to fit as well as possible the special needs of the end-users. It also indicates the specialised training required for personnel in charge of preparing these forecasts. These are:

- the *Guide to practices for meteorological offices serving aviation* (WMO N° 732, second edition, 2003); the chapters 5 and 7 are particularly relevant with respect to specific aeronautical tasks and corresponding training;

- the *Guide to marine meteorological services* (WMO N° 471, third edition, 2001); the chapter 1 provides guidance on the various marine meteorological services, preparation of weather bulletins for shipping and coastal storm warnings, and chapter 7 gives information on training in marine meteorology.

- the *Guide to public weather services practices* (N° 834, second edition 1999); many examples explain how to present weather products for the public; chapter 8 considers coordination problems within the meteorological service and with various partners, while chapter 9 points out the need to develop awareness of meteorological phenomena among the public. This excellent document is complemented by a set of 4 CD-ROMs giving helpful advice on preparation of weather bulletins with many exercises to train the personnel.

- the *Guide to hydrological practices* (N° 168, fifth edition 1994, which contains 770 pages and is available on a CD-ROM). This comprehensive guide consists of 59 chapters covering the entire field of operational hydrology, as it is currently perceived, with its applications to water management. It describes with many details the various aspects of hydrological phenomena and the corresponding forecasting methods (Part B, chapters 41 to 46).

A.8 - Numerous NMHSs or national organizations have taken advantage of recent developments in NWP and dynamic meteorology to define methodologies for preparing weather forecasts. Several attractive training materials based on Computed Aided Learning (CAL) and New Information Technologies have been developed and are now available. The information about these products can easily be found on the Web and a few references are given below :

- COMET: http://comet.ucar.edu/modules/index.htm; a very comprehensive set of modules covering meteorological phenomena and weather prediction techniques;

- EUROMET: http://euromet.meteo.fr/; a course on NWP and satellite meteorology, developed by a consortium of meteorological services and universities;

- SATREP: http://www.knmi.nl/satrep/startpage.html; a methodology devoted to the interpretation of meteorological information by the forecaster, developed by ZAMG, FMI, KNMI and Eumetsat;

- ANASYG-PRESYG: http://www.meteorologie.eu.org/anasyg; a Computed Aided Learning focussed on synoptic meteorology from the point of view of the forecaster;

- ASMET: http://www.comet.ucar.edu/modules/ASMETI.htm; a Computed Aided Learning focussed on forecaster's work in Africa, developed by EAMAC (Niger) and Eumetsat;

A.9 – Despite these developments, further work is required to produce specialised training material devoted to forecasters working in tropical areas. During the meeting organized by the Bureau of Meteorology (Australia) in January 2001 in Darwin, it was recognized that: "*While there has been much progress in recent years in understanding the large-scale dynamics of the tropical atmosphere on intraseasonal and longer time scales, there has been rather less focus on the morphology and dynamics of tropical weather systems that are of importance in day-to-day weather forecasting, perhaps with the exception of tropical cyclones, but including monsoonal weather. Forecasters in tropical regions have few conceptual models at their disposal and there is a notable lack of useful theory that they can call upon*".

A.10 - There are also many Organisations or Training Schools associated with NMHSs which regularly organize training courses and provide training materials for operational weather forecasting. Only a few are listed below with their Web address:

- COMET/UCAR (USA): http://www.comet.ucar.edu/modules/index.htm

- The Met-Office College (UK): http://www.met-office.gov.uk/training

- Ecole Nationale de la Météorologie (France): http://www.enm.meteo.fr

A.11 - Several organizations and professional bodies provide accreditation or certification for meteorologists. Examples include the American Meteorological Society in the USA, the Canadian Meteorological and Oceanographic Society in Canada and the Royal Meteorological Society in the UK.