WORLD METEOROLOGICAL ORGANIZATION

GUIDELINES FOR THE EDUCATION AND TRAINING OF METEOROLOGICAL PERSONNEL

Prepared by

The Executive Committee Panel of Experts on Meteorological Education and Training

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NOTE

This document, being of an advisory character, is not intended to have the same status as a Guide defined in the special context of Resolution 18, Second Congress.

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NOTE

The designations employed and the presentation of the material in this publication do not imply the expression of any opinion whatsoever on the part of the Secretariat of the World Meteorological Organization concerning the legal status of any country or territory or of its authorities, or concerning the delimitation of its frontiers.

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FOREWORD

Atmospheric processes profoundly affect every facet of the economic and social welfare of nations and communities and cannot be ignored in planning the development and use of natural resources.

Awareness of the influence exerted by weather has long ago been forced upon mankind in such activities as agriculture and transport by sea. More recently, meteorology has played an increasingly important role in achieving safety and efficiency of air transport. And there are many other fields in which the judicious application of meteorological science will bring equal or greater rewards.

Every agricultural operation involves meteorological factors which must be correctly assessed before any decision is made. In planning land utilization, a choice must be made of those farming activities that are most suited to the local climate. Introduction of new plant varieties or animal breeds must be determined by an appreciation of the similarities and differences of climate between the original and new locations. Knowledge of local weather variability guides the farmer in providing shelter for crops against wind and sandstorms, irrigation in periods of deficient rainfall and protection against frost. In his day-to-day decisions, the farmer relies upon detailed weather forecasts for 48 hours and general weather outlooks for longer periods.

The safety of sea transport depends largely upon weather conditions. Forecasts of weather over the oceans lead to forecasts of the state of the sea and weather hazards, and these forecasts in turn make possible the choice of the fastest and safest routes.

The critical importance of weather in air transport has led governments to invest heavily in observation stations, forecast centres, and basic research. Meteorologists provide advice on choice and timing of flying routes, enabling pilots to avoid weather conditions that may be dangerous or uncomfortable to their passengers and to choose routes for minimum flying time between airports. The age of supersonic flight demands much more extensive application of meteorological science.

Land transport is often hampered or brought to a standstill by snow, freezing rain, high winds, heavy rains and extremes of temperature which cause icing on highways, freezing of rail switches, buckling of pavements, and malfunction of motor transport. Warnings of these conditions are of inestimable value. Climatological information enables the engineer to design highways that avoid marshy regions with frequent fog, provide shelters or fences to keep drifting snow off the pavement, allow for expansion or contraction in temperature extremes, and install adequate drainage to prevent flooding in heavy rains.

Water resources are best utilized when the location and design of dams and reservoirs are based upon climatological records of average precipitation and extremes of heavy precipitation and drought. The meteorologist also can give essential information to the engineer such that utilization of water resources is accompanied by practical means of flood control.

The effects of weather, climate and microclimate on life of all forms are continually being revealed in more and more detail. Further research in this area will certainly discover many other ways in which man can live more nearly in harmony with his environment. Steadily increasing pollution of our atmosphere is in part a meteorological problem since a stagnant, subsiding air mass traps and accumulates pollutants that might otherwise be dispersed through a large volume of air.

Meteorological factors have too often been ignored in the siting and design of buildings, construction of electric power systems, and planning of cities. The result has been unnecessary damage by soil erosion, flooding, failures of huge power networks, and air pollution.

In the recent past, meteorology has evolved from a science of observation and empirical deduction into a sophisticated branch of physics, utilizing the most advanced methods of mathematics and numerical processes to describe the state of the atmosphere accurately and to predict its future state by objective, scientific methods.

The intelligent application of science of meteorology will yield great profits in national and private enterprises. It is the purpose of this publication to recommend appropriate syllabi for education and training of meteorological personnel, to the end that maximum benefits will be gained from the practical application of the science of meteorology.

For the past ten years, WMO has been acutely conscious of the urgent need for a publication of this nature. The emergence of many newly independent nations in the late fifties and early sixties emphasized the need for guidance material for training of meteorological personnel. With the approval of the thirteenth session of the Executive Committee (1961), the Secretary-General engaged a highly qualified and experienced consultant, Professor J. Van Mieghem (Belgium), to prepare reports on various aspects of the problem. One of these reports "The problem of the professional training of meteorological personnel of all grades in the less-developed countries" was subsequently published as WMO Technical Note No. 50 and contained detailed syllabi for training the various classes of meteorological personnel mainly in the fields of dynamic and synoptic meteorology. This Technical Note was received with great enthusiasm and used widely in training schools throughout the world.

In view of this development, the eighteenth session of the Executive Committee (1966), requested its Panel of Experts on Meteorological Education and Training under the chairmanship of Professor J. Van Mieghem to prepare comprehensive syllabi for specialization in all fields of meteorological activities and for all classes of personnel. The fruits of this important undertaking are contained in this publication.

I wish therefore to take this opportunity to convey the gratitude of the Organization to the Chairman and Members of the Panel for their excellent work in compiling the syllabi.

I would also like to thank the Chairmen and Members of the various Working Groups on Training set up by the WMO Technical Commissions who prepared many of the syllabi included in the publication. I am likewise grateful to Professors M. Petrosiants (Director of the Institute of Experimental Meteorology, Obninsk, USSR), P. Sheppard (Imperial College, London, UK), R.C. Sutcliffe (University of Reading, UK, and President of the International Association of Meteorology and Atmospheric Physics), and A. Wiin-Nielsen (University of Michigan, USA), who acted as special advisers to the Panel, and to the many Professors and staff members of the various Universities and other training Institutions throughout the world who contributed to the material contained in this publication.

Finally I wish to pay special tribute to the Permanent Representatives of Members of WMO whose constructive comments and constant encouragement made this publication possible.

D A Davies

(D. A. Davies)
Secretary-General

P R E F A C E

by
Professor J. Van Mieghem
Chairman of the Executive Committee Panel of Experts
on Meteorological Education and Training

Since its creation, WMO has concerned itself with the problems related to the training of meteorological personnel of all grades. In so doing, it has fulfilled its responsibilities as stated under Article 2 (e) of the WMO Convention. As many WMO Members became independent, these problems assumed much greater importance. Consequently, in 1959 the Third Congress of WMO recommended that more attention be paid to these problems than had been the case in the past. On the initiative of the Secretary-General of WMO, the Executive Committee, at its thirteenth session (1961), entrusted a Consultant with the task of preparing overall plans for the Organization's future activities in the field of education and training of meteorological personnel. In January 1962, the Consultant presented the following three reports:

- The problem of the professional training of meteorological personnel of all grades in the less-developed countries.
- Plan for the development of professional meteorological training in Africa.
- Establishment of a training section in the WMO Secretariat to be in charge of problems arising out of the professional training of meteorological personnel in the less-developed countries.

The following year, the Consultant prepared a second plan: "Plan for the development of professional training of meteorological personnel in South America".

On the express recommendation of the Fourth Congress of WMO (1963), a Training Section was subsequently created in 1964 within the Secretariat. One of the first tasks of the Head of the new Section was to complete a survey on the training of personnel of the national meteorological services in Central America and the Caribbean. At its seventeenth session (1965), the Executive Committee created the Panel of Experts on Meteorological Education and Training.

At its eighteenth session (1966), the Executive Committee requested the Panel to "prepare a Comprehensive Guide containing syllabi for both basic and specialized fields of meteorological training".

Two preliminary remarks should be made:

- Although the objectives of education and training are the same throughout the world, it should be borne in mind that this publication has been prepared in response to the explicit requests of national Meteorological Services of developing countries. The latter will find in it the information which they seek. Nevertheless, the need for highly-qualified staff is just as great in developed as in developing countries. For this reason, no effort should be spared in maintaining the training of meteorological personnel at as high a standard as possible in all regions of the world.

- In drawing up syllabi for the different grades of meteorological personnel, the Organization's purpose is to apprise the academic and educational communities of its Members of the levels of general and specialized training that should be attained by meteorologists of all grades to enable them to carry out their respective tasks. It is therefore hoped that this volume will provide a source of information for those who wish to make use of it.

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Before dealing with the problems involved in the training of meteorological personnel of all grades and the requisite basic education, it is essential to be quite clear in one's mind as to the purposes of a national Meteorological Service.

A national Meteorological Service is a scientific institution which discharges, at national and international levels, all public service responsibilities related to meteorology, and carries out research within its sphere of scientific activity. It is essential that the scientific staff of a national Meteorological Service engage in research, not only because it provides a beneficial and necessary source of competition amongst themselves, but also because it is the only effective way of keeping abreast of scientific progress - otherwise, methods of work are apt to deteriorate very rapidly, as also the quality of service to the community. In this connexion, it should be recalled that meteorology has evolved from a natural into a physical science. Empiricism belongs to the past. Over the past twenty years, not only has mathematics been increasingly applied to meteorology, but also the world of instruments has been taken over by advanced electronics, and methods of observations and data processing invaded by automation. Routine manual operations are gradually becoming obsolete, and men are progressively being replaced by machines. Meteorological Services today are making use of all kinds of information techniques (automatic data collection and processing): automatic plotting and analysis of aerological soundings and synoptic charts are one example. Finally, computers are being increasingly used by more and more meteorological services, not only for research but also to carry out public service tasks seven days a week.

When tackling the problems involved in the education and training of meteorological personnel, it is important to take the above facts into account. It follows clearly that the scientific staff of a Meteorological Service should have specialized University training in mathematics or physics (or better still, in both subjects if possible), before beginning their meteorological training. Every Meteorological Service keen to maintain its scientific standing should be ready to put all necessary facilities at the disposal of any of its scientific staff who wish to prepare a thesis for a doctorate. It is impossible to carry out research, to accomplish scientific work of value to the public or to implement certain essential parts of the World Weather Watch (WWW), for instance the Global Atmospheric Research Programme (GARP), without highly qualified meteorological personnel. It goes without saying that the scientific personnel of every Meteorological Service should be supported by assistants.

The purpose of the Guide-lines is twofold: (1) to define the various Classes of meteorological personnel required for public service and scientific research; and (2) to draw up detailed syllabi of the basic and professional knowledge required of meteorological personnel of all grades.

Many different systems are used throughout the world to define the various types of meteorological personnel. It is not possible to draw up a uniform system applicable to all countries. The Guide-lines propose four Classes, with detailed courses for each Class, ranging from University graduates called upon to discharge highly scientific duties, down to staff to carry out humble but essential tasks, such as observing the weather.

Meteorological personnel may be classified according to the basic education required or the level of professional training to be attained. Both classifications are equally logical and at first sight equally reasonable. In practice, however, curricula - whether at primary school, general or technical secondary school, professional and high technical school, or University level - are so diverse everywhere that a classification according to basic education does not appear to be feasible. On the other hand, because meteorology must be organized on an international basis, it is essential to aim, so far as possible, at a standard level of professional training for each Class: many of the tasks of national Meteorological Services must be carried out in accordance with regulations agreed upon by all WMO Members. The implementation of the World Weather Watch will in fact require even greater uniformity of professional training at the various levels; and consequently, a classification of meteorological personnel according to level of professional training would be more appropriate.

To direct scientific operations, carry out certain essential scientific functions and to carry through research to a successful conclusion, Class I personnel are essential. Routine professional tasks requiring some degree of initiative and a sense of responsibility can be carried out by Class II personnel. To assist members of Class I and II, personnel of Class III will be required, while personnel of Class IV will perform the humbler everyday tasks.

It is clear, however, that there exists some correlation between the level of professional training and that of basic knowledge: when the former is high, the latter must also rise in proportion. Thus, Class I meteorological personnel must be University-trained; Class II should have completed one or two preliminary years at University, or hold a diploma of a higher technical school;

Class III should have successfully completed their secondary education (general or technical); while Class IV should have passed through primary school and the lower grades of general or technical secondary education (first three years in secondary school).

While practically all WMO Members are in agreement as to the definitions of Classes I, III and IV, a substantial minority have formulated objections concerning Class II. It should be recalled, in the first place, that Class II is not a temporary substitute for Class I, and secondly, that Class II meteorological personnel do not operate solely in the national meteorological services of the developing countries. Members of this Class are also to be found in a growing number of developed countries.

National Meteorological Services throughout the world will require an ever-increasing number of Class II personnel, in particular, forecasters and climatologists, and also specialists in telecommunications and information techniques, and in programming and electronics. In addition, one inevitable consequence of the World Weather Watch will be a substantial reduction in the quantity of "pre-processed data" circulating among meteorological telecommunication circuits, with a corresponding increase in "end products". The implementation of the World Weather Watch will thus result in an increase in Class II personnel. While Class I personnel must be available in order to obtain "end products", it will be sufficient to have Class II personnel, with the assistance of Class III, to utilize them.

In the syllabi, a very sharp distinction is made for each Class between the prior basic knowledge required and meteorological training as such. Similarly, where the latter is concerned, those elements of meteorology which all members of any one Class must know are set out in the syllabi along with a description of the knowledge necessary at the level of that Class in each field of specialization.

It should be noted that the syllabi provide only a qualitative indication of the subjects taught. Their actual scope is more difficult to determine. This is a complex task, and in practice can only be carried out by recommending textbooks or by setting test-questions with detailed model answers. It is also possible to set out the contents of a teaching-course by preparing lecture notes or problem workbooks with keys to selected exercises.

The period required for teaching a subject depends as much on the teacher's ability as on the average level of intelligence of his students. Teaching weak and brilliant pupils in the same class is particularly unrewarding. That is why syllabi do not specify the time needed for the various curricula.

A definition of "satisfactory knowledge" of a subject is not given in the Guide-lines since this type of appreciation is subjective in the extreme. Satisfactory knowledge can only be indicated by the candidates' replies and the marks awarded - a highly complex and invidious task.

Finally, recent advances in meteorology have been so swift and working methods have developed with such rapidity, that it is absolutely essential to see to it that the various parts of the Guide-lines are continually kept up - to-date.

To conclude, I now enumerate the sources of information used in drawing up the syllabi:

(i) The surveys carried out in the last ten years by the WMO Secretariat

on all questions related to meteorological education and training in the national Meteorological Services.

(ii) Report on meteorological training facilities

published for the first time in 1959 by the WMO Secretariat and since then kept regularly up-to-date.

(iii) The problem of the professional training of meteorological personnel of all grades in the less-developed countries

by J. Van Mieghem (WMO Technical Note No. 50 (1963)).

(iv) Plan for the development of professional meteorological training in Africa

by J. Van Mieghem (WMO Information Report (1963)).

(v) Plan for the development of professional training of meteorological personnel in South America

by J. Van Mieghem (WMO Information Report (1964)).

(vi) Survey on the national Meteorological Services of Central America, the Caribbean countries and territories

by H. Taba (WMO Information Report (1965)).

(vii) Reports by Working Groups on meteorological education and training of the WMO Technical Commissions

(viii) Documents prepared for the various WMO Conferences on meteorological education and training

(ix) Reports of the Leningrad Conference

organized in July 1967 by the Hydrometeorological Service of the USSR.

(x) Minutes of meetings of the Executive Committee Panel of Experts on Meteorological Education and Training

held from 1966 to 1969.

Acknowledgement

I have great pleasure in expressing my warmest thanks to all those who helped me carry out the tasks entrusted to me, and especially to the Members and Secretary of the Panel of Experts on Meteorological Education and Training

July 1969

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C H A P T E R I

INTRODUCTION AND BACKGROUND INFORMATION

1.1 GENERAL

The purpose of this chapter is to illustrate the wide variety of meteorological personnel required in order to carry out the operational duties of a national Meteorological Service. The need for qualified scientists and trained technicians is also emphasized.

In the following paragraphs the duties of a national Service and the personnel required are considered; then the role of the World Meteorological Organization in education and training is discussed. Finally, there is an outline of the objectives of the World Weather Watch, which will demand a substantial increase in the number of qualified personnel of all grades.

Subsequent chapters will define the grades of personnel, from the meteorologist to his assistants, and will recommend curricula in the basic sciences, in fundamental meteorological education, advanced training and in various fields of specialization.

1.2 DUTIES OF A NATIONAL METEOROLOGICAL SERVICE

The functions carried out by a national Meteorological Service can be summed up as follows:

(1) The organization, operation and maintenance of networks of surface and upper-air observing stations.

(2) The evaluation, processing and archiving of the observational data.

(3) The establishment, operation and maintenance of an efficient telecommunication system for the collection and dissemination of both observational and processed data.

(4) The provision of meteorological information and advice including weather forecasts, climatological statistics and information on physics of the atmosphere.

(5) Advancement of meteorology by scientific research.

(6) Application of the science of meteorology.

(7) The promotion of meteorology throughout the world by international co-operation.

In order to carry out these duties efficiently the Service must have qualified and trained personnel.

1.3 FIELDS OF SPECIALIZATION

The variety of fields of human endeavour that can benefit from the science of meteorology is so wide that no one meteorologist can be expected to acquire the knowledge which would permit him to give expert advice on all of these topics. Consequently, as in other scientific fields, the science of meteorology has been conveniently subdivided into a number of branches, each of which calls for specialized study. The main fields of specialization including border fields and fields of application, are:

(a) Dynamic meteorology;

(b) Synoptic meteorology;

(c) Physical meteorology;

(d) Aeronautical meteorology;

(e) Climatology;

(f) Agricultural meteorology;

(g) Hydrometeorology;

(h) Maritime meteorology;

(i) Meteorological instruments;

(j) Chemistry and radioactivity of the atmosphere.

In accepting any such subdivisions of the science of meteorology, it must be borne in mind that no single field of specialization is completely independent of the others. In some cases a major portion of the knowledge required for specialization in one field may also be required for specialization in another. In all cases a basic minimum knowledge of meteorology is required. Moreover, not all branches of specialization are covered in the above classification: refinements of the main fields will uncover additional areas such as urban meteorology (including air pollution), biometeorology, and micro-meteorology. Although the latter fields will not be the subject of detailed syllabi in this publication, some general ideas will be given where possible, on the background and experience required by personnel engaged in them. In the following paragraphs, a brief description of the various fields of specialization is given:

Dynamic meteorology: This is the study of the basic thermohydrodynamic processes which determine the motions of the air and the phenomena it produces. Within dynamic meteorology the study of numerical models for simulating atmospheric processes and for numerical weather prediction has developed since the late forties. Because of the rapid calculations possible on modern computers, the theories of dynamic meteorology are being applied directly to the existing weather situation to calculate its future development. Dynamic meteorology covers motions of all scales including meso and small scale systems.

Synoptic meteorology: This is the branch of meteorology in which the analysis and study of the atmosphere are performed in order to understand its behaviour and to predict its future evolution. The basic sciences for synoptic meteorology are dynamical and physical meteorology, the basic tools being weather charts of synchronous observations describing the three dimensional physical state of the atmosphere.

Physical meteorology: This field includes thermodynamics, cloud physics, radiation, chemical composition and optical, electrical, acoustical phenomena of the atmosphere. As generally accepted, it does not include mathematical theory of the motions of the atmosphere and the forces responsible for them (which fall in the field of dynamic meteorology). Atmospheric thermodynamics lies so near the borderline of physical and dynamical meteorology that it is treated as often in one as in the other branch. All these subjects have received much attention during recent years. The experts in the field of physical meteorology have the advantage that most of the problems they deal with are amenable to the techniques of experimental physics and most of their experiments can be carried out both in the laboratory and in the free atmosphere.

Aeronautical meteorology: Aeronautical meteorology was developed as an application of the synoptic and dynamic branches of the science to answer the specific meteorological problems of air transport and aircraft design and performance. The results of synoptic analyses and prognostic fields of atmospheric parameters are used to develop flight, route, area and aerodrome terminal weather forecasts for use in flight planning operations and briefing of crew members. Aeronautical meteorology includes also aeronautical climatology.

Climatology: Climatology is the study of the collective state of the atmosphere at a given place or over a given area within a specified period of time. It can be subdivided into distinct fields of specialization such as micro-climatology, bioclimatology and applied climatology.

Agricultural meteorology: This is concerned with the application of the knowledge of the atmosphere to agricultural practice. Its scope is wide and includes the study of the relationship between meteorological factors and such things as the soil, plants, animals and the related diseases and pests. Its ultimate aim is to provide meteorological, including climatological, information to the agriculturalist, in a form suitable for use in his day-to-day operations, and at the same time give accurate guidance for his seasonal and long-range planning.

Hydrometeorology: This is the study of the surface water regime (rivers, lakes, reservoirs, etc.) and of the interaction between the water cycle and meteorological processes. It includes the computation of the water balance, hydrological and meteorological calculations of related parameters and the preparation of forecasts necessary for water management.

Maritime meteorology: To be completed later.

Meteorological instruments: This field is becoming increasingly important with the appearance of an ever-widening variety of instruments. The instruments at present in use, range from the simple ones found at most weather stations such as barometers, barographs and anemometers

to more complicated types including meteorological radar, automatic weather stations, and meteorological satellites.

Chemistry and radioactivity of the atmosphere: This is the study of the atmospheric processes influencing chemical composition of the air and precipitated water and of air pollution.

1.4 WMO AND METEOROLOGICAL EDUCATION AND TRAINING

The Convention of the World Meteorological Organization *, requires the Organization to encourage training in meteorology and to assist in solving the problems of co-ordination arising out of the training of meteorological personnel of all grades. Weather knows no national boundaries. Its effects are international. Consequently, the degree of efficiency of any one country's Meteorological Service will obviously affect that of all other national Meteorological Services, especially those of neighbouring countries. No country can for example dispense with the meteorological observations carried out by a neighbour. Thus, any defects in a national Meteorological Service have immediate and troublesome international repercussions.

1.5 WORLD WEATHER WATCH

In view of its implications in the field of meteorological education and training, it is appropriate to include in this publication a brief summary of the purposes and plans for the World Weather Watch.

The primary aim of the World Weather Watch is to ensure that all national Meteorological Services obtain the meteorological information they require for operational and research purposes. It is conceived as a world-wide system composed of the facilities provided by individual nations, as co-ordinated and in some cases supported by WMO and other International Organizations.

Its organization and functions can be loosely compared to those of a highly developed national Meteorological Service, as outlined before. Its essential elements are therefore:

(a) An observational network, and other observational facilities, called the Global Observing System;

(b) Arrangements for the processing of observational data and for the storage and retrieval of data, called the Global Data Processing System;

(c) Telecommunications facilities and arrangements for the rapid exchange of observations and processed data called the Global Telecommunications System;

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* Article 2(e)

(d) A comprehensive research programme;

(e) The education and training of meteorological personnel.

The implementation of the World Weather Watch plans is the concern of Members of WMO. However, not all the Members are in a position to meet their full responsibilities in order that the objectives of the WWW can be attained. Substantial assistance is required by many developing countries. For this purpose a Voluntary Assistance Programme (VAP) was designed by the Congress of WMO. Under this programme, assistance is provided by the Members of WMO who are in a position to offer such assistance. This is normally in the form of meteorological equipment, cash contributions or long-term fellowships.

In the actual implementation of the World Weather Watch, it is essential that maximum use be made of existing facilities and arrangements, especially of advanced facilities such as meteorological satellites, electronic computers, high-speed telecommunications, etc. In addition, new techniques of observation telecommunications and data processing should be introduced as soon as they have proved sufficiently reliable and economical. The World Weather Watch programme will therefore consist of two continuous and parallel streams of action.

In the first stream, proven technology will be introduced into the existing international meteorological system.

In the second, new technology will be developed in order to achieve the ultimate goals of the World Weather Watch.

In broad terms, the objectives of the first stream are:

(i) A substantial improvement in the Global Observing System to provide better and more complete data for meteorological analysis and forecasting;

(ii) The implementation of the Global Data Processing System;

(iii) The improvement of the Global Telecommunication System.

If all these projects are to be properly implemented, qualified staff must be available. Thus, a concentrated effort must be made to accelerate the programme of education and training of meteorological personnel, both at the national level and under international auspices. The importance of training cannot be over-emphasized. In the training of meteorological personnel, the United Nations Development Programme and VAP play an important role.

C H A P T E R 2

CLASSIFICATION OF METEOROLOGICAL PERSONNEL AND THEIR DUTIES

2.1 GENERAL

Establishing a uniform classification of meteorological personnel which will satisfy the requirements of the various branches of meteorology and the various national Meteorological Services is a difficult task. The wide variety of functions carried out by a national Meteorological Service and the equally wide range of personnel required have already been discussed in the previous chapter. Moreover, the diversity of personnel grading systems among the various countries has been clearly demonstrated in the "Report of Meteorological Training Facilities"* published by the WMO, and in the training curricula prepared by certain national meteorological training schools. As a prerequisite, however, to establishing syllabi for guidance in the training of meteorological personnel, we must first have a clear idea of the grades of personnel involved, and so far as possible the duties carried out by each grade.

There is no doubt that meteorological personnel can be graded in a number of ways, each with its own particular merit and convenience. It is equally certain however, that no one system will adequately define all types of personnel required. It is therefore necessary to accept a compromise classification, all the while recognizing its deficiencies and limitations. With this in mind, one can develop a system of classification which can be usefully employed as a basis for establishing syllabi for the education and training of meteorological personnel.

The following classification of meteorological personnel has been adopted in this publication on the basis of the duties to be undertaken and qualifications required.

2.2 CLASS I

These are University trained personnel with adequate education in mathematics and physics and who have successfully completed a course in meteorology to the standard specified by the syllabi. In this group there can be various levels, or degrees of qualifications.

All meteorological services should have personnel of this Class. Their duties should include, inter alia operational day-to-day work such as weather forecasting as well as consulting, directing and decision-making and management. Clearly also they will be responsible

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* WMO. No. 240.TP.131

for research and development. This may require additional training either through systematic academic courses or as a result of personal study.

2.3 CLASS II

Such personnel will have undergone a complete secondary or equivalent school education and introductory training in mathematics and physics to the standard specified by the syllabi as well as successfully completing a meteorological course. Such training should be given at a university or other appropriate institution having Class I instructors.

The function of Class II meteorological personnel is to carry out duties relative to the analysis and interpretation of observational data. More specifically, their duties will include under guidance by Class I personnel the analysis of synoptic charts, weather forecasting, study of data relating to physical meteorology (radiation, ozone, etc.), observational instruments and methods, telecommunications, inspections of meteorological networks, etc.

The distinction between Class I and Class II personnel lies not in the skills acquired, since Class II may have a very high degree of skill in some fields, but in the fund of knowledge as organized into a consistent body of theory which supports those skills.

2.4 CLASS III

They will have received complete secondary or equivalent school education and training in meteorology either with emphasis on the utilization of observational data or training of an applied and technical nature with emphasis on the use of observational instruments.

Class III personnel should be suitably qualified to carry out a wide variety of tasks in connexion with the processing of observational data or the handling of meteorological instruments. They are responsible for the decoding and checking of incoming messages, plotting of meteorological charts, aerological diagrams and cross sections. They should assist personnel of higher classes in the analysis and interpretation of observational data, supplying meteorological information under supervision, checking monthly weather summaries of the network stations, and calculating statistical parameters on the basis of such summaries. In accordance with their qualifications, Class III personnel would also be responsible for the calibration of meteorological instruments used in the surface observation network, calibration of aerological sondes, operation of aerological and radiation stations, and other allied duties.

2.5 CLASS IV

They should have sufficient training in meteorology to enable them to observe meteorological phenomena accurately and objectively and to understand the underlying significance of their routine tasks. The duties of Class IV meteorological personnel will include all routine surface observations such as atmospheric pressure, temperature, humidity, evaporation, rainfall, speed and direction of wind, sunshine, total radiation, grass minimum temperature, ground temperature, cloud visibility and present weather. They will also maintain instruments such as barometers and barographs, thermometers and thermographs, maximum and minimum thermometers, psychrometers and hygrographs, and all other instruments used in surface observations. In addition, their duties may include office work such as the reduction of observation data, transmission of synoptic messages, maintenance of the observation log and preparation of monthly summaries, processing of recording diagrams and the calculation of hourly totals, means and extreme values. Class IV personnel may also be required to plot meteorological charts and diagrams.

2.6 TOTAL PERIOD OF STUDY FOR VARIOUS CLASSES OF METEOROLOGICAL PERSONNEL

In view of the fact that the periods of primary and secondary school are also the school entry age vary from country to country an indication of the total period of study is highly necessary. For this purpose the following scheme is presented on the assumption that the age at school entry is 6 years:

Class IV - The background education should correspond to at least 9 years of schooling. This should be supplemented by a minimum of 4 months formal training in meteorology and an extensive period of on-the-job training.

Class III - A minimum of 12 years schooling is required before the candidates embark on meteorological study. This corresponds to GCE "A" level in the United Kingdom. The period of the meteorological course should be 8-10 months supplemented by adequate practical and on-the-job training.

Class II - The same general background education as Class III. This should be supplemented by courses in mathematics, physics and other pre-requisite subjects together with meteorological training over a period of 2 years. A minimum of 9 months on-the-job training will be required to complete training.

Class I - The same general background education as for Classes III and II plus university training in pre-requisite subjects and meteorology for a period of at least 4 years. This should be supplemented by on-the-job training of at least 6 months in a Meteorological Service.

2.7 In this publication syllabi for training personnel in each of the above four classes are presented. Attention is given to variations or additions to these syllabi for personnel engaged in the various fields of specialization of meteorology.

It should be understood, however, that in establishing these syllabi, it is not the intention to lay down standard curricula. To do so would be inadvisable. Training programmes throughout the world must take into account local circumstances and, consequently, variations in the syllabi adopted in the various countries are inevitable. It is hoped, however, that the syllabi presented here will serve as guidance material for meteorological training required for the various classes of personnel.

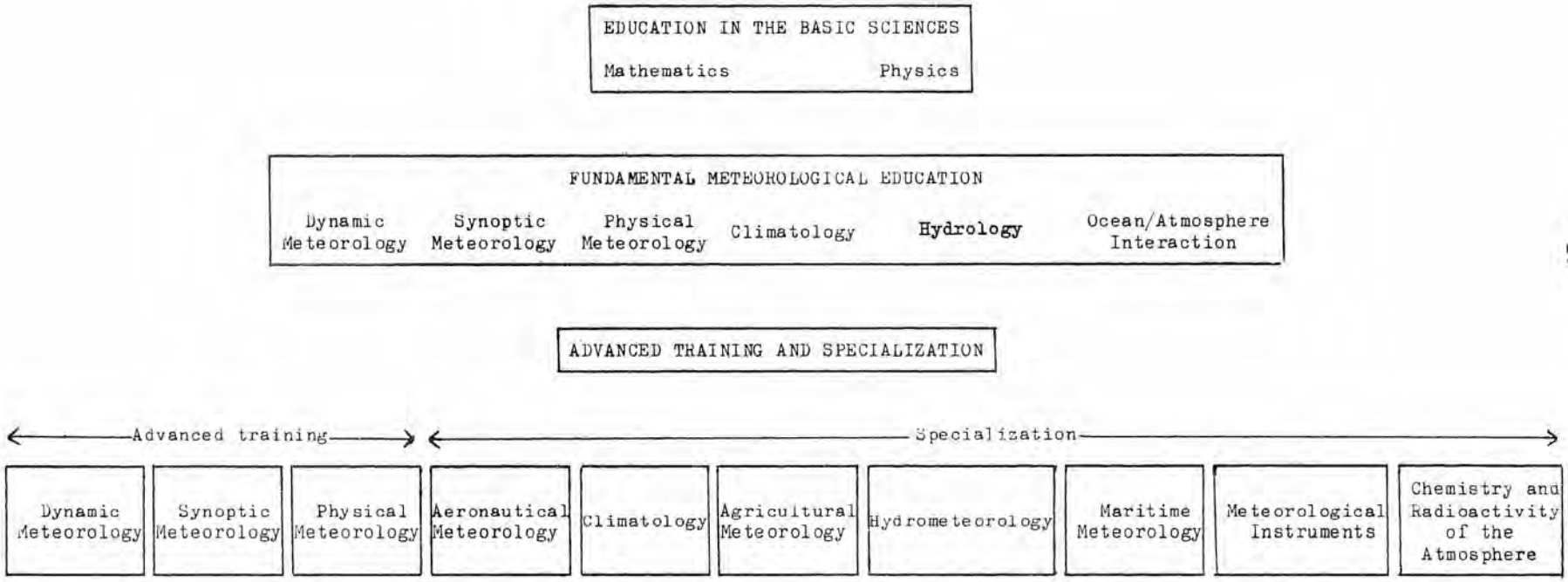
It is emphasized once more that the above classification is not expected to be adopted universally since some countries do have other systems which are more suitable to their requirements. It is however the most readily acceptable compromise as demonstrated by many members of WMO.

C H A P T E R 3

CURRICULA FOR TRAINING ALL CLASS I METEOROLOGICAL PERSONNEL IRRESPECTIVE OF THEIR FIELDS OF SPECIALIZATION

CURRICULA FOR TRAINING CLASS I METEOROLOGICAL PERSONNEL

SCHEMATIC REPRESENTATION OF CONTENTS



3.1 GENERAL

Although in some cases the syllabi for Class I are given in less detail than for Class II, it is, of course, expected that the Class I courses will cover the whole of Class II.

Since courses in mathematics and physics for Class I personnel are taught by mathematicians and physicists, it is unnecessary for WMO to elaborate detailed syllabi in these subjects. There is sufficient uniformity of nomenclature to permit the scope of the material to be indicated briefly. Furthermore although university education may vary from country to country the level of knowledge required in these subjects is implied by the syllabi in meteorology.

The syllabi given below therefore list, without going into detail, the main topics to be covered. However in hydrodynamics and thermodynamics, which are of prime importance in meteorology and in oceanography a certain amount of detail has been maintained.

3.2 EDUCATION IN THE BASIC SCIENCES (CLASS I)

3.2.1 Mathematics

3.2.1.1 Algebra

- Classic linear and non-linear algebra with special emphasis on vectors and tensors; elements of modern algebra: fields, rings, groups, lattices.

3.2.1.2 Differential and integral calculus and advanced calculus

- The classical course in differential and integral calculus including the theorems of Green, Ostrogradsky, Stokes and Gauss; methods of evaluating the asymptotic value of integrals.
- Functions of a complex variable.
- Classical course in series, including Fourier series and orthogonal functions; Fourier integrals.
- Ordinary differential equations including linear and higher order and degree equations; solutions in series and the theory of special functions.
- Classical course in differential and integral vector and tensor calculus.
- Calculus of variation.

3.2.1.3 Partial differential and integral equations

- Boundary value problems in heat conduction.
- Special functions.
- Eigen functions and Eigen values.

3.2.1.4 Probability theory and statistics

- Foundations of probability theory.
- The statistical method and its scope.
- Contingency and correlation.
- Time series; random series; trends in time series; harmonic analysis; spectrum analysis (power spectra).

3.2.1.5 Numerical and graphical calculation

- Numerical calculation of an expression involving only arithmetical operations.
- Numerical differentiation and integration.
- Numerical calculation of series.
- Solution of ordinary differential equations; numerical approximation and graphical method.
- Simultaneous linear equations.
- Partial differential equations; relaxation methods.
- Non-linear algebraic equations; numerical solution of cubic equations; graphical methods.
- Approximation functions.
- Solution of the standard transcendental equations; graphical methods.
- Standard integral equations.

3.2.1.6 Machine computation

- The use of computers in meteorology : computers, working principles; coding; general construction, central unit, in- and output devices; memories; principles; lineprinters; tapes and cards, tape and punch-card machines; sorting and selection stages; programming principles; flow diagrams; programming languages (ALGOL, FORTRAN); compilers; statistical, accounting and information handling machines; application of machine methods in meteorological services; analogue computers; processing of continuous variables; applications.

3.2.2 Physics

3.2.2.1 Particle dynamics

- Kinematics of a particle.
- Dynamics of a particle.

3.2.2.2 Rigid body dynamics

- Kinematics of a rigid body.
- Dynamics of a rigid body.

3.2.2.3 Elastic media

- Equilibrium of elastic bodies.
- Elastic waves.

3.2.2.4 Hydrodynamics

Kinematics

- Eulerian and Lagrangian variables; decomposition of a field of motion in the vicinity of one of its points into a field of translation; a field of rotation and a field of deformation and divergence; physical significance of vorticity and divergence; application to plane motion.

Statics

- Pressure; force due to the pressure gradient; equations of state and of change of state of a fluid; perfect gas equation; surface tension of fluids; capillarity; barotropic and baroclinic fluids; isobarisostere solenoids; Pascal's law; Torricelli's experiment; barometer; Archimedes' principle and buoyancy applications; hydrostatic equation along the vertical; altimetry, application to the atmosphere; Laplace's equation.

Dynamics

- Eulerian and Lagrangian motion; boundary and initial conditions; continuity equation; case of gases and liquids; compressibility and incompressibility.
- Work-energy theorem, balance of mechanical energy (potential and kinetic energy); application to aerodynamics; Bernouilli's theorem.

- Vorticity and divergence; rotational form of the equations of motion; irrotational motion and two or three-dimensional rotational motion; irrotational motion in three dimensions due to sources, sinks, doublets and line sources; images; flow around an obstacle.

- Circulation and vorticity : absolute and relative circulation and vorticity; case of the barotropic fluid : the Lagrange-Helmholtz theorem; case of the baroclinic fluid : V. Bjerknes's theorem and its interpretations.

- Small disturbances and their propagation in a fluid in equilibrium; compressibility waves (sound waves); gravity and inertia waves.

- Viscous fluids; coefficient of viscosity; case of gas; case of liquids; Navier-Stokes' tensor; integration of the viscous fluid equations in simple cases; Poiseuille's flow and Couette's flow; resistance of fluids to the motion of immersed bodies; Stokes' formula, limiting velocity, applications.

- Turbulent fluids; one and two-dimensional turbulent flow; boundary layer; eddy lines and eddy motions in the wake of an obstacle; Reynolds' number; Reynolds' tensor; turbulent diffusion of heat and momentum, eddy conductivity and eddy viscosity; application to the atmosphere, turbulent diffusion of water vapour in air.

3.2.2.5 Thermodynamics

- Object of thermodynamics : thermodynamic system; definition; exchanges of energy and matter with the external world; closed and open systems; physical state of a system; variables of state; (p,v) systems; Clapeyron's diagram.

- Definition of temperature : temperature scales (Celsius, Fahrenheit, Kelvin); variables of state and the equation of state of a system; homogeneous and non-homogeneous systems; thermal expansion of solids, liquids and gases; case of gases : the laws of Boyle-Mariotte, Gay-Lussac, Avogadro and Dalton (gas mixtures); equation of state of a gas : perfect gas and Van der Waal's gas.

- Definition of heat : quantity of heat; calories; thermal conductivity; specific heat; case of gases; heat of change of phase; heat of reaction (chemistry); calorimetry.

- First law of thermodynamics : various forms of energy (work, heat, electrical and chemical energy, etc.); principle of the conservation of energy; principle of the equivalency of heat and work (Joule); statement and meaning of the first law in the cases of systems at rest and in motion (atmospheric air); in the cases of closed and open systems (clouds in the case of precipitation); case of systems in motion; consequences of the first law and of the kinetic energy theorem as applied to the system; internal energy; enthalpy; Gibbs's system; work accomplished by the expansion of an ideal fluid; reversible exchange of work and heat; calorimetric coefficients of a fluid; adiabatic transformations; case of the perfect gas.

3.2.2.6 Electromagnetism

- Electrostatics.
- Direct current.
- Magnetostatics.
- Alternating current.
- Electromagnetism.

3.2.2.7 Electromagnetic radiation

- Geometric optics.
- Wave optics.
- Spectroscopy.
- Theory of electromagnetic radiation.

3.2.2.8 Atomic and molecular physics

- Concept of the composition of matter.
- Elements of wave and quantum mechanics, and atomic physics.

3.3 FUNDAMENTAL METEOROLOGICAL EDUCATION (CLASS I)

In any Meteorological Service there will be day-to-day operational tasks calling for the exercise of independent judgement based on scientific principles. Work of this kind will necessitate a cadre of well-qualified and skilful personnel. Such personnel must have a thorough grounding in dynamic, synoptic and physical meteorology. Syllabi in these subjects are given in paragraphs 3.3.1, 3.3.2 and 3.3.3 respectively. For convenience the syllabus on the statics and thermodynamics of the atmosphere, an essential aspect of both dynamic and synoptic meteorology and also necessary background for the study of cloud precipitation physics, has been reproduced separately in paragraph 3.3.4 rather than under dynamic or synoptic meteorology as is often the case. Further, Class I personnel should also have basic knowledge of climatology, hydrology and the interaction of the ocean and atmosphere. Appropriate syllabi are given in paragraphs 3.3.5, 3.3.6 and 3.3.7 respectively.

3.3.1 Dynamic meteorology

3.3.1.1 Formulation of basic equations

- Equations of motion in vector form as derived from Newton's second law; discussion of pressure force and gravitation; transformation from non-rotating to rotating co-ordinate systems; discussion of centripetal acceleration and Coriolis force; the concept of gravity.
- Equations of motion in Cartesian co-ordinates (tangent plane approximation) and in spherical co-ordinates; orders of magnitude of various terms (based on observations) leading to the simplified equations.
- Introduction of the hydrostatic approximation; justification of this approximation.
- Equation of quasi-hydrostatic motion using pressure as vertical co-ordinate.
- The continuity equation; Cartesian co-ordinates: pressure as vertical co-ordinate; homogeneous and incompressible fluid.
- The hydrodynamic equation and equation of state.
- Principles of dimensional analysis.

3.3.1.2 Circulation, vorticity, divergence and deformation

- Vorticity and circulation; Bjerknes' circulation theorem with interpretations.

- Divergence of the three dimensional and horizontal wind field.

- Vorticity and divergence equations in co-ordinate systems with pressure as independent variable; discussion of the order of magnitude of the various terms.

- Introduction of the stream function and velocity potential - Helmholtz theorem; streamlines and trajectories.

3.3.1.3 Static stability

- Equilibrium stratification of mass in the gravity field; pure gravity oscillation; stable, unstable and neutral stratification.

3.3.1.4 The circular vortex

- The stationary circular vortex; the thermal wind relationship; stable, unstable and neutral conditions; elementary treatment of stability criteria.

3.3.1.5 Dynamics of mesoscale phenomena

- Sea breezes.

- Mountain-valley winds.

- Thunderstorms and tornadoes.

3.3.1.6 Atmospheric turbulence

- The nature of turbulent flow; flow near a boundary; the mixing-length hypothesis; velocity profile near a boundary (smooth surface, rough surface); power-law profiles; the vorticity transport hypothesis; statistical theories of turbulence.

- Eddy transport of momentum, heat and water vapour, in the planetary atmospheric boundary layer; the Taylor-Ekman theory of the vertical variation of the wind in the boundary layer.

- The heat flux equation and the problem of convection; Richardson criterion; forced and free convection.

3.3.1.7 Small scale turbulence convection

- Plumes.

- Bubbles.

3.3.1.8 Atmospheric waves

- The elements of linear perturbation theory; compressibility waves; gravity waves; internal and external gravity waves; the importance of the boundary conditions; rigid and free surfaces.

- Inertia waves; inertia stability; calculation of the inertia circle; combined gravity-inertia waves.

- Barotropic waves (Rossby waves).

- Elementary treatment of baroclinic waves.

5. .1.9 The general circulation of the atmosphere

Observational studies

- A description of the mean state of the atmosphere and its variation with the seasons; distributions of the zonal wind and the zonal temperature field as a function of latitude and pressure; the latitudinal, vertical and seasonal variation of the intensity of atmospheric disturbances; definition of zonal and eddy quantities; algebra of average values and the associated fluctuations; distinction between stationary and transient disturbances.

Momentum heat and water balance

- The time variation of absolute and relative angular momentum; the meridional transport of relative angular momentum by atmospheric disturbances; the convergence of the momentum transport and its importance for changes in the mean zonal wind; the importance of the mean meridional circulation and of the friction for changes in the mean zonal winds.

- The maintenance of the mean zonal temperature field; the meridional transport of sensible and latent heat by atmospheric disturbances; the convergence of the eddy heat transport and its importance for changes in the mean zonal temperature field; the importance of the mean meridional circulation for changes in the mean zonal temperature field; temperature changes caused by the zonal heat sources and sinks.

- Global water circulation; evaporation; precipitation; transport and divergence of the transport.

Energetics of the atmosphere

- Definition of kinetic, potential and internal energy; the proportionality between potential and internal energy in quasi-static flow; the concept of available potential energy; conservation theorems.

- Derivation of the kinetic energy equation for a finite volume, in particular in a zonal ring; transport of kinetic energy in the meridional and vertical direction.

- The maintenance of temperature variance in a finite volume, in particular a zonal ring; the importance of horizontal and vertical heat transports.

- General treatment of atmospheric energetics considering available potential energy and kinetic energy in their zonal and eddy forms and their interaction.

3.3.1.10 Numerical weather prediction

- General principles of objective analysis.
- Models of large-scale atmospheric motion systems : scale analysis of atmospheric motions; the filtering of scales of motions without meteorological significance such as external gravity waves and the short internal gravitational and inertial waves.
- Balanced motions : horizontally balanced motion; motion with no tangential acceleration; gradient wind relation; geostrophic wind relation; comparison of geostrophic and gradient winds with actual winds; the divergence and the velocity of the geostrophic wind; the geostrophic thermal wind; deduction of the balance equation from the divergence equation; simplified forms; the balance equation as a generalization of the geostrophic and gradient wind relations.
- The barotropic model.
- Some simple baroclinic models.

3.3.1.11 Laboratory work

- Numerical computation of map factors and of geostrophic winds from height data given in grid points; static stability computations; barotropic and elementary baroclinic forecasts by the relaxation method, etc.

3.3.2 Synoptic meteorology

In these suggested outlines no syllabus relating to organization and historical development of meteorological services, and technical aspects of communication systems has been given with the thought that this material is appropriate for on-the-job training within the various national Meteorological Services.

For laboratory exercises, where a high-speed computing facility is not available graphical methods can still be used to advantage in a number of instances.

Availability of the products of a meteorological service is assumed to broaden the student's experience through contact with a large number of weather situations in real time. It is difficult otherwise to obtain a feel for the processes and problems of forecasting.

3.3.2.1 The synoptic data

- Surface, upper-air and special observations; satellite data; radar; sferics, etc.; representation and analysis of fields of meteorological elements.

3.3.2.2 Air masses

- Characteristics and analysis; production and modification.

3.3.2.3 Wind and pressure

- Geostrophic and thermal wind; gradient wind; streamlines; divergence; vorticity and other kinematical aspects; friction layer; barotropic and baroclinic systems.

3.3.2.4 Fronts

- Frontogenesis and frontolysis; structure of fronts; kinematics and dynamics of fronts.

3.3.2.5 Cyclones and anticyclones

- Frontal and baroclinic models; structure development.

3.3.2.6 Synoptic climatology

- Jet stream and frontal climatology; long waves; blocking.

3.3.2.7 Tropical meteorology

- Streamline analysis; easterly waves; monsoon circulation; convective systems; tropical cyclones.

3.3.2.8 Synoptic weather analysis

- Surface analysis; analysis in constant pressure surfaces and other surfaces; cross-section analysis.

3.3.2.9 Meso-scale analysis

- Convection systems; local winds and other weather phenomena.

3.3.2.10 Weather prediction

- Short-range forecasting by traditional methods; medium range and long-range forecasting; objective analysis and numerical weather

prediction; prediction of individual weather elements.

3.3.2.11 Satellite data and other modern techniques as developed

- Applications to synoptic meteorology of satellite photography and radiation measurements; constant level balloons; automatic buoys; rockets, etc.

3.3.2.12 Laboratory exercises

- Practical work in synoptic laboratory is a necessary part of the course of instruction. This should cover a wide range of methods of analysis and prediction.

3.3.3 Physical Meteorology

3.3.3.1 Radiation in the atmosphere

- Basic black body laws; definition of terms and units used in radiation; the exponential extinction law; absorption; Rayleigh and Mie scattering; the solar constant; transmission of solar radiation in the atmosphere; effects of clouds; surface albedo; sky radiation; empirical formulae for solar radiation at surface; instruments used for measuring solar radiation; spatial and temporal distribution of solar radiation over the earth including astronomical factors; origin and nature of long-wave radiation in the atmosphere; simple discussion of spectral lines, line shape, bands, effects of pressure and temperature and band models; absorption and emission by water vapour; carbon dioxide and ozone; radiation charts; effects of clouds; nocturnal or net radiation and empirical formulae; diurnal and annual variations of the radiative balance; the heat balance of the earth and atmosphere; principles of radiative sensing of vertical structure of the atmosphere from artificial earth satellites; ozone and its relation to radiation; temporal and spatial variation of ozone and its use as an atmospheric tracer; radiative processes in the stratosphere and mesosphere.

3.3.3.2 Meteorological optics

- Refraction of electromagnetic radiation in the atmosphere; microwave ducting, optical mirages as examples; review of the geometric optics of reflection, refraction and diffraction; applications to rainbow, halo, mock sun, sun pillars, glory, corona; transparency of the atmosphere; the visual range; turbidity and its measures.

3.3.3.3 Water substance in the atmosphere

- Solid, liquid and gaseous phases of water; saturation vapour pressures over liquid/solid; specification of water substances in atmosphere; relative, specific, etc. humidity; liquid/solid water content; variation of humidity with height; evaporation; condensation; sublimation at (a) earth's surface, (b) suspended

particles; formation of fog, mist and cloud; classification of clouds; precipitation; types and classification; snow cover, properties; melting and evaporation; broad features of water cycle in the atmosphere.

3.3.3.4 Cloud micro-physics

- Nucleation of the liquid phase from the vapour; condensation nuclei, their properties and distribution; ice nuclei and their properties and distribution in time and space; growth of cloud drops and ice crystals by diffusion, snow crystal habit; size, number, fall speed of drops and crystals; limit on diffusional growth and need for precipitation mechanisms; Bergeron-Findeisen process; coalescence of cloud drops; growth of warm rain; formation of graupel and hail, growth of precipitation in convective, stratiform and orographic clouds; icing of aircraft; artificial modification of clouds; critical assessment of techniques for stimulation of rain, prevention of hail, dissipation of fog and cloud.

3.3.3.5 Atmospheric electricity

- The fair-weather electric field of the atmosphere; ions and ionizing radiations; the conduction current; world-wide aspects of the diurnal variation of electric field and conductivity; observational aspects of thunderstorm electrical properties; theories of thunderstorm electrification; the lightning discharge; thunderstorms as a mechanism for maintaining the fair-weather electric field.

3.3.4 Statics and thermodynamics of the atmosphere

- Atmospheric pressure and its variation with altitude; geopotential and the geopotential metre; the hydrostatic equation, its importance in meteorology; height of a pressure surface and thickness of a pressure layer; altimetry; barometric pressure and its precision; the standard atmosphere.

- Additional thermodynamics : second law of thermodynamics; general statement and meaning; reversible transformations; statement and implications of the law; one and two-source cycles; Carnot's theorem; thermodynamic temperature scale; entropy; irreversible transformations; statement of the law; Clausius's inequality and non-compensated heat; entropy; evolution of an isolated system; degradation of the energy of a system.

- Consequences of the two laws : thermodynamic potential; Gibbs's equations; chemical potential, application to ideal systems; mixtures of perfect gases (moist air) and dilute solutions; thermodynamic and chemical equilibrium; displacement from equilibrium; change of phase; interphase equilibrium; heat of change of phase; Clapeyron's equation; lag in change of phase; dilute solution; osmotic pressure; Van't Hoff's law : chemical equilibrium between a solution and the solid phase of the solvent;

electrolytic solutions; phase rule; Nernst's and Le Chatelier's laws : capillary systems, application to water drops (Kelvin's law) and to ice crystals; steam and internal combustion engines; efficiency; Watt's indicator; refrigeration; jets and nozzles.

- Thermodynamic systems in meteorology : dry air; liquid water; water vapour; ice; non-saturated moist air; aqueous clouds; ice clouds; clouds formed of water droplets and ice crystals; thermodynamic properties of water in its three phases and the changes of phase; properties of dry air and moist air; virtual temperature.

- Adiabatic transformations of dry and moist air; potential temperature; wet-bulb temperature and the psychrometric formula; equivalent temperature; wet-bulb pseudo-potential temperature and pseudo-potential equivalent temperature; dew-point temperature and its variation with altitude; dry and saturated adiabatic lapse rates; Clausius-Clapeyron equation; mixing of the masses of moist air.

- Aerological diagrams; diagrams equivalent to Clapeyron's diagram; choice of a diagram; use of diagrams in synoptic meteorology.

- Stability of vertical dry and moist air; stability criteria and instability criteria; conditional instability and latent instability; the parcel and slice methods and a comparison of the two; convective flow in the atmosphere; importance of relief; diurnal variation of stability and convection.

- Precipitable water; quantitative precipitation forecasting; latent heat relationship; the thermodynamics of the hail stage; energy changes on the thermodynamic diagrams; stability changes and large-scale vertical velocity fields; entrainment during convection; the bubble theory of penetrative convection.

3.3.5 Climatology

3.3.5.1 General climatology

- Notions of climate, definition of climate.

- Physical factors of climate : heat; light; moisture.

- Astronomical factors : solar climate and climatic zones; solar, lunar, planetary and cosmic influences; influence of latitute; effects of variation in the earth's axis of inclination and in elements of the earth's orbit; zonal contrasts and continentality; mean temperature of the earth's surface as a function of the solar constant, albedo, emissivity; geometry of radiation - "meridional contrast" (contrasts meridional).

- Geographical factors of climate : environmental influences on climate; distribution of sea and land surfaces; degree of continentality; topography and aspect; soil and subsoil

(physical state and water retention capacity of the soil); regional and local influences; influences of water masses (oceans, lakes, rivers); effects related to the nature of the earth's surface (snow, ice, forests, prairies, crops); influence of towns, buildings and other human activities; effects of volcanic eruptions on climate; geographical distribution of climates.

- Climatic factors : air, water and soil temperature; atmospheric pressure, wind, humidity, evaporation, evapotranspiration, sunshine duration, radiation, cloud amount, visibility; composition of air; atmospheric pollution; state of the ground; state of the sea; hydrometeors; lithometeors; photometeors; electrometeors; instruments and methods of observation for the various climatic elements; variability of the climatic elements, their variations and ranges (daily, monthly, seasonal, annual, etc.); variability of the climatic elements in space.

3.3.5.2 Physical climatology

- Thermal radiation; energy and water balance of the earth's surface; geographical distribution of the energy balance; geographical distribution of solar and terrestrial radiation albedo; comparison of the normal values and variability of climatic elements at the various latitudes in the two hemispheres; hydrological cycle; region to region variations of the water balance; climatic aspects of turbulence and diffusion; heat transfer in the soil; heat capacity; evaporation and evapotranspiration; frequency and variations of electrical phenomena (potential, conductivity, vertical currents, etc.); geographical distribution of thunderstorms over the earth's surface.

3.3.5.3 Dynamical climatology

- Climatological aspects of the general circulation of the atmosphere and of the centres of activity; possible circulation patterns; Bjerknes' circulation theorem and "cold anticyclones"; experimental models; Rossby number; wave number and air blocking in the mountains; autoregulation in open sea and pack-ice; surface wind field and upper wind field; divergent fields and vorticity; metastable and multistable behaviour of the atmosphere; climatological aspects of dynamical meteorology; preparation of numerical models; long-range forecasting; forecasts for contingency tables; use of the information ratio in the choice of "predictors".

3.3.5.4 Synoptic climatology

- Climatology of air masses; mean values or frequency of climatic elements associated with types of weather; frequency of simultaneous occurrences of two or more climatic elements; natural synoptic periods; special phenomena; geographical and seasonal distribution of fronts, convergence zones and air masses; fronts; polar front waves; moving anticyclones; other disturbances and climatological phenomena associated with them.

3.3.5.5 Upper-air climatology

- Troposphere and lower stratosphere; climatological data for standard levels (standard isobaric surfaces) and significant levels; temperature; water vapour (mixing ratio of moist air); pressure; wind; radiation; ozone; atmospheric chemistry; geopotential; thickness of isobaric layers; freezing level; tropopause (geopotential, pressure, temperature); jetstreams (position of axis); temperature inversion (base, top, geopotential, temperature, humidity); height of freezing level (0° isotherm); cloud base; correction of observational errors; presentation of climatological upper air data; presentation of charts, diagrams, etc.; stratosphere; mesosphere; thermosphere (ionosphere); importance of the upper atmospheric layers for thermal processes in the atmosphere in general.

3.3.5.6 Types of climate - Classification of climates

- Cause of formation of climates; principles of climatic classifications; one example of classification.

3.3.5.7 Regional climatology

- Seasonal variations of the atmospheric circulation; monsoons; local and diurnal winds; climatic elements, their frequency, characteristics and distribution; climate source regions; role of oceans and continents; storm trajectories and frequencies; complex of weather types and grouping of climatic elements according to air masses; geographical distribution of air masses and frontal zones; regionalization of climates; effects of relief, oceans, vegetation, etc.; climatological conditions of continents and oceans.

3.3.5.8 Elements of meso- and microclimatology and maritime climatology

3.3.5.9 Applied climatology

- Elements of aeronautical climatology, agricultural climatology, urban climatology and bioclimatology.

- Application of climatological methods to industrial activities, insurances, legal proceedings, tourism, sports, transportation, etc.

3.3.5.10 Climatic changes

- Elements and basic notions.

3.3.5.11 Special climatological methods

- Elements and basic notions of random variable and probability theory; description of population by means of frequency

distribution; estimation problems; test of hypothesis; relationships problems.

3.3.6 General hydrology

- Role of water in economic activities; bodies of water on the globe; general information on oceans; seas, large lakes and rivers; the water cycle on the globe; the general principles of water balance; general information on the structure of water, ice, snow and water vapour; river systems and basins; definition of rivers; formation of river system; watershed divides; definition of a basin; boundary and configuration of basins; measurement of basins; morphological and physico-geographical characteristics of basins; characteristics of river systems; classifications of tributaries; river valleys and channels; river valleys and their types; river beds and flood plains; plane formation of river channels; formation of bed cross-section; types of movement of water in river beds, circulation currents and vortex motion; sources of runoff; runoff from rainfall; runoff from snowfall, glaciers and permanent snow; runoff from groundwater; influence of climate, relief, soil, geological and other factors on runoff processes; water stage and runoff regime; typical hydrographs; phases of the hydrologic year; regulated regime (natural and artificial); floods, their development and laws governing their movement; general principles of streamflow and water balance; water balance equation and its analysis; characteristics of streamflow; discharge, volume, depth of runoff discharge in seconds; litre per km^2 and runoff coefficient; average annual runoff; long-term average annual runoff; seasonal runoff; thermal variations in rivers; temperature variations in rivers; river freezing processes and ice formation; ice break processes; sediment transport; energy of running water; erosive action of rivers; suspended load and its transport; relationship of suspended load to water stage and discharge; sediment transport of rivers and factors governing the degree of it; bed load, its formation and regime; deformation of the river channel; channel formation processes and their variation in time and along the length of the river; influence of hydraulic structures on channel formation processes; chemical sediment; basic elements of chemical regime of rivers; river estuaries and their hydrological peculiarities; hydrology of lakes and reservoirs; lake formation processes and the inflow-outflow balance of lakes; temperature variations in lakes; calculations of the heat balance of lakes; salinity, chemical and gaseous composition of lake water; waves on lakes and reservoirs; calculations of wave height; erosion banks; current in lakes and reservoirs; lake deposits, their classification and morphology; main characteristics of the hydrological regime of reservoirs; biology of lakes and rivers; relation between the biology of lakes and rivers and the chemical composition of waters; notions on hydrology of marshes.

3.3.7 Interaction of the ocean and the atmosphere

- Wind currents and wind waves.

- Structure of the upper ocean.

- Interaction between the atmosphere and the oceans : character of interaction; the oceans and the climate; the oceans and the weather.

C H A P T E R 4

ADVANCED TRAINING AND SPECIALIZATION FOR CLASS I METEOROLOGICAL PERSONNEL

4.1 GENERAL

Specialization in dynamic, synoptic and physical meteorology will normally occur only at the research level. The syllabi in sections 4.2, 4.3 and 4.4 respectively below indicate the advanced training required in each of these fields to equip personnel for research work. The syllabi for specialization in the essentially practical fields of aeronautical meteorology, climatology, agricultural meteorology, hydrometeorology, maritime meteorology, meteorological instruments and atmospheric chemistry are given in sections 4.5 to 4.11.

4.2 ADVANCED DYNAMIC METEOROLOGY (CLASS I)

A characteristic feature of the development of the natural sciences is the steadily increasing use of numerical theoretical investigation methods. In meteorology, in particular, this process has been very rapid, especially as regards the general laws governing atmospheric motion, their theory being part of the study of dynamic meteorology.

The programme has therefore been divided into two parts - the first part deals with the classical studies of the analytic solutions of simple models of the atmosphere, including the structure of baroclinic waves on a model with a constant shear basic current. More realistic and therefore more complex models require the use of numerical methods. These are dealt with in the second part of the programme. Here the method is applied in two directions : as a tool for weather prediction or as a tool for research. In the second case it should be kept in mind that numerical solutions provide numerical results but not physical explanations. The researchers should therefore take the numerical results as the starting point for the physical study of the processes involved.

This method of investigation has been called numerical experimentation. At the present time, numerical experiments are used to study a very wide variety of atmospheric processes, from general atmosphere circulation to small-scale processes of a local nature. Numerical experiments are used to investigate not only atmospheric dynamics but also other atmospheric processes. Recently, the numerical experimental method has also come to be used in the solution of problems in applied meteorology, agriculture, building, aeronautics, and so on.

In particular, several important developments have occurred in the field of dynamic meteorology over the last few years.

(a) Objective analysis : the techniques for objective numerical weather analysis developed since the mid-fifties in several parts of the world have been adopted by weather services to such an extent that the standard synoptic weather map analysis carried out

by the professional meteorologist now plays a minor role in many countries. It is therefore, of the highest importance that meteorologists using such objective weather map analyses should understand the principles underlying the analysis procedures. The standard procedures applied in weather map analysis are therefore included in the syllabus given below.

(b) Numerical weather prediction : numerical weather forecasts of height, temperature and wind fields, including vertical velocity, are now available to many meteorological forecasting offices throughout the world. Clearly, the user of numerical forecasts must know how they are prepared in order to make use of them in his particular region. It is therefore essential that the graduate student receives a thorough grounding in numerical weather prediction techniques, including the detailed analysis of the possible sources of error inherent in such a forecast.

(c) Simulation models of the atmosphere : during the last decade, great progress has been made in simulating long-term developments in the atmosphere by means of numerical models, which are in fact very similar to the most advanced short-range prediction models. A description of the models, and the results obtained from their use are therefore included in the syllabus for dynamic meteorology.

4.2.1 Hydrodynamics

The syllabus given in section 3.2.2.4 should be expanded as follows:

Dynamics

- Small disturbances and their propagation in fluids with mass and velocity stratification; stability studies of linear models : two and three layer models with density discontinuities (Helmholtz waves); waves on a single layer shear flow (Kelvin waves); two and three layer models with shear discontinuities (Rayleigh waves); combination of shear and density discontinuity effects on the wave motion; models with continuous variations of density and velocity profiles.

- Small disturbances and their propagations in rotating fluids - inertial effects.

4.2.2 Formulation of basic equations

Section 3.3.1.1 should be supplemented as follows:

- Equations of quasi-hydrostatic motion using potential temperature or density as vertical co-ordinate - the equation of motion in σ co-ordinate systems.

- The continuity equation in co-ordinates other than pressure; homogeneous and incompressible fluid.

4.2.3 Energetics of the atmosphere

Section under 3.3.1.9 should be expanded as follows:

- Conversion and transport processes with reference to pressure averages and corresponding fluctuations.

- The selective role of the various scales of atmospheric motions in the energy processes; the generation, conversion and transfer of energy as a function of wave number.

4.2.4 Atmospheric wave motion

- Short wave lengths (ray theory); analysis of the propagation of stable gravity; accoustic and Rossby waves in a variable basic state; fundamental oscillation; eigen modes of model atmosphere; atmospheric tides.

4.2.5 The circular vortex

- Symmetric perturbations of a circular vortex; the stability tensor; application of calculus of variation and other methods to reduce the stability criteria; meridional circulations generated by heat and momentum sources and sinks.

4.2.6 Barotropic stability

- Horizontal motion on a sphere of an inviscid non-divergent fluid; stable and unstable distribution of the vorticity field.

4.2.7 Baroclinic stability

- Baroclinic waves on a basic current which is a linear function of height; stabilizing influence of the static stability on short waves and of the β-effect on long waves; various models.

4.2.8 Mountain waves

- Lee waves; short and long waves.

4.2.9 The theory of turbulence

- Atmospheric and oceanic turbulence; the occurrence of turbulence; the energy equation for turbulence; the spectrum of turbulence; local similarity theory; the maintenance of Reynolds stresses; turbulence in the surface layer; entrainment.

4.2.10 Numerical method

Quasi-geostrophic models

- Integration of quasi-geostrophic models : formation of the equivalent-barotropic model; the equivalent-barotropic level; vertical velocity and divergence in the equivalent-barotropic model; formulation of multi-level models, in particular the two-level model; the modification of the equations due to the map projection; finite difference approximation in space and time for the quasi-geostrophic equations; the horizontal grid distance; the time step; truncation errors; solution of Laplace; Poisson and Helmholtz equations by iterative methods; Liebmann procedure; extrapolated Liebmann procedure; over-relaxation factors : filters designed for special purposes such as eliminating almost all short-wave noise; investigation of the typical errors in quasi-geostrophic forecasts, in particular errors due to the neglect of topographic effects; energy sources and sinks; frictional dissipation and erroneous boundary conditions; considerations of the performance of ultra-long waves in quasi-geostrophic forecasts, in particular the equivalent barotropic in determining the speed of very long waves; the effects of mountains, friction and heat sources and sinks; incorporation of a moisture parameter in a numerical prediction model for precipitation forecasts.

- The stability properties of the two-level quasi-geostrophic models; derivation of explicit formulae for the real and imaginary parts of the phase speed; the neutral or critical stability curve; a calculation of the amplification rate of purely baroclinic disturbances.

Integration of the non-geostrophic equation for quasi-static models

- Quasi-static formulation of a non-geostrophic model in adiabatic and frictionless flow; the numerical stability problem (in particular the length of the time in relation to the grid size); finite difference formulations of the non-geostrophic equations on a map projection; a comparison of the baroclinic stability problem for the non-geostrophic equations and the quasi-geostrophic equations.

Numerical simulation of the general circulation

- The formulation of numerical models used in simulating the general circulation; integrations over very long time periods; descriptions of the performance of the experiments; initial states; time developments of the flow; zonal and eddy flow; the energetics of the numerical models; comparisons between the energetics of the models and the energetics of the real atmosphere; problems of parameterization and limits of predictability.

- Detailed treatment of various general circulation models.

- Numerical methods of long-range forecasting.

Objective weather map analysis

- The purpose of objective analysis; procedure used by a numerical prediction unit; analysis by surface fitting over small regions; operational objective analysis; the use of numerical forecasts as a first guess; the use of height and wind data in height analysis; weighting functions, empirical and idealized; application of normal charts or other climatological information; analysis in data sparse regions; the estimation of upper-air data from surface data over oceans; comparisons of objective and conventional analysis.

Laboratory models of atmospheric circulation

- Rotating tanks, tornado models, low speed wind tunnels, etc.

4.2.11 Laboratory work

To familiarize the students with the various techniques used in numerical models, a laboratory course should be introduced to solve exercises. In order to perform the problems without excessive hand calculations it is advisable to have access to a medium size electronic computer.

4.3 ADVANCED SYNOPTIC METEOROLOGY (CLASS I)

4.3.1 The kinematics of horizontal motion

- Field of horizontal motion represented by zonal and meridional components and by direction and speed; features of the field of flow: troughs; ridges; singular points; axes of confluence and diffluences; relation between streamlines and trajectories in moving features of the field of flow; divergence, relative vorticity, and deformation in cartesian co-ordinates and in natural co-ordinates; stream function and velocity potential.

- Laboratory exercises : analysis of isogons, streamlines and isotachs for a selected synoptic case; sample measurements of divergence, relative vorticity and deformation; discussion of effects of error in the wind measurement; sample construction of trajectories; calculations of stream function and velocity potential for a given wind field.

4.3.2 Relationships between wind, pressure, and temperature fields

- The geostrophic and thermal wind; acceleration and geostrophic departure; gradient and cyclostrophic winds; balance of forces in the surface friction layer; the Ekman spiral; the balance equation; the slope and modification of pressure systems with height; thickness and temperature fields; advection of thickness and temperature by the geostrophic wind.

- Laboratory exercises : analysis of height and thickness fields for various pressure levels for a selected synoptic case; sample calculations of geostrophic and gradient winds and comparison with observed winds; sample calculations of thickness and temperature advections associated with cyclonic and anticyclonic systems; calculation of balance wind for a given pressure field.

4.3.3 Fronts and frontogenesis

- Discontinuities of zero, first and second order; relationships between pressure and temperature fields in the vicinity of frontal discontinuities; kinematics of frontogenesis; the horizontal confluence effect and the effect of vertical motions; characteristics of the frontal structure in surfaces, cyclones and in upper-level troughs; theories of frontogenesis in linear fields of motion and numerical models; dynamics of fronts.

- Laboratory exercises : analyses of cases of frontogenesis in the lower and in the upper troposphere; analyses of frontal structure in vertical cross-sections; sample frontogenetical calculations.

4.3.4 Quasi-geostrophic diagnosis

- The thickness tendency equation; the effects of advection, adiabatic heating and cooling; the quasi-geostrophic vorticity

equation; the effects of advection and divergence; the geopotential tendency equation.

- Applications : steering of short waves by large-scale flow; deepening and filling of ridges and troughs due to field of temperature advection; steering of shallow cyclones and anti-cyclones by upper-level flow.

- Association of vertical motion with fields of vorticity advection and temperature advection; orographic vertical motion and orographic cyclogenesis; vertical motions generated within the surface friction layer; the so-called omega equation.

- The effects of diabatic heating.

- Conditions for surface cyclogenesis.

- Distribution of geopotential tendency and vertical motion for idealized cyclonic and anticyclonic systems and for jet entrance and exit regions.

- Laboratory exercises : diagnostic calculation of geopotential tendencies and vertical motions for a selected synoptic case; qualitative application of concepts to analysis from operational forecast centre.

4.3.5 Prediction models for large-scale flow

- Equivalent barotropic model; limits of applicability; associated vertical motions; control of ultra-long waves.

- Structure of a simple two-layer baroclinic model.

- Structure of non-geostrophic models.

- Laboratory exercises : graphical methods of prediction with barotropic and simple baroclinic models; critical appraisal of circulation forecasts prepared at operational forecast centre.

4.3.6 Prediction by statistical and probability methods

- Prediction screening techniques.

- Regression methods.

- Forecast probability statements.

4.3.7 Prediction of surface temperature

- Relation of surface temperature to thickness.

- Effects of heat transfer between atmosphere and surface of earth.

- Effects of wind in the turbulent boundary layer : effects of cloud cover.

- Laboratory exercises : practice forecasting of surface temperature; critical appraisal of objective forecasts prepared at operational forecast centre.

4.3.8 Prediction of cloudiness and precipitation

- Morphology of cloud systems; use of satellite information.
- Statistical relationship of cloudiness and precipitation to large-scale circulation parameters.
- Dynamical models for large-scale humidity prediction : statistical relationship of cloudiness and precipitation to large-scale humidity.
- Cumulus convection; stability indices; relationship to large-scale vertical motion; structure of instability lines and meso-scale circulations; use of radar information.
- Fog : radiation, advection, upslope and frontal types; geographical and temporal distribution.
- Laboratory exercises : analysis of patterns of cloud, precipitation and humidity for a selected synoptic case; graphical prediction of large-scale moisture field; meso-analysis of a selected case of severe convective phenomena; practice forecasting of cloud and precipitation; critical appraisal and use of objective forecasts prepared at operational forecast centre.

4.3.9 Analysis and prediction in low latitudes

- Structure of circulation features; low-level easterlies and high-tropospheric vortices; monsoon circulations; intertropical convergence zone; wind information from satellite data.
- Tropical storms; geographical and temporal distributions; structure and evolution; statistical and dynamical prediction of tracks; numerical models of tropical storm development.
- Laboratory exercises : analysis of a selected synoptic case with tropical storm activity; application of satellite information; sample statistical and dynamical predictions of storm track.

4.3.10 Objective analysis

- Surface fitting methods.
- Scanning methods; weighting factors.
- Regression methods; correlation as a function of separation distance.
- Detection of erroneous data.
- Treatment of data sparse regions.

- Laboratory exercises : preparation of objective analyses for a selected synoptic case; comparison with manual analyses; critical appraisal of analyses prepared by operational forecast centre.

4.3.11 Forecast verification and evaluation

- Measures of forecast skill and forecast utility; use of climatology and persistence as control forecasts.
- Statistical analysis of probability forecasting and analysis.
- Present levels of forecast skill for various elements as a function of time range.
- Limits of predictability.
- Laboratory exercises : verification and evaluation of practice forecasts.

4.4 ADVANCED PHYSICAL METEOROLOGY (CLASS I)

4.4.1 Basic radiation laws

- Rayleigh-Jeans law; review of quantum theory of radiation; Planck distribution law, Wien's displacement law and the Stefan-Boltzmann law; Kirchoff's law and its dependence on thermodynamic equilibrium; the black body and the grey body; the exponential relation of Bouguer; absorption, scattering and extinction coefficients.

4.4.2 Scattering in the atmosphere

- Rayleigh scattering, its angular distribution and polarization; Mie scattering, its angular distribution and polarization; Rayleigh scattering and geometric optics as limiting cases of Mie scattering; molecular scattering in the atmosphere; scattering by the typical atmospheric aerosol; scattering by absorbing particles and the effects of absorption in the gaseous medium; scattering by non-spherical particles; multiple scattering.

4.4.3 Solar radiation and its disposition

- Solar physics as related to solar radiation; photosphere, reversing layer and Fraunhofer lines, chromosphere, corona, sunspots, flares, faculae; the solar constant and methods for its determination; the solar spectrum outside the atmosphere; the solar wind and corpuscular emissions; critique on the variability of solar emissions; transmissivity of the atmosphere as a function of wavelength and its decomposition into absorption and scattering; astronomical and geometric factors; diffuse or sky radiation as a result of multiple scatter in a Rayleigh atmosphere and modifications due to the aerosol; scattering and absorption by clouds as computed from multiple scattering theory and the observed albedo and transmissivity; empirical formulae for the effect of clouds; the temporal and spatial distributions of global, diffuse and direct beam solar radiation; surface albedos; the planetary albedo of the earth and comparisons with albedos of other planets; the vertical variation of absorption in the atmosphere.

- Atmospheric aerosols.

- Interpretation of radiation data obtained from meteorological satellites.

4.4.4 Long wave or terrestrial radiation

- Introduction to the theory of spectra; electronic lines; vibrational and rotational modes and their interaction; infrared bands of the triatomic molecules; survey and identification of the principal absorption bands of the atmosphere; spectral line shapes and dependence on temperature and pressure; foreign gas and self-

broadening; limits on applicability of Kirchoff's law and relaxation emissions; band models of Ladenburg and Reiche, Elsasser, Goody; observations of band absorption and fit of band models; pressure scaling and the Curtis-Godson approximation; derivation of the radioactive transfer equation; numerical and graphical methods for determining radiative fluxes and the vertical flux divergence; methods of treating band overlap; effects of clouds; emissivity of the surface; net radiation at the surface and empirical formulae; instruments for long-wave radiation; the determination of the vertical distributions of temperature and water vapour from observations of long-wave radiation taken by artificial satellites.

4.4.5 Radiative and heat balances

- Diurnal variation of radiative and heat balances at the surface; annual and seasonal radiation balance of the earth atmosphere and in the atmosphere; radiative balance in troposphere and stratosphere and implications relative to tropopause; radiative processes in the mesosphere.

4.4.6 Ozone

- Observational information on geographical and temporal variations of total ozone and on its vertical distribution; absorption and emission bands of ozone; photo-chemical theory of ozone and comparisons of theoretical and observational distributions; effects of vertical and horizontal circulations on ozone distribution and correlations between ozone and weather systems; radiative effects of ozone, the sharp lower limit of the UV solar spectrum at the surface and the radiative contribution to the tropopause; ozone destruction near the surface; ozone as an atmospheric tracer; measurements of ozone by Dobson spectrophotometer, ozone sondes, Umkehr method, from satellites and during solar eclipse.

4.4.7 Physics of the upper atmosphere

- Composition and structure; standard atmosphere.
- Solar radiation; absorption in the upper atmosphere; absorption spectra of N_2, O_2, O_3, etc.
- Energy exchange by collisions.
- Transport processes : (mean) circulation; eddy transport.
- Model atmospheres; photochemical equilibrium; the effect of transport processes on model atmosphere.
- Atmospheric tides.
- The ionosphere; composition and general properties; observational methods.

- Aurora and air glow.

- Noctilucent clouds; nacreous clouds.

4.4.8 Cloud physics

- Thermodynamic-kinetic theory of nucleation; homogeneous and heterogeneous nucleation; condensation nuclei and their properties; Kohler curves; observational methods and results on size and concentration of condensation nuclei; maritime and continental nuclei spectra; sources of condensation nuclei; homogeneous nucleation of ice in water; heterogeneous nucleation of ice and properties of ice nuclei; sublimation nuclei, crystal lattice, epitaxy, bonding forces; strain, steps, dislocations, adsorption; observations of natural ice-forming nuclei and evidence of their nature; ice crystal habit in relation to temperature and supersaturation; equations for diffusional growth of drops and crystals; effects of shape and fall speed; computations of evolution of cloud drops from nuclei; comparison with observed cloud drop spectra and possible explanations; computations of growth of ice crystals and comparison with observations; limits on size of cloud drops and ice crystals attainable by diffusional growth; the two major precipitation processes and computations to show conditions required for each and particle sizes attained; comparisons with observed sizes; the coalescence of drops; collection efficiency; effects of electric fields and charges; disruption of rain drops and the Langmuir chain reaction; growth by accretion in the form of ice-graupel and hail; clumping of snow crystals; melting of snow and hail; evaporation of liquid drops; observational data on the characteristics of precipitating clouds; evidence on the occurrence of ice in natural clouds; the release of precipitation from convective clouds, from stratiform clouds, from orographic clouds; artificial modifications of the precipitation process on the basis of the foregoing; the artificial dissipation of fog and low cloud.

4.4.9 Radar meteorology

- Basic principles of microwave radar; wavelengths; antenna factor; peak power; pulse length; pulse repetition rate; scanning modes; polarization; methods of presenting data; calibration techniques; propagation of microwaves in the atmosphere and attenuation; backscatter of microwaves from hydrometeors on the basis of Rayleigh and Mie theory; convective precipitation as seen by radar and deductions; the radar first echo; radar echoes of hail and tornadoes; stratiform precipitation on radar; the bright band and rain versus snow; cellular structure of stratiform precipitation; the hurricane as seen by radar; the use of Doppler radar for measuring horizontal and vertical motions; the pulse integrator and the "R" meter; isoecho contouring circuits; automatic data handling systems; the measurement of rain-fall by radar; the Z-R relationships from observed rain-drop spectra; comparisons of rainfall observed by radar with that from rain gauge networks; millimetre radars for observations of non-precipitating clouds.

4.4.10 Atmospheric electricity

- The fair weather electrical structure of the atmosphere; ionizing radiations and the formation and recombination of small ions; general orientation on the ionosphere (full discussion should be given under upper atmosphere); large or Langevin ions: method of formation, mobilities, variations in time and space; electrical conductivity of the air and its variations; the air-earth current; gross electrical structure of the thunderstorm and methods of observation; the space charge; shielding of cloud charge; observed electrical properties of non-thunderstorm clouds; charge on blowing snow and triboelectric effects; rate of charge separation in thunderstorms from observations; theories of thunderstorm electrification and comparison of their possible charging rates with observations; the lightning discharge: stepped leader, dart leader, main stroke, repetitive strokes; observational evidence of time sequence of events in discharge, quantity of charge in a stroke, peak current and waveform, time between strokes, fraction of total strokes to ground; discussion of the physics of the lightning stroke; thunder, its origin and propagation; the thunderstorm as a mechanism for maintaining the earth-atmosphere charge; vertical electric current above a thunderstorm; estimates of the total number of thunderstorms required and that observed; the diurnal variations of the electric field in universal time and its implications; electric charge on hydrometeors; corona discharges; lightning strikes on aircraft; instruments for the measurement of atmospheric electrical paramaters.

4.5 SPECIALIZATION IN AERONAUTICAL METEOROLOGY (CLASS I)

The development of a world-wide air transportation system calls for efficient meteorological service in all parts of the world, thus enhancing the need for guidance to administrations in regard to the standard they should aim at in the recruitment and training of personnel for the field of aeronautical meteorology. The quality of the meteorological service provided is a major factor in safe and economic air transportation. Changes in navigational systems enable the new types of aircraft to land under lower minima; meteorological observations and forecasts of even greater accuracy than before will thus be required. This will make it imperative that the personnel engaged in the activities of an aeronautical Meteorological Service are highly qualified and fully aware of the importance of their responsibilities.

Those engaged in the provision of meteorological forecasts should be Class I personnel. Their education and training should be programmed in a similar manner to that of Class I personnel engaged in dynamic or synoptic meteorology. This should be supplemented by special courses in aviation knowledge and procedures for meteorological service to international air navigation. Syllabi for these subjects are given below.

4.5.1 Aeronautical meteorological knowledge

Aircraft icing

- Theory of formation; processes and dependence upon temperature; drop size; liquid water content; airframe configuration and aircraft speed.
- Types of icing: clear ice, rime ice and hoar frost.
- Ice accretion rates; association with cloud types (stratiform and cumuliform clouds); thunderstorms; freezing precipitation; orographic and frontal lifting effects.
- Methods of forecasting the risk of ice formation and means of avoiding icing areas.
- Effects of inflight structural icing on wing and tail surfaces, propellers, Pitot tube, antennas and windshield.

Turbulence

- Turbulence near the ground; mechanical turbulence as a function of wind speed, wind shear and terrain roughness; convective turbulence as related to hydrostatic instability; effects of boundary layer turbulence on take-offs and landings of aircraft; turbulence related to clouds, fronts, and thunderstorms.

- High-level turbulence (CAT); association with horizontal and vertical wind shear, jet stream, stability and tropopause inversion.

- Mountain wave turbulence applied to both boundary layer and high-level.

- Effects of severe turbulence on the control of the aircraft and possibility of structural damage.

- Methods of forecasting the risk of the existence of turbulence; means of avoiding turbulence areas.

Other meteorological phenomena hazardous to aviation

- Reduced surface visibility: fog - its manner of formation and dissipation; the relationship of visibility to fog type and duration, to the various hydrometeors as rain, drizzle, snow and to air pollutants such as smoke.

- Knowledge of the theory and practical techniques for the artificial dissipation of fog.

- Thunderstorms; association with in-flight turbulence, hail icing and lightning; surface conditions related to thunderstorms such as strong, gusty winds, wind shifts, poor visibility; frontal and air mass thunderstorms; squall line thunderstorm.

- Specific knowledge in the interpretation of weather radar information towards making short-term terminal forecasts.

- Effects of accumulated snow, slush and water during take-off, landing and taxi-ing operations.

Meteorological aspects of flight planning

- Meteorological basis for pressure pattern flying; definitions of Rhumb line, great circle, and composite tracks; wind components.

- Minimal flight paths; least time tracks; use of "D" factor; determination of drift angle; single heading flight; radio-navigation.

- Meteorological requirements for en-route winds and temperatures, weather and terminal forecasts for advance operational planning, pre-flight planning and in-flight planning.

- Preparation of area forecasts, route forecasts (e.g. cross-sections) and flight forecasts.

- Special emphasis on the importance and techniques of briefing of flight crews and operational personnel.

4.5.2 Aeronautical operational knowledge

Definition

Definition and meaning of the following terms used in international air operations:

- Air report; briefing; forecast; landing forecast; meteorological information; meteorological report; observation; SIGMET.
- Altitude; cruising level; transition altitude; transition level; transition layer.
- Operator; operator's local representative; pilot-in-command.
- Airway; control area; control zone; controlled airspace; flight information region.
- Aerodrome; instrument runway; landing area; movement area; aerodrome traffic zone.
- "Service"; "provide"; "issue"; "make available"; "supply".

Procedures for meteorological services for international air navigation

Knowledge of the functions or the appropriate regional procedures associated with the items listed below:

- Meteorological offices; main, dependent and supplementary meteorological offices; meteorological watch offices.
- Aeronautical meteorological observations; routine and special observations; selected special reports; reports for take-off or landing.
- Aerodrome forecast; area covered; period of validity; amendment criteria.
- Information for operators or operators' local representatives; advance, preliminary, and pre-flight planning; in-flight operational planning; briefing and display of meteorological information required by operators; information required from operators.
- Information for pilots-in-command prior to departure; briefing; documentation; flight forecasts; pictorial cross-sections; aerodrome forecasts; surface and upper-air charts; prognostic charts.
- Information for pilots-in-command during flight; scope and responsibility of area meteorological watch; en-route forecast service; information available from ocean weather vessels; supply of meteorological information in exceptional circumstances; diversion procedure.
- Information for and from air traffic services; types of meteorological information required by aerodrome control towers, approach

control offices and area control/flight information centres; collection of aircraft meteorological reports.

- Forms of meteorological messages; routine and special reports in code or plain language; reports for take-off and for landing; forecasts and amendments to forecasts; trend forecasts; ditching reports; flight, route and area forecasts; SIGMET information; dimensional units.

- Information for search and rescue according to local procedures.

- Aeronautical climatological information; forms used; publication of records.

Air traffic services

- Knowledge of the functions of and distinctions between area control centres, approach control office and aerodrome control tower and flight information centres, and the part played by the air traffic services in the provision of in-flight meteorological service.

- Knowledge of operational terms such as IFR, IMC, VFR, VMC, the rules governing terrain clearance and vertical separation; quadrantal cruising levels; methods of effecting horizontal separation; alerting and search and rescue services; methods of aerial search; holding and approach procedures.

Operation of aircraft

- Aerodrome meteorological minima and the minima applicable to at least the regular and alternate international aerodromes.

- Altimeter setting procedures and the ICAO Standard Atmosphere.

- Knowledge of general flight navigation; the principal aids to navigation and methods of determining upper winds in flight.

- The effects of air density, humidity, icing, turbulence and wind on aircraft performances; fuel consumption of aircraft; the effects of various weather phenomena on aerodrome ground services; aids to approach and landing.

Private aviation and aerial work

- Meteorological requirements for private pilots, for agricultural flights and other non-scheduled operations.

Organization

- Organization for the provision of services in meteorology to international civil aviation; telecommunications, means, systems and plans for the concentration and diffusion of information; forms of traffic; international co-ordination of procedures (WMO and ICAO).

Regulatory documents

Familiarization with the following documents:

WMO	ICAO
- Technical Regulations, Chapter 12	- Annex 3 - PANS-MET ..... Doc 7605 - MET/526/4
- **Publication No. 9 - TP.4 Volume B - Codes**	- Regional Supplementary Procedures. Doc 7030 - ICAO Abbreviations and Codes ..... Doc 8400 - Location indicators. Doc 7910 - Meteorological tables for international air navigation ..... Doc 7155 - MET/522

NOTE - Use has been made of the part dealing with "Aviation Knowledge" of ICAO Doc. 7192-AN/857 PART 7/2, Training Manual, Part 7 - Aeronautical Meteorological Forecasters.

4.6 SPECIALIZATION IN CLIMATOLOGY (CLASS I)

4.6.1 Chemistry and radioactivity

- General notions and principles of chemistry.
- Basic laws of chemistry.
- Periodic system of the elements.
- Isotopes.
- Metalloid elements; methods of preparation; their components.
- Metals; extraction methods; their components.
- Radioactive elements: disintegration of radium; the families of radioactive elements; natural and artificial transmutation.
- General notions and methods of organic chemistry; generalities on the categories of organic matters.

4.6.2 Elements of astronomy and geodesy

- Celestial sphere : diurnal motion; horizontal and equatorial co-ordinates : hour angle; height and declination of a star; theodolite and sextant; elements of spherical astronomy related to the determination of the celestial position of the sun; general characteristics of the planet earth; shape and dimensions of the earth; horizon; laws governing the motion of the earth; reception of solar energy by the planets; causes of the unequal distribution of solar energy over the surface of the globe; alternation of day and night; equinoxes and solstices; seasons of the year; thermal zones of the globe; grid points; geographical co-ordinates; types of maps; continents; oceans of the globe and their distribution.

4.6.3 Physical geography

- Lithosphere : structure of the earth; core; biosphere; tectonics; secular land changes; folding and the formation of mountains; folds and faults in the earth's crust; reasons for earthquakes; seismic-centre; epicentre; outside exogenous forces altering the surface of the earth; erosion, physical, chemical and organic (biological); erosive and accumulative action of the wind, streams, rivers, snow and ice; the role of endogenous and exogenous factors in the formation of the earth's surface; nature of the coastlines of continents; peninsulas and islands; continental, volcanic and coral islands; the main islands and peninsulas of various parts of the world; seas and gulfs; various types of shores; relief and its forms; indication of relief on maps; flat land relief; mountainous relief and its forms; earth's magnetism.

- Hydrosphere : hydrological cycle; oceans and seas; principal ocean currents; water on land; rivers and their basins; river valleys; main rivers of the world; lakes; classification of lakes; principal lakes of the world; glaciers; snow line; glacier movement; role of glaciers in river feed; mountain flood waters; avalanches; marshes; formation of marshes; types of marshes.

- Landscape (natural) zones : biosphere; soils; description of natural (landscape) zones; landscape zones of the cold, temperate and tropical zones of the earth, their geographical distribution and brief description of natural conditions; mountainous areas; vertical zonality.

- General physical geographical description of continents : geographical situation, coastline, relief, inland water; soil and flora of continents : Eurasia, North and South America, Africa and Australia, Antarctic.

- Elements of palaeontology, stratification and fossils, historical geology, geological periods.

- Mineralogy and petrography : forms of minerals, systems of crystallization, the various categories of minerals; rocks : eruptive rocks, aqueous rocks, crystallophyllic rocks.

- Topography : instruments and methods of topography, measurement of level differences (contouring), topographic maps, determining the position of a meteorological station on a topographic map.

4.6.4 Elements of botany, biology, ecology

- Botany : organography, morphology, anatomy and histology of plants; physiology of plants : mineral nutrition through the roots, transpiration, assimilation, respiration, effect of meteorological elements on physiological functions; classification of plants : the principal branches of cryptograms and phanerograms.

- Biology : reproduction, heredity, genetics, variation and mutation of the types of living beings; evolution of living beings, mechanism of the evolution (Darwin, Lamark).

- Ecology : geography of living beings (phytogeography, zoogeography, anthropogeography).

4.6.5 Meteorological instruments and methods of observation

4.6.6 Climatology

Types of climate - Classification of climates

- Classification based on atmospheric circulation and geographical conditions; genetic classification; classification based on the effects originated at the surface; types of climates; various

classifications of climates (Köppen, Thornthwaite, Handel etc.) one of which will be described in detail.

Regional climatology

- Function and physical description of the climates of the different continents and oceans; detailed climatology of the country where the education is given; qualitative description; numerical data; maps and atlases.

Meso- and microclimatology

- Radiation properties of natural surfaces; radiation in crops, forest canopy, cities, dwellings; response functions; vertical variation and distribution of climatic elements; convective processes; heat exchange and conduction near the soil surface; interaction between climate and plants; atmospheric pollution; effect of stability and wind on air pollution in the boundary layers; microclimates due to special features, to details of the nature of the soil, to surface topography, microclimates of slopes, thermal belts, cold air pooling, frost pockets, etc.

Maritime climatology

- Climatological aspects of the organization of observations on ships (ocean weather ships, commercial vessels, etc.); preparation of climatic atlases and the publication concerning the oceanic regions for general meteorological purposes of the users; the climates of oceanic regions in relation to maritime activities (transport, fishing, etc.).

Applied climatology

- Bioclimatology : bioclimatology in relation to botany, zoology, medicine, physiology, pathology and other therapeutic factors; bioclimatology in relation with heating; ventilation; regulation of humidity; man in unfavourable environment (desert, arctic, tropics, index of comfort, effect of altitude, etc.); man in controlled or partly controlled environment (dwellings, tunnels, mines, caves, etc.); biochemical, physical and biological effects of heat and cold; lethal temperatures; acclimatization; temperature regulation; evolution, and mechanism in man; stress and homeostasis; heat budget of the body; housing and climate; solar and ionizing radiation, and effects.

- Urban and building climatology : urban climate; general principles, concepts and definitions of climatic conditions at the boundary layer and modification of these conditions caused by buildings - isolated or in groups; urban climatology and town planning for various types of climate on scales ranging from regional to local; study of the variations in air flow, radiation exchange, temperature, degree of air pollution, humidity, visibility and precipitation (amount and intensity); building climate : temperature of materials; albedo; thermic variations; corrosion etc; wind

and its technical aspects; humidity, evaporation and enthalpy of air; rain and snow - intensity, density and weight; present application and presentation of climatological data for technical use.

- Application of climatological methods to industrial activities, insurances, legal proceedings, tourism, sports, transportation, etc.

Climatic change

- Some fundamental meteorological factors affecting the climate; climatic change during the past two hundred years as given by meteorological observations, local and planetary; historical and archeological evidence of climatic change; methods of paleo-climatology; climatic indicators of warm and cold, wet and dry climates, etc.; the C^{14} - method for dating; the O^{18}/O^{16} method for determining temperature; some fundamental factors determining the paleoclimate; general circulation during a warm age and during an ice age; paleographic conditions affecting the climates through the ages; pole wandering and continental drift; description of the paleoclimate from Cambrian to the present time; possible causes of climatic changes; extraterrestrial climatic factors (Simpson's ice age hypothesis, changes in the orbital elements of earth, climate and sunspots); terrestrial climatic factors with special emphasis upon the back-feeding effects of atmosphere and surface conditions; influence of man on climatic changes.

Special climatological methods

- Climatological statistics : random variable and probability theory frequency (absolute - relative); probability (prior - posterior); likelihood; Bayes theorem; independent, joint, conditional probabilities; random variable (Von Mises definition); discrete, continuous random variable, climatological series; population - sample; application to climatological data.

- Description of populations by means of frequency distributions (climatological prediction) : probability and statistical distribution; frequency distribution; frequency function; cumulative distribution (discrete and continuous case); symmetrical, asymetrical, multivariate, conditional, marginal distributions; truncated distributions; mixed distributions; climatological series; mean recurrence interval; mean; median; mode, quintiles; variance; standard deviation; moments; moment generating function; binomial, Poisson, negative-binomial, multinomial distributions; normal distribution; central limit theorem; skew, mesokurtic, leptokurtic distributions; gamma distribution; log-normal distribution; transformation to normal distributions; Edgeworth series; distribution of extremes; smallest, largest value; the three asymptotes; t-distribution, X^2-distribution, F-distribution; degree of freedom.

- Estimation problems : empirical frequency estimates; parametric estimation; point estimation; estimator; sampling error; biased, unbiased, consistent, efficient, sufficient estimator; information

amount; estimation procedures; method of moments; maximum likelihood, least square, minimum chi-square; interval estimation, confidence intervals; adjustment of climatological parameters for discontinuities of the station location.

- Test of hypothesis : null hypothesis and alternative, statistic; level of significance; type I error; type II error; power; parametric and non-parametric tests; order statistics; Student's test; Fisher-test; Behrens-Fisher problem; variance analysis; likelihood ratio; Chi-square-test; one-sample; two-sample; k-sample cases; test of normality; tests of goodness of fit; tests of homogeneity; sequential tests.

- Relationship problems : correlation; covariance in normal bivariate, multivariate distributions; coefficient of correlation; partial, multiple correlation; tests of correlations (parametric or distribution free); rank correlation; contingency tables; regression (linear, non-linear, multiple); significant, non-significant regression coefficients in adjusted relations; discriminent analysis; factor analysis.

- Time series : stochastic processes; random series; stabilization of variance; test for randomness; test against trend; test for autocorrelation; space-time representation of climatological variables; filters; Markov processes; spectral analysis; power spectrum; white noise; cross spectrum.

- Computation - mathematical tools : digital computer; programming; numerical models; Fourier analysis; double Fourier-series; spherical harmonics; Fourier-Bessel functions; orthogonal polynomials, Tshebycheff-Hermite; matrix calculus; Eigenvectors.

4.7 SPECIALIZATION IN AGRICULTURAL METEOROLOGY (CLASS I)

The personnel employed in agricultural meteorology can be grouped in two main classes:

- Personnel with a basic training in meteorology.
- Personnel with a basic training in agricultural sciences.

In each of these two classes, a further distinction should be made between graduates and non-graduates.

In preparing syllabi for the various classes of personnel, distinction is made between the following groups:

(a) Professional meteorological personnel (graduates with basic training in meteorology);

(b) Agricultural scientists (graduates with basic training in agricultural sciences);

(c) Technical assistants in Agrometeorological Services (non-graduates with training in mathematics and physics at secondary school level).

Duties and training of the various groups of agrometeorological personnel

The graduate personnel (professional meteorological personnel and agricultural scientists) are responsible for the organization and supervision of Agrometeorological Services and for research in agricultural meteorology.

Technical assistants would carry out the following duties : agrometeorological observations (instrumental, visual, phenological); installation maintenance, checking and calibration of instruments, with the exception of very delicate instruments, the adjustment of which should be entrusted to professional officers (a) and (b) above; elementary processing of agrometeorological data; routine computations of averages, normals, frequencies, etc; preparation of punched cards; statistical analysis of agrometeorological data under guidance of the professional officers; assisting in research projects.

The qualifications and training programmes proposed for these classes of personnel are shown in the form of syllabi indicating the standard of knowledge required and the extent to which the subject should be covered. The syllabi are prepared for the three classes of personnel mentioned above, and an additional syllabus is given for the purpose of teaching agricultural meteorology in secondary level schools of agriculture, horticulture and forestry. Further, in the case of professional meteorological personnel (Syllabus I) the candidates must have attained the required standard in physics, mathematics, meteorology and climatology, and have a sufficient background in the biological and agricultural sciences (if he has not already taken a degree in agriculture).

This syllabus can be covered:

(a) As part of a four-year B.Sc. Agric. course in agrometeorology;

(b) During post-graduate work in agricultural meteorology after a degree in pure science;

(c) During post-graduate work in agricultural meteorology after a degree in agricultural science.

While instruction in biometry, botany (including plant physiology), crop science and soil science is considered essential for this course in agricultural meteorology, a knowledge of animal science, entomology and plant pathology will, under certain circumstances, also be desirable.

Syllabus I must be considered as the minimum requirement for the training of Class I agrometeorological personnel. Personnel engaged in advisory tasks in agrometeorology, should receive training in the appropriate parts of this syllabus.

A one-year course in agricultural meteorology (Syllabus II) is proposed for candidates holding degrees in agricultural sciences. The purpose of this course is to make the agricultural scientist more conscious of weather and climate and to train him to measure meteorological and climatic influences whenever he should engage in research. The standard of mathematics and physics required will be that of the first year at University. If the postgraduate work of the agricultural graduate leans towards agricultural meteorology in animal, crop and soil studies, he may receive training in appropriate parts of Syllabus I for professional meteorological personnel.

The syllabus for technical assistants in Agrometeorological Services (Syllabus III) is given in Chapter 8 of this Guide. The standard of mathemathics and physics required will be that of secondary or high school.

The syllabus for teaching agricultural meteorology at secondary level schools of agriculture, horticulture and forestry (the word "secondary" in this context implies advanced education below university level) (Syllabus IV) is given in Chapter 9 of this publication, and consists of a number of lectures and practical exercises. The purpose of including these lectures and exercises is twofold:

(a) To avoid elementary meteorology being taught at Universities. The time thus saved can be devoted to agricultural meteorology;

(b) To prepare a certain number of observers for agrometeorological stations.

Syllabi I and II are given below.

4.7.1 SYLLABUS I - for meteorological personnel

4.7.1.1 Biological sciences

- Soil science : composition and formation of soils; weathering of rocks and minerals; the soil profile; simple classification of soils; plant nutrition and soil fertility; organic matter in soils; micro-organisms; the physical and chemical properties of soil; soil and plant relationships; soil erosion - types, causes; principles of soil conservation.

- Botany : the morphology, anatomy and histology of flowering plants; systematic classification of plants; life-histories and reproduction of the more important plants; economic botany.

- Plant physiology : the plant cell; solutions and membranes; the roots of plants; the intake of water and solutes by plants; the loss of water by plants; the processes of photosynthesis, including CO_2 requirements; respiration and growth in plants; the translocation of water and materials in plants; frost and drought hardiness; photoperiodicity.

- Ecology : plant association, successions and climaxes.

- Field crops : physiographic, climatic, edaphic and biotic factors in relation to plant growth; crop production in relation to the agro-ecological conditions of the country concerned; agronomic practices; crop and fodder production; land utilization and industrial crops.

- Horticultural crops : classification of horticultural plants; climatic and soil requirements; elementary morphology and physiology; propagation; pruning; orchard layout and culture.

- Pastures : the origin, development and stabilization of vegetation in relation to the environment; vegetation types, their management and application in veld management; the establishment and management of cultivated pastures.

- Plant pathology : importance of plant diseases; causes and classification; diseases caused by parasitic bacteria and fungi, viruses and non-parasites; influence of environmental factors on diseases of economic plants; principles of plant disease control.

- Zoology : the elements of anatomy, histology and physiology; distinguishing characteristics of the major groups of the animal kingdom; a knowledge of the morphology, physiology and reproduction of representative types; elementary cytology, embryology and genetics.

- Animal anatomy and physiology : the form, structure and functions of the locomotory, nervous, circulatory, respiratory, digestive, excretory, endocrine and reproductive systems of farm animals.

- Animal husbandry and disease of livestock : the principles of animal production; the nutrition of farm animals; physiological reaction to environmental changes in relation to food utilization;

ecology of livestock; factors influencing growth and development; important animal diseases.

- Entomology : embryology, histology, physiology, ecology and the chemical, biological or other methods of control of the more important insect pests injurious to vegetables, fruit trees, field crops and pastures, stored grain and grain products, forests.

4.7.1.2 Agricultural meteorology

Introduction

- The importance of weather and climate for agricultural production: the adaptation of plants, crops and animals to the climate; the necessity of adjusting farming systems to the natural environment; critical growth periods in relation to temperature and soil moisture; the importance of weather and climatic data in determining the irrigation requirements of crops; climate in relation to insect pests and plant diseases; production and cultivation practices in relation to climate; climatic hazards affecting agricultural output, e.g. drought, hail, frost, strong wind, etc.; effects of climate and weather upon storage and transportation.

- Agricultural meteorology : definition, aims and scope; difference between meteorology and agricultural meteorology; a short history of agricultural meteorology in relation to the needs of agriculture and the development of meteorological apparatus.

- National Meteorological Services and the World Meteorological Organization (WMO); national agrometeorological organizations and the Commission for Agricultural Meteorology (CAgM).

Agrometeorological observations, instruments, stations, networks, and processing of data

- Meteorological observations : units; accuracy required; sources of errors; exposure of instruments; general rules and procedures for the observation and recording of pressure, air temperature, atmospheric humidity, wind, sunshine and radiation, precipitation, soil temperature, soil moisture content and soil moisture tension, evaporation, evapo-transpiration; interpretation and analysis of autographic charts; cloud classification; cloud cover; estimation of cloud base; horizontal visibility; existing weather conditions; state of the ground.

- Biological observations : observations on native plants, cultivated crops and trees, farm animals, diseases, insect pests and general activities on the land.

- Instruments and methods of observation : the choice of a site for an instrument enclosure; a detailed study of the procedures for installation, maintenance, checking and calibration of the instruments used in agricultural meteorology.

- Pressure : the mercury barometer : method of observation, exposure, transportation and installation; correction of barometer readings to standard conditions; index error, gravity correction, tempera-

ture correction; the barograph; the aneroid barometer; the hypsometer.

- Surface wind : the pressure plate anemometer; cup and fan anemometers; the hand anemometer; the totalizing anemometer; contact and generator types of anemometer and anemograph; the pressure tube anemograph; the hot-wire anemometer; etc.

- Duration of sunshine : sunshine recorders; exposure, maintenance and evaluation of records.

- Radiation : pyrheliometers; solarimeters; pyranometers; pyrradiometers; net radiometers; illuminometers and devices for measuring the spectral distribution of solar radiation; instruments designed for use within crop canopies; estimates of radiation using sunshine, cloudiness and haze data.

- Temperature : liquid-in-glass thermometers - ordinary thermometers, maximum thermometers, minimum thermometers, soil thermometers; reading a thermometer; electrical thermometers - resistance thermometers, thermocouples, thermistors; auxiliary electrical equipment; thermographs - bimetallic type, Bourdon-tube type, mercury-in-steel type; thermometer and thermograph exposure - general requirements in order to obtain representative air temperature; thermometer screens; artificial ventilation; exposure of grass minimum thermometers; the importance of calibration certificates; possible sources of defects in thermometers and the various procedures to rectify them.

- Atmospheric humidity : psychrometers - simple psychrometer without artificial ventilation, the sling psychrometer, the Assmann-type psychrometer; exposure and observational procedure; care of the wet bulb; operation of wet bulb below freezing; sources of error in psychrometry; the psychrometric formula; tables and slide rules; hair hygrographs - general requirements, exposure, management and transportation, accuracy and sources of errors, washing the hairs; dew-point and frost-point hygrometers; electrical absorption-type hygrometers.

- Precipitation : the ordinary and totalizing raingauges; rainfall recorders - natural siphon type, float type, tilting-bucket type, weighing type; rainfall intensity recorders; snow measurements - snow depth and density; the measurement of rainfall and hail by radar.

- Dew : artificial grass mats and asbestos plates; Parchinger's absorption method; the Leick porcelain plate; the paper-strip dew indicator; the Hiltner dew recorder; the Kessler dew recorder; the dew balance of Monteith; leaf-wetness recorders.

- Soil moisture : soil moisture content; electrical resistance units; electrical capacitance; thermal conductivity; neutron scattering; mechanical and chemical resistance; gamma-ray absorption; nuclear magnetic resonance; soil moisture tension; tensiometers; suction plate, pressure plate and pressure membranes; absorption by porous material; vapour pressure and freezing point.

- Soil temperature, heat flow and soil properties : different kinds of soil thermometers and thermographs; methods of measurement of heat flux; heat flux plates; methods of measuring heat capacity, conductivity and diffusivity.

- Evaporation and evapotranspiration : evaporation - small and large evaporation pans, porous porcelain bodies, porous wick devices, lysimeters; exposure, maintenance, scale; observations and entries; calculations; advantages and disadvantages of different types of pan let into the ground and exposed above the surface; factors influencing evaporation from a pan - depth of evaporating surface, rim effect, colour and size of pan, netwire cover, microclimate; comparison of different types of pan; evaporation from a free water surface (pan) in relation to evaporation from other types of evaporimeter; estimating evaporation from empirical formulae based on Dalton's law; aerodynamic and energy balance approaches; eddy correlation and water balance techniques; evapotranspiration - lysimeters, types and application; various types of atmometer and evaporation pan; micrometeorological methods - aerodynamic energy-balance, eddy correlation; approaches of Thornthwaite, Penman, Blaney-Criddle, Haude, Turc, Prescott, Hedke, Lowry and Johnson, Hoffmann and others; the relation between actual and potential evaporation.

- Agrometeorological stations and networks : classification of stations - principal, ordinary and auxiliary; design of networks.

- Processing of agrometeorological data : meaning of an observation; errors of observation; observations as samples of a population; the use of statistical methods for the quality control and processing of observations; the collection, treatment, representation and storage of climatic data; the tabulation and cataloguing of climatic observations; the publication of climatic data; nomenclature of different maps used in climatology, climograms and phytoclimograms; correlation between agrometeorological and biological data; preparation of plans for statistical studies; systematic and accidental errors; machine methods; the need for simultaneous biological and meteorological measurements of comparable accuracy and validity of sample.

Micrometeorology, microclimatology and topoclimatology

Definition and scope of micrometeorology, micro- and topoclimatology.

- Heat budget at the earth's surface : incoming and outgoing radiation types; net radiation; heat flux in the soil; soil temperature; heat transfer in the lower air layers; free convection; turbulence; latent heat flux.

- Temperature, humidity and wind relations near the ground surface : variations in air temperature; temperature profiles (day and night); humidity fluctuations; wet and dry type moisture distribution profiles; wind structure near the ground; laminar and turbulent flow; wind profiles; effect of wind on microclimate, air pollution and dispersal of spores and seeds.

- The influence of the ground surface on the microclimate : type, colour and structure of the soil; microclimatic soil cover and

cultural practices; the influence of soil moisture and soil freezing on the air layer near the ground; the microclimate above water surfaces : pools, lakes, rivers, sea; the influence of snow cover and ice on soil and microclimate; the microclimate in the boundary zone between different types of soil surface.

- The influence of plant cover (crops) on micrometeorology and microclimatology : the heat budget of plants; radiation penetration and exchange within a low plant cover (crop) and within a tall plant cover (forest); air temperature and humidity within a plant cover; evapotranspiration within a plant cover; the leaf area index; dew; rainfall interception; leaf-wetness within agricultural crops and forests; the influence of forests on the climate of the surrounding area.

- The influence of topography on the microclimate : the radiation budget of different slopes; the influence of topography on day- and night-time temperature profiles, on temperature distribution, cold air drainage, frost hollows, etc; the influence of topography on air humidity; the influence of topography on wind speed and wind direction; local winds : down- and up-slope winds, down- and up-valley winds; the influence of topography on soil temperature and soil moisture; the influence of topography on rainfall.

Instrumentation and methods of observation for micrometeorological and microclimatological measurements

- Methods of evaluating and presenting micro- and topoclimatological data : the use of statistics in microclimatology; methods for estimating long-range macroclimatological possibilities from short-term microclimatic measurements; representation of microclimatological results : diagrams, large-scale maps, etc.

- Importance for agriculture of the air layer near the ground : influence of the variation in and the distribution of radiation temperature, humidity, and wind profiles on plants, animals, insects and plant diseases; influence of the microclimate on soil management practices, plant disease control (spraying, dusting), irrigation, combined-harvesting, etc.

- Modification of the microclimatological environment : the modification of the climate within plant covers (crops) by planting, manuring, cultivation, etc; the influence of shading, mulching, glass screens, walls, changing the colour of the soil or screens, and irrigation on the heat and water budget of plant covers and on the whole microclimate.

Soil climate

- Soil temperature : heat exchange at the soil surface; the soil heat flux as part of the energy budget; factors affecting the soil heat flux; sharing of heat between air and soil.

- Heat conduction in the soil : the classical theory of heat conduction in solids; transfer of heat by movement of water and water vapour within a soil.

- Thermal properties of soils, their variation and measurement : heat capacity; conductivity; diffusity.

- Soil temperature variations : diurnal and annual cycles at the surface and other depths; theory of periodic temperature variations; equations for calculation of temperature at any depth and time given certain boundary conditions; Fourier analysis of soil temperatures; non-periodic variations of soil temperature; application of Laplace transforms to soil temperature studies; sinusoidal temperature variations in natural layered soils.

- Factors influencing soil temperature : source and amount of heat; the energy balance; latitude, slope of land, distribution of land and water soil colour; albedo in different parts of the spectrum; thermal properties of soil; soil moisture, evaporation and condensation; vegetative cover, snow cover; frost penetration.

- Modification of soil temperature by cultural practices : shading; mulching; changing colour of surface; irrigation and drainage; tillage; glass and plastic covers.

- Influence of soil temperature on agricultural production : influence of soil temperature on plant growth; germination and seedling emergence, sprouting of bulbs and tubers, growth of roots and shoots, effect on nutrient uptake; interactions between soil and air temperatures on plant growth, crop quality; extreme soil temperatures and plant injury, plant diseases, extent, thickness and duration of snow cover, alternate freezing and thawing, soil heaving, moisture movement; influence of soil temperature on activity of micro-organisms : distribution, growth and numbers; decomposition of organic matter; ammonification and nitrification; soil aggregation; influence of soil temperature on insect life.

- Soil moisture : soil moisture content - percentage by volume, bulk density; hygroscopic water, capillary water, gravitational water; soil moisture-energy relations; total potential in the soil system, the capillary potential, free energy, soil moisture potential pF and log-tension, relation between soil moisture content and soil moisture tension for different types of soil; the movement of water in the soil; movement of liquid water in saturated and unsaturated soils; movement of water vapour; movement in relation to plant-root extraction; the influence of soil moisture content and potential on plant growth; field capacity; wilting point; available soil moisture in relation to germination, transpiration and vegetative growth, maturation and yield of crops; critical growth periods; farming systems in relation to available soil moisture; the importance of water conservation for agricultural purposes.

- Evaporation and evapotranspiration : evaporation; the theory of evaporation; factors influencing the evaporation from a free water surface : radiation, temperature of the water surface, wind movement, air pressure, quality of water; evaporation losses and the future of evaporation pans in agricultural research; evapotranspiration; the individual and combined influence of soil, plant and climatic factors on evapotranspiration; irrigation scheduling; effect of soil, crops and climatic factors on irrigation needs; application of estimating evapotranspiration on the scheduling of irrigation.

The hydrological cycle in agriculture

- The hydrological cycle : rainfall and its interception by plants, crops and forests; runoff; infiltration; moisture retention of the soil; percolation; evaporation; evapotranspiration, its importance in agriculture; effects of agricultural practices on component parts of the cycle; soil moisture budgets; use of models appropriate to alternative husbandry practices, fallow periods, irrigation, etc.

- Droughts (long-period) : definition; possible causes; frequency; principal drought-afflicted areas and countries; long-term planning against drought; the possibility of cloud stimulation.

- Excess of precipitation : runoff, soil erosion and their control; flood causes, frequency, prediction and control; snow melt.

- Hail : occurrence and frequency of hail storms; extent and pattern of hail damage; meteorological conditions favourable for the formation of hail; types of hailstones; artificial prevention of hail; statistical evaluation of experimental results; experimental procedure for growing artificial hailstones; radar studies in connexion with hail storms.

- Dew : the theory of dew formation; conditions favouring the formation of dew; the importance of dew for plants, plant diseases, animals and insects.

Biological measurements (phenology)

- Introduction : definition, history; the need for phenological data and studies for agriculture.

- Phenological observations for agriculture : phenological observations of plants; plants (native and cultivated) and their growth phases; time of germination, energence, shooting, flowering, ripening, harvesting, defoliation, etc; measurement of plant-growth (phenometry); leaf-size, length of stalks, thickness of tubers, etc; observations of birds, insects and diseases; migration; appearance; outbreak of diseases and epidemics; collection of data; networks and stations; phenological gardens.

- Evaluation of phenological data : examination of data and possible errors; statistical methods; mean values, parallelism of different phases, duration of growing periods, etc; representation of data, diagrams, maps, profiles, etc.

- Research : research on observations made at one station (time sequence, etc.); research on observations at different stations (area analysis, etc.); periodicity and prediction; influence of weather, climate, topography, soil, etc. on biological events.

- Application to agriculture : delimitation of natural growing (farming) areas; phenological climatology; management decisions, irrigation, etc.; improvement of cultural practices; forecasting of biological phenomena for crop production; plant disease-control and seasonal operations; advising for agricultural trade and commerce (export, import, etc.).

Weather and climate in relation to plants and crops, animal production, insects and plant diseases

- Plants and crops : growth and development in plants - annual life cycle, phasic divisions of the plant, measurement of growth and development, effect of weather factors on the growth and development of plants and on quality and quantity; air temperature : plant temperatures; cardinal temperatures; optimal temperature ranges; temperature efficiency; temperature and transpiration; thermoperiodism; low temperatures - stimulating effects, cold injury, the hardiness problem, frost damage and frost resistance; insufficient cold during dormant period; delayed foliation of deciduous fruit trees; high temperature injury; sun-scald; importance of temperatures over the whole growing season and during critical growth periods; heat unit systems; intensity, duration and quality of light; effects on photosynthesis; optimum leaf area index; photoperiodism; transpiration; germination; reproduction; growth forms; physiological characteristics; atmospheric humidity; optimum humidity ranges for growth; effects on transpiration and plant diseases; wind : effects on transpiration, desiccation, dwarfing, deformation, anatomical modifications, pollination, dissemination, soil temperature, soil moisture; the climatic requirements of crops, e.g. corn, wheat, small grains, sorghum, cotton, tobacco, sugar cane, sugar beet, fruit trees (tropical, subtropical and deciduous), vines, berries, vegetables, etc.; the adaptation of plant to the environment; use of climographs in introducing new varieties; plant-climate relationships and the use of phenology in ascertaining the thermal and photo-thermal requirements of crops, e.g. wheat, barley, rye; well-established relations between weather and climatic factors, severally or jointly, on the growth and quantitative yield of crops; critical periods for growth and production; significance of such studies for crop forecasting; influence of weather and climate over the growing season upon the quality of the crop, the length of its storage life or storage behaviour, e.g. deciduous fruit.

- Animal production : thermal balance - the necessity of maintaining a thermal balance in animals between heat production or gain from the environment and heat lost to the environment; the thermal balance equation; the direct effects of weather and climate upon livestock production; the effects of solar radiation, temperature (high or low), atmospheric humidity, length of day and altitude, severally or jointly, upon respiration, pulse rate and body temperature; loss of water from the body; growth rate and body weight; reproduction; grazing habits and food intake; mild production; sunburn, skin cancers and photosensitive disorders; the indirect effects of weather and climate upon livestock production ; effects of weather on the gross yield and quality of feed supply and hence on rate of growth and on milk production; regional effects of seasonal weather and climate upon the type, spread and intensity of parasitic diseases; influence of weather on diseases caused by viruses, bacteria, protozoa, helminths and metabolic disorders; use of meteorological data for forecasting disease outbreaks; effects of weather on the storing and handling of animal products.

- Acclimatization : comfort zone for different breeds of animals; differences between species and breeds in their ability to withstand extreme climatic conditions; symptoms of inadaptability; adaptation

to new environments ; heat stress in relation to acclimatization; the Bergman law; physiological adaptation; use of climographs in evaluating the possibility of adaptation to new environments; overcoming climatic disadvantages by selecting and breeding.

- The climatic aspects of livestock production in super-humid, humid, subhumid, semi-arid and desert areas.

- Protection against cold and excessive radiation : loss of stock in cold weather; the need for shelter - shade trees, artificial shelters and air conditioned barns; protection against excessive radiation - ameliorating thermal stress on animals by such methods as shading, sprinklers, mechanical air circulation, wallows and air conditioning; the effect of heated barns on milk and butterfat production; effect of shade on rate of growth.

- Research : instrumentation - direct observations in the field; psychrometric chambers; thermometers, thermocouples and thermistors for measuring rectal and skin temperatures; instruments for measuring the cooling power of the air, e.g. the katathermometer, frigorimeter, coolmeter, hot-wire anemometer; climatic indices for indicating heating or cooling power of the air.

- Insects : effects of weather factors on insect life and activity - the effect of radiation, temperature, atmospheric humidity, light, air movement, atmospheric pressure and electricity on such physiological processes and insect activities as respiration, development, duration of life, reproduction, stridulation, movement, flight and dispersion; effect of daily and seasonal changes in weather on the daily rhythm and seasonal cycles of insects.

- Climate and insect distribution : vital limits for insect life; climatic factors assisting and limiting the dispersal of insects; the importance of ecoclimates and microclimates in the distribution of insects; use of climographs in studying insect distribution; acclimatization.

- Effect of climate on abundance : direct effects of temperature, precipitation, wind, atmospheric pressure, thunderstorms or a combination of these factors in insect abundance; influence of climate upon the number of generations; indirect effects of climate on food and natural enemies; climate in relation to control, course and periodicity of outbreaks.

- Bioclimatic studies on insect pests : procedure; field studies ; physiological life-history; climatic observations (normal and microclimatic); analysis of meteorological data; quantitative studies on insect abundance; correlation of climatic data with quantitative data; artificial climatic studies; controlled climatic chambers, biotron.

- Plant diseases : weather factors conducive to infection; temperature ; optimum temperatures for infection; effect of temperature on incubation period; effect of high temperatures on sporulations of fungus pathogens and longevity of spores; temperature in relation to disease proneness of the host; humidity - the importance of free water (rain, fog, dew, water of guttation), snow cover, and duration of surface wetness for spore germination and infection; the effect of high atmospheric humidity on sporulations of fungus

pathogens and on longevity of spores; light - injuries to infection process by light; wind - dissemination of fungus spores and bacteria by wind; windbreaks in relation to infection; electrostatic charge - possible effects of electrostatic charges carried by fungus spores on epidemiology of disease.

- Effects of temperature and moisture on the seasonal and geographic distribution of diseases.

- Methods and techniques : correlations between natural or induced diseases and meteorological records or of synthesized environments; the need for microclimatic observations; artificial climates - greenhouses and phytotrons.

- Disease forecasting.

- Treatment of a few typical plant diseases , e.g. apple scab, caused by fungus Venturia inaequalis; potato late blight, a fungus disease caused by Phytopthora infestans, wheat stem rust caused by a fungus Puccinia graminis tritici. (Diseases appropriate to the area concerned to be selected).

Agroclimatic classifications

- Existing classifications : the need for agroclimatic classifications; existing classifications (for details, see section 7.3 of the Guide to Agricultural Meteorological Practices. WMO - No. 134.TP.61); limitations of the present classifications.

- Factors to be considered in agroclimatic classifications : elements important to the vegetative growth of plants, e.g. water balance, temperature, duration of frost-free period, duration of sunshine; elements important to the development of successive phases in plant life, e.g. day length; annual temperature variation; daily temperature range, both in the warm and cold seasons; duration of frost-free period; duration of rainy and dry seasons.

Frost and protection against frost

- Economic phases of frost protection; the extent of damage to crops by frost during the growing season and by freezing temperatures during the winter; the possibility of minimizing frost damage to plants.

- Physical processes involved : causes of frost.

- Radiation and advective frosts : seasonal occurrence; related weather patterns; donor areas and the flow and pooling of cold air; temperature inversions; effect of soil conditions, ground cover and cultural practices on frost intensity.

- Physiological processes involved : theories on mechanism of frost injury; frost hardiness; critical temperatures for plants and crops.

- Frost protection methods : diminution of frost damage by changing the microclimate by temporary or permanent measures; passive methods ; location of growing areas; choice of growing season; time of planting and sowing; selection and breeding; cultivation practices - soil management, plant management, use of growth regulators; active methods - pre-irrigation, coverings, smoke and artificial fogs, wind machines, sprinkler irrigation, orchard and soil heating, a combination of two or more of these methods.

- Frost combating : operational procedure; applicable frost protection methods; critical temperatures and when to protect; coverage, economic phases of frost protection; type of crop to be protected; installation, overhead, operation, fuel storage costs; comparative costs of frost protection methods.

- Advisory services to farmers : climatological temperature surveys and microclimatological variations; advice to farmers on choice of crop species and varieties, choice of growing areas, choice of planting dates, source regions of cold air, frost risks, average date of last frost in spring and first frost in fall, length of growing season, probability of frost occurrence, frequency and severity of frosts; establishment of microclimatic frost stations; local frost-fighting organizations.

- Frost forecasts and warnings.

Windbreaks and shelterbelts

- Introduction : definition of windbreaks and shelterbelts; the need for protecting soil, soil water, plants and animals, or for improving the soil micro and crop climates by windbreaks or shelterbelts.

- Effects of shelterbelts on the micro and soil climate : the modification of the microclimate, especially wind speeds, by using shelterbelts and windbreaks.

- On airflow : the effect of width, shape and density of shelterbelts on airflow when wind is blowing perpendicular, oblique or parallel to the belt; the effectiveness of different systems (parallel rows or networks of belts) on air flow; wind conditions at the ends of and at gaps in shelterbelts; the effect of surface roughness and thermal stratification; the effect of topography.

- On heat balance : on radiation; air and soil temperature.

- On water balance : on atmospheric humidity; dew-fall and fog precipitation; precipitation; snow-cover; evapotranspiration; soil moisture.

- Counteracting wind and water erosion by shelterbelts.

- Effects of shelterbelts : on crops, livestock, fauna and buildings.

- Climatological information required in the regional planning of shelterbelts and windbreaks.

- Meteorological, agricultural and biological observations in long-term trials on the effects of shelterbelts and windbreaks.

- Selecting, planting, care and maintenance of shelterbelts.

Information, forecasts and warnings for agriculture and forestry

- Agrometeorological information : bulletins (pentad, weekly, decadal, monthly); organization of information service - -code, network, communications, sending in reports, synoptic method of working out bulletins, issue and distribution.

- General weather forecasts : weather forecasts covering a period of time as required by agriculture (period of vegetation, ten days, a week, five days) given in simple clear wording; stress on factors particularly important for agriculture such as strong winds and cold waves, frost possibility, heavy rain, storms, droughts, etc.; daily weather forecasts on a regional scale giving a rough estimate of the essential factors, e.g. temperature, cloudiness, precipitation (seasonal and climate change forecasts).

- Special weather forecasts and warnings : weather forecasts relating to the seasonal requirements of cultivated plants, e.g. the planting and growing season, frost, plant diseases, noxious insects, spraying and dusting operations, irrigation requirements, harvest conditions, post-harvest and storage conditions, weather during transport of agricultural products, forestry operations, fire weather (including forest fire warnings), agricultural aviation, etc.

- Agrometeorological forecasts : local frost forecasts; formulae for predicting minimum air temperature; the importance of the "no-danger" forecast; soil humidity forecasts; forecasts of dates of successive phases of plants development; forecasts of yield and crop quality; forecasts and warnings concerning livestock; disease forecasting; forecasts on relative abundance, expected periods of increase or decrease, time of peak infestation; forecasts on the distribution, outbreaks and seasonal events of insects (pests and beneficial); parameters used in forecasting; the most widespread methods; issue of forecasts and warnings.

Artificial climates

- Glasshouses, cloches, hotbeds, etc. : ventilation; heating and cooling; illumination; soil moisture and evapotranspiration.

- Growth cabinets, growth room, phytotron, climatron, biotron : the variation of all meteorological entities over a wide range.

- Animal and poultry houses : site orientation; colour; texture; construction; ventilation; heating and cooling; air composition; humidification; illumination; photoperiodicity; quality of light; air and litter moisture content; air circulation.

- Storage rooms, clamps, pits.

4.7.2 SYLLABUS II - for agricultural scientists

4.7.2.1 Introduction

- The concepts weather and climate (macro, meso and microclimate).
- The importance of weather and climate for agricultural production : the adaptation of plants, crops and animals to the climate; the necessity of adjusting farming systems to the natural environment; critical plantgrowth periods in relation to temperature and soil moisture; the importance of weather and climate data in determining the irrigation requirements of crops; climate in relation to insect pests and plant diseases; production and cultivation practices in relation to climate; climatic hazards affecting agricultural output, e.g. drought, hail, frost, strong winds, etc.
- Agricultural meteorology : definition, aims and scope; difference between meteorology and agricultural meteorology; a short history of agricultural meteorology in relation to the needs of agriculture and the development of meteorological apparatus.
- National Meteorological Services and the World Meteorological Organization (WMO); national agrometeorological organizations and the Commission for Agricultural Meteorology (CAgM).

4.7.2.2 The atmosphere and pressure variation

- Its nature, composition and properties; air pollution; carbon dioxide; extent and structure - troposphere, stratosphere, mesosphere, ionosphere and exosphere; pressure of the atmosphere; units; variation of pressure with height; mercury barometers; the aneroid barometer; the barograph; altimeters.
- Daily and seasonal variations; some effects of variations in air pressure upon animals and insects.

4.7.2.3 Radiation in the atmosphere

- Sources of heat for the atmosphere; the sun and radiant energy; the electro-magnetic spectrum; Wien and Stefan-Boltzmann radiation laws; Lambert's law; the solar constant.
- Seasonal and latitudinal variation in length of day; factors influencing the amount of radiation incident upon the earth's surface; absorption, reflection and transmission; albedo; terrestrial radiation.
- Instruments for measuring incoming solar radiation; pyrheliometers of Ångström and Abbot (silver disk) for measuring direct radiation; the Eppley and Moll Gorczynski actinometers and the Robitzch bimetallic actinograph for measuring direct and diffuse radiation.
- Energy in different parts of the spectrum and its biological significance; illumination; penetration of radiation through a crop canopy.

- Radiation balance : its importance to plant and animal processes; bright sunshine duration and its measurement, e.g. with the Campbell-Stokes, Marvin and Jordan photographic recorders.

4.7.2.4 Meteorological elements

- Air temperature : different temperature scales; representative air temperature and its measurement; thermometers and thermographs (liquid-in-glass, deformation, liquid-in-metal, electrical resistance thermometers, thermocouples, thermistors); maximum, minimum and mean air temperature; daily and seasonal variations; vertical temperature gradient; temperature inversion; isotherms; the importance of temperature in the growth of plants; frost-free growing season; vegetative period.

- Atmospheric humidity : water vapour in the atmosphere and its variation with height; importance in determining the possibility of rain, snow and hail and its role in the development of thunderstorms; importance in the growth of plants; effect on the loss of heat from the human and animal body; absolute humidity, relative humidity, saturation deficit, dew point, specific humidity, mixing ratio, vapour pressure; daily variation of the absolute and relative humidity, and their variation with height and latitude; instruments for measuring humidity; absorption hygrometers; the psychrometric formula.

- Condensation, precipitation and evaporation : the process of condensation in the atmosphere; its importance in the formation of fog, clouds, rain, hail, snow, frost and dew; fog and cloud formation -a simple classification of clouds, cloud covers; thunderstorms : formation, frequency; lightning; precautions against lightning; hail; the structure of hailstones; theories of hail formation; precipitation; the size and rate of fall of raindrops; types of rain; seasonal variation of rainfall; the measurement of rainfall (the ordinary raingauge and continuous rainfall recorders, rate-of-rainfall recorder); snow and its measurement; statistics on extreme precipitation; the process of evaporation; factors influencing the rate of evaporation; simple formulae for calculating the rate of evaporation; instruments for measuring evaporation; the relation between evaporation from a free water surface and evaporation from moist soil and leaf surfaces; degrees of error inherent in measurements and in estimates from calculations.

- Winds and circulation patterns : wind and air currents; the cause of winds; direction, speed and pressure; wind roses; daily and seasonal variations and variation with height; the measurement of wind direction and speed isobars, field of pressure, pressure gradient.

- The general circulation of the atmosphere; the effect of the earth's rotation on the flow of winds across the isobars; Buys-Ballot's law; planetary, terrestrial and continental winds; land and sea breezes, mountain and valley winds of local importance, e.g. Föhn or Chinook, Bora, Harmattan, Mistral, Sirocco; the tropical cyclone or hurricane; tornadoes; water-spouts; dust

storms; the extra-tropical cyclone; its origin; the polar front theory; air masses; weather along the cold and warm fronts; the occluded front; anticyclonic or high pressure systems and associated weather.

4.7.2.5 Weather and climate

- Pressure systems and other factors such as latitude, altitude and sea currents affecting the country's weather and climate; discussion of climate of the country concerned; the distribution and intensity of rainfall and its efficiency for agricultural production; temperature : seasonal variation and extremes of temperature affecting agricultural output; lack of sufficient sunshine; excessive evaporation; climatic trends and changes.

4.7.2.6 Microclimatology

- The importance of the air layer near the ground to agriculture; heat exchange at the ground surface; the flow of heat into the ground; soil temperature and its effect on plant growth and soil activity; factors affecting soil temperature; instruments for measuring soil temperature; air temperature, humidity and wind variations in the micro-layer; the importance of these variations for plants, animals, insects and plant diseases; influence of type and soil condition, plant cover and topography on the microclimate; influence of the microclimate on the formation and occurrence of frost; diminishing frost damage by altering the microclimate; the influence of shelterbelts and framing systems on the microclimate.

4.7.2.7 Climatic hazards adversely affecting agricultural output

- Insufficient soil moisture during critical growth periods; the hydrological cycle - rainfall, infiltration, moisture retention capacity of the soil, percolation, runoff, evaporation, transpiration and evapotranspiration; the importance of soil moisture for plant growth; soil moisture measurements, soil moisture conservation; farming systems in relation to available soil moisture in the arid, semi-arid, sub-humid and humid regions; irrigation and supplementary irrigation; water conservation; application of climatic data in scheduling irrigation; estimating actual and potential evapotranspiration.

- Droughts (long period) : definition; possible causes; frequency; principal drought-afflicted areas; long-term planning against drought; the possibility of cloud stimulation.

- Hail : frequency of hail storms; hail damage and its prevention.

- Frost and frost combating : extent of frost damage; intensity and frequency of damaging frosts; sensitivity of plants to low temperatures; radiation and advective frosts; methods for predicting frost conditions; methods of preventing frost damage at the time of planting; ways of diminishing frost damage, e.g. cloches, chemical smokes, orchard heating, sprinkler irrigation, wind machines.

- Strong winds : the importance of windbreaks and shelterbelts; the detrimental effects of strong winds on plants, animals and the soil; the effects of windbreaks upon the environment; different types of windbreak; the advantages and disadvantages of shelterbelts; trees and types of shelterbelt suitable for local conditions.

4.7.2.8 Ecology of crops, animals and insects

- Well-established relations between meteorological and climatic factors, severally and jointly, on the growth and yield of crops and animals; effect of weather and climate on insect pests and plant diseases; climatic requirements of crops, fruit trees and animals with respect to heat, light and moisture; adaptation of plants and animals to the climate.

4.7.2.9 Agroclimatic stations

- Classification (principal, ordinary and auxiliary); networks; observations; equipment; relevant biological observations.

- The processing, tabulation and interpretation of agrometeorological data; statistical and mathematical methods of analyses.

4.7.2.10 Crop forecasts

- Crop forecasting techniques and examples of forecasting time of emergence of seed, vegetative growth periods, flowering, maturity and yield of crops.

4.7.2.11 Investigations and research

- Development of crop-weather relationships; use of semi-empirical models.

4.7.2.12 Special weather forecasts for agriculture

- Elementary forecasting technique, interpretation of daily weather charts; frost danger warning for crop protection; veld and forest fire warnings; planting and harvesting weather forecast; insect and disease forecast; spraying and dusting weather forecast; livestock weather forecast; postharvest and storage forecast; agricultural aviation forecast; warm and cold spells; wet and dry spells; severe weather.

4.7.2.13 Practical work on meteorological instruments and methods of observation

- Pressure : units and relation between different units; reduction of pressure to other levels; mercury barometers; method of observation; correction of barometer readings to standard conditions - index error, gravity correction, temperature correction; exposure, transportation and installation of the mercury barometer; the

barograph - care and maintenance, evaluation of the records; the aneroid barometer.

- Surface wind : units; relation between different speed units; determination of true North, the compass points; estimation of wind speed, the Beaufort scale; different types of anemometer and anemograph; evaluation of the records; exposure of wind equipment.

- Temperature : Fahrenheit, Celsius and Absolute temperature scales; liquid-in-glass thermometers - the ordinary thermometer, the maximum thermometer, the minimum thermometer, the soil thermometer; reading a thermometer; electrical thermometers - the resistance thermometer, thermocouples, the thermomistor; auxiliary electrical equipment; thermographs - the bimetallic type, the Bourdon-tube type, the mercury-in-steel type; evaluation of the records; thermometer and thermograph exposure; general requirements in order to obtain representative air temperature; thermometer screens; artificial ventilation; exposure of soil thermometers and grass minimum thermometers; the importance of calibration certificates; possible sources of defects in thermometers and the various procedures to rectify them.

- Duration of sunshine : sunshine recorders; exposure and installation of sunshine recorders; evaluation of the records.

- Atmospheric humidity : units and methods; simple psychrometer without artificial ventilation; the sling psychrometer; the Assmann type psychrometer; exposure and observational procedure; care of the wet bulb; operation of wet bulb below freezing; sources of error in psychrometry; the psychrometric formula; tables and slide-rules; hair hygrographs - general requirements, exposure, management and transportation; accuracy and sources of errors; washing the hairs; evaluation of the records; dew-point and frost-point hygrometers; electrical absorption-type hygrometers.

- Precipitation : units; errors and accuracy of reading; the ordinary and totalizer raingauges; rainfall recorders; rainfall intensity recorders; evaluation of the records; exposure of raingauge, - general rules; influence of strong and gusty winds; rainfall measurement on slopes; snow measurements; dew and leaf-wetness measurements.

- Evaporation : the main classes of evaporimeter; large evaporation tanks; small evaporation tanks; porous bodies; porous paper wick devices; exposure, maintenance, scale, observations and entries; calculations.

- Soil moisture : units of measurement; visual observation; gravimetric method; obtaining percentage moisture by volume; tensiometers; electrical methods; thermal methods; neutron scattering method; gamma-ray absorption method.

- Radiation : units, types of instrument; estimates from simple data.

4.7.2.14 Practical work based on the theoretical course

- Climatological analysis : processing of observation data preparatory to ultimate use and interpretation, e.g. averages, normals, frequencies, standard deviation, etc; study of the climate of the region or continent concerned - statistical analysis of representative climatic elements, the drawing of isopleths, etc.

- Calculation of derived parameters, e.g. evaporation, radiation, climatic indices; testing of "models".

- A study of the variation of temperature, humidity and wind in the microlayer; a microclimatological study of a suitable area.

- A study of the influence of different windbreaks and shelterbelts on the microclimate.

- A study of frost-protection methods.

- A study of meteorological aids to irrigation practice.

- Analysis and interpretation of elementary synoptic charts; preparation of routine forecasts; examples of special weather forecasts for agriculture.

- Practical crop-forecasting, including yields, quality, sowing and harvest dates.

- A monograph by each student on the application of agrometeorology to his or her particular field of study in agricultural science.

4.8 SPECIALIZATION IN HYDROMETEOROLOGY (CLASS I)

Owing to the increasing demand for water for agricultural, industrial power, transport and domestic purposes, a large number of countries are obliged to undertake comprehensive water management measures with a view to the re-organization of the water balance of river basins, major river diversions, the creation of reservoirs, the regulation and transfer of run-off from one basin to another, etc.

These measures in turn call for a timely and detailed investigation of water resources and the hydrological regime of rivers and lakes; similarly, all hydrometeorological factors and the possibility of their modification must be studied.

However, these investigations are hampered in developing countries by the shortage - or even the total absence - of national cadres of hydrologists (hydrometeorologists).*)

During the past few years, in connexion with the International Hydrological Decade (under UNESCO auspices), a number of steps have been taken to train hydrological experts for the developing countries. WMO naturally also wishes to contribute to the task of training national cadres of hydrometeorologists.

A distinction is made between the following four categories of personnel :

(a) Class I hydrometeorologists (specialists with a University degree in engineering or appropriate science);

(b) Class II hydrometeorologists (specialists with a thorough training in hydrometeorology but who need not necessarily have obtained a University degree;

(c) Class III hydrometeorologists (specialists trained to a semi-professional technician level);

(d) Class IV hydrometeorologists (specially trained observers, hydrometric assistants).

This section is devoted exclusively to the syllabi for training Class I hydrometeorologists.

Class I hydrometeorologists are highly qualified specialists with comprehensive training in one or more branches of the hydrological discipline - such as hydrological design, the organization of hydrological investigations, the study of the laws governing hydrological and related meteorological processes, the hydrological analysis and forecasting, hydrological and related meteorological surveys, and the management and control of station networks for hydrological purposes.

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*) In referring to these specialists (hydrologists) we shall, for the sake of convenience, use the WMO term "hydrometeorologist", which emphasizes the close relationship between hydrological and meteorological processes.

The recommended standard curricula for training Class I hydrometeorologists are given below. They are optimum programmes and provide for the study of special subjects, as well as of a large number of general subjects. For this reason, the content of the course may be modified in the light of circumstances and the qualifications of the students.

4.8.1 General chemistry and hydrochemistry

- General chemistry : atomic-molecular theory; structure of the atom and the periodic system of elements; chemical combination and the structure of molecules; kinetics and chemical equilibrium; theory of solutions; basic principles of electrochemistry; general properties of metals; alloys; first group of the periodic system of elements; second group; third group; fourth group; organic combination; fifth group; sixth group; seventh group; eighth group; zero group.

- Hydrochemistry; water as a solvent; its properties; electrolyte solutions; principles of physico-chemical analysis; surface phenomena and absorption; basic problems of colloidal chemistry; chemical composition of natural water; chemical composition of atmospheric precipitation; chemistry of rivers, lakes and reservoirs; chemistry of ground water; chemistry of seas and oceans.

- Water pollution.

4.8.2 Principles of geophysics, geology, geomorphology and soil science

- Principles of geophysics and general information about the globe : shape, dimensions and types of motion of the globe; layers surrounding the globe - atmosphere, hydrosphere, biosphere, lithosphere and bathysphere; their composition, structure, thermodynamic conditions and state of aggregation; terrestrial magnetism, density of the earth and distribution of gravity forces over its surface; distribution of and relationship of water and land on the earth's surface.

- Principles of geology : composition of the earth's crust, distribution of chemical elements in the earth's crust; minerals and rocks; geological processes, tectonics and mountain formation phenomena; historical geology methods.

- Principles of geomorphology : classification of types of relief - morphological, orographic and genetic; action of flowing water and erosion; rivers and climate; water-accumulation forms of relief; karst and glacier forms of relief; forms of relief in deserts and mountainous areas.

- Principles of soil science : soil formation, soil as polydispersion system; physics of soil; chemistry of soil; classification of soils; soil and water; movement of soil water; hydrological properties of soils; soil water balance.

4.8.3 Surveying

- Plan and map; principles of theory of errors in measurements; measurement of lines in the field; optical parts of geodetic instruments; theodolite and theodolite survey; levelling; combined planimetric-altimetric surveys; approximation surveys; geodetic network; geodetic applications in stationary and field hydrological surveys; principles of aerial photography; principles of cartography..

4.8.4 Hydraulics: open channel flow dynamics and channel processes (river bed formation)

- General hydraulics : hydrostatics; principles of hydrodynamics; flow through small and large orifices at constant and variable pressure; steady flow in open channel; pressure flow of a liquid in pipes; non-steady flow; spillways and flow over structures; hydraulic jump and energy dissipators.

- River hydraulics : non-uniform flow in channels; flow with a variable discharge; unsteady flow in open channels; hydraulics of bifurcations and estuaries.

- Principles of similitude.

- Principles of the dynamics of streams with a non-erodable bed : mechanics and structure of two-dimensional channel flow; hydromechanical analysis of two-dimensional turbulent flow; non-rectilinear flow and additional resistance of channel to flow.

- Physical and hydromechanical basis of the theory of flow in an eroding channel : main mechanical and hydraulic characteristics of river beds and sediments; mechanism of sediment transport.

- Channel processes : hydrodynamic and hydromorphological approach to the channel processes theory; basic river bed processes produced by the construction of hydraulic structures.

4.8.5 Streamflow and hydrological calculations

- Runoff process theory.

- The use of mathematical statistics and the probability theory in hydrology.

- Meteorological conditions governing streamflow : air temperature as a factor in the transformation of water balance elements; precipitation, its various types and intensity; calculations of average precipitation in river basins; evaporation from free water surface and from the surface of a river basin; instruments for measuring

evaporation and evaporation calculation methods.

- Water and heat balance equations; the use of water and heat balance equations for solving various water management problems.

- Mean annual runoff; determination of annual runoff for subsequent hydrological calculations and its accuracy; influence of climatic and other physical geographic factors on mean annual runoff; compilation of maps of mean annual runoff isolines, their accuracy and importance.

- Variability of annual runoff : methods of determining variations in annual runoff on the basis of the relationship with precipitation and variations in types of circulation; use of frequency distribution curves to determine annual runoff variations; coefficients of variations of annual runoff series and their dependence on the size of the drainage basin and other physiographic factors; methods of determining coefficient of skewness.

- Distribution of flow during the year : statistical and physical methods of calculating this distribution; nature and types of river inflow methods of compiling runoff hydrographs; runoff isoline maps and their use; mass curves of daily flow; methods of calculating minimum and maximum discharges; meteorological factors of rain runoff; methods of calculating the intensity and depth of rainstorms.

- Flood flow : definition of flood, rainfall and snow melting floods, maximum probable flood, design flood, recurrence interval flood; overland flow of flood, infiltration; hydrograph analysis, unit by hydrograph concept; flood estimation in small basins, empirical formulae, synthetic hydrograph; flood frequency analysis; minimum flow, depletion curves.

- Discharge of suspended and chemical load; methods of calculating this load.

- Special aspects of hydrological calculations : methods of calculating runoff in planning drainage and irrigation; methods of calculating irrigation requirements on the basis of water and heat balance equations; flood routing; calculation of maximum water stage of various frequency; calculation of evaporation from free water surface and from bare soil; other hydrological calculations.

- Water balance surveys : organization and methods of multipurpose studies of the water balance of basins of rivers and lakes; methods of stationary and field surveys of water balance elements.

4.8.6 Hydrometry

- State regime studies : principles of the stage regime of rivers, lakes and reservoirs; gauges and datum systems; types of gauges; choice of reaches for hydrometric observations; observation times and their dependence on water level regime; recording of maximum and minimum stage; measurement of the hydraulic slope; instruments for stage observations (including stage recorders); water temperature observations; processing of hydrometric observations (stage and temperature).

- Soundings : organization of soundings; river soundings by cross-sections, longitudinal sections and diagonals; determination of sounding profiles; sounding instruments - manual, mechanical, hydrostatic and acoustic; processing of sounding data.

- Measurement of stream velocity : general notions on streamflow regime; basic principles of flow; distribution and pulsation of velocities; point and integration methods of measuring velocity; points on the vertical; instruments for measuring amount and direction of flow and their classification; gauging station equipment, calibration of hydrometric instruments; processing of velocity data.

- Determination of discharge; classification of discharge measurement methods; volumetric method; slope-area method and its various applications; control cross-sections and conditions of their use; floats; weirs and flumes; dilution method; use of isotopes; processing of discharge data by graphical and analytical methods and processing of integration measurements.

- Relationship between discharge and stage, and calculations of mean daily discharge; plotting of a rating curve, evaluation of its accuracy and extrapolation of it; discontinuous rating curves; calculation of mean daily discharge and compilation of discharge yearbooks.

- Sediment discharge computations : basic data on the regime and the movement of sediment in rivers; measurement of suspended sediment; methods and instruments; measurement of bed load; methods and instruments; laboratory analysis of samples of transported suspended sediment and bed load and sedimentation; processing of suspended sediment transport and bed load discharge data.

- Other types of observations; their conduct and processing; use of instruments : thermal regime observations and winter regime observations (snow, ice, ice phenomena); water transparency and colour observations; observations of chemical quality of water; wave observations.

- Special work : determination of the discharge of small rivers using hydraulic structures; measuring of discharge at hydraulic structures and hydro-power plants.

- Technical instructions for hydrological stations and their inspection.

- Methods of hydrometric measurements in laboratory; principles of the similarity theory and modelling methods.

- Hydrologic field investigations : relationship between investigations, planning and construction; stages of an investigation; characteristic features of investigations used as a basis for the planning and construction of hydraulic engineering works (hydro-power plants); characteristic features of investigations for navigation and timber floating; characteristic features of investigations for planning and construction of irrigation systems; characteristic features of investigations for designing and constructing roads and bridges.

- Basic safety techniques and labour protection rules to be observed in carrying out hydrological observations on rivers and lakes.

4.8.7 Hydrological forecasts

- General information on hydrological forecasts : organization of a hydrological information network and a hydrological forecast service; types of hydrological and meteorological information; codes for transmission of hydrological and meteorological information and forecasts; collection of scientific and operational hydrological and meteorological data necessary for the computation of hydrological forecasts; evaluation of forecast errors; reliability of specific methods and natural reliability.

- Short-term flow forecasts (stage and discharge) : classification of short-range hydrological forecasts and forecasting methods; physico-empirical relationships; correlation relationships; isochrone method; rainfall - loss rate - unit hydrograph method; stage forecasting.

- Long-term flow forecasts : classification of long-term runoff forecasts and forecasting methods; methods of corresponding volumes (by volume of water in channel system); water balance method; methods of analogy and methods of standard forecasts.

- Forecasting of temperatures.

- Short-term and long-term forecasts of ice phenomena.

- Use of computers and models in hydrological forecasts.

4.8.8 General and special hydrogeology

- General hydrogeology : unity of the natural waters in the world; role of groundwater; classification of rocks and their physical properties; forms of the physical state and movement of groundwater; physical properties, chemical composition and radioactivity of groundwater; origin and classification of groundwater; water of the aeration zone and water in the soil; non-artesian (ground) and artesian water; groundwater in fissured rocks; mineral waters.

- Dynamics of groundwater : laws of groundwater dynamics; determination of percolation coefficient and yield for various types of wells; methods of determining velocity and direction of groundwater flow.

- Hydrogeological investigation : networks of hydrological observation wells ; hydrogeological calculations for water management.

- Elementary principles of hydraulic machinery.

4.8.9 Principles of hydraulic engineering, water management and water management calculations

- Principles of hydraulic engineering : construction operations and materials used in hydraulic engineering; basic hydraulic engineering structure.

- Water resources utilization and control : hydropower development; inland waterways; transport of timber by water (floating); irrigation; drainage; water supplies to population and industry; hydraulic engineering in the fishery industry; soil erosion control; hydraulic engineering, bridges.

- Water resources management : water resources, their evaluation and economic importance; water requirements of various sectors of the economy and flow regulation regime; average per capita consumption for urban water supply and variations in domestic and industrial consumption.

- Water management calculations : water resources management installations and reservoirs; basic data in water resources management planning; basic principles of flow regulation theory; calculations using mass diagrams and demand lines; flow regulation calculations using stochastic methods; regulation calculations using storage behaviour diagrams for developing release role graphs; other applications of statistical methods to water resource problems; hydraulic power calculations; flood control and flood damage mitigation methods; reservoirs in series and compensation regulation and methods of calculation.

4.9 SPECIALIZATION IN MARITIME METEOROLOGY (CLASS I)

To be provided by the WMO Commission for Maritime Meteorology.

4.10 SPECIALIZATION IN METEOROLOGICAL INSTRUMENTS (CLASS I)

To be completed by the CIMO Working Group on Training in Instruments and Methods of Observation.

4.11 SPECIALIZATION IN CHEMISTRY AND RADIOACTIVITY OF THE ATMOSPHERE (CLASS I)

To be completed later.

C H A P T E R 5

CURRICULA FOR TRAINING ALL CLASS II METEOROLOGICAL PERSONNEL IRRESPECTIVE OF THEIR FIELDS OF SPECIALIZATION

CURRICULA FOR TRAINING CLASS II METEOROLOGICAL PERSONNEL

SCHEMATIC REPRESENTATION OF CONTENTS

EDUCATION IN THE BASIC SCIENCES

Mathematics Physics

FUNDAMENTAL METEOROLOGICAL EDUCATION

Dynamic Meteorology | Synoptic Meteorology | Physical Meteorology | Climatology | Hydrology | Instruments and methods of observation | Ocean/Atmosphere Interaction

FIELDS OF SPECIALIZATION

Synoptic Meteorology | Aeronautical Meteorology | Climatology | Hydrometeorology | Maritime Meteorology | Meteorological Instruments

5.1 GENERAL

Class II meteorological personnel must exercise skill and judgment in the interpretation of meteorological data. They must have a thorough understanding of the underlying meteorological principles. Their education must be broadly based but, since their work is concerned mainly with application of meteorological knowledge, the emphasis should be on practice. The Class II syllabi, although just as extensive in many respects, will consequently not contain the same amount of theory as that for Class I. This is an important factor which should be borne in mind by Instructors in connexion with the syllabi given below.

In the syllabi for the basic sciences those parts of the general subjects which are considered prerequisites for meteorological training at Class II level, namely mathematics and physics, are emphasized. As a general principle, it is recommended that the instruction in these subjects be confined to those fields which are essential for that level.

As has already been stated elsewhere, in many Meteorological Services Class II personnel are engaged mainly in forecasting. Consequently, to train personnel for fields such as climatology or meteorological instruments, it may be necessary to adjust the syllabi given - which are primarily based on forecasting - by placing more emphasis on certain aspects at the expense of others. The extent of such alterations is of course a matter for decision by the training institution. In this publication provision is made for specialized training in synoptic meteorology, aeronautical meteorology, climatology, hydrometeorology, maritime meteorology and meteorological instruments.

Class II meteorological training is often carried out at Centres where a well-established mathematics or physics institution does not exist. In such cases the Instructors should have at their disposal detailed syllabi and it is for this purpose that in the following paragraphs syllabi for mathematics and physics are given in detail.

5.2 EDUCATION IN THE BASIC SCIENCES (CLASS II)

5.2.1 Mathematics

5.2.1.1 Algebra

- Permutations and combinations; binomial theorem.
- Arithmetic and geometric progressions; calculations of the nth term;sum of the first n terms.

- Infinitely large and infinitely small quantities; limit of a variable; limit of a function; operations on limits.

- Calculation of a limit - examples : elementary knowledge of the continuity of a function; algebraic functions.

- Real numbers; complex or imaginary numbers; conjugate imaginary numbers; graphical representation of complex numbers; modulus; arguments; formula $x + iy = x\ (\cos \alpha + i \sin \alpha)$.

- Limits; sequences; convergence and divergence of sequences; series; convergence and divergence of series; criteria of convergence of series of positive terms deduced from the study of U_{n+1}/U_n, n/U_n, $n \alpha U_n$; absolutely convergent series; alternating series; limit of $(1 + \frac{1}{n})^n$ and $(1 + \frac{x}{n})^n$ where n is infinite; the number e; Napierian logarithms; series defining the exponential function e^x and the inverse function lgx; the hyperbolic functions; function defined by a complete series in x with real coefficients; interval of convergence; addition and multiplication within this interval; expansion of : $1\ (1 \pm x)$, $lg\ (1 \pm x)$ and $lg\left[(1-x) / (1+x)\right]$ exponential series e^x and a^x; binomial series; expansion of circular functions; hyperbolic functions and their inverses; the complex variable $z = x + iy$; functions e^z, $\sin z$, $\cos z$; relations $e^{x + iy} = e^x e^{iy} = e^x (\cos y + i \sin y)$; hyperbolic sines and cosines, their relation to ordinary sines and cosines.

- Determinants and systems of linear equations : solution of 2 or 3 linear equations; definition of a determinant of order n; interchange of rows and columns; interchange of two columns or two rows; expansion, removal of factors; sum of determinants; addition of columns and rows; rank, systems of n linear equations in n unknowns.

5.2.1.2 Solid analytic geometry

- Solid analytic geometry : co-ordinate systems in space; the distance between two points in space; direction numbers or direction components of a line; parametric equations of a line; direction angles; direction cosines; equation of a plane in space; conditions under which two planes are parallel, coincide or are perpendicular; the "normal form" of a plane in space; quadratic surfaces in space as represented by the equation
$Ax^2 + By^2 + Cz^2 + Dxy + Exz + Fyz + Gx + Hy + Jz + K = 0$

- Cylindrical co-ordinates; spherical co-ordinates.

5.2.1.3 Spherical trigonometry

- Introduction to spherical trigonometry; spherical triangle; properties of spherical triangles; formulae relating to right spherical triangles; Napier's rules; solution of right spherical triangles; isosceles and quadrantal spherical triangles; oblique spherical triangles; the law of sines; the law of cosines for sides; the law

of cosines for angles; formulae for the tangents of the half angles; formulae for the co-tangents of half the sides; areas of spherical triangle; areas of a spherical triangle; brief description of the applications of spherical trigonometry.

5.2.1.4 Differential and integral calculus

Much greater emphasis should be given to the practical aspects of the subject and the applications to meteorology.

- Concept of a function of a variable and of a continuous function; concepts of limit, derivative and infinitesimals, principal part, first differential of a function; elements of length, area and volume in various systems of variables; derivatives of the functions of a function; derivatives of the common functions :

  x^m ($m \gtrless 0$), sin x, ... arc sin x, ... e^x, a^x, $lg_e x / lg_a x$;

  derivatives of a compound function; application of the concept of derivative; slope of a curve at a point, tangent at that point; study of the variation of a function; extremes of a function ; maximum and minimum meaning of the sign of the second derivative; curvature; inflection.

- Function of a variable; Rolle's theorem on finite increments; graphical representation; function of two independent variables; graphical representation using a surface; function of several variables; partial derivatives; formulae for finite increments; application to error calculation; higher order derivatives of a function of several variables.

- Taylor's theorem for functions of one and several variables and its application; convergence of the Taylor series and the remainder of the series; MacLaurin's formula; application of Taylor's theorem to the study of the quotient of two functions of x in the neighbourhood of a given value of x; case where the two functions of x are zero for this value; other forms of indeterminacy; rate of change of e^x and lg x compared to that of x^m; determination of the limit of e^x/x^m for infinite x and of $x^m \lg x$ for $x = 0$.

- Implicit functions; Jacobians; change of independent variables.

- Concept of the primitive functions; Riemann definition of an integral; indefinite integral; integration of rational functions and of some special common functions; integration by parts and by change of variable definite integrals; theorem of the mean; mean values of a function in an interval; limit of definite integrals when a limit of integration approaches infinity or when the function under the integral sign becomes infinite; rule for differentiation under the integral sign and differentiation of definite integrals; line integral; circulation of a vector; double integrals (flux of a vector across a surface) and multiple integrals.

- Numerical calculation of definite integrals; length of a curve; areas and volumes; calculation of the moment of inertia and of the co-ordinates of the centre of gravity.

- Exercises in differential and integral calculus.

5.2.1.5 Vector algebra and vector calculus

- Introduction; definitions; addition and subtraction of vectors; magnitude of a vector; scalar time vector; applications to geometry; scalar product of two vectors; unit vectors; direction cosines; direction numbers; orientation in space; vector product; scalar triple product; vector triple products; vector identities; vector functions of one variable; derivative of a vector function; velocity vector; application of vectors in mechanics; vector fields and scalar fields; the gradient field; divergence of a vector; curl of a vector.

5.2.1.6 Differential equations

This subject should be considered as a course of applied mathematics. All matter relative to partial differential equations should be reduced to a strict minimum. Emphasis will be given primarily to the subject's practical aspects. Numerous examples should be taken from meteorology with particular reference to atmospheric disturbances.

- Ordinary differential equations : equations of the first order and degree; integral curves; equation of higher degree; equations of second and higher order; linear equation; a brief description of how the ordinary differential equations could be solved in series, in particular in the Taylor and Fourrier series.

- Partial differential equations: linear partial differential equations of first and second order in two independent variables; the wave equation in one dimension; the vibrating string; normal modes of vibration and heat equation.

5.2.1.7 Probability theory and statistics

- The statistical method and its scope; presentation of data; population and sample; discrete and continuous variables; frequency distributions; histograms; cumulative frequency distributions; ogives; vectorial frequency distributions; wind roses.

- Elementary probability theory; statistical parameters of central tendency, mean, median, mode; quintiles; statistical parameters of variability, range, mean deviation, standard deviation and variance; coefficient of variation; moments, skewness and kurtosis.

- Theoretical frequency distributions; the binomial distribution, the normal distribution, the Poisson distribution; transformations and probability papers.

- Sampling theory; sampling distributions, Central Limit Theorem, standard error; estimation of parameters, confidence intervals and limits; tests of hypothesis and signifiance.

- Small sampling theory; Student's test; Chi^2 test.

- Curve fitting; scatter diagrams; method of least squares; linear regression, scatter about a regression line; the linear correlation coefficient, covariance, significance of the correlation co-efficient; multiple regression, multiple and partial correlation.

- Analysis of variance; the F test.

- Extreme value distributions; return period.

- Time series, trends, moving averages; harmonic analysis; auto-correlation and spectrum analysis.

5.2.1.8 Numerical and graphical calculations

- Tabulation and differences.

- Interpolation; application of the method of least squares.

- Brief description of numerical differentiation and integration: numerical approximation of the derivatives of a function; graphical calculation; numerical approximation of definite integrals (Simpson's rule); graphical approximation of definite integrals; numerical approximation of double integrals.

- Machine computation: for those Class II personnel who will use numerical techniques in their work, a course on this subject should be organized. In view of the rapid advances which are taking place in construction of computers and the relatively wide variations in their types no suitable syllabi for such training could be included here. This is left to the Instructors conducting such courses.

5.2.2 Physics

5.2.2.1 Kinematics

- Kinematics of a point: rectilinear and curvilinear motion; relative motion.

- Rectilinear motion: velocity, acceleration; uniform and accelerated motion, vibratory motion; simple harmonic oscillation and damped harmonic oscillation; superposition of simple harmonic oscillations.

- Motion referred to rectangular, polar, cylindrical and spherical co-ordinates.

- Kinematics of solid bodies: translation; rotation about a fixed axis; helicoidal motion.

- Change of reference systems: absolute and relative motion; entrainment; composition of velocities and accelerations (Coriolis's theorem).

5.2.2.2 Electricity and magnetism

- Properties of magnets; static electricity; electric currents; electromagnetism; radio-electricity.

5.2.2.3 Optics

- Geometric optics: laws of reflection and refraction; index of refraction; plane and spherical mirrors; lenses, prisms; regular and diffuse reflexion; diffusion.

- Wave optics; theory of light; period, frequency and velocity of propagation; interference; diffraction; Doppler effect; polarization of light; velocity of light; phase and group velocity.

5.2.2.4 Hydrodynamics

- Fluid mechanics: fluid kinematics expressed briefly in Eulerian and Lagrangian variables; decomposition of a field of motion in the vicinity of one of its points into a field of translation, a field of rotation and a field of deformation; physical significance of vorticity and divergence; application to plane motion; continuity equation; case of gases and liquids, compressibility; ideal fluid, pressure force due to the pressure gradient; equations of state and of change of state of a fluid, perfect gas equation; surface tension of fluids, capillarity; barotropic and baroclinic fluids, isobar-isostere solenoids; fluid equilibrium (hydrostatics), Pascal's law, Torricelli's experiment, barometer, Archimedes' principle and buoyancy; applications: hydrostatic equation along the vertical; altimetry, application to the atmosphere; fluid dynamics, Eulerian and Lagrangian motion equations, boundary and initial conditions; work-energy theorem, balance of mechanical energy (potential and kinetic energy); Bernouilli's theorem; vorticity and divergence; rotational form of the equations of motion; irrotational motion and two or three dimensional rotational motion; circulation and vorticity; absolute and relative circulation and vorticity; case of the barotropic fluid; cyclonic and anti-cyclonic circulation.

5.2.2.5 Thermodynamics

Emphasis should be laid on the applications to meteorology.

- Object of thermodynamics; thermodynamic system - definition, exchanges of energy and matter with the external world, closed and open systems; physical state of a system, variables of state, (p.v) systems, Clapeyron's diagram.

- Definition of temperature, temperature scales (Celsius, Fahrenheit, Kelvin); variables of state and the equation of state of a system; homogeneous and non-homogeneous systems; thermal expansion of solids, liquids and gases; case of gases - the laws of Boyle-Mariotte, Gay-Lussac, Avogadro and Dalton (gas mixtures); equation of state of a gas - perfect gas and Van der Waals' gas.

- Definition of heat; quantity of heat, calorie, thermal conductivity, specific heat, case of gases, heat of change of phase, heat of reaction (chemistry); calorimetry.

- First law of thermodynamics: various forms of energy (work, heat, electrical and chemical energy, etc.); principle of the conservation of energy; principle of the equivalency of heat and work (Joule);

statement and meaning of the first law in the cases of systems at rest and in motion (atmospheric air), in the cases of closed and open systems (clouds in the case of precipitation); case of systems in motion; consequences of the first law and of the kinetic energy theorem as applied to the system; internal energy, enthalpy; work accomplished by the expansion of an ideal fluid; reversible exchange of work and heat; calorimetric coefficients of a fluid; adiabatic transformations, case of the perfect gas.

5.2.2.6 Atomic and molecular physics

Recourse to equations and formulae should only be made where they are indispensable to the understanding of the subject matter; only the very simplest of such equations and formulae should be referred to.

- Concepts of the composition of matter; the molecule; the atom; structure of the atom; nucleus and electrons; ions.

- Atomic and molecular theory: atomic and molecular spectra; X-rays to infrared; continuous and discontinuous spectra; width of spectral lines; thermionic electrons; photoelectric effect; nuclear structure and elementary particles; natural radioactivity; X-rays; cosmic rays.

5.2.3 Chemistry

It is desirable that all Class II meteorological personnel possess some knowledge of chemistry. Since however chemistry forms part of the curriculum in practically all secondary school systems, students will normally have acquired sufficient basic knowledge of chemistry during their secondary school studies. A deeper knowledge of chemistry will only be required by those Class II personnel whose work is related to such subjects as atmospheric chemistry, radioactivity or air pollution. A broad outline of the knowledge likely to be required by such personnel is given below. In general, however, it is left to Instructors to decide on whether, and to what extent, chemistry should be a prerequisite to meteorological training.

5.2.3.1 General chemistry

- Introduction; basic laws of chemistry; structure of the atom and Mendeleiev's periodic system of elements; chemical bonds and structure of molecules; speed of chemical reaction; oxidizing-reduction processes; basic principles of electro-chemistry.

5.3 FUNDAMENTAL METEOROLOGICAL EDUCATION (CLASS II)

Class II meteorological training in the fields of dynamic and synoptic meteorology is essentially the same as that for Class I personnel. In principle, therefore, the syllabi for these subjects for both classes should be the same (see sections 3.3.1 and 3.3.2). For Class II, however, topics should be taught with a view to their practical applications.

5.3.1 Dynamic meteorology

5.3.1.1 Formulation of basic equations

- Equations of motion in vector form as derived from Newton's second law; discussion of pressure force and gravitation; transformation from non-rotating to rotating co-ordinate system; discussion of centripetal acceleration and Coriolis force.
- The concept of gravity.
- Equations of motion in Cartesian co-ordinates (tangent plane approximation) and in spherical co-ordinates; orders of magnitude of various terms (based on observations) leading to the simplified equations.
- Introduction of the hydrostatic approximation; justification of this approximation.
- Equation of quasi-hydrostatic motion using pressure as vertical co-ordinate.
- The continuity equation; Cartesian co-ordinates; pressure as vertical co-ordinate; homogeneous and incompressible fluid.

5.3.1.2 Circulation, vorticity, divergence and deformation

- Vorticity and circulation; Bjerknes' circulation theorem with interpretations.
- Divergence of the three dimensional and horizontal wind field.
- Vorticity and divergence equations in co-ordinate systems with pressure as independent variable; discussion of the order of magnitude of the various terms.
- Introduction of the stream function and velocity potential - Helmholtz theorem - streamlines and trajectories.

5.3.1.3 Balanced motions

- Horizontally balanced motion; motion with no tangential acceleration; gradient wind relation; geostrophic wind relation; comparison of geostrophic and gradient winds with actual winds; the divergence and the velocity of the geostrophic wind; the geostrophic thermal wind.

5.3.1.4 The circular vortex

- The stationary circular vortex; the thermal wind relationship; stable, unstable and neutral conditions; elementary treatment of stability criteria.

5.3.1.5 Atmospheric disturbances

This section should be reduced to its simplest form.

- Disturbances superposed on a state of hydrostatic equilibrium in the field of gravity - static stability; compressibility and gravity waves in the atmosphere; waves in a surface of discontinuous flow and discontinuous specific mass; disturbances superposed on a rectilinear flow; barotropic waves and cases of two-dimensional disturbances.

- Rossby long waves; brief description of the baroclinic waves and baroclinic instability.

5.3.1.6 General circulation of the atmosphere

- Angular momentum of the atmosphere about the earth's axis; relative and absolute momentum; balance of angular momentum; meridional transport by atmospheric disturbances; relation between this transport and zonal circulation; the balance of the atmosphere's kinetic energy and internal energy; production, destruction and transport of energy; the role of baroclinicity; the energy cycle of the general circulation; influence of oceans, continents and large-scale orographic features on the general circulation.

5.3.1.7 Atmospheric turbulence

Reference should be limited to equations and formulae which are essential, with particular emphasis on those employed in synoptic meteorology.

- The nature of turbulent flow; flow near a boundary; the mixing-length hypothesis; velocity profile near a boundary (smooth surface, rough surface); power-law profiles; the vorticity transport hypothesis; statistical theories of turbulence.

- Eddy transport or momentum, heat and water vapour in the planetary atmospheric boundary layer; the Taylor-Ekman theory of the vertical variation of the wind in the boundary layer.

- The heat flux equation and the problem of convection; Richardson criterion; forced and free convection.

5.3.2 Physical meteorology

5.3.2.1 Composition of the atmospheric air

- Dry air and its composition : water vapour; carbon dioxide and ozone; properties of these gases, their distribution in space; weather and climate in relation to meteorological phenomena; the aerosols; atmospheric pollution.

5.3.2.2 Phenomena of radiation in the atmosphere

- Radiant energy : emission and propagation; solar radiation both outside the atmosphere and within it; reflection, diffusion and absorption of solar radiation; direct solar radiation on the surface of the globe as a function of geographic latitude; time of day and season of the year; sky radiation, global radiation and sunshine duration; infra-red radiation of the earth-atmosphere system; temperature of the surface of the globe and temperature of the atmospheric air; long-term radiation equilibrium and thermal equilibrium of the earth-atmosphere system; radiation measurements from meteorological satellites.

5.3.2.3 Electrical and optical phenomena

- Electrical field of the earth; electrical conductivity of the atmosphere; atmospheric ionisation; electrical currents in the atmosphere; electrical charges in clouds; electrical discharge in the troposphere.

- Atmospheric transparency; atmospheric turbidity; turbidity coefficient;visibility.

- Mirages, rainbows, halos, coronas and other optical phenomena.

5.3.2.4 Statics and thermodynamics of the atmosphere

- Dry air; liquid water; water vapour; ice; non-saturated moist air; aequeous clouds; ice clouds; clouds formed of water droplets and ice crystals; thermodynamic properties of water in its three phases and the changes of phase; properties of dry air and moist air; virtual temperature.

- Atmospheric pressure and its variation with altitude; geopotential and the geopotential metre; the hydrostatic equation, its importance in meteorology; height of a pressure surface and thickness of a pressure layer; altimetry; barometric pressure, its precision; the standard atmosphere.

- Adiabatic transformations of dry and moist air; potential temperature; wet-bulb temperature and the psychrometric formula; equivalent temperature; wet-bulb pseudo-potential temperature and pseudo-potential equivalent temperature; dewpoint temperature and its variation with altitude; dry saturated adiabatic lapse rates; mixing of the masses of moist air.

- Aerological diagrams; diagrams equivalent to Clapeyron's diagram; choice of a diagram; use of diagrams in synoptic meteorology.

- Stability of vertical dry and moist air; stability criteria and instability criteria; conditional instability and latent instability; the parcel and slice methods and a comparison of the two; convection in the atmosphere; the importance of relief; diurnal variation of stability and convection.

5.3.2.5 Cloud physics

- Cloud microphysics and precipitation microphysics; condensation of water vapour in the atmosphere; condensation nuclei; influence on the saturation pressure of water vapour, surface tension and solubility of nuclei in water; formation of raindrops and of ice crystals; cloud structure, size of drops and crystals; raindrop formation processes.

- Clouds : large-scale and small-scale cooling of moist air by adiabatic and non-adiabatic processes; stratiform clouds (up-draught of air on the synoptic scale); cumuliform clouds (small-scale up-draught); international cloud classification; genera; species and variety; cloud cover; radiation fog and advection fog.

- Frontal clouds; cloud systems and their classification.

- Current techniques on artificial stimulation of precipitation.

5.3.2.6 Snow and ice

- Snow cover and its properties; snow thawing; products of ground condensation and conditions of their formation.

5.3.3 Synoptic meteorology

This syllabus should be followed only be personnel working in fields other than synoptic and aeronautical forecasting. For the latter fields, additional material is given in section 6.1.

- The meaning of weather : the synoptic method.

- World weather network : surface synoptic network; upper-air network; ocean network; automatic weather station network; radar network; rocket network; satellite observations.

- Synoptic weather analysis : the concept of synoptic analysis; preparation of synoptic charts; symbols; drawing of isobars; synoptic representation of the pressure field; isobars on a level surface and contours on an isobaric surface; geostrophic wind; thermal wind; geopotential of isobaric surfaces and thickness of an isobaric layer; geometry and kinematics of surface isobars; contours of constant pressure; surfaces and thickness lines.

- Air masses : source, characteristics and classifications; frontal surfaces and frontal zones; cold front, warm front and occluded front; patterns of the pressure field; patterns of the vertical component of the geostrophic vorticity and the flow patterns associated with them; air mass analysis.

- Outline of frontal disturbances : polar front waves; evolution of frontal depressions; occluded depressions; jet streams and their analysis; satellite cloud pictures and data as an aid to synoptic analysis.

- Elements of surface and upper-air analysis in low latitudes; monsoons and tropical disturbances.

- General circulation : the average fields of the atmosphere; the atmosphere as a circular vortex; the meridional profile of temperature; the meridional profile of pressure; the meridional profile of mass; the meridional profile of zonal geostrophic wind; the maintenance of the atmospheric field of temperature; the geographical distribution of net radiation; the principles of the general circulation; the budget of angular momentum in zonal rings.

- The normal fields of temperature and pressure at sea level : normal sea level isotherms and isobars in the Northern and Southern Hemispheres; zonal averages of sea-level temperature with two hemispheres; zonal averages of sea-level pressure in the two hemispheres.

- The normal three-dimensional fields of temperature and pressure in the Northern Hemisphere : the polar vortex; quasi-stationary disturbances superimposed on the polar vortex; the monsoon circulation; the quasi-permanent subtropical highs; the doldrum zone; surface-air and upper-air currents in the equatorial belt.

- Weather forecasting : progress of weather forecasting; scope and essential nature of the forecast problem; types of weather forecast-time, range, content and performance; forecasting techniques or aids - their merits and limitations; extrapolation techniques; kinematic methods; statistical methods; physical techniques of forecasting the weather; approach to the problem of numerical weather forecasting.

- Laboratory exercises : surface and upper-air synoptic observations; special observations by means of electronic equipments; coding and decoding synoptic information; plotting of data on surface and upper-air synoptic charts; synoptic analysis of scalar functions on a plane; pressure field analysis; synoptic analysis of charts of isobaric surfaces; geopotential temperature and moisture; analysis of relative topographies between isobaric surfaces;

isallobaric, isallophysographic and isallothermic charts; computations of geostrophic gradient and thermal wind; analysis of plotted thermodynamic and wind data; application of the various stability criteria (hydrostatic, slice method, convective stability, entrainment, etc.); analysis of surface and upper-air synoptic sequences for typical weather situations.

5.3.4 Climatology

- General climatology : notion of climate; definition of climate.
- Physical factors of climate : importance of heat, radiation and humidity in climatology.
- Astronomical and geographical factors : notions of solar climates; influence of latitude; environmental influences on climate; effects of the distribution of sea and land; degree of continentality; effects of water masses.
- Climatic elements : mean climatic elements; classification; representation (mean, sum, frequency, normal, variability); instruments and methods of observation for the various climatic elements.
- Physical climatology : notions relating to the radiation, heat, energy and water balances; elementary notions on diffusion and turbulence; comparison of normal values and variability of climatic elements at the various latitudes.
- Dynamical climatology : general atmospheric circulation; centres of activity and types of climate associated with them; climatological aspects of dynamical meteorology; representation of climatological data.
- Synoptic climatology : grouping of climatic elements according to the nature of the air masses; mean or frequency of climatic elements associated with types of weather; geographical distribution of fronts; frontal zones and air masses and climatological phenomena associated with them.
- Regional climatology : description of the climate of the globe; climatology of the region or country where the training is given - qualitative description, numerical data, maps and atlases.
- Meso- and microclimatology : general principles, concepts and definitions; examples of microclimates.
- Bioclimatology : general principles, concepts and definitions; bioclimatology related to the various human activities and associated fields.
- Applied climatology : general notions on the application of climatology to the various human activities (agriculture, aeronautics, marine, public works, transport, etc.).
- Climatic changes : basic notions.

- Special climatological methods.

- Climatological statistics : emphasis should be laid particularly on the practical aspects. This training should be illustrated by many examples.

- Machine processing of climatological data : punched cards, magnetic tapes, punched tapes, etc.

- Use of computers : programming (principles and simple applications).

5.3.5 Hydrology

Same as for Class I (section 3.3.6, page 32).

5.3.6 Meteorological instruments and methods of observation

- General - general knowledge of instruments and methods of observation; basic principles of measurement in meteorology; the idea of scale; synoptic scale and local scale; choice of site for an instrument enclosure; precision of measurements and readings; procedures for installation, maintenance and checking of instruments; calibrating procedures.

5.3.6.1 Surface observations

- Air temperature : thermometers and thermographs; mercury and alcohol thermometers; maximum and minimum thermometers; bimetallic thermometers and their time constants.

- Ground temperature : soil thermometers and thermographs.

- Atmospheric pressure : mercury barometers; aneroid barometers; hypsometers; corrections and reductions to be applied to reading.

- Humidity : psychrometric measurements; naturally ventilated psychrometer; aspirated psychrometer; hair hygrometer; dewpoint hygrometer; use of psychrometric tables.

- Precipitation : raingauges and siphon-type recording raingauges; rates of rain-fall recorder; dew measurement.

- Evaporation : evaporimeter; evaporation pan.

- Speed and direction of the wind : wind vanes; anemometers and anemographs; definition of the surface wind for synoptic purposes.

- Duration of sunshine and of global solar radiation; sunshine recorders; actinometers and actinographs.

- Horizontal visibility : estimation from the use of landmarks by day and light at night.

- Clouds : genera, species and variety; cloudiness; measurement of the ceiling by estimation, using pilot balloons in the daytime and cloud searchlights at night by the optical echo method; automatic cloud base recorder; the comb nephoscope for measuring cloud speed and direction.

- Hydrometeors : exploration at a distance using radar echoes, radar.

- Thunderstorms : atmospherics direction-finder.

- Distant recording : automatic instruments; automatic stations.

5.3.6.2 Upper-air observations

- Pilot balloons; radiosondes; radio and radar measurements; analysis of a sounding and presentation of the results of the sounding on an aerological diagram; use of diagrams.

- Information from meteorological rockets (temperature up to approximately 60 km, wind, pressure, density).

- Meteorological observations carried out from artificial satellites: clouds; albedo; infra-red radiation.

- Meteorological codes for transmitting synoptic surface and upper-air data; special codes.

- Record keeping.

5.3.7 Interaction of the ocean and the atmosphere

Only a general treatment of the topics given below is required :

- Transfers between atmosphere and ocean : momentum; heat; water vapour; carbon dioxide.

- The atmosphere's action on the ocean : sea-surface winds and currents; waves; swell; bores and tidal waves; storm tides; cold upwelling.

- The ocean's action on the atmosphere : climatic action; modification of air masses due to heating or cooling; sea fogs.

C H A P T E R 6

FIELDS OF SPECIALIZATION (CLASS II)

6.1 SPECIALIZATION IN SYNOPTIC METEOROLOGY (CLASS II)

For specialists in the fields of synoptic and aeronautical meteorology paragraph 5.3.3 should be supplemented by the following :

- Kinematic analysis, wind and pressure : classification of winds; the effect of changing pressure distribution; the effect of friction; comparison of gradient wind with observed winds; the geostrophic wind scale; boundary conditions; trajectories; streamlines; relation between trajectories and streamlines; divergence and convergence.

- Kinematic analysis-frontogenesis : definition of frontogenesis; frontogenesis in a conservative field of property; linear fields of motion; frontogenetical and frontolytical sectors.

- General circulation in the troposphere : air masses and the polar front; the subtropical high pressure belt; the subpolar low pressure belt; the cyclonic polar vortex; jet stream : the flow lines and isotachs of a jet stream; tropospheric and stratospheric circulations and the jet stream; the polar front jet stream; frontal jet stream; the multiple jet stream; the subtropical jet stream; stratospheric jet streams; climatography of tropospheric jet streams.

- The characteristic large-scale patterns of standard isobaric surfaces, of their relative topography (temperature field) and of the field of the vertical component of geostrophic vorticity; stable and unstable waves of the zonal westerly current of middle latitudes; formation in the middle and upper troposphere of mobile troughs and wedge lines in the pressure field, of cold cyclones in low latitudes and of warm anticyclones in high latitudes; the phenomenon of blocking; stable and unstable waves of the easterly zonal current in low latitudes; tropical cyclones.

- Common characteristics of atmospheric circulation on the synoptic scale, from 700 to 100 mb; tropospheric and stratospheric disturbances; contour patterns at the 50 mb level and at higher levels; the seasonal changes in the stratospheric circulations; the cyclonic vortex of the polar night and the jet stream associated with it.

- Polar meteorology as applied to weather analyses and forecasting.

- Tropical meteorology : representative value of surface and upper-air measurements of meteorological elements; their diurnal variations; local factors; the orders of magnitude of the terms used in dynamical meteorology (motion, continuity, thermodynamics) in the tropical latitudes; relation between the wind and the isobars in the low latitudes; validity of the geostrophic hypothesis; stream lines and synoptic analysis; computation of the horizontal divergence and the vertical component of vorticity in the tropical latitudes; inter-tropical convergence; the trade winds; the interaction of tropical and mid-latitude weather systems; the

general circulation in the low latitudes; mean flow at the surface and in the upper-air; tropical tropopause; seasonal variations of the pressure and wind fields; equatorial low pressures; anticyclones of the subtropical high-pressure belt; trade winds and monsoons; tropical clouds; hydrometeors and meteors of the intertropical zone; air masses in the tropics and their transformations; waves of the easterly current; squall lines; tornadoes; tropical cyclones; their evolution and trajectories; the interaction between the low and middle latitudes; penetration of the polar front in the tropics, its transformations; upper-air front; associated pressure troughs; zonal weaterly circulation; shearlines; analysis and evolution of stream lines on synoptic charts.

- Forecasting large-scale patterns of the height and temperature fields by using the vorticity equation; graphical and numerical methods.

- Analysis and forecasting of large-scale patterns of atmospheric distribution of water vapour, cloud cover and precipitation : physical relation between these patterns and those of the forecast horizontal flow and the forecast field of vertical motion; formulation of the physical forecast (temperature, cloudiness, hydrometeors) from the numerical forecast of the field of motion.

- Fine structure associated with the large-scale pattern of the field of motion : convection clouds; use of aerological diagrams; thunderstorms; squall lines; tornadoes; clear-air turbulence; icing; fog; influence of local geographical factors on wind, temperature, clouds and hydrometeors; mountains and hills, coastal and urban area effects.

- Preparation of general and special forecasts; forecasts for shipping, agriculture, etc. (storm warnings, flood forecasting, etc.)

- Extended weather forecasting : synoptic extrapolation for two or three days; extended forecasting based on extrapolation of individual upper long waves; extended forecasting based on five-day mean circulation; extended forecasting based on analogous sequences of weather maps; extended forecasting by means of statistical extrapolation; general form of long-range weather forecast; long-range forecasting by means of physical models; numerical long-range forecasting.

- Satellite data in meteorological analysis and forecasting; use of satellite data in weather analysis; large-scale cloud system; synoptic application of satellite-borne infra-red window measurements; local circulations as seen from satellite cloud pictures; satellite cloud pictures and jet stream structure; use of satellite data in mesometeorology; uses of satellite data in severe thunderstorm detection; use of satellite data in the tropics; brief description of the technical aspects of meteorological satellite photography; satellite radiation measurements; radiometric measurements of midstratospheric temperatures; water vapour content from satellite radiation measurements; participation in the workshop on the use of satellite data in meteorological research.

- Meteorological telecommunications : principles of organizing intercommunication between stations; utilization of the various transmission methods, their advantages and disadvantages; elementary notions of telegraphy; description and working of the teleprinter and facsimile; electronic programming devices.

- Collection and diffusion of meteorological data; need for an international organization; international and national telecommunication procedures; continental or world broadcasts; sub-continental broadcasts; transmission of data required for the protection of aircraft; sub-regional and regional broadcasts.

- Systems for transmitting data in flight.

- Meteorological transmission programmes; message writing, exercises.

- Practical exercises on operational regulations concerning telephony, telegraphy and radiotelegraphy and on the functioning of the principal apparatus used (teleprinter, facsimile, radiotelegraphy reception apparatus, telegraph switchboard), installation and day to day maintenance of this equipment; simple repairs; sound reception.

- Laboratory exercises : graphical arithmetical operations and graphical differentiation; graphical constructions of thermodynamic charts or nomographs; plotting of data on thermodynamic and wind sounding charts; isobaric advection of scalar synoptic parameters : computation and analysis; thermal wind analysis; thermal advection as advection of thickness lines; hodographic analysis; isogon and streamline analysis; horizontal and isobaric trajectories; computation of the fields of isobaric divergence, vertical vorticity component and deformation; methods for analysis - at synoptic scale - of vertical velocity fields; evaluation of frontogenetic factor; constant absolute vorticity trajectories computation; Rossby long waves computation; isotach and jet stream analysis; analysis of tropopause; analysis of maximum wind layer; isentropic analysis, isentropic thermal and relative pressure field; surface synoptic analysis : air-mass analysis; allobaric fields; cloud and weather systems analysis; frontal analysis; tropical analysis : streamline and isotach analysis; vertical time-section analysis; isobaric analysis in the low latitudes; plotting of data on synoptic cross-sections and time-sections; space cross-section analysis; local analysis and time-section analysis; cloud weather systems analysis by satellite photos and radar echoes; synoptic weather forecasting and construction of surface and upper-air prognostic charts : displacement of upper-air troughs and ridges, jet-stream prognosis; displacement of fronts and surface systems; intensity change of weather systems (graphical kinematical extrapolation, graphical application of vorticity equation, interpretation and utilization of numerical weather prediction, etc.); forecasting of weather elements (cloud systems, precipitation, winds, temperature, severe weather conditions); synoptic weather analysis and forecasting on the basis of current synoptic surface and upper-air data, collected in a didactical simulated meteorological office; objective forecasting; local forecasting techniques; verification of forecasts; coding and decoding synoptic analyses and forecasts.

6.2 SPECIALIZATION IN AERONAUTICAL METEOROLOGY (CLASS II)

6.2.1 Synoptic meteorology

As for Specialization in Synoptic Meteorology (Class II): see section 6.1, page 109.

6.2.2 Aeronautical meteorological knowledge

Aircraft icing

- Theory of formation; processes and dependence upon temperature; drop size; liquid water content; airframe configuration and aircraft speed.
- Types of icing: clear ice, rime ice and hoar frost.
- Ice accretion rates; association with cloud types (stratiform and cumuliform clouds); thunderstorms; freezing precipitation; orographic and frontal lifting effects.
- Methods of forecasting the risk of ice formation and means of avoiding icing areas.
- Effects of inflight structural icing on wing and tail surfaces, propellers, Pitot tube, antennas and windshield.

Turbulence

- Turbulence near the ground; mechanical turbulence as a function of wind speed, wind shear and terrain roughness; convective turbulence as related to hydrostatic instability; effects of boundary layer turbulence on take-offs and landings of aircraft; turbulence related to clouds, fronts, and thunderstorms.
- High-level turbulence (CAT); association with horizontal and vertical wind shear, jet stream, stability and tropopause inversion.
- Mountain wave turbulence applied to both boundary layer and high-level.
- Effects of severe turbulence on the control of the aircraft and possibility of structural damage.
- Methods of forecasting the risk of the existence of turbulence; means of avoiding turbulence areas.

Other meteorological phenomena hazardous to aviation

- Reduced surface visibility: fog - its manner of formation and dissipation; the relationship of visibility to fog type and duration, to the various hydrometeors as rain, drizzle, snow and to air pollutants such as smoke.

- Knowledge of the theory and practical techniques for the artificial dissipation of fog.

- Thunderstorms; association with in-flight turbulence, hail icing and lightning; surface conditions related to thunderstorms such as strong, gusty winds, wind shifts, poor visibility; frontal and air mass thunderstorms; squall line thunderstorm.

- Specific knowledge in the interpretation of weather radar information towards making short-term terminal forecasts.

- Effects of accumulated snow, slush and water during take-off, landing and taxi-ing operations.

Meteorological aspects of flight planning

- Meteorological basis for pressure pattern flying; definitions of Rhumb line, great circle, and composite tracks; wind components.

- Minimal flight paths; least time tracks; use of "D" factor; determination of drift angle; single heading flight; radio-navigation.

- Meteorological requirements for en-route winds and temperatures, weather and terminal forecasts for advance operational planning, for pre-flight planning and in-flight planning.

- Preparation of area forecasts, route forecasts (e.g. cross-sections) and flight forecasts.

- Special emphasis on the importance and techniques of briefing of flight crews and operational personnel.

6.2.3 Aeronautical operational knowledge

Definition

Definition and meaning of the following terms used in international air operations:

- Air report; briefing; forecast; landing forecast; meteorological information; meteorological report; observation; SIGMET.

- Altitude; cruising level; transition altitude; transition level; transition layer.

- Operator; operator's local representative; pilot-in-command.

- Airway; control area; control zone; controlled airspace; flight information region.

- Aerodrome; instrument runway; landing area; movement area; aerodrome traffic zone.

- "Service"; "provide"; "issue"; "make available"; "supply".

Procedures for meteorological services for international air navigation

Knowledge of the functions or the appropriate regional procedures associated with the items listed below:

- Meteorological offices; main, dependent and supplementary meteorological offices; meteorological watch offices.

- Aeronautical meteorological observations; routine and special observations; selected special reports; reports for take-off or landing.

- Aerodrome forecast; area covered; period of validity; amendment criteria.

- Information for operators or operators' local representatives; advance, preliminary, and pre-flight planning; in-flight operational planning; briefing and display of meteorological information required by operators; information required from operators.

- Information for pilots-in-command prior to departure; briefing; documentation; flight forecasts; pictorial cross-sections; aerodrome forecasts; surface and upper-air charts; prognostic charts.

- Information for pilots-in-command during flight; scope and responsibility of area meteorological watch; en-route forecast service; information available from ocean weather vessels; supply of meteorological information in exceptional circumstances; diversion procedure.

- Information for and from air traffic services; types of meteorological information required by aerodrome control towers, approach control offices and area control/flight information centres; collection of aircraft meteorological reports.

- Forms of meteorological messages; routine and special reports in code or plain language; reports for take-off and for landing; forecasts and amendments to forecasts; trend forecasts; ditching reports; flight, route and area forecasts; SIGMET information; dimensional units.

- Information for search and rescue according to local procedures.

- Aeronautical climatological information; forms used; publication of records.

Air traffic services

- Knowledge of the functions of and distinctions between area control centres, approach control office and aerodrome control tower and flight information centres, and the part played by the air traffic services in the provision of in-flight meteorological service.

- Knowledge of operational terms such as IFR, IMC, VFR, VMC, the rules governing terrain clearance and vertical separation; quadrantal cruising levels; methods of effecting horizontal separation; alerting and search and rescue services; methods of aerial search; holding and approach procedures.

Operation of aircraft

- Aerodrome meteorological minima and the minima applicable to at least the regular and alternate international aerodromes.

- Altimeter setting procedures and the ICAO Standard Atmosphere.

- Knowledge of general flight navigation; the principal aids to navigation and methods of determining upper winds in flight.

- The effects of air density, humidity, icing, turbulence and wind on aircraft performances; fuel consumption of aircraft; the effects of various weather phenomena on aerodrome ground services; aids to approach and landing.

Private aviation and aerial work

- Meteorological requirements for private pilots, for agricultural flights and other non-scheduled operations.

Organization

- Organization for the provision of services in meteorology to international civil aviation; telecommunications, means, systems and plans for the concentration and diffusion of information; forms of traffic; international co-ordination of procedures (WMO and ICAO).

Regulatory documents

Familiarization with the following documents:

WMO	ICAO
- Technical Regulations, Chapter 12	- Annex 3 PANS-MET ..... Doc 7605 - MET/526/4
- Publication No. 9 - TP.4 Volume B - Codes	- Regional Supplementary Procedures. Doc 7030
	- ICAO Abbreviations and Codes ..... Doc 8400

WMO	ICAO
	- Location indicators. Doc. 7910
	- Meteorological tables for international air navigation . ..... Doc. 7155 - MET/522

NOTE - Use has been made of the part dealing with "Aviation knowledge" of ICAO Doc. 7192-AN/857 PART 7/2, Training Manual, Part 7 - Aeronautical Meteorological Forecasters.

6.3 SPECIALIZATION IN CLIMATOLOGY (CLASS II)

6.3.1 Chemistry and radioactivity

- Isotopes; metalloid elements, methods of preparation, their components; metals; extraction methods, their components; radioactive elements; disintegration of radium; the families of radioactive elements; natural and artificial transmutation; general notions and methods of organic chemistry; generalities on the categories of organic matters.

6.3.2 Elements of astronomy and geodesy

- Celestial sphere : diurnal motion; horizontal and equatorial co-ordinates ; hour angle; height and declination of a star; theodolite and sextant; elements of spherical astronomy related to the determination of the celestial position of the sun; general characteristics of the planet earth; shape and dimensions of the earth; horizon; laws governing the motion of the earth; reception of solar energy by the planets; causes of the unequal distribution of solar energy over the surface of the globe; alternation of day and night; equinoxes and solstices; seasons of the year; thermal zones of the globe; grid points; geographical co-ordinates; types of maps; continents; oceans of the globe and their distribution.

6.3.3 Physical geography

- Lithosphere : structure of the earth; crust; core; biosphere; tectonic; secular land changes; folding and the formation of mountains; folds and faults in the earth's crust; reasons for earth-quakes; seismic centre; epicentre; outside exogenous forces altering the surface of the earth; erosion, physical chemical and organic (biological); erosive and accumulative action of the wind, streams, rivers, snow and ice; the role of endogenous and exogenous factors in the formation of the earth's surface; nature of the coastlines of continents; peninsulas and islands; continental, volcanic and coral islands; the main islands and peninsulas of various parts of the world; seas and gulfs; various types of shores; relief and its forms; indication of relief on maps; flat land relief; mountainous relief and its forms; earth's magnetism.

- Hydrosphere : hydrological cycle; oceans and seas; principal ocean currents; water on land; rivers and their basins; river valleys; main rivers of the world; lakes; classification of lakes; principal lakes of the world; glaciers; snow line; glacier movement; role of glaciers in river feed; mountain flood waters; avalanches; marshes; formation of marshes; types of marshes.

- Landscape (natural) zones : biosphere; soils; description of natural (landscape) zones; landscape zones of the cold, temperate and tropical zones of the earth, their geographical distribution and brief description of natural conditions; mountainous areas; vertical zonality.

- General physical geographical description of continents : geographical situation, coastline, relief, inland water, soil and flora of continents — Eurasia, North and South America, Africa and Australia, Antarctic.

- Elements of palaeontology, stratification and fossils; historical geology, geological periods.

- Mineralogy and petrography : forms of minerals, systems of crystallization, the various categories of minerals; rocks : eruptive rocks, aqueous rocks, crystallophyllic rocks.

- Topography : instruments and methods of topography, measurement of level differences (contouring), topographic maps, determining the position of a meteorological station on a topographic map.

6.3.4 Elements of botany, biology, ecology

- Botany : organography, morphology, anatomy and histology of plants; physiology of plants : mineral nutrition through the roots, transpiration, assimilation, respiration, effect of meteorological elements on physiological functions; classification of plants : the principal branches of cryptograms and phanerograms.

- Biology : reproduction, heredity, genetics, variation and mutation of the types of living beings; evolution of living beings, mechanism of the evolution (Darwin, Lamark).

- Ecology : geography of living beings (phytogeography, zoogeography, anthropogeography).

6.3.5 Climatology

- Regional climatology : climatic classifications; climates of the world.

- Applied climatology : importance of climatological data to agriculture, public works, road traffic and other human activities; particular needs of the users (early and late frosts, importance of precipitations, intensity and frequency of precipitations, droughts, etc.).

- Climatic changes : existence of climatic changes; purposes and nature of paleoclimatology.

Special climatological methods

- Random variable and probability theory : elementary notions of frequency (absolute-relative), probability (prior-posterior); likelihood; random variable (Von Mises definition); discrete, continuous random variable climatological series; population: sample; application to climatological data.

- Description of populations by means of frequency distributions (climatological prediction) : practical notions on following topics and use of tables : climatological series; mean recurrence interval; mean; median; mode; quintiles; variance; standard deviation; moments; moment generating function; binomial, Poisson; negative-binomial; multinomial distributions; normal distribution; gamma distribution; log-normal distribution; transformation to normal distributions; Edgeworth series; distribution of extremes; smallest, largest value; the three asymptotes.

- Estimation problems : practical notions on : empirical frequency estimates; parametric estimation; estimation procedures; methods of moments, maximum likelihood, least square, minimum chi-square; interval estimation, confidence intervals; adjustment of climatological parameters for discontinuities of the station location.

- Test of hypothesis : practical notions on : parametric and non-parametric tests; order statistics; Student's-test; Fisher-test; variance analysis; Chi-square-test; test of normality; tests of goodness of fit; tests of homogeneity.

- Relationship problems : practical notions on : coefficient of correlation; partial, multiple correlation; tests of correlation (parametric or distribution free); rank correlation; contingency tables; regression (linear, non-linear, multiple); significant, non-significant regression coefficients in adjusted relations; discriminant analysis; factors analysis.

- Time series : practical notions on : test for randomness; test against trend; test for auto-correlation.

- Computation mathematical tools : practical notions on : digital computer; programming; Fourier analysis; matrix calculus.

6.4 SPECIALIZATION IN HYDROMETEOROLOGY (CLASS II)

Class II hydrometeorological personnel must have a thorough training in hydrometeorology to enable them to carry out some of the functions of the Class I personnel. Their duties, though of an essentially routine and practical nature, demand complete understanding of the principles involved. Therefore the syllabi for training Class II personnel in this field are essentially the same as those given for Class I in sections 4.8.1 to 4.8.9 (pages 81 - 86)

It should be mentioned, however, that for Class II personnel more emphasis should be placed on practical aspects of the programme. Due consideration should also be given to the eventual field in which the student would be employed.

6.5 SPECIALIZATION IN MARITIME METEOROLOGY (CLASS II)

To be prepared by the WMO Commission for Maritime Meteorology.

6.6 SPECIALIZATION IN METEOROLOGICAL INSTRUMENTS (CLASS II)

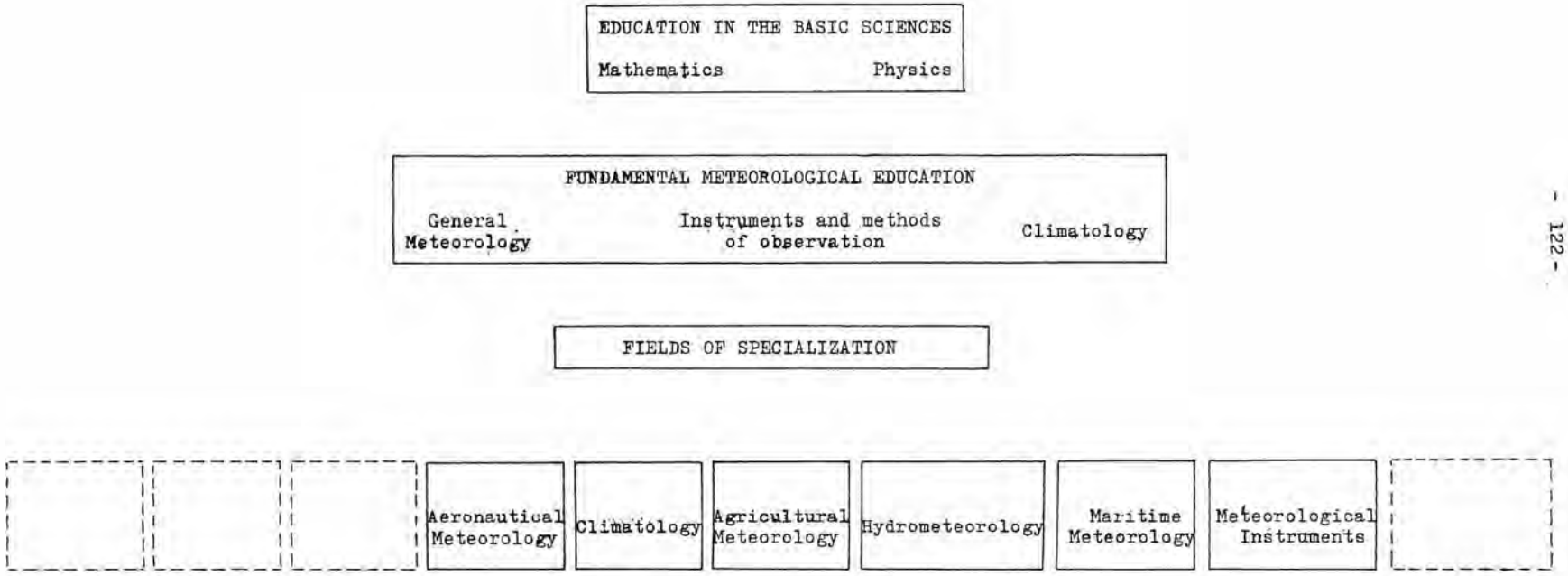
To be completed by the CIMO Working Group on Training in Instruments and Methods of Observation.

C H A P T E R 7

CURRICULA FOR TRAINING ALL CLASS III METEOROLOGICAL PERSONNEL IRRESPECTIVE OF THEIR FIELDS OF SPECIALIZATION

CURRICULA FOR TRAINING CLASS III METEOROLOGICAL PERSONNEL

SCHEMATIC REPRESENTATION OF CONTENTS



7.1 GENERAL

In their work, the higher Classes of meteorological personnel are assisted by Class III, namely, plotters of synoptic charts and aerological diagrams, assistant forecasters, assistant climatologists, radiation and aerological station personnel, surface observing station inspectors within national networks, and so on. When they have acquired sufficient experience, Class III personnel may participate in the interpreting of observational data and, under supervision, provide users with meteorological information or inspect the observation network. In view of the wide spectrum of duties carried out by this Class, it is not easy to draw up training syllabi which will be suitable for all staff, irrespective of their individual functions.

As mentioned in chapter 2 (Section 2.4), Class III meteorological personnel can in principle be divided into two categories :

- Category A : the training of these personnel will require particular emphasis on the utilization of observational data. In the fields of synoptic and aeronautical meteorology, they will work closely with forecasters.

- Category B : the training of these personnel will place especial emphasis on the use of observational instruments. Within this category will be operators of radiosonde, rawin and radar equipment.

The syllabi given in 7.3.1 "General Meteorology", 7.3.2 "Meteorological Instruments and Methods of Observation" and 7.3.4 "Climatology" are primarily designed for personnel of Category A. For Category B, the syllabi given in 7.3.1 and 7.3.4 could be reduced. However, the syllabus given in 7.3.2 should be supplemented as indicated in paragraph 7.3.3.

7.2 EDUCATION IN THE BASIC SCIENCES (CLASS III)

It is essential that all meteorological staff have a thorough understanding of the science of meteorology if they are to carry out their duties efficiently. To acquire this understanding a preliminary grounding in the basic sciences is necessary. The duties of Class III personnel are of the utmost importance and must therefore be carried out in full awareness of their value and the uses to which they are directed.

The purpose of the syllabi in mathematics and physics given in the following paragraphs is to indicate in broad lines, the knowledge in these subjects which one would normally expect Class III personnel to possess prior to taking up meteorological studies. Except, perhaps, for the section on integral calculus a student with 12 years primary and secondary schooling is already familiar with the material contained in

the syllabi. The syllabi will however be of value to instructors conducting refresher courses, or preparing supplementary courses for promotion of Class IV personnel.

7.2.1 **Mathematics**

7.2.1.1 Algebra

- Natural logarithms.
- Quadratic equations, algebraic and graphical solution; real and imaginary roots; sign of the quadratic expression; biquadratic equation; transformation of a double radical into the sum of two simple radicals.
- Concept of the function of a variable, its graphical representation; examples, among others,

  $y = ax + b$, $y = (ax + b)/(cx + d)$ with $c \neq o$,
  $y = ax^2 + bx + c$ with $a \neq o$.

- Infinitely large and infinitely small quantities; limit of a variable; limit of a function; operations on limits; calculation of a limit - examples : elementary knowledge of the continuity of a function; algebraic functions.

7.2.1.2 Plane and solid geometry

- Geometric loci points equidistant from one or two other points; points equidistant from one or two straight lines; geometric construction of loci.
- Theorem of the external and internal bisectors of an angle of a triangle.
- Polygons : similarity of polygons; regular polygons and their properties; equilateral triangles; square; regular hexagons; polygons inscribed in, and circumscribed about a circle.
- Length of a circumference and of an arc; definition and value of π
- Surface : unit of surface; equivalent surfaces.
- Angle between a straight line and a plane; trihedrons; polyhedrons; regular polyhedrons; prisms; pyramid; frustum of a pyramid; cylinder; cone; frustum of a cone; their surface areas and volumes; surface and volume of the sphere; surface of spherical zone; the solid angle.

7.2.1.3 Plane analytic geometry

- Cartesian, rectangular and polar co-ordinates; change of cartesian co-ordinates; distance between two points; co-ordinates of the mid-point of a segment; geometric locus, its equation.

- Equation of a straight line : general form; equation of the straight line passing through two points; equation of two parallel and of two perpendicular straight lines; equation of a circle.

- Some standard, simple, plane curves : parabola; ellipse; hyperbola; their equations and construction in the plane.

7.2.1.4 Trigonometry

- Definition of arc and angle; measurement of an angle; units; positive and negative angles; circular functions of an angle; sine, cosine, tangent, cotangent, secant, cosecant and their variation as a function of the angle and their graphical representation; circular functions of the sum or difference of two angles; circular functions of two complementary or supplementary angles, of vertically opposite angles, and of two angles whose sum or difference equals 2; reduction to the first quadrant; noteworthy values of the circular functions; classical elementary formulae; relation between the trigonometric functions of the same angle; conversion of the sum or the difference of two sines or cosines into their product and vice versa; trigonometric tables and their use; solution and discussion of certain classical trigonometric equations; relation between the sides and angles of a triangle; solution of triangles.

7.2.1.5 Differential and integral calculus

- Continuous function of a variable derived from a continuous diferential function; derivative of the sum and the difference of two functions and of the product and the quotient of two functions; derivative of

$$x^n \ (n \leq 0), \ \sin x \text{ and } \cos x.$$

- Applications : (1) tangent to a curve and slope of a curve, at a point; gradient of a scalar; rate of increase or decrease; (2) movement of a point on a straight line : relation between the distance covered and the time taken and between the velocity of the point and the time; maximum and minimum of the function of a variable.

- Simple cases of functions of a function.

- Intuitive notion of the integral of a function; integral of common functions : x^n, sin x, cos x.

- Applications : the area defined by the arc of a curve; the axis of the abscissae and the ordinate of the end points of the arc; lateral area and volume of a body of revolution.

7.2.1.6 Statistics

- Purpose and scope of statistics; frequency distribution.
- Tabulation and graphical representation of statistical data.
- Mean; median; mode; variance; percentile.
- Method of least squares; contingency and correlation; harmonic analysis.
- Measures of dispersion : mean deviation and standard deviation.
- Exercises in statistics.

7.2.2 Physics

- Properties of matter : fundamental physical measurements; linear motion of a particle; Newton's laws of motion, definition of unit force; circular motion and simple harmonic motion; work and energy; equilibrium of systems of co-planar forces; motion of rotation; moment of inertia; compound pendulum; friction; viscosity; impact; hydrostatics; gases; elasticity; surface tension; diffusion; osmosis; occlusion.
- Heat : temperature, thermometry; expansion of solids; expansion of liquids; expansion of gases; gas thermometers; quantity of heat; specific heat; calorimetry, fusion; vaporization; relation between temperature, pressure and volume of any substance; Dalton's law; dew point; hygrometry; modes of transference of heat; nature of heat; mechanical equivalent of heat; adiabatic expansion of a gas; kinetic theory of gases.
- Acoustics : nature of sound; wave motion and sound; determinations of frequency; vibrating systems producing sounds; resonance; composition and resolution of harmonic vibration; Döppler's principles.
- Light : reflection and refraction of light; principles of optical measurements; optical instruments; colour; the eye; nature of light; visible and invisible radiation; corpuscular and wave theories; polarization effects; velocity of light.
- Magnetism : magnetic phenomena; law of magnetic force; magnetic potential; magnetic intensity; terrestrial magnetism; permeability; susceptibility; magnetic circuit.
- Static electricity : elementary phenomena; induction of electricity; law of electric force; electric potential; capacity; condensors; energy of charged conducting systems; electrical machines; electrometers.
- Current electricity : elementary phenomena; cells; electric circuits; magnetic action of an electric current; electrical units; Ohm's law; resistance of Kirchhoff's laws; measurement of

resistance; electro-thermal and thermoelectric effects; chemical action of a current; electrolysis; electromagnetic induction; galvanometers; ammeters; voltmeters; high-frequency oscillations; wireless telegraphy.

7.3 FUNDAMENTAL METEOROLOGICAL EDUCATION (CLASS III)

The syllabus in general meteorology, meteorological instruments and methods of observation, and climatology, given below, are designed primarily for those Class III personnel who are responsible for processing observational data (Category A of WMO Technical Note No. 50).

7.3.1 General meteorology

The syllabus for Class IV personnel (section 9.2.1) should be supplemented as follows :

- Thermodynamics of the atmosphere : adiabatic transformation of non-saturated air and of air saturated with water vapour; the psychrometric formula (Regnault); potential wet-bulb temperature; elementary aerological diagram theory; choice of a diagram; problems that can be solved using this diagram; vertical stability and instability of air; conditional equilibrium and latent instability; thermal convection and convection clouds; moisture indicators : absolute humidity; specific humidity; mole fraction : virtual temperature.

- Clouds, fog and precipitation : basic knowledge of their formation; saturation, condensation nuclei; influence of the surface; tension of raindrops and of the hygroscopicity of nuclei on saturation pressure; the process of raindrop formation; large-scale and small-scale cooling of the air due to adiabatic and non-adiabatic processes; frontal, generally stratiform, clouds (up-draught on the synoptic scale); cumuliform clouds (thermal up-draught); orographic clouds; turbulence clouds (small-scale up-draught); international cloud classification; fog classification; meteors; artificial rain.

- Dynamic meteorology* : ideas of scale in meteorology; motion on different scales; synoptic wind; geostrophic approximation (Buys-Ballot's law); ageostrophic local winds; equations of motion on the synoptic scale; geostrophic wind and gradient influence of the temperature field on the wind field; thermal wind; horizontal divergence and convergence and the existence of vertical velocities; consequences of the existence of vertical velocities; detection of horizontal convergence and divergence regions on synoptic charts.

- Synoptic meteorology* : air masses; their sources; their physical characteristics on the surface and in the upper air; their circulation; the phenomena of condensation associated with them; their classification; geographical and thermodynamic classifications and their development; fronts; their formation and development; cold, warm and occluded fronts; secondary cold fronts; fronts and

*To be reduced to essentials for Category B.

temperature; fronts and wind; fronts and clouds; fronts and precipitation; frontal depression of the temperature regions; the incipient depression (wave); the warm sector depression; the occluded depression; the phenomena of condensation (cloud systems) and of precipitation associated with them; families of frontal cyclones; influence of orography on fronts and frontal disturbances; mobile troughs and wedge lines of the pressure field; retrograde depressions; tornadoes; tropical cyclones.

- Atmospheric turbulence; turbulence of mechanical and of thermal origin; turbulent diffusion of heat and of water vapour; effect of the earth's friction on air movement on the synoptic scale; change of wind direction with height in the surface layer (friction layer).

- Local circulation of the air : sea breezes and land breezes; dynamic and thermal action of hills and valleys; height and range of influence of a mountain; orographic clouds; modifications of the thermal field caused by topography; Föhn effect.

- General circulation of the atmosphere; the use of monthly mean isobaric charts at the earth's surface and monthly mean contour charts at 700, 500, 300 and 100 mb levels; average general circulation and instantaneous general circulation, index of zonal circulation, circulation pattern; average general circulation and air masses, introduction of average positions of the polar and Arctic fronts.

- The synoptic observation network; representative value of a meteorological element; synoptic weather charts; fundamental rules and analytical techniques; weather charts and their analysis; synoptic representation of the pressure field; the isobars of a level surface and the contours of an isobaric surface; quasi-static approximation; geopotential (height) of isobaric surfaces and thickness of an isobaric layer; geostrophic approximation; geostrophic wind and thermal wind; pattern and movement of isobars, contours and lines of equal thickness.

- Jet streams : streamlines and isotachs of a jet; the wind field and the temperature field of a jet; tropospheric and stratospheric circulations and jets; the polar front jet; frontal jets; multiple jets; subtropical jets; stratospheric jets; climatography of tropospheric jets.

- Tropical meteorology : representative value of surface and upper-air measurements of meteorological parameters; their daily variation; local factors; general circulation at low latitudes; seasonal variations of the pressure and wind fields; equatorial low pressure areas; intertropical convergence; intertropical front; sub-tropical anticyclones; trade-winds and monsoons; air masses in the tropics and their transformation; penetration of polar air into the tropics; wave-motions of the zonal easterly current; tropical cyclones; squalls; tornadoes; upper front; pressure troughs associated with the zonal westerly circulation; analysis and evolution of stream lines on synoptic charts.

- Elements of atmospheric optics and electricity : refraction, rainbow; halo; corona; blue of the sky; transparency of the atmosphere and visibility; application of notions of static electricity to the

electric field of the atmosphere; atmospheric ions and the conductivity of the air; lightning discharge and thunderstorms.

7.3.2 Meteorological instruments and methods of observation (Category A)

The syllabus for Class IV (section 9.2.2) should be supplemented by the following :

7.3.2.1 Upper-air measurements

- Pilot balloons : lift speed; valve adjustment; inflation; hydrogen generators : principle and use.
- Wind measurement : principles ; description and setting up of the theodolite ; sighting pilot balloons with the theodolite; recording theodolite; analysis and graphic representation of a sounding; meteorological code.
- Measurements relating to clouds : height of cloud base determined by pilot balloon in the daytime and by a cloud searchlight at night; cloud speed and direction determined by using the comb nephoscope; the theodolite used as a nephoscope.
- Data from radiosondes and rawins.

7.3.2.2 Meteorological codes

- Upper-air observation codes; symbolic forms and description of radiosonde and radiowind codes.
- Technical messages (special observation codes, forecast codes, etc.)

7.3.3 Meteorological instruments and methods of observation (Category B)

The syllabus in section 7.3.2 above should be supplemented as follows :

7.3.3.1 Upper-air measurements

- Vertical measurement of air pressure, temperature and humidity : principle of radiosonde, telemetering systems in use, radiosonde : types, description, working, adjustment, preparation for a release; basic equipment of a radiosonde station; day to day functioning and maintenance; release; reception; analysis of the sounding; representation of the sounding on an aerological diagram, computation of altitudes.
- Wind measurement : radio-theodolite and radar; description, working principles; preparation for a release, release, reception, analysis of the sounding, day to day maintenance of the equipment.

7.3.3.2 Meteorological transmissions

- Principles of organizing intercommunication between stations; collection and dissemination of meteorological data; meteorological transmission.

7.3.4 Climatology*

7.3.4.1 General climatology

- Physical, astronomical and geographical factors of climate; climatic elements; succinct notions.

7.3.4.2 Physical climatology

- Notions relating to the radiation, heat energy and water balances; elementary notions on diffusion and turbulence; comparison of normal values and variability of climatic elements at the various latitudes.

7.3.4.3 Dynamical climatology

- General atmospheric circulation; centres of activity and types of climate associated with them; climatological aspects of dynamical meteorology; representation of climatological data.

7.3.4.4 Synoptic climatology

- Grouping of climatic elements according to the nature of the air masses; mean or frequency of climatic elements associated with types of weather; geographical distribution of fronts; frontal zones and air masses and climatological phenomena associated with them.

7.3.4.5 Regional climatology

- Geographical distribution of climates; climatography of the region; numerical data; maps.

7.3.4.6 Meso- and microclimatology

- General principles and concepts; various types of microclimates.

7.3.4.7 Bioclimatology

- General principles; bioclimatology related to human activities (notions).

* To be reduced to essentials for Category B.

7.3.4.8 Applied climatology

- Succinct notions on the application of climatology (agriculture, aeronautics, marine, public works transport, etc.).

7.3.4.9 Climatic changes

- Basic notions.

7.3.4.10 Special climatological methods

- Basic notions.

7.3.4.11 Climatological statistics

- Basic notions.

7.3.4.12 Machine processing of climatological data

- Basic notions.

C H A P T E R 8

FIELDS OF SPECIALIZATION (CLASS III)

8.1 GENERAL

In several fields of specialization, such as dynamic meteorology, physical meteorology, or chemistry and radioactivity of the atmosphere, there is no requirement for Class III personnel. In other fields, such as synoptic meteorology, no further training over and above that given under fundamental meteorological education is necessary. In certain applied fields, however, such as aeronautical meteorology, climatology, agricultural meteorology, hydrometeorology, maritime meteorology, or meteorological instruments, additional training is required. The syllabi for these areas of specialization are given below.

8.2 SPECIALIZATION IN AERONAUTICAL METEOROLOGY (CLASS III)

Observations for aeronautical purposes are characteristically different from those for synoptic purposes. While the synoptic observations aim at determining a representative value for the area concerned, meteorological observations for aeronautical purposes (made for the value to be considered in consequential changes in a rather short period necessary for operational requirements) are taken over rather limited areas such as approach, touch down, take-off area and/or areas along the direction of runway as necessitated by the prevailing present weather and the operational requirements.

8.2.1 Observations peculiar to aviation meteorology

- Surface wind direction and speed, including changes and variations.
- Visibility and runway visual range, including spatial and temporal variations; RVR observations, associated with precision instrument runway systems (ILS, PAR, etc.), by visual means or by use of automatic instruments such as transmissometer.
- Cloud amount, height and type and spatial and temporal variations; ceiling observations using automatic instruments such as ceilometer.
- Accurate pressure measurements for the purpose of determining QFE, QNH.
- Aircraft icing; elementary knowledge of icing types; formation, accretion rates and association of icing with clouds, freezing precipitation, orographic and frontal lifting.

- Turbulence : elementary knowledge of turbulence near the ground as related to topography, air mass stability, clouds, fronts and thunderstorms.

- Elementary knowledge of high-level turbulence (CAT) and its association with wind shear and jet stream.

- Meteorological aspects of flight planning : meteorological basis for pressure pattern flying; meteorological requirements for en-route winds and temperatures; weather and terminal forecasts.

- Interpretation of area, route and terminal forecasts and preparation of material for briefing of flight crews.

8.2.2 Effects of weather elements on ground operations

- Elementary understanding of the operational effects of wind direction and speed and runway temperature on the take-off and landing length of the runway.

- The effects on aerodrome ground services of various weather phenomena such as fog, sandstorm, smoke, hydrometeors, thunderstorms and associated phenomena; squalls; hail; lightning, etc.

8.2.3 Reporting and dissemination of weather information

- Complete knowledge of International Meteorological Codes, especially : METAR, SPECI, PILOT, TEMP, etc., and TAF, ARFOR, ROFOR, FIFOR, etc.

- Knowledge of procedures for dissemination of weather information at the aerodrome.

8.2.4 Aeronautical operational knowledge

Definitions

- Altitude; elevation; height; meteorological information; meteorological report; observation; SIGMET.

- Air-report; briefing; flight level; forecast.

8.2.5 Procedures for meteorological services for international aviation

Elementary understanding of the definitions and procedures listed below:

- Functions of various types of meteorological offices and stations; the part played by the meteorological offices in the exercise of operational control; notification required by meteorological offices; aircraft observations; meteorological watch; dissemination of meteorological information; register of meteorological information requested and issued; dimensional units; ICAO regional supplementary procedures for meteorology.

8.2.6 Air traffic services

- Functions of the air traffic services units, including the part played by these units in the exercise of operational control.

8.2.7 Operation of aircraft

- Definition and significance of aerodrome meteorological minima.
- Definitions of aerodrome elevation, density altitude, instrument runway and landing area.
- Flight planning; in-flight procedure; duties of flight operations officers when exercising operational control; diversion procedures; navigation and landing aids.

8.2.8 International meteorological co-operation

- An introduction to the work of ICAO and WMO.

8.2.9 Regulatory documents

Familiarization with the following documents :

WMO	ICAO	
- Technical Regulations, Chapter 12	- Annex 3 PANS-MET	Doc 7605 - MET/526/4
- Publication No. 9 - TP.4 Volume B - Codes	- Regional Supplementary Procedures	Doc 7030
	- ICAO Abbreviations and Codes	Doc 8400
	- Location indicators	Doc 7910

NOTE - Use has been made of the part dealing with "Aviation Knowledge" of ICAO Doc. 7192-AN/857 PART 6/2, Training Manual, Part 6 - Aeronautical Meteorological Assistants.

8.3 SPECIALIZATION IN CLIMATOLOGY (CLASS III)

8.3.1 Physical geography

- Lithosphere : structure of the earth; crust; core; biosphere; tectonics; secular land changes; folding and the formation of mountains; folds and faults in the earth's crust; reasons for earth-quakes; seismic centre; epicentre; outside exogenous forces altering the surface of the earth; erosion, physical, chemical and organic (biological); erosive and accumulative action of the wind, streams, rivers, snow and ice; the role of endogenous and exogenous factors in the formation of the earth's surface; nature of the coastlines of continents, peninsulas and islands; continental volcanic and coral islands; the main islands and peninsulas of various parts of the world; seas and gulfs; various types of shores; relief and its forms; indication of relief on maps; flat land relief; mountainous relief and its forms; earth's magnetism.

- Hydrosphere : hydrological cycle; oceans and seas; principal ocean currents; water on land; rivers and their basins; river valleys; main rivers of the world; lakes; classification of lakes; principal lakes of the world; glaciers; snow line; glacier movement; role of glaciers in river feed; mountain flood water; avalanches; marshes; formation of marshes; types of marshes.

- Landscape (natural) zones : biosphere; soils; description of natural (landscape) zones; landscape zones of the cold, temperate and tropical zones of the earth, their geographical distribution and brief description of natural conditions; mountainous areas; vertical zonality.

- General physical geographical description of continents; geographical situation, coastline, relief, inland water, soil and flora of continents - Eurasia, North and South America, Africa and Australia, Antarctic.

- Elements of palaeontology, stratification and fossils, historical geology, geological periods.

- Mineralogy and petrography : forms of minerals, systems of crystallization, the various categories of minerals; rocks : eruptive rocks, aqueous rocks, crystallophyllic rocks.

- Topography : instruments and methods of topography; measurement of level differences (contouring), topographic maps, determining the position of a meteorological station on a topographic map.

8.3.2 Climatology

General climatology

- Main climatic elements; elements representative of climate : means, normals, frequencies, deviations.

Physical, dynamical and synoptic climatology

- Comparison of normal values and variability of climatic elements at the various latitudes; notions of general circulation, centres of activity, air masses and types of climate associated with them.

Regional climatology

- Climatic classifications.

Climatological statistics

- Random variable and probability theory : elementary notions of : frequency (absolute-relative); probability (prior-posterior); likelihood; random variable (Von Mises definition); discrete, continuous random variable; climatological series; population sample; application to climatological data.

- Description of populations by means of frequency distributions (climatological prediction) : practical notions of the following topics and use of tables : climatological series; mean recurrence interval; mean; median; mode; quintiles; variance; standard deviation; moments; moment generating function; binomial, Poisson, negative-binomial, multi-nomial distributions; normal distribution.

- Estimation problems : practical notions of : estimation procedures; method of moments; maximum likelihood; least square; minimum chi-square; adjustment of climatological parameters for discontinuities of the station location.

- Test of hypothesis : practical notions on : Student's test; Fisher test; Chi-square test.

- Relationship problems : practical notions of : coefficient of correlation; partial, multiple correlation; regression (linear, non-linear, multiple).

- Time series: practical notions of : test for randomness; test against trend; test for autocorrelation.

- Computation - mathematical tools : practical notion of : digital computer; programming; Fourier analysis; matrix calculus.

8.4 SPECIALIZATION IN AGRICULTURAL METEOROLOGY (CLASS III)

- Biological sciences : an elementary knowledge of appropriate biological sciences.

- Scope of agricultural meteorology : definition, aims; the relationship between weather, climate and agriculture; soils; plants; farm animals; diseases and pests of crops and animals; farm buildings and equipment; artificial modifications of the meteorological and hydrological regime; a short history of agricultural meteorology in relation to the needs of agriculture and the development of meteorological apparatus; national Meteorological Services; the World Meteorological Organization (WMO); the Commission for Agricultural Meteorology (CAgM).

8.4.1 Agrometeorological observations

- Meteorological observations : units; accuracy; importance; exposure of instruments and general rules for the observation of pressure, air temperature, atmospheric humidity, wind, sunshine and radiation; precipitation; evaporation; soil temperature; soil moisture content and soil moisture tension; interpretation and analysis of autographic charts; cloud classification; genera; species and varieties; the synoptic classification; significant cloud; cloud cover; estimation of cloud base; horizontal visibility; existing weather conditions; state of the ground (dew, etc.).

- Biological observations : observations on native plants and on cultivated crops and trees, farm animals, diseases, insect pests, and general activities on the land.

8.4.2 Agrometeorological instruments

- The choice of site for an instrument enclosure; a detailed study of the procedures for installation, maintenance, checking and calibration of the following instruments.

- Pressure : the mercury barometer, method of observation; exposure; transportation and installation; correction of barometer readings to standard conditions; index error; gravity correction; temperature correction; the barograph; the aneroid barometer.

- Surface wind : the pressure plate anemometer; cup and propeller anemometers; the hand anemometer; the totalizing anemometer; contact and generator type of anemometer and anemograph; the pressure-tube anemograph; the hot-wire anemometer; etc.

- Radiation : the exposure and maintenance of the major instruments for measuring short-wave, long-wave, and net radiation; spectral distribution; the measurement of illumination; evaluation of the records.

- Duration of sunshine : sunshine recorders; exposure and installation; maintenance; evaluation of records.

- Temperature : liquid-in-glass thermometers; ordinary thermometers; maximum thermometers; minimum thermometers; soil thermometers; reading a thermometer; electrical thermometers; resistance thermometers; thermo-couples; thermistors; auxiliary electrical equipment; thermographs; the bimetallic type; the Bourdon-tube type; the mercury-in-steel type; thermometer and thermograph exposure; general requirements in order to obtain a representative air temperature; thermometer screens; artificial ventilation; exposure of soil thermometers and grass minimum thermometers; the importance of calibration certificates; possible sources of defects in thermometers and the various procedures to rectify them.

- Atmospheric humidity : psychrometers; simple psychrometer without artificial ventilation; the sling psychrometer; the Assmann-type psychrometer; exposure and observational procedure; care of the wet bulb; operation of wet bulb below freezing; sources of error in psychrometry; the psychrometric formula; tables and slide-rules; hair hygrographs; general requirements; exposure; maintenance and transportation; accuracy and sources of error; washing the hairs; dew-point and frost-point hygrometers; electrical absorption-type hygrometers.

- Precipitation : the ordinary and totalizing raingauges; rainfall recorders; rainfall intensity recorders; snow measurements; depth and density.

- Dew and leaf wetness : the Duvdevani dew block; Leick plates; weighing type of apparatus; leaf wetness recorders.

- Evaporation and evapotranspiration : the main classes of evaporimeter; large evaporation tanks; small evaporation tanks; porous porcelain bodies; porous paper wick devices; lysimeters; exposure; maintenance; scale; observations and entries; calculation.

- Soil moisture content and soil moisture tension : tensiometers; the gravimetric determination of soil moisture content; resistance of porous blocks; the neutron moisture meter.

8.4.3 Processing of agrometeorological data

- Statistics : meaning of an observation; errors of observation; observations as samples of a population; quality control and processing of observation; climatological data; collection; treatment; storage; cataloguing; publication.

- Statistical methods : frequency distributions; relative frequency; cumulative frequency; histogram; statistical parameters; mode; median; quartiles; percentiles; arithmetic mean; standard deviation; variance; weighted and adjusted means; means from grouped data; significance tests; Student's t-test; the X^2 test; regression; significance of a regression coefficient; correlation; significance of a correlation coefficient; analysis of variance.

8.4.4 Microclimatology

- Importance of the air layer near the ground for agriculture; variations of leaf and air temperature; humidity and wind in the microlayer; influence of topography; soil type; soil condition and vegetation on the microclimate.

8.4.5 Soil temperature

- Flow of heat in the soil; diurnal and seasonal variation of soil temperature at different depths; factors affecting soil temperature; the importance of soil temperature for plant growth.

8.4.6 Soil moisture

- The hydrological cycle; the importance of soil moisture for plant growth.

8.4.7 Weather hazards adversely affecting agricultural output

- Droughts : definition; frequency; long-term planning against drought; the possibility of cloud stimulation.

- Hail : frequency of hail storms; hail damange and its prevention.

- Frost : extent of frost damage; sensibility of plants to low temperatures; radiation and advective frosts; taking account of frost in agricultural planning; ways of diminishing frost damage; artificial methods of combating frost damage - e.g. orchard heating, sprinkler irrigation.

- Strong winds : the importance of windbreaks and shelterbelts; the detrimental effects of strong winds on plants, animals and the soil; the effects of windbreaks upon the environment; different types of windbreak; the advantages and disadvantages of shelterbelts; trees and types of shelterbelt suitable for local conditions.

8.4.8 Practical applications

- Practical application of meteorological and climatological data of plants, crops, animals, insects and plant diseases.

8.4.9 Agrometeorological research

- A discussion on research problems applicable to the region or country concerned.

8.4.10 Practical training

- The theoretical course must be supplemented by an intense training in outdoor practical work, especially concerned with the maintenance of instruments and the taking of observations.

8.5 SPECIALIZATION IN HYDROMETEOROLOGY (CLASS III)

A summary of the main findings of the Working Group on Training in Hydrometeorology, set up by the WMO Commission for Hydrometeorology, has already been presented in Chapter 4 (page 80).

Class III hydrometeorological personnel are qualified specialists thoroughly trained in the conduct of all types of hydrological and meteorological observations, the processing of observation data and their preparation for publication in yearbooks or reference books, the installation, checking and field repair of hydrological instruments and equipment, and the management and control of hydrological station networks.

The recommended standard curricula for training Class III hydrometeorological personnel are given below. These are optimum programmes and provide for the study of special subjects, as well as of a large number of general subjects. For this reason, the content of the courses may be modified in the light of circumstances and the qualifications of the students.

8.5.1 Principles of technical drawing

- Geometrical drawing; drawing instruments and equipment; forms of drawings; inscriptions used in drawing; geometrical constructions; scales of drawings; graphs and collation maps; projection geometry; general information on projections; projection methods; projection of a point and straight line; projection of plane figures; projection of geometrical bodies and objects; section of geometrical bodies by a plane surface; mutual intersection of the surfaces of geometrical bodies; axonometric projections; principles of axonometric projections and their classification; construction of axonometric projections; principles of topographic drawing; principles of topographic maps and plans; agreed symbols in topographic drawings; relief and cross-sections; conventional signs in topographical plans; peculiarities of drawings of hydrological structures.

8.5.2 Surveying

- General information; plans and maps; orientation of plans and maps; measurement of azimuths and rhumbs; simple surveying measurements; measurement of lines and vertical angles; angular-theodolite surveys; instruments and the conduct of surveys; processing of angular survey data; geometrical levelling; instruments and the conduct of levelling; processing of levelling data; graphic representation of local relief; plane-table topographic survey; plane-table and alidad; conduct of plane-table surveys;

processing of plane-table survey; data tacheometric survey; instruments for and conduct of survey; processing of tacheometric survey data; barometric levelling and approximation surveys; barometric levelling; approximation surveys; surveying work in hydrological stations; levelling of the longitudinal section of a water surface; levelling of the cross-section of a river valley; altitude relation of the station datum level to the levelling network; levelling of gauging instruments; semi-instrumental and instrumental survey of reaches at hydrological stations; elementary principles of aerial photogrammetry.

8.5.3 Hydrology

- Physical properties of water and the water cycle on the globe : physical properties of water; the hydrological cycle on the earth; ground water; origin and classification of ground water; physical properties of rocks in relationship to water; physical states and movement of ground water; ground water and its relationship to rivers; confined aquifer ground water and its role in the river feeding; lakes and reservoirs; morphology of lakes; sources of inflow to lakes; water balance of lakes; dynamic phenomena on lakes (waves and currents); heat regime of lakes; chemical composition of lake water; biological processes in lakes; reservoirs, their regime and water balance; swamps; formation and classification of swamps; hydrological regime of swamps; formation and movement of glaciers, their influence on river inflow and regime; rivers; river systems; river basins; river valleys and channels; sources of river flow; temperature regime of rivers; regime of river stages; movement of water in rivers; flow velocity; discharge in rivers, hydrograph analysis; sediment transport; chemical composition of river water; channel formation processes; water balance and runoff; units used to measure runoff and flow; water balance of bodies of water; calculation of evaporation from the surface of a basin.

- Average long-term annual runoff : distribution of annual runoff in months and seasons; flow duration curves, mass diagrams and storage behaviour diagrams; maximum discharge and its calculation; minimum flow and its calculation; sediment discharge and its calculation.

8.5.4 Hydrometry

- Water stage and water temperature observations : choice of area for a gauging station and its establishment; observations of water stage and water temperature; processing of observation data; sounding; instruments used for soundings; sounding methods; processing of sounding data; measurement of flow velocity; general notions; velocity at a point; pulsation; instantaneous and average velocity; distribution of velocity in verticals, across and in the plane of the cross-section of the river; instruments for measuring velocity and direction of flow; calibration of current meters; measurement of flow velocity using current meters; calculation of velocity; measurement of discharge; general notions on discharge; methods of measuring discharge; choice of emplacement of the gauging station and its equipment; measurement of

discharge by current meter; measurement of discharge using floats; methods of measuring discharge on small rivers; calculation of flow at hydro-power stations; measurement of suspended sediment and bed load discharge; measurement of suspended sediment calculation of suspended sediment discharge; measurement of bed load; calculation of suspended and bed load discharges; processing of suspended sediment and bed load samples; observations of ice phenomena and of physical properties and chemical composition of water; observations of ice conditions; determination of the physical properties of water; determination of the chemical composition of water; estimation of discharge and sediment transport; plotting of rating curve and calculation of discharge; extrapolation of rating curve; calculation of discharge in unstable channel; calculation of discharge with a variable back water and in channels with vegetation; calculation of discharge at hydro-power station; hydrological observations on reservoirs and lakes; observations of stage and water temperature; observations of transparency, colour and chemical composition of water; observations of wind waves, current and ice phenomena; observations of resistance of reservoir banks; hydrological observations in swamps; technical instructions for hydrological stations and their inspection; organization of field hydrological surveys and technical investigations; basic safety techniques and labour protection rules to be observed in carrying out hydrological surveys on rivers and lakes.

8.5.5 Basic principles of hydrological forecasts

- Collection of hydrological and meteorological data for hydrological information and forecasts; codes for transmission of hydrological and meteorological information and forecasts; processing of hydrological and meteorological data required for hydrological forecasts; basic principles for developing and evaluating the reliability of hydrological forecast methods; physical elements of hydrological forecasts; physico-empirical relationships; correlation relationships; general principles for the evaluation of forecast methods and reliability; permissible error; river regime forecasts; forecasts of stage and discharge on river reaches without tributaries; forecasts of stage and discharge on river reaches with tributaries; forecasts of stage and discharge on the basis of corresponding discharge and amount of water in river channels; general principles of rainfall flood forecasts; general principles of mountain river flow forecasts and ice forecasts.

8.5.6 Elements of hydraulic engineering, water resources management and calculations

- Main types of hydraulic engineering structures; the use of water power; water transport and timber floating; irrigation and drainage; water supply and sewerage systems; water pollution; purification and filtering of waste waters; notions on and elements of water management calculations.

8.6 SPECIALIZATION IN MARITIME METEOROLOGY (CLASS III)

To be prepared by the WMO Commission for Maritime Meteorology.

8.7 SPECIALIZATION IN METEOROLOGICAL INSTRUMENTS (CLASS III)

To be completed by the CIMO Working Group on Training in Instruments and Methods of Observation.

C H A P T E R 9

CURRICULA FOR TRAINING ALL CLASS IV METEOROLOGICAL PERSONNEL IRRESPECTIVE OF THEIR FIELDS OF SPECIALIZATION

9.1 EDUCATION IN THE BASIC SCIENCES (CLASS IV)

The minimum pre-requisite is nine years primary and secondary school education. It is assumed that the student will by then have reached a certain level in mathematics, physics, chemistry and physical geography.

Since countries' educational programmes vary considerably and, thus also, the depth of treatment of the basic sciences, no attempt is made here to set out detailed syllabi in mathematics, physics, chemistry and physical geography. This is left to national educational authorities.

As against that, it is felt that an indication should be given of the general level of knowledge which a student should have reached prior to entering on the study of meteorology : the syllabus on Earth Science given below covers all that a student needs to know before commencing the Class IV course. If a student is weak in some subjects, it is left to the Instructor to decide whether he requires supplementary training.

9.1.1 Earth science

- Structure of the earth : lithosphere; hydrosphere; atmosphere; the structure of the earth's crust; composition of the atmosphere and hydrosphere; shape of the earth; various dimensions of the earth; the shape of the earth as a result of external forces; formation of rocks due to processes within the earth.

- Motions of the earth : rotation of the earth around its axis; revolution of the earth around the sun; various seasons; the cause of tides.

- The gravitational field of the earth; laws of gravitation; measurements of earth's gravity.

- Earth's interior; the distribution of the mass of the earth; the structure of the earth's interior; the temperature of the earth's interior; the state of the earth's interior.

- Magnetic field of the earth; the direction of the magnetic field; the changes of the earth's magnetic field.

- Energy : definition of energy; flow of energy; change of energy; relation between various kinds of energy; conservation of total energy; the source of the energy of the earth.

- Definition of heat and temperature; the flow of heat from the interior of the earth; the energy output from the sun; conversion of mass into energy in the interior of the sun.

- Solar radiation : the radiant energy from the sun; the effect of the atmosphere on the incoming radiation; the distribution of insolation on the earth.

- The causes of the motion of the atmosphere : the effects of the earth's rotation on the winds; the effects of lands and water in modifying the motion of the air.

- Water in the atmosphere : the definition of water cycle; evaporation; condensation; release of the condensed water from the atmosphere; latent heat.

- Waters of the land : the movement of the water in the earth; storage of water in the ground; flow of water over and through the ground; definition of water budget; investigating and interpreting the water budget.

- Sea water : the composition of the sea water; the motion of the sea; waves; transport of energy by waves; winds and water currents; currents caused by differences in density.

- Measurement of time : the definition of time; relative time and measured time; clocks and calendars; geologic clocks; geologic time scales.

- Solar system : planets and their motion; the two distinct groups of planets; difference among planets; asteroids and meteoroids; origin of the solar system; nebular theory.

- Other solar systems : luminosity of the stars; radiation from the stars; movement of the stars in space; stellar temperatures; the origin of the stars; the life history of a star; what is a galaxy; what is the Milky Way; various groups of galaxies.

9.2 METEOROLOGICAL TRAINING (CLASS IV)

The concept of fundamental and specialized training of meteorological personnel as envisaged in previous chapters of the Guidelines does not strictly apply in the case of Class IV meteorological personnel. On the other hand it is true that not all such personnel carry out the same duties; some are engaged in taking synoptic observations and others man agrometeorological or hydrometeorological observing stations. As a result the training of these personnel is more need oriented than for other Classes. Various working groups of the WMO Technical Commissions have proposed appropriate syllabi for training Class IV personnel in specific fields. As far as available these syllabi are quoted below.

For Class IV meteorological personnel who are engaged in taking synoptic observations, the syllabi given in sections 9.2.1, 9.2.2 and 9.2.3 are quite adequate. For aeronautical, climatological, agrometeorological and hydrometeorological observers, these syllabi could be reduced and be supplemented by additional material as given in Sections 9.3 to 9.8.

An important factor in training Class IV meteorological personnel is on-the-job training. Every effort should therefore be made to strengthen this aspect.

9.2.1 General meteorology

- Horizontal and vertical dimensions of the atmosphere - the composition of the atmosphere : dry air and moist air; the meteorological elements; air temperature, atmospheric pressure, density of dry air; moisture content of the air; speed and direction of the wind.

- Heat exchange processes in the atmosphere : radiation; conduction and convection; the air motion; advection and turbulence; mechanical and thermal turbulence (or thermo-convection); the fundamental role of solar radiation in the atmosphere's heat budget; global solar radiation; nocturnal radiation; the influence of clouds on radiation phenomena.

- Air temperature; rudiments of thermometry; the thermometric scales (Celsius, Fahrenheit, Kelvin).

- Thermometers (dry, max., thermograph); their basic principles and handling; air temperature, its horizontal and vertical variations as a function of the time of day and the season of the year; temperature in troposphere and stratosphere; tropopause.

- The effect of gravity on the atmosphere; air density; surface and upper-air pressure; horizontal and vertical variations in pressure:

the hydrostatic equation; significance of pressure gradient; reduction of pressure to sea level; the mercury barometer; its principle, setting up and handling; the aneroid barometer; the standard atmosphere; the barometer used as an altimeter.

- Humidity : density of moist air; evaporation; water vapour pressure; dry vapour and saturated vapour; condensation, freezing, sublimation and solidification; latent heat; moisture indicators : vapour pressure; relative humidity; mixing ratio and dew point; rudiments of cloud, fog and precipitation formation; elementary theory of the wet bulb thermometer; principles of the psychrometer and the hydrometer; visibility, the influence of water vapour, of water drops and dust (aerosols).

- Expansion or compression of a rising or falling air bubble : variation of the bubble's temperature with height; isobaric expansion and adiabatic expansion; the influence of condensation; basic knowledge of the vertical stability or instability; non-saturated air and saturated air.

- Elementary knowledge of synoptic and dynamic meteorology : air motion; significance of scale; the winds and their causes; rudiments of the general circulation in the tropics and in non-tropical regions; local winds; diurnal wind variation (breezes) and annual wind variations (monsoons); relation between the horizontal pressure gradient and the wind; Buys-Ballot's law and the geostrophic wind; cyclones and anticyclones; air masses, their sources and the frontal zones.

9.2.2 Meteorological instruments and methods of observation

Surface observations

- Sunshine recorder : correct position of the instrument according to whether the station is situated North or South of the equator; types of charts used; measurement of sunshine duration.

- Thermometers for measuring the temperature of the air : mercury thermometers and alcohol thermometers; observation hours; correction and coding; meteors; setting; observation hours; bimetallic thermometers; meteorological screens; types and orientation; thermographs; calibrating corrections and analysis.

- Thermometers for measuring water temperature.

- Thermometer for measuring ground temperature at 10, 20 and 50 cm depth; observation hours.

- Mercury barometers : Fortin and Kew; observation hours; reading the barometric height to 0.1 mm; corrections and reduction of the reading to mean sea level; conversion of mm to mb; use of correction tables; coding the corrected and reduced measurement; barograph; barometric tendency and characteristic; barograms; calibration.

- Psychrometer : principle; maintenance; reading of thermometers; use of psychrometric tables; relative humidity and dew point, computation of dew point; coding; hygrograph; diagrams; calibration; corrections and analysis.

- Evaporimeter (Piche) : principle; maintenance; reading; evaporation pans.

- Wind measurement on the surface : wind speed units; methods of observing wind direction; methods of obtaining wind speed; types of anemometers; analysis of anemographs; gustiness; squalls; coding of wind direction and wind speed.

- Direct-measuring raingauges and snow gauges : observation hours and procedures; coding rainfall measurements; recording raingauge; analysis of rainfall curves; rate of rainfall recorder.

- Visibility : horizontal visibility, measured by estimation or using landmarks in the daytime and light sources at night; coding of observed visibility; horizontal, oblique and vertical visibility.

- Clouds : international classification of clouds; general; species and variety of clouds; orographic clouds and special clouds; the meteorological code of clouds; cloud amount; height of cloud base and estimated classification of fog according to its formation; cloud system and cross-sections of cloud systems.

- Hydrometeors : rain; drizzle; snow; snow pellets; snow grains; ice pellets; hail; ice prisms; mist; drifting snow and blowing snow; spray; dew; hoar-frost; rime; glaze (clear ice); water spout; lithometeors; haze (optical haze); sand haze; smoke; drifting and blowing dust or sand; dust (or sand) storm; dust (or sand) whirl; photometeors; halos; corona; irisations; glory; rainbow; electrometeors; lightning; thunderstorm; St. Elmo's fire (polar aurora).

- Principal forms of precipitation and the clouds associated with them; cloud systems; present weather and past weather; meteorological codes of present weather and past weather.

- State of ground and sea.

9.2.3 Climatology

- General climatology : notion of climate; climatic elements (temperature, pressure, wind, humidity, evaporation, sunshine duration, radiation, cloud amount, visibility, state of the sea, state of the ground); hydrometeors; lithometeors; photometeors; electrometeors; elements representative of climate: means, normals, deviation; brief description of the climates of the world; the main climate of the region; daily and monthly climatological reports.

- Microclimatology and bioclimatology : general principles.

- Applied climatology : importance of climatic factors in various human activities.

- Special climatological methods : mechanical computation.

- Exercises in climatology : drafting of monthly climatological bulletins.

9.3 CLASS IV PERSONNEL ENGAGED IN AERONAUTICAL METEOROLOGY

9.3.1 General meteorology

(See section 9.2.1)

9.3.2 Meteorological instruments and methods of observation

(See section 9.2.2)

9.3.3 Climatology

(See section 9.2.3)

9.3.4 Aeronautical meteorological knowledge

Observations for aeronautical purposes are characteristically different from those for synoptic purposes. While the synoptic observations aim at determining a representative value for the area concerned, meteorological observations for aeronautical purposes (made for the value to be considered in consequential changes in a rather short period necessary for operational requirements) are taken over rather limited areas such as approach, touch down, take-off area and/or areas along the direction of runway as necessitated by the prevailing present weather and the operational requirements.

Observations peculiar to aviation meteorology

- Surface wind direction and speed, including changes and variations.
- Visibility and runway visual range, including spatial and temporal variations; RVR observations, associated with precision instrument runway systems (ILS, PAR, etc.), by visual means or by use of automatic instruments such as transmissometer.
- Cloud amount, height and type and spatial and temporal variations; ceiling observations using automatic instruments such as ceilometer.
- Accurate pressure measurements for the purpose of determining QFE, QNH.

Effects of weather elements on ground operations

- Elementary understanding of the operational effects of wind direction and speed and runway temperature on the take-off and landing length of the runway.
- The effects on aerodrome ground services of various weather phenomena such as fog, sandstorm, smoke, hydrometeors, thunderstorms and associated phenomena, squalls, hail, lightning, etc.

Reporting and dissemination of weather information

- Complete knowledge of International Meteorological Codes, especially : METAR, SPECI, PILOT, TEMP, etc., and TAF, ARFOR, ROFOR, FIFOR, etc.

- Knowledge of procedures for dissemination of weather information at the aerodrome.

9.3.5 Aeronautical operational knowledge

Definitions

- Altitude; elevation; height; meteorological information; meteorological report; observation; SIGMET.

- Air-report; briefing; flight level; forecast.

Procedures for meteorological services for international aviation

Elementary understanding of the definitions and procedures listed below:

- Functions of various types of meteorological offices and stations; aircraft observations; dissemination of meteorological information; register of meteorological information requested and issued; dimensional units.

Air traffic services

- Elementary understanding of the functions of the air traffic services units, including the part played by these units in the exercise of operational control.

Operation of aircraft

- Definition and full significance of aerodrome meteorological minima.

- Definitions of aerodrome elevation, instrument runway and landing area.

Regulatory documents

Familiarization with the following documents :

WMO	ICAO	
- Publ. No. 9.TP.4 Volume B - Codes, especially the part dealing with aeronautical meteorological codes	- Annex 3, Attachment A, Aeronautical Meteorological Codes and Notes on their Use	
	- ICAO Abbreviations and Codes	Doc 8400
	- Locations indicators..	Doc 7910

NOTE - Use has been made to a large extent of the part dealing with "Aviation Knowledge" of ICAO Doc. 7192 - AN/857 PART 6/2, Training Manual, Part 6 - Aeronautical Meteorological Assistants.

9.4 CLASS IV PERSONNEL ENGAGED IN CLIMATOLOGY

9.4.1 General meteorology

(see section 9.2.1)

9.4.2 Meteorological instruments and methods of observation

(see section 9.2.2)

9.4.3 Climatology

The syllabus in section 9.2.3 should be supplemented as follows. Particular attention should be paid to the practical aspects of climatology.

- Special climatological methods and practical works : random variable and probability theory: elementary notions of frequency (absolute, relative); description of populations by means of frequency distributions (climatological prediction); practical notions of climatological series, mean, median, mode and standard deviation, and use of tables; relationships problems; practical notions of coefficient of correlation.

9.5 CLASS IV PERSONNEL ENGAGED IN AGRICULTURAL METEOROLOGY

9.5.1 General meteorology

(see section 9.2.1).

9.5.2 Meteorological instruments and methods of observation

(see section 9.2.2).

9.5.3 Climatology

(see section 9.2.3).

9.5.4 Air and soil temperature

- Air temperature measurements; daily and annual variation of air temperature; vertical air temperature distribution; temperature inversions; horizontal distribution of air temperature; charts of isotherms at sea-level and at surface; soil temperature measurements; daily and annual variation of soil temperature; factors influencing soil temperature; influence of air and soil temperature upon plants and the processes of growth; photosynthesis and respiration; resistance of plants to high and low temperature; frost and frost protection.

9.5.5 Water vapour in the atmosphere and soil moisture

- Atmospheric humidity; definitions, significant values, measurements; evaporation; evaporation process; measurement of evaporation from water and land surfaces; transpiration and evapotranspiration; soil moisture, kinds of soil water; agrohydrological soil properties; soil moisture measurements; soil water balance.

9.5.6 Biological measurements (phenology)

- Importance of phenology for meteorology and agriculture; phenological observations; phenological seasons; phenological cartography.

Note : Stress to be laid on observations dealing with practical agriculture.

9.5.7 Agrometeorological stations

- Organization; equipment; measurements; observations; information provided.

9.6 CLASS IV PERSONNEL ENGAGED IN HYDROMETEOROLOGY

9.6.1 General meteorology

(see section 9.2.1)

9.6.2 Climatology

(see section 9.2.3)

9.6.3 Surveying

- General information; plans and maps; scale; type of relief and its representation on plans and maps; cross sections and longitudinal sections; indication of ground points and bench marks; measurement of lines; methods of determining ground distances; simplest instruments; horizontal and vertical surveys; principles of measuring horizontal units; instruments used; principles of levelling; simple levelling and the instrument used; levelling of a guage; processing of gauge data.

9.6.4 Hydrology

- Physical properties of water; the hydrological cycle; hydrographic networks; river basins; river valleys and channels; ground water; origin of ground water and its classification; relationship between surface and ground water; lakes and reservoirs; origin and classification of lakes; basic morphological and hydrological characteristics of lakes and reservoirs; marshes, their origin and hydrological regime; formation and types of glaciers, their influence on river feeding; stream flows, sources of stream flow; thermal regime of rivers; stage regime of rivers; stream velocity in rivers; discharge in rivers; sediments (suspended and bed load); chemical composition of water; elements of the water balance.

9.6.5 Hydrometry

- Water stage observations; types of gauging instruments and their maintenance; datum level; reductions; the conduct and times of observation at gauging stations; initial processing of observation materials; compilation of tables and graphs; observations of water temperature and ice phenomena on rivers; soundings, simple instruments used in sounding and sounding methods; processing of sounding data; compilation of cross-section profiles; measurement of stream velocity; instruments; basic information on stream velocity and its distribution; methods of measuring stream velocity; types and design of instruments used for measuring stream velocity and its direction; maintenance of instruments; equipment of hydrometric station and its maintenance; discharge measurement; discharge measurement methods; methods of processing discharge data; rating curves; calculation of mean daily discharge; the theory of run-off; suspended sediment and bed load discharge measurement; measurement of suspended sediment, types of instruments; methods of measuring bed load; types and design of instruments; initial processing of suspended sediment and bed load discharge measurements; observations of the chemical composition of water; collection and storage

of water samples; first day chemical analysis; basic safety techniques and labour protection rules to be observed in carrying out hydrological observations on lakes and rivers; information activities of the hydrological stations; codes for the transmission of hydrological information; records; maintenance of instruments; installation in stations.

9.7 CLASS IV PERSONNEL ENGAGED IN MARITIME METEOROLOGY

To be prepared by the WMO Commission for Maritime Meteorology.

9.8 CLASS IV PERSONNEL ENGAGED IN METEOROLOGICAL INSTRUMENTS

To be completed by the CIMO Working Group on Training in Instruments and Methods of Observation.

PUBLICATIONS OF THE WMO

Technical publications

WMO – No.

2. TP. 1 – Meteorological services of the world. Bilingual (English and French).
   – Services météorologiques du monde. Bilingue (anglais et français).
5. TP. 2 – Composition of the WMO. 1969 edition. Bilingual (English and French).
   – Composition de l'OMM. Edition 1969. Bilingue (anglais et français).
8. TP. 3 – Guide to Meteorological Instrument and Observing Practices. 3rd edition.
9. TP. 4 – Weather reports: Stations, Codes and Transmissions.
   – Messages météorologiques : Stations, Codes et Transmissions.
17. TP. 5 – Bibliographie météorologique internationale. Année 1952. Fascicules I, II, III, IV.
21. TP. 6 – World distribution of thunderstorm days. Part 1: Tables. Bilingual (English and French).
   – Répartition mondiale des jours d'orage. 1re Partie: Tableaux. Bilingue (anglais et français).
   – World distribution of thunderstorm days. Part 1: Tables. Supplement No. 1. Bilingual (English and French).
   – Répartition mondiale des jours d'orage. 1re Partie: Tableaux. Supplément N° 1. Bilingue (anglais et français).
39. TP. 14 – Guide to Meteorological Library Practice.
   – Guide du bibliothécaire météorologiste.
42. TP. 16 – The forecasting from weather data of potato blight and other plant diseases and pests – The standardization of the measurement of evaporation as a climatic factor.
47. TP. 18 – International list of selected, supplementary and auxiliary ships. Bilingual (English and French). 1966 Edition.
   – Liste internationale de navires sélectionnés, supplémentaires et auxiliaires, bilingue (anglais et français). Edition 1966.
21. TP. 21 – World distribution of thunderstorm days. Part 2: Tables of marine data and world maps. Bilingual (English and French).
   Répartition mondiale des jours d'orage. 2e Partie : Tableaux des données maritimes et cartes mondiales. Bilingue (anglais et français).
56. TP. 22 – Regional charts of meteorological observing station networks – Region VI – Europe. Bilingual (English and French). 1st edition.
   – Cartes régionales des réseaux de stations d'observation météorologiques – Région VI – Europe. Bilingue (anglais et français). 1re édition.
63. TP. 23 – Notes on the problems of cargo ventilation.
56. TP. 24 – Regional charts of meteorological observing station networks – Region I – Africa. Bilingual (English and French). 1st edition.
   – Cartes régionales des réseaux de stations d'observation météorologiques – Région I – Afrique. Bilingue (anglais et français). 1re édition.
66. TP. 25 – Les diagrammes aérologiques.
68. TP. 26 – Aviation aspects of mountain waves.

WMO – No.

72. TP. 28 – The climatological investigation of soil temperature – Measurement of evaporation; humidity in the biosphere and soil moisture.
77. TP. 31 – Turbulent diffusion in the atmosphere.
82. TP. 32 – Design of hydrological networks – Techniques for surveying surface-water resources.
56. TP. 33 – Regional charts of meteorological observing station networks – Region V – South-West Pacific. Bilingual (English and French). 1st edition.
   – Cartes régionales des réseaux de stations d'observation météorologiques – Région V – Pacifique Sud-Ouest. Bilingue (anglais et français). 1re édition.
56. TP. 34 – Regional charts of meteorological observing station networks – Region III – South America. Bilingual (English and Spanish). 1st edition.
   – Cartes régionales des réseaux de stations d'observation météorologiques – Région III – Amérique du Sud. Bilingue (anglais et espagnol). 1re édition.
56. TP. 36 – Regional charts of meteorological observing station networks – Region IV – North and Central America. Bilingual (English and Spanish). 1st edition.
   – Cartes régionales des réseaux de stations d'observation météorologiques – Région IV – Amérique du Nord et Amérique centrale. Bilingue (anglais et espagnol). 1re édition.
90. TP. 37 – Seasonal peculiarities of the temperature and atmospheric circulation regimes in the Arctic and Antarctic.
94. TP. 38 – Upper-air network requirements for numerical weather prediction – Rapport préliminaire du Groupe de travail de la CMS sur les réseaux.
96. TP. 40 – Meteorological service for aircraft employed in agriculture and forestry.
97. TP. 41 – Meteorological aspects of the peaceful uses of atomic energy. Part I – Meteorological aspects of the safety and location of reactor plants.
56. TP. 42 – Regional charts of meteorological observing station networks – Region II – Asia. Trilingual (English–French–Russian). 1st edition.
   – Cartes régionales des réseaux de stations d'observation météorologiques – Région II – Asie. Trilingue (anglais–français–russe). 1re édition.
98. TP. 43 – The airflow over mountains.
100. TP. 44 – Guide to Climatological Practices.
   – Guide des pratiques climatologiques.
106. TP. 45 – Techniques d'analyse et de prévision des champs de vent et de température à haute altitude.
108. TP. 46 – Ozone observations and their meteorological applications.
109. TP. 47 – Aviation hail problem – Turbulence in clear air and in cloud – Ice formation on aircraft – Occurrence and forecasting of Cirrostratus clouds.
110. TP. 48 – Climatic aspects of the possible establishment of the Japanese beetle in Europe – Forecasting for forest fire services.
111. TP. 49 – Meteorological factors influencing the transport and removal of radioactive debris.

NOTE: Publications in the "Technical Note" series not appearing in this list are out of print, and will not be reprinted.

WMO – No.

113. TP. 50 – Weather and Food.
– Le temps et la production alimentaire.
– El tiempo y la alimentación.

114. TP. 51 – Guide to Qualifications and Training of Meteorological Personnel employed in the Provision of Meteorological Services for International Air Navigation.
– Guide des qualifications et de la formation du personnel météorologique employé à la protection météorologique de la navigation aérienne internationale.

117. TP. 52 – Climatological Normals (CLINO) for CLIMAT and CLIMAT SHIP stations for the period 1931–1960. Bilingual (English and French).
– Normales climatologiques (CLINO) relatives aux stations CLIMAT et CLIMAT SHIP pour la période 1931–1960. Bilingue (anglais et français).

118. TP. 53 – Numerical methods of weather analysis and forecasting.

119. TP. 54 – Performance requirements of aerological instruments.

124. TP. 55 – Methods of forecasting the state of sea on the basis of meteorological data – Precipitation measurements at sea.

126. TP. 56 – The present status of long-range forecasting in the world.

127. TP. 57 – Catalogue of Ozone Stations. Bilingual (English and French).
– Catalogue des stations d'observation de l'ozone. Bilingue (anglais et français).

131. TP. 58 – Reduction and use of data obtained by TIROS meteorological satellites.

132. TP. 59 – The problem of the professional training of meteorological personnel of all grades in the less-developed countries.
– Le problème de la formation professionnelle du personnel météorologique de tous grades dans les pays insuffisamment développés.

133. TP. 60 – Protection against frost damage.

134. TP. 61 – Guide to Agricultural Meteorological Practices.
– Guide des pratiques de météorologie agricole.

135. TP. 62 – Automatic weather stations.
– Stations météorologiques automatiques.

136. TP. 63 – The effect of weather and climate upon the keeping quality of fruit.

138. TP. 64 – Meteorology and the migration of Desert Locusts. Applications of synoptic meteorology in locust control.

140. TP. 65 – The influence of weather conditions on the occurrence of apple scab.

141. TP. 66 – A study of agroclimatology in semi-arid and arid zones of the Near East.
– Une étude d'agroclimatologie dans les zones arides et semi-arides du Proche-Orient.

143. TP. 67 – Weather and Man.
– Le temps et l'homme.
– El tiempo y el hombre.

146. TP. 69 – Tidal phenomena in the upper atmosphere.

147. TP. 70 – Windbreaks and shelterbelts.

115. TP. 71 – Guide to the Preparation of Synoptic Weather Charts and Diagrams.
– Guide pour la préparation des cartes et des diagrammes de météorologie synoptique.

WMO – No.

152. TP. 72 – Report on meteorological training facilities.
– Rapport sur les possibilités de formation météorologique.

153. TP. 73 – Meteorological soundings in the upper atmosphere.

154. TP. 74 – Note on the standardization of pressure reduction methods in the international network of synoptic stations.

155. TP. 75 – Problems of tropical meteorology.

156. TP. 76 – Sites for wind-power installations.

159. TP. 77 – High-level forecasting for turbine-engined aircraft operations over Africa and the Middle East.

160. TP. 78 – A survey of human biometeorology.

162. TP. 79 – WMO-IUGG Symposium on Research and Development Aspects of Long-Range Forecasting.

165. TP. 80 – The present situation with regard to the application of numerical methods for routine weather prediction and prospects for the future.

166. TP. 81 – Meteorology in the Indian Ocean.

168. TP. 82 – Guide to Hydrometeorological Practices.
– Guía de prácticas hydrometeorológicas.

169. TP. 83 – Meteorological aspects of atmospheric radioactivity.

170. TP. 84 – Short-period averages for 1951–1960 and provisional average values for CLIMAT TEMP and CLIMAT TEMP SHIP stations. Bilingual (English and French).
– Moyennes portant sur de courtes périodes (1951–1960) et valeurs moyennes provisoires relatives aux stations CLIMAT TEMP et CLIMAT TEMP SHIP. Bilingue (anglais et français).

171. TP. 85 – Meteorology and the Desert Locust.

174. TP. 86 – Catalogue of meteorological data for research (Part I).

176. TP. 87 – The circulation in the stratosphere, mesosphere and the lower thermosphere.

178. TP. 88 – Statistical analysis and prognosis in meteorology.

179. TP. 89 – The preparation and use of weather maps by mariners.

180. TP. 90 – Data processing in meteorology.

182. TP. 91 – International Meteorological Vocabulary. Quadrilingual (English – French – Russian – Spanish).
– Vocabulaire météorologique international. Quadrilingue (anglais – français – espagnol – russe).

183. TP. 92 – World Weather Watch.
– Veille météorologique mondiale.
– Vigilancia meteorológica mundial.
– Всемирная служба погоды.

186. TP. 93 – Manual of aerodrome meteorological office practices.
– Manuel du fonctionnement des centres météorologiques d'aérodrome.

188. TP. 94 – International meteorological tables.
– Tables météorologiques internationales.

189. TP. 95 – Data-processing by machine methods.

190. TP. 96 – The use of satellite pictures in weather analysis and forecasting.

191. TP. 97 – Instruments and measurements in hydrometeorology.

192. TP. 98 – Lower troposphere soundings.

193. TP. 99 – Use of ground-based radar in meteorology (excluding upper-wind measurements).

WMO – No.

195. TP. 100 – Climatic change.
196. TP. 101 – Utilization of aircraft meteorological reports.
197. TP. 102 – Manual on meteorological observing in transport aircraft.
199. TP. 103 – Some methods of climatological analysis.
200. TP. 104 – Automatic weather stations — Technical Conference, Geneva, 1966 (Contributions in English or French).
201. TP. 105 – Measurement and estimation of evaporation and evapotranspiration.
202. TP. 106 – Syllabi for instruction in agricultural meteorology.
204. TP. 107 – Weather and water.
– Le temps et l'eau.
– El tiempo y el agua.
– Погода и водные ресурсы.
208. TP. 108 – A note on climatological normals.
209. TP. 109 – Précisions des mesures pyrhéliométriques (contributions en anglais et français).
210. TP. 110 – An agroclimatology survey of a semiarid area in Africa south of the Sahara.
– Etude agroclimatologique dans une zone semi-aride en Afrique au sud du Sahara.
211. TP. 111 – Polar meteorology.
212. TP. 112 – Aeronautical meteorology in Latin America.
217. TP. 113 – Basic synoptic networks of observing stations.
216. TP. 114 – Meteorological problems in the design and operation of supersonic aircraft.
218. TP. 115 – The nature and theory of the general circulation of the atmosphere.
219. TP. 116 – Training of hydrometeorological personnel.
220. TP. 117 – Harvest from weather.
– Les récoltes du ciel.
– El tiempo y las cosechas.
– Погода и урожай.
223. TP. 118 – Problem workbook for the training of class III meteorological personnel. (English – French – Arabic)
225. TP. 119 – Measurement of peak discharge by indirect methods.

WMO – No.

226. TP. 120 – Methods in use for the reduction of atmospheric pressure.
227. TP. 121 – Aeronautical meteorology.
228. TP. 122 – Hydrological forecasting.
230. TP. 123 – Vertical wind shear in the lower layers of the atmosphere.
231. TP. 124 – The measurement of atmospheric radioactivity.
232. TP. 125 – Instrument development inquiry.
233. TP. 126 – Estimation of maximum floods.
234. TP. 127 – Air pollutants, meteorology, and plant injury.
235. TP. 128 – Practical soil moisture problems in agriculture.
237. TP. 129 – Manual for depth-area-duration analysis of storm precipitation.
238. TP. 130 – Meteorological factors affecting the epidemiology of wheat rusts.
240. TP. 131 – Report on meteorological training facilities.
– Rapport sur les possibilités de formation météorologique.
242. TP. 132 – Data processing for climatological purposes.
243. TP. 133 – Meteorology and grain storage.
246. TP. 134 – Seiches et dénivellations causées par le vent dans les lacs, baies, mer, estuaires.
247. TP. 135 – Sea-surface temperature (Contributions in English, French or Russian).
248. TP. 136 – Proceedings of the WMO/IUGG symposium on radiation, including satellite techniques. *In preparation.*
249. TP. 137 – Artificial modification of clouds and precipitation.
250. TP. 138 – International noctilucent cloud observation manual. *In preparation.*
251. TP. 139 – Meteorological aspects of air pollution (Contributions in English or French).
253. TP. 140 – Meteorological observations in animal experiments. *In preparation.*
254. TP. 141 – Urban climate. *In preparation.*
255. TP. 142 – Building climatology. *In preparation.*
257. TP. 143 – How to become a meteorologist ? *In preparation.* (English – French – Russian – Spanish).

Other series of publications issued by the WMO Secretariat : Basic documents, Records, Reports *and the* WMO Bulletin.