Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology

Volume I – Meteorology

2023 edition

WEATHER CLIMATE WATER

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WMO-No. 1083

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EDITORIAL NOTE

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FOREWORD

This guide constitutes the next edition of the *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology* (WMO-No. 1083). It is the result of a three-year process that began with a meeting held in Geneva in November 2018 to discuss the results of a survey and position papers from several stakeholder groups. At the meeting, a review team was formed to consider how to implement the changes identified.

The purpose of this document is to establish a common understanding of the qualifications required for individuals to be recognized as meteorologists or as meteorological technicians, as defined in the *Technical Regulations* (WMO-No. 49), Volume I, and to assist the National Meteorological and Hydrological Services (NMHSs) in establishing their personnel classifications and educational programmes to bring them in line with international standards. Organizations are expected to adapt or extend, to match their local and regional circumstances, the minimum core knowledge in the Basic Instruction Packages contained in this guide. This will empower individuals to meet the knowledge, skill and behavioural requirements for the specific tasks they must perform in their positions within their organization.

A key focus of this edition has been to update the Basic Instruction Package for Meteorological Technicians (BIP-MT). In previous editions, the Basic Instruction Package for Meteorologists (BIP-M) has received greater attention, probably owing to its complexity and sensitivity to external drivers. This edition focuses at least as much on BIP-MT as on BIP-M, based on the abovementioned survey and the unprecedented amount of feedback from the stakeholder groups. It is intended that the resulting guidance in part 3 of this document will assist NMHSs to achieve consistency in the classification of their meteorological technicians and compliance with qualification standards as set out in the *Technical Regulations* (WMO-No. 49), Volume I, Part V.

I express my gratitude to the review teams led by Colleen Rae (South Africa), Steven Callaghan (United Kingdom), Christopher Webster (New Zealand) and Winifred Jordaan (South Africa), for their long-term commitment and dedication to this new edition. I extend my gratitude to the team members: Diakaria Kone (the Niger), Moira Doyle (Argentina), John Peters (British Caribbean Territories), Noer Nurhayati (Indonesia), Anna Timofeeva (Russian Federation), Peter Odjugo (Nigeria), Yao Xiuping (China), Somenath Dutta (India), Kevin Scharfenberg (United States of America), Peter Davidson and Mick Pope (Australia), and Isabelle Beau and Ludovic Bouilloud (France). I would also like to thank the advisers Robert Riddaway, Sally Wolkowski and John Methven (United Kingdom), and all who contributed to the development of this document, in particular the directors of Regional Training Centres (RTCs) and others who reviewed the first and subsequent drafts and whose valuable input has made this document a far better product. Finally, I thank the WMO Secretariat coordinating team lead by Dr Yinka Adebayo, with the support of Dr Patrick Parrish (retired), Ms Luciane Veeck and Mr Mustafa Adiguzel of the Education and Training Office.

Prof. Petteri Taalas
Secretary-General

1. INTRODUCTION

The Basic Instruction Package for Meteorologists and the Basic Instruction Package for Meteorological Technicians (hereafter referred to as BIP-M and BIP-MT respectively) define the educational requirements of those studying to become a meteorologist and meteorological technician. It is by attaining the outcomes contained in BIP-M and BIP-MT that somebody qualifies as a meteorologist or meteorological technician according to the definitions in the *Technical Regulations* (WMO-No. 49). On completion of the Basic Instruction Package (BIP), a meteorologist or meteorological technician will have demonstrated – through the study and application of the atmospheric sciences – the ability to apply, develop and communicate that science professionally for the benefit of society.

The competencies and skills required of meteorologists working in diverse fields, including research, consultancy and operational forecasting, will often be highly localized to a certain region, country, service, etc. Similarly, the competencies and skills required of meteorological technicians working in diverse fields, including meteorological observing, instrumentation and climate-data control, will often be localized. These competencies and skills will evolve quickly as science, technology and service provision change. The role of BIPs is to provide the underlying knowledge and skills common to all meteorologists and meteorological technicians that they can use as a platform to develop the necessary skills and competencies for specific roles and continue to learn throughout their careers.

This edition remains focused on specifying the learning outcomes required by meteorologists and meteorological technicians of all types, including underlying knowledge and skills common to the WMO competency frameworks. At the same time, it explicitly provides latitude for institutions, WMO Members and employers to tailor learning outcomes to the nature of the course of study or national needs. This creates a seemingly contradictory set of requirements: how is it possible to maintain an international standard while maintaining the necessary pragmatism and flexibility?

In the last major review of BIPs, the *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258) were replaced by the *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology* (WMO-No. 1083), Volume I: "Meteorology". At the core of this change was a move from a system of personnel classification and associated syllabuses to a system based on learning outcomes – in other words, a move to a system in which the learner's attainment was central. This edition goes further, abstracting the essence of what all meteorologists and meteorological technicians must be able to do into a set of overarching learning outcomes while making it explicit that the role of the more detailed outcomes is to guide rather than to restrict institutions.

1.1 BIPs in context

Since the publication of the previous edition of these guidelines, attainment of BIP-M[1] has been mandatory for meteorologists who provide services to civil aviation (as aeronautical meteorological forecasters, or AMFs), which naturally means there is more focus on the contents of BIP-M itself. At the same time, much work has been done to define the role of job competencies and competency frameworks, notably in aviation forecasting and observing, other forecasting, climate services, instrumentation and observing. The community has also started to develop skills frameworks such as in satellite and radar meteorology. WMO has published these in a *Compendium of WMO Competency Frameworks* (WMO-No. 1209).

It is the acquisition of skills and competencies, either as described in the competency frameworks or as defined by employers or training institutions such as universities, that mark somebody as being a competent professional. Achieving the learning outcomes as specified in BIP-M or

[1] Or at least those elements directly relevant to the work of aeronautical meteorological forecasters. See the *Technical Regulations* (WMO-No. 49), Volume I, Part V.

BIP-MT is a pre-requisite to gaining workplace competence. However, BIP-M and BIP-MT do not define job competencies and are thus insufficient by themselves to prepare someone to do a particular job.

It is recognized that there are a number of pathways for meteorological education and training to lead someone to become a professional meteorologist or meteorological technician. Many education and training programmes will contain a combination of the underpinning atmospheric science and other outcomes (from BIP-M and BIP-MT) and skills (from the skills frameworks). Programmes will likely also include other complementary academic subjects, often related to the interests of the institution, or even significant portions of the competencies needed for certain jobs (from the competency frameworks).

Institutions and employers must define an overall set of learning outcomes that meet national needs, using BIP-M or BIP-MT as the foundation. WMO Members are encouraged to work with educational institutions to ensure education programmes are designed with the future employability of students and the human resources needs of NMHSs in mind by considering the need to include the application of the science as described in the competency frameworks.

The key aims of this edition of BIP-M and BIP-MT are:

- To place BIPs in the context of an overall framework for education and training, encompassing educational foundations, skills and competency frameworks.

- To ensure BIPs meet the needs of diverse and evolving job roles and provide clarity and guidance on how to apply BIPs to these roles, with standard skill and competency frameworks being central for many of them.

- To meet the needs of the entire global meteorological community, regardless of size or level of development. In particular to remove barriers to the education and training of meteorologists and meteorological technicians, who are vital to the delivery of operational services to key industries such as aviation.

- To be flexible enough to meet future needs in a rapidly evolving world.

- To maintain the intellectual rigour of BIPs so that, although the packages will be designed for people to enter roles related to research or operations, they will continue to offer an attractive option for those wanting a grounding in a numerate, physically based, Earth-science subject.

- To minimize the work needed to validate or change existing programmes while clearly highlighting the necessary changes.

Details of how these aims were achieved are discussed in the sections that follow.

1.2 Main changes to this edition

1.2.1 *A hierarchy of learning outcomes*

To ensure that BIPs are not misinterpreted as being made up of a series of related but disconnected topics, a set of overarching learning outcomes[2] has been developed that summarize the demonstrable abilities of meteorologists and meteorological technicians. These overarching outcomes are intended to provide the "glue" that connects the educational learning outcomes and to encourage holistic education and training programmes in which interconnections between the various components are made explicit and the application of our science to solving real-world problems is central.

2 The phrase "overarching learning outcomes" is defined in section 1.6.

The value to students of contextualizing and applying their learning as they go, in terms of retention and transfer, is well known.[3] Through the overarching learning outcomes, BIPs will encourage this in line with the ideas of Rossby (1934), who wrote:

> It would seem, then, that the principal task of any meteorological institution of education and research must be to bridge the gap between the mathematician and the [practitioner], that is, to make the weather [expert] realize the value of a modest theoretical education and to induce the [theoretician] to take an occasional glance at the weather map.[4]

The changes made during the most recent major revision of BIPs included replacing a list of topics with a system of learning outcomes. We have continued and extended this work, and made the learning outcomes explicitly state what is expected of a meteorologist or meteorological technician by the end of an academic programme that is compliant with BIP-M or BIP-MT. Part of this work – particularly with respect to BIP-M – has focused on higher-order cognitive processes so that students' and instructors' minds focus on the application of the science to real-world problems across domains and across spatial and temporal scales.

To support the shift in emphasis of certain learning outcomes, we added a short section explaining the philosophy used and the intended meaning of certain verbs used in the outcomes.

1.2.2 Reducing barriers to access

The messages received from WMO Members in the survey included the need to minimize the burden – whether real or perceived – that BIPs place on educators, learners and employers. Education opportunities in meteorology could be improved by reducing burdens or barriers to access resulting from geographical location, financial considerations or work and family commitments that make attending full-time and off-site courses impossible.

Some WMO Members also highlighted what they considered to be an overly theoretical tone in places, which they said was out of touch with the human resource needs of NMHSs. The comments touched upon the overall size of BIPs and the relevance and nature of specific sections.

Rather than remove topics wholesale (there was no consensus as to which topics were unnecessary), several approaches have been taken:

- The information on the knowledge and thinking skills required of meteorologists and meteorological technicians is more specific.

- A range of methods is given for teaching and assessing the learning outcomes so that the document is not inadvertently prescriptive.

- Alternative approaches to meeting the learning outcomes are described, such as through the WMO Global Campus, which provides a platform and reference material.

Another way to reduce barriers to careers in meteorology is by making the programmes accessible and inclusive to all members of society, as discussed in section 1.9, on inclusive teaching and assessment.

1.2.3 *Bringing BIPs in line with national needs*

Later sections of part 1 contain a discussion on the application of the learning outcomes to building a programme of study, including restating the fact that how outcomes are achieved is a decision that should be made by institutions and individual instructors based on their specific national or regional needs. This structure allows for a spectrum of implementations

[3] See, for example, Hoffman, et al., 2017.
[4] The square brackets in this quotation improve the gender balance of the original text.

of BIPs. For example, BIP-M may take highly mathematical or theoretical approaches geared towards research careers, or it may take more qualitative but still rigorous approaches that meet the needs of NMHSs to have people who can apply meteorology to support customers in an operational setting.

A new section (1.8) briefly explains a process that can be used to map BIPs into a curriculum suited to national needs.

1.2.4 *Influencing best practice in teaching, learning and assessment*

A short section has been added (in 1.6) to highlight the continuing need to embed evidence-based teaching and assessment practices into meteorological education and training.

1.2.5 *Future-proofing BIPs*

Later sections (2.5 and 3.5) include a set of professional learning outcomes to give institutions guidance on areas such as communication skills and information technology, of which students must learn certain aspects to achieve the overarching outcomes.

Also included in these sections are outcomes associated with the skills of current and future meteorologists and meteorological technicians for which there is no separate competency framework. For meteorologists, these skills include research and data science. These sections are intended to act as the basis for discussion and course development to meet the needs of these roles. Institutions are encouraged to provide opportunities for students to learn these skills and complementary topics such as business and management that will aid their future career progression.

1.2.6 *Review process of BIP-M and BIP-MT*

It is important to keep BIPs and associated guidance up to date as the science, technology and practice of meteorology evolve. Additionally, it is recognized that, despite the meticulous care taken in the preparation of this edition, some errors or omissions might be discovered after publication.

To meet these needs, a review process has been drawn up that will allow WMO Members to propose corrections and amendments and for a more proactive assurance review to be held regularly.

The General Provisions section of the *Technical Regulations* (WMO-No. 49) includes the process to be followed to make changes to standard practices, including to BIPs. The process to be carried out is as follows:

– The Education and Training Office will request and collate suggestions for amendments from WMO Members.

– Should evidence emerge of the need or desire to amend BIPs, the Education and Training Office will task an expert team to consider and report on the changes.

– Should no proposals for amendments be received from WMO Members, a regular review will be undertaken by an appointed expert team at eight-year intervals to consider whether BIPs need to be updated.

– If changes are recommended by the expert team, broad consultations will take place on the amended BIPs, and if the changes are supported, they will be put forward for approval by Congress.

The guidance in this volume does not form part of the *Technical Regulations* (WMO-No. 49), but corrections or amendments do need to be approved by the Executive Council. To facilitate the necessary changes to this guidance, the Education and Training Office will:

– Collate suggestions for corrections or amendments from WMO Members.

– Maintain and publish updates every two years for changes that are minor and non-contentious.

– Conduct a thorough review of the guidance alongside the eight-yearly review of BIPs, as described above.

1.3 Transitioning to this edition

In preparing this edition of BIP-M and BIP-MT, we considered additional work that institutions might have to do to ensure their programmes remain compliant. Many institutions adopted the previous edition only fairly recently and doing so was a major undertaking for them.

It is hoped that immediate changes to existing programmes will not be necessary following the publication of this edition. Instead, the philosophy of holistic and pragmatic learning encapsulated by the overarching learning outcomes and the amended educational outcomes should be used when modules, courses or programmes undergo routine review as part of local quality-assurance processes.

1.4 Purpose and nature of BIP-M and BIP-MT

BIP-M and BIP-MT define the essential knowledge that all professional meteorologists and meteorological technicians must acquire and how they need to be able to think and act using that knowledge. As such it must reflect the role of meteorologists and meteorological technicians of all types, whether they are developing the science or practice of meteorology or applying that science to the benefit of society.

Professionals in any field are identified not necessarily by what they do, but by why they do it. They take certain actions rather than others by having deliberated on the matter and having made an informed decision based on their knowledge of the domain and the critical-thinking skills they have developed.[5] For this reason, BIPs mandate that, in addition to atmospheric science, students learn an array of applied professional knowledge; BIP-M, in particular, focuses on higher-order cognitive skills rather than specifying declarative knowledge to be covered in a syllabus.

People arriving at an NMHS, Regional Training Centre (RTC), university or other institution to learn meteorology will have a wide range of prior education, exposure to weather and climate science, and reasons for choosing their path. They will also go on to embark on a wide spectrum of careers, both in meteorology and other fields, including research, consultancy, instrumentation and forecasting. BIPs cannot define learning that meets the individual needs of all these learners or the requirements of all career paths. By necessity, this document must make certain assumptions about the general level of prior education while providing guidance on which areas – such as mathematics and physics – are essential to gain an understanding of atmospheric science.

This publication cannot, and does not attempt to, define the detailed skills and competencies needed in particular branches of professional practice, such as forecasting, observing and research. It is expected that additional and more specific education and training is needed beyond or alongside BIPs for somebody to be able to take up a professional role unsupervised. More details on how to achieve this for some of these contexts is contained in other WMO publications, as described in section 1.10 ‘Case studies in the application of BIPs’.

[5] See, for example, Biggs & Tang, 2011, p. 160–161.

1.5 Meeting the needs of the meteorological community

A key driver for the current revision of BIPs was the desire to remove obstacles – whether real or perceived – to the education and training of meteorologists and meteorological technicians to meet the needs of society. One of those obstacles identified by WMO Members was the range of learning outcomes contained within BIPs. Some said there were too many outcomes, or that the outcomes were too academic; others wanted additional topics to be introduced or existing topics to be covered in greater depth.

Because the time available for education and training programmes is finite, considerations of breadth versus depth in curriculum design become critical. Robustly covering a broad syllabus in its entirety would be expensive, and much of the knowledge imparted would be covered only briefly and would quickly be forgotten. The developmental psychologist Howard Gardner said (Brandt, 1993) that "[t]he greatest enemy of understanding is coverage. As long as you are determined to cover everything, you actually ensure that most … are not going to understand."

One of the pressing needs of the WMO community today is the shortage of BIP-M-qualified forecasters,[6] particularly in the aviation sector. Least developed countries in particular, but also many other countries, rely on university courses in more developed countries to educate and train people who will meet their urgent needs for forecasters. In the context of BIP-M and BIP-MT, the study of meteorology as an academic discipline remains essential to maintain the vigour of meteorological research and development of meteorological practice, so the global education and training system must be flexible enough to meet the human resource needs of both research and operations.

This edition of BIPs has been designed to be applied flexibly to respond fully to this conundrum. Certain overarching learning outcomes that are applicable to all countries are mandatory. With the more specific outcomes, WMO Members and their education institutions are explicitly required to apply them flexibly to meet their particular needs; detailed guidance on how to do so is provided below.

It is incumbent on the global education and training community to ensure that programmes of study meet the needs of those who will apply meteorological science to the needs of people, businesses and society in the many service-delivery roles, including what is traditionally thought of as the role of the forecaster or technician. In the case of BIP-M, few universities offer courses in forecasting or other applied areas of meteorology (Hoffman, et al., 2017, p. 55), leaving post-employment training to fill the gap, if employers have the capability to provide it. It is hoped that making BIPs more flexible will allow more programmes to emerge to bridge the divide between academic study and on-the-job competencies.

1.6 Structure of BIP-M and BIP-MT

A new set of overarching learning outcomes[7] has been developed that lays out in broad terms the philosophy of BIP-M and BIP-MT by defining the knowledge and set of abilities that are common to all meteorologists and those that are common to all meteorological technicians. These outcomes will be achieved through the learning and assessment of atmospheric science and related topics.

The previous version of BIP-M grouped learning outcomes under five headings: foundation topics in mathematics, physics and complementary subjects; physical meteorology; dynamic meteorology; synoptic and mesoscale meteorology; and climatology. This remains a logical and useful division of the main learning outcomes and is largely retained for convenience (with a slight change of emphasis). Nevertheless, changes have been made to the outcomes within these sections in terms of the content and the cognitive level.

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[6] The terms "forecaster" and "operational meteorologist" are treated as synonyms here. "Forecaster" and "forecasting" are used for the sake of brevity. It is widely acknowledged that forecasters' roles have evolved. They now undertake a wider range of tasks, many of which go beyond those traditionally considered forecasting tasks.

[7] The notion of "overarching learning outcomes" is defined in the section 1.6.1.

The previous version of BIP-MT grouped learning outcomes under the headings of foundation topics in mathematics, physics and complementary subjects; basic physical and dynamic meteorology; basic synoptic and mesoscale meteorology; basic climatology; and meteorological instruments and methods of observation. As with BIP-M, the foundation topics are largely retained but with a change of emphasis. The remaining learning outcomes are reorganized into eight mandatory topics: basic geography and oceanography; basic hydrology; basic physical, dynamic, synoptic and mesoscale meteorology; global and local climatology; cloud formation; communication; IT skills; meteorological parameters; and climate-data quality control. In addition there are the selective specializations: meteorological technician (usually based on the relevant competency criteria), aeronautical meteorological observer, meteorological instrument technician, air-quality instrument technician, marine meteorological observer, climate-data controller, and public/marine forecasting technician.

The hierarchy of outcomes is presented in Figure 1(a) and 1(b). At the top of the hierarchy sit the competency frameworks as defined in the *Compendium of WMO Competency Frameworks* (WMO-No. 1209). The *Guide to Competency* (WMO-No. 1205) describes more fully the relationships between the competencies required for a given job role and qualifications required to enter a profession. The competency frameworks should be the primary guide to assess whether an individual is competent for any given role, and the *Guide to Competency* (WMO-No. 1205) should be consulted for guidance in using the frameworks.

Although the learning outcomes are presented in several distinct sections, there are connections within and among the sections. For instance, meteorologists and meteorological technicians must be able to synthesize knowledge across these boundaries to solve problems and create solutions. It is therefore important to bear in mind that the division of learning outcomes into distinct sections does not imply that the outcomes should be taught in isolation. Cross-disciplinary thinking should be encouraged and may be explicitly included in curricula.

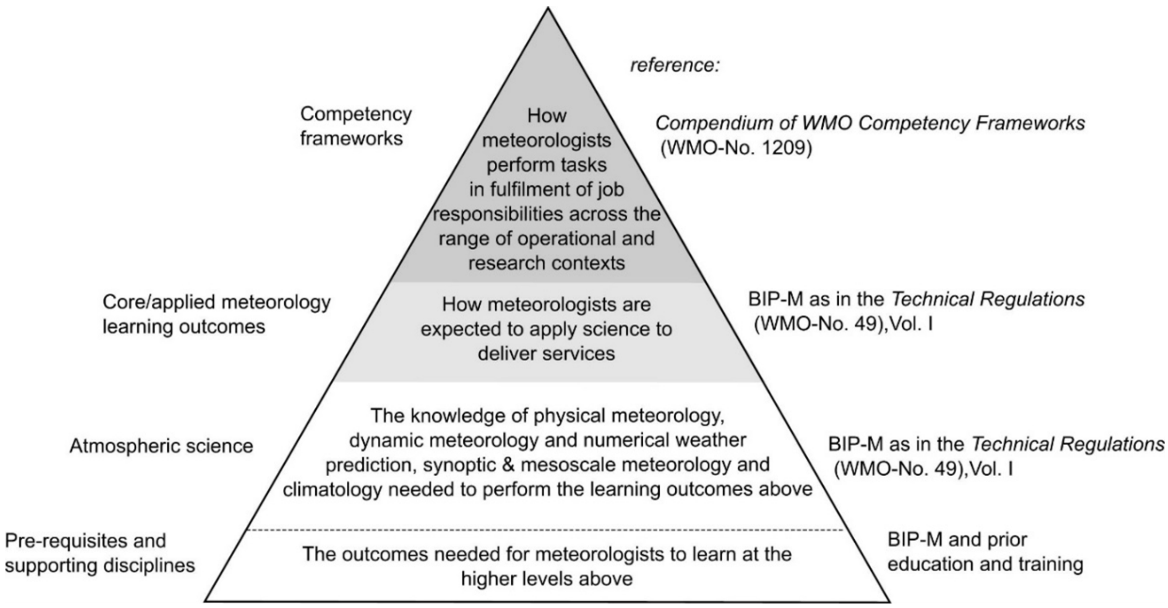

Figure 1(a). A Hierarchy of education and training for meteorologist

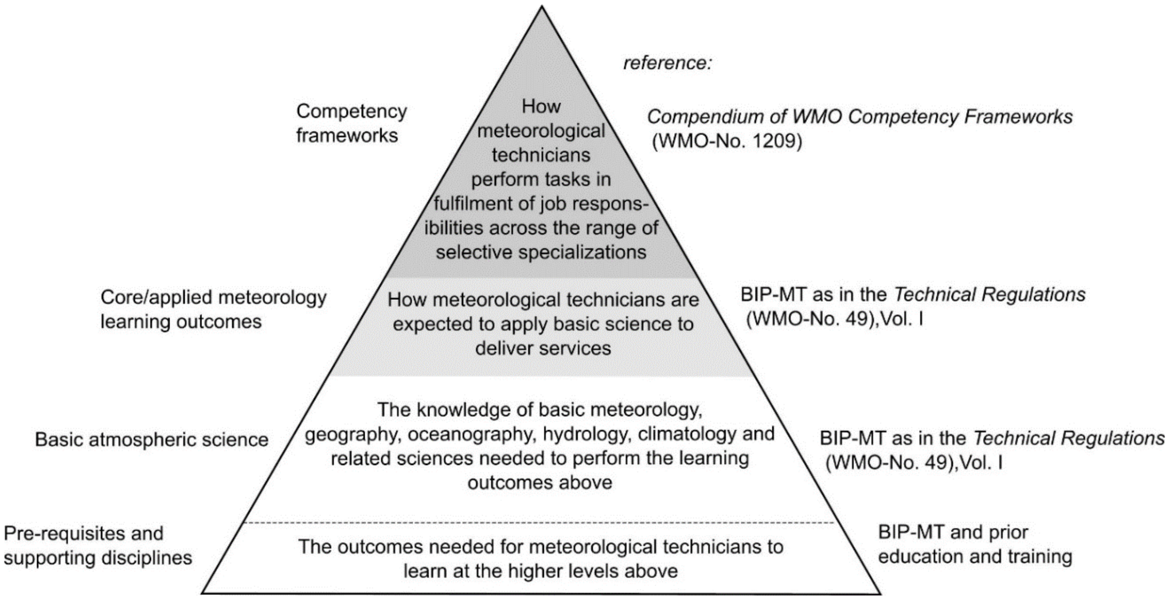

Figure 1(b). A hierarchy of education and training for meteorological technicians

1.6.1 *The learning outcomes-based approach*

The main innovation introduced in the most recent edition of BIPs was a change from an outline syllabus to a system of learning outcomes. The reasons for this change are still very much valid today, as explained in the 2015 edition of the *Guide to the Implementation of Education and Training Standards in Meteorology and Hydrology* (WMO-No. 1083):

> [T]he emphasis is on the achievements of the learner rather than the intentions of the instructor or the subjects to be covered as specified in a syllabus. Specific learning outcomes are beneficial both for the instructor and for the students, as they provide clarity about the purpose of the programme of study. They also provide a more robust basis for assessing whether the required learning has taken place.

This change benefited BIPs by making them better able to describe how knowledge should be demonstrated by meteorology students. This current version of BIPs goes further, using the learning outcomes-based approach to define the overall aims of BIPs and making explicit the need for institutions to map the BIP outcomes to their own programme and course outcomes and to map teaching and assessment activities to the course and BIP outcomes.

Learning outcomes have been usefully categorized (see, for instance, Krathwohl & Payne (1971)) into the following three levels of specificity, though in reality they lie on a continuum:

- Overarching outcomes[8]
- Educational outcomes
- Instructional outcomes

BIP-M and BIP-MT comprise a set of overarching outcomes that, together, specify the philosophy and vision of BIPs. These overarching outcomes are the desired end; the means to achieve them should be the study and assessment of the educational outcomes in atmospheric science.

For convenience and continuity with previous editions, the BIP-M educational outcomes are grouped into four broad themes: physical meteorology, dynamic meteorology, weather systems and services,[9] and climate variability, change and services.[10] Because of the greater need for

[8] Termed “global outcomes” by Krathwohl & Payne (1971). Here the phrase “overarching outcomes” is used instead to prevent any confusion with the other meaning of “global” that is used.
[9] Previously “synoptic and mesoscale meteorology”.
[10] Previously “climatology”.

revision of BIP-MT in this edition, the BIP-MT educational outcomes are grouped into a range of mandatory topics related to meteorological science, as well as selective specializations that address the competencies that define and describe critical skills, and the required knowledge underpinning each of their specific jobs.

It is the overarching and educational learning outcomes (as set out in the *Technical Regulations* (WMO-No. 49)) that define BIPs. Excerpts from these regulations are provided in parts 2 and 3, where they are clearly distinguished from indicative instructional outcomes and where explanatory narrative is included as guidance.

BIP-M and BIP-MT do not include instructional outcomes as such, but some are presented in the tables within parts 2 and 3 of this guidance to suggest the breadth and depth of outcomes that institutions might develop. Instructional learning outcomes are the detailed pieces of learning defined on a per-module or per-learning activity basis as part of the process of designing those learning activities to help students meet the course- or module-level outcomes. They will expand on the educational outcomes to include the declarative knowledge and lower-level procedural knowledge required to demonstrate the higher-level educational outcomes (see the next section for definitions).

The relationships between overarching, educational and instructional learning outcomes are summarized in Table 1.1.

Table 1.1. The specificity level of learning outcomes. Adapted from Anderson et al. (2001).

	Level of outcome		
	Overarching	*Educational*	*Instructional*
Scope	Broad	Moderate	Narrow
Time needed to learn	One or more years	Weeks or months	Hours or days
Purpose or function	Provide vision	Design a local curriculum	Prepare lesson/ assessment plans
Example of use	Plan an overall programme of study and training	Plan modules or units of instruction	Plan daily activities, lessons, exercises
Included in BIPs?	Yes	Yes	No (but guidance given)

1.6.2 ***Defining learning outcomes***

As previously noted, modern theories of how learning takes place have moved away from focusing on the intent of the instructor and towards the role and active participation of the learner. Learners are not passive recipients of knowledge given to them through lectures and textbooks, among other methods, but are active agents who engage with learning activities through various cognitive and metacognitive[11] processes, building meaning from them in the context of their prior learning and experience.

We must therefore explicitly identify and specify the body of knowledge we expect a meteorologist or a meteorological technician to learn and the types of cognitive process we expect them to apply to make use of that knowledge. To ensure that a common language is used to describe learning outcomes in this explicit fashion, and for continuity with the previous edition, we have used the revised version of Bloom’s taxonomy, which is widely used in the field (Anderson, et al., 2001).

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[11] That is, “thinking about thinking”, or the knowledge people have about themselves as learners, about the processes and techniques they can use to learn, and about when to use those techniques. Metacognition is regulated by conscious planning, monitoring and evaluation of the learning process (Schraw, 1998).

The taxonomy consists of two dimensions: the cognitive process dimension and the knowledge dimension. Both are necessary to fully describe what we expect a student to know and how we expect a student to demonstrate that knowledge. In this section, we briefly discuss these dimensions and how we apply these to BIPs.

Care must be taken not to interpret the taxonomy hierarchically. Acquisition of declarative and procedural knowledge are equally important. Further, cognitive processes such as remembering or understanding should not be seen as less valuable than applying or evaluating; indeed, they are often complementary, since a body of declarative domain knowledge in memory is necessary for the higher-order processes.

The knowledge dimension

The earliest versions of these guidelines were largely outline syllabuses – that is, a high-level list of the topics it was deemed a meteorologist or meteorological technician should learn during their initial education. Since then, although the fundamentals of the atmospheric sciences have indeed evolved, transformational change has taken place within the technological domains of pervasive computing, radar and satellite observations, numerical modelling and others. The societal and economic context within which meteorologists and meteorological technicians operate has also changed radically.

While the domain of meteorological expertise has grown, cognitive science has transformed our knowledge of the processes through which humans learn, that is, how we organize and structure knowledge.

Declarative knowledge can be broken down into knowledge of facts and knowledge of concepts.

> Factual knowledge consists of the basic terms and facts that meteorologists and meteorological technicians use to communicate about the discipline. This form of knowledge is very specific, in that pieces of factual knowledge can be isolated as atomic “bits” of information. The learning of factual knowledge is vital both for learning the necessary general types of knowledge and for applying them in the workplace, but care needs to be taken to ensure that students (or instructors) do not overemphasize it. Students must learn to make the connections between and among the various facts, building the schemata that characterize an “expert’s” knowledge of the science. A problem that students and their instructors must both address is being able to transfer or apply facts to the more complex situations a professional will encounter, rather than simply acquiring a body of so-called “inert” factual knowledge.
>
> Conceptual knowledge consists of the more general schemata, theories and mental or conceptual models that include the inter-relationships between and among the facts of the subject matter. A deep understanding of the subject with a clear mental understanding of the myriad facts is a hallmark of an expert in a field and is helpful in the transfer of knowledge to new situations. The bulk of the learning outcomes specified in BIP-M and BIP-MT are related to forms of conceptual knowledge.

Procedural knowledge consists of our knowledge of how to accomplish something, such as solving a quadratic equation, interpreting a synoptic chart or plotting a time series of data using Python.

The cognitive process dimension

While it is true that retention of knowledge is an important educational goal, the transfer of that knowledge is important for professional qualifications such as BIPs, particularly BIP-M. Transferring knowledge means having a deep understanding of it and being able to apply it in different ways to a range of tasks and problems, including in novel situations.

A brief explanation of each of the cognitive processes in the taxonomy is given below, including the definition of the process (Anderson, et al., 2001), simple examples, and notes on how we have represented the process in the BIP learning outcomes. As already noted, there is no inherent hierarchy in this list of processes (remembering complex material is mentally more demanding than creating something simple) and the verbs selected in the outcomes are intended to describe the most common application of the subject knowledge.

Remember means "retrieve relevant knowledge from long-term memory", such as being able to recognize presented information as being prior knowledge or recalling relevant information. Learning outcomes commonly pair the "remember" cognitive process with factual knowledge and are important in testing the meaningful learning of the fundamental empirical facts and terminology of a discipline.

Examples of learning outcomes using the "remember" process are:

- "Identify a tropical cyclone on the presented synoptic chart."
- "Recall the definition of potential temperature."

Although we do not understate the importance of remembering facts to learning, we have tried to avoid the use of such learning outcomes in BIPs, especially BIP-M. Instead, we have focused on higher-order cognitive processes and left supporting lower-order processes as implied in order to clearly represent the higher-order thinking that professional meteorologists and meteorological technicians are required to have.

Understand means "construct meaning from instructional messages, including oral, written and graphic communication". "Understanding" in this context refers to the building of connections between the concepts in the instructional messages on the one hand and existing schemas in the long-term memory on the other, giving the student the ability to apply the new concepts with existing knowledge and concepts in mental tasks such as interpreting, exemplifying, classifying, summarizing, inferring, comparing and explaining.

The ability to understand concepts, as defined here, makes up the largest subset of outcomes presented in BIPs, especially BIP-M, in particular across the more fundamental topics such as physical meteorology and the more elementary parts of dynamic meteorology. Where a need exists for both understanding and higher-order processes, we have presented the higher-order process, with the supporting understanding outcome implied. Many of these outcomes require the student to explain a concept. The verb "explain" means more than simply describing the component parts of a concept. Students need to understand the interconnections and feedbacks between the parts of the system or concept and be able to think through cause-and-effect problems.

A complaint heard from many educators is that learning outcomes such as "a student should understand the Coriolis force" are not helpful. Since "understanding" is an internal cognitive process that it is impossible to observe and test, we have not used the word as a verb in the outcomes.

Apply means "carry out or use a procedure in a given situation". Often used with procedural knowledge, these outcomes are used when the ability to carry out a task is required, such as in a calculation. Outcomes at this level can be placed in one of two categories. First, "executing" or "carrying out" a known procedure for a familiar task. This is the case of exercises in learning situations, where a "recipe" for carrying out a task exists and worked examples will have been presented. Second, implementing a procedure that is unknown, requiring the student to determine which conceptual knowledge to use in building a strategy that they then use to work out a solution. This is the case for problems in learning situations, where the student is required to work out how to solve the problem.

Analyse means "break material into its constituent parts and determine how those parts are related to one another and to an overall structure". Analysing can be thought of as an extension of "understanding", in that it is the process used to determine how ideas are related to one another, to support conclusions with supporting evidence, and to distinguish relevant material from extraneous material. The verbs used that require learners to use the "analyse" process include "select", "integrate" and "outline".

Evaluate means "make judgments based on criteria and standards". Relevant uses of evaluation in meteorological education include detecting inconsistencies within a prognosis and between it and newly available data, and determining the most likely best approach to solving a particular problem.

Create is a cognitive process that is often misunderstood as requiring the generation of novel ideas or processes. In reality, it encompasses functions that are pervasive within meteorology, even during education, such as generating hypotheses to account for observed phenomena, planning a small piece of research, or even generating a customer-focused weather briefing.

We have also defined some of the other words and phrases used within the learning outcomes to assist the reader in understanding the authors' intention.

Table 1.2. Definitions of words used in learning outcomes.

Word or phase	*Intended meaning*
And (when used to join two clauses in a sentence)	For the sake of brevity, we have sometimes included more than one distinct outcome in a single sentence, in which case the student must attain the outcome in all the clauses.
For example	Used before a list of possible topics or options.
Such as	
Including	

Evolution of the BIP learning outcomes (an example relating to BIP-M)

To demonstrate how the contents of BIP-M (and its antecedents) have evolved over the past 50 years, an example set of outcomes from dynamic meteorology are presented in Table 1. The change from a list of topics to assessable learning outcomes is clearly represented, as is the change from an academic or theoretical perspective to one grounded in the application of the science. The final two rows exemplify the application of the approach described above in terms of the use of higher-order thinking skills.

This table shows that it is now possible to design BIP-M courses of study along the spectrum that ranges from the more academic to the more applied, as previously discussed, with all courses being of equal worth. All programmes should be designed with employers' needs in mind and should use a range of evidenced-based teaching methods to maximize the transfer of learning.

Table 1.3. Analysis of dynamic learning outcomes as stated in four iterations of BIP-M

Version	*Sample outcomes/ topics*	*Description of knowledge*	*Cognitive level*	*Character*
WMO-No. 258, 1969	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.	– (list of topics)	–	More theoretical
WMO-No. 258, 2001	Scalar and vector fields; Gauss and Stokes theorems; kinematics of flow fields; material derivative; Eulerian and Lagrangian rates of change; conservation of mass, momentum and energy. Navier-Stokes equations. Rotating frames of reference; equations of motion in co-ordinate form: spherical co-ordinates; preliminary approximations to the equations in spherical co-ordinate form; Coriolis parameter; tangent-plane geometry; f- and βplane approximations.	– (list of topics)	–	More theoretical
WMO-No. 1083, 2015	Explain the physical basis of the equations of motion in terms of forces and frames of reference, apply scale analysis to identify the dynamic processes in balanced flows, describe the characteristics of balanced flows, and use the equations of motion to explain quasi-geostrophy, ageostrophy, and the structure and propagation of waves in the atmosphere;	Concepts	Understand	Theoretical

Version	*Sample outcomes/ topics*	*Description of knowledge*	*Cognitive level*	*Character*
This edition	Outline the application of the concepts of force, acceleration and frames of reference to a physics of atmospheric dynamics, as exemplified in the equations of motion. Apply conceptual models derived from dynamic meteorology to explain and predict the evolution of the atmosphere in the area of interest. Evaluate the extent to which conceptual models resemble reality. Use numerical model outputs to represent phenomena of interest based on knowledge of the characteristics of the modelling system, the spatial and temporal scales under consideration and the need to represent uncertainty.	Concepts, procedures	Understand, apply, evaluate	Mix of theory and application

Since the first edition of the *Guidelines for the Education and Training of Meteorological Personnel* (WMO-No. 258), BIP-MT has undergone fewer modifications than BIP-M. The main reason for this has been the greater breadth of BIP-M and thus the greater need to update it. In this edition, BIP-MT has received at least as much attention as BIP-M, with more feedback from the global community than it has ever had since its inception in 1969 under the now superseded "Class of personnel" system.

1.7 Design of teaching and learning, and assessment activities

Traditionally, education and training in university and professional contexts relied on lectures for imparting information. These lectures were supported by tutorials and laboratory work to deepen students' understanding and application of knowledge. In the same way that our approach to curriculum design has evolved from a syllabus describing what knowledge should be covered to a learner-centric, outcomes-based approach, it has become standard practice to have a more diverse range of learning activities in which the student actively applies knowledge.

Given the well-defined learning outcomes set out in the previous section, it should be straightforward to design teaching and learning methods and assessment methods that will allow students to achieve those outcomes. Unfortunately, traditional methods such as the lecture, which remain widespread, are often not well suited to learning or assessing our outcomes.

This process is illustrated by the concept of constructive alignment (Biggs & Tang, 2011), as shown in

Figure 2.[12] The constructive-alignment approach is based around constructivism and states that, for learning to be effective, three elements need to be both appropriate and relevant to one another:

– Learning outcomes.

– Learning and teaching activities that enable learners to meet those outcomes.

[12] Imperial College London (n.d.).

– Assessment methods through which learners can show that they have achieved those outcomes.

Figure 2. Constructive alignment between outcomes and activities

1.7.1 *Learning declarative knowledge*

Consider, as an example, a lecture designed to meet one of the BIP-M learning outcomes in climatology, namely, "Apply physical and dynamical reasoning to explain the mechanisms responsible for climate variability and climate change". The action verb in this learning outcome is "explain", which, as described above, requires the student to tell somebody how the components of the climate system interact with one another in a complex cause-and-effect chain to produce the observed phenomena. The summary in Table 4 is the result of analysing the lecture to determine the activities being carried out by the instructor on the one hand and the students on the other.[13]

Table 1.4. Analysis of lecture activities

Instructor activity	Student activity
Introduce	Listen
Explain	Take notes
Elaborate	Understand (but does the student understand correctly and in enough depth?)
Show some slides and a video	Watch, take notes
Questions on slides	Write answers to questions
Conclude	Listen, and possibly ask a question

In this example, the student's role is passive. The desired outcome is for the student to be able to "explain" something, but the student is not given the opportunity or motivation to do any "explaining" in this setting. The lecturer's "explaining" may be good, but the learners are busy receiving declarative knowledge that they are working hard to "remember". A disciplined student with a good study technique and enough spare cognitive load may internally build the schema, including connections between the information they are receiving, and may explain the whole; otherwise, the actual outcome is entirely different from the intended one ("remembering" versus "explaining").

To facilitate the acquisition of the body of declarative knowledge needed in meteorology, activities in which the student is active and in control of the learning should be preferred over passive experiences. A combination of instructor-led and self-led learning can be used. The key is that, whether the student is listening to a lecture, actively reading, or participating in group discussions, the student is using the right metacognitive skills to actively retrieve and use the knowledge required. If the learning outcome is to recall a certain fact, then the student should be doing "recall"; if the outcome is to explain, the student should be doing "explaining"; in either case, the teaching and learning activity needs to be aligned with the learning outcome.

[13] Biggs and Tang (2011, p. 134).

1.7.2 *Learning procedural knowledge*

Many of the learning outcomes in BIPs, in particular BIP-M, are written in terms of higher-order cognitive process skills; the procedural knowledge associated with the "apply", "analyse", "evaluate" and "create" categories in the taxonomy really defines what it is to be a professional meteorologist or meteorological technician.

Teaching and learning activities must activate those cognitive processes in the student for the student to master both the knowledge and the use of those very processes. Examples of teaching and learning activities that encourage or require the use of the processes include case study-based learning, group and individual projects, and workplace-based learning (known as placements, internships and practicums, among other terms).

Development of the necessary metacognitive abilities such as problem-solving are likely beneficial to the learning of procedural knowledge but are unfortunately often not taught explicitly.

1.7.3 *Assessment*

Just as the methods used in teaching and learning must be aligned with the learning outcomes, so must the means of assessing learning. Clear learning outcomes that specify the knowledge and cognitive process needed should be made available to learners to allow them to self-assess and gauge their progress. The aim of constructive alignment between the learning outcome and the assessment item should make devising those assessment items far easier but might require innovation in the assessment methodology.

If students are being asked to explain a piece of knowledge, then assessment items should give them the opportunity to explain it. Similarly, learning outcomes that require students to evaluate a situation must be assessed in ways that test students' critical thinking and analytical ability. It is often easier to test students' ability to recall declarative knowledge than their application of procedural knowledge, but if the outcome calls for procedural knowledge, that is what needs to be tested.

As described in the previous subsection, activities such as the development of case studies, individual research projects, etc. and the presentation of results are useful for learning but are also useful for the assessment of a range of higher-order cognitive processes.

1.8 Curriculum design

It remains the case that institutions must define their own detailed outcomes at the level of the programme, modules and learning/assessment activities. The institutions will use BIPs as one of the bases for doing so and they must enable learners to achieve the overarching and educational outcomes, – but BIPs will necessarily be tailored to regional, national, and local needs.

Whether developing new programmes or reviewing existing ones, institutions should adopt a systematic approach to designing their curricula, such as the approach set out in

Figure 3. This is to ensure that each programme meets the requirements of BIPs and enables prospective students and their future employers to understand clearly how the programme will benefit them. A holistic, systematic approach to curriculum design should also ensure that the connections and interdependencies between the components are made explicit and that activities are designed that utilize those connections. This will give students an overall picture of how the weather and climate system works and how NMHSs and other providers of weather and climate services contribute to society.

The present guide does not provide the detailed module-level instructional outcomes that include the detailed guidance needed by instructors who will develop instructional materials and assessments. That is because such outcomes are dependent on local needs, national educational practices and instructional approaches. This detailed design of learning and assessment activities is vitally important and must be a deliberate act of design taking advantage of evidence-based teaching and assessment practice, educational technologies, etc.

Given the wide range of programme modalities, aims, prior education of students and more, BIP-M and BIP-MT do not define a recommended programme duration. As has been stated already, it is the achievement of the outcomes that mark a person as a meteorologist or meteorological technician, not the fact the person has spent a certain amount of time carrying out the learning and assessment activities.

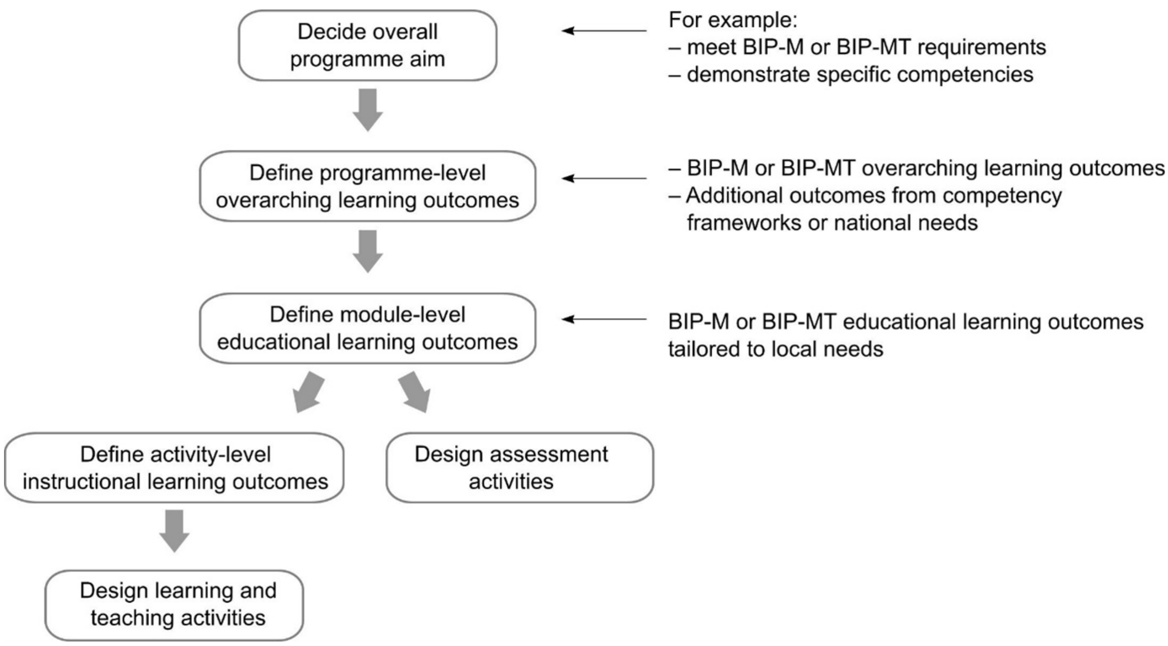

Figure 3. Mapping BIPs to programme outcomes

1.9 Inclusive teaching and assessment

Objective 5.3 of the *WMO Strategic Plan 2020–2023* (WMO-No. 1225) is to "[a]dvance equal, effective and inclusive participation in governance, scientific co-operation and decision-making". The Plan states:

> Organizations that respect diversity and value gender equality demonstrate better governance, improved performance and higher levels of creativity. Gender equality and the empowerment of women are further key to scientific excellence and essential to meeting the challenges of climate change, disaster risk reduction and sustainable development, particularly Sustainable Development Goal 5.

To contribute towards that objective and obtain the benefits described, it is important to have equal access to education and training programmes and for learning and teaching materials and assessments to be fully accessible to all and representative of the diversity of the potential student base. Programmes that are inclusive and accessible to part-time students, including for those who need childcare, benefit gender equality in particular, as was highlighted during the coronavirus disease (COVID-19) pandemic. This applies equally to education and training staff.

As has already been discussed, having clear learning outcomes coupled with transparent and fair assessment policies benefits student attainment and contributes to a more inclusive culture.

1.10 Case studies in the application of BIPs

The sections of BIP-M and BIP-MT are not intended to mandate a course structure or to rigidly define the contents of a programme of study. Since each WMO Member, NMHS, university or other training institution will have its own requirements, systems of regulation and education systems, it is necessary to develop course curricula and outcomes that are aligned with these. Courses will also include content, such as other complementary subjects, aimed at meeting an institution's research or operational interests and to ensure their graduates have a well-balanced education.

1.10.1 *Application of BIP-M*

The outline programmes described below are examples of how BIP-M might be implemented, but other structures are equally valid.

Case 1 – Undergraduate programme in meteorology

One way of implementing BIP-M is by placing it at the core of a three-year or four-year undergraduate programme in meteorology. An outline example of such a programme is illustrated below. In this example, it is assumed that students have the secondary-school mathematics and physics qualifications required to access the more advanced undergraduate programmes in those fields.

Unless specific courses in weather forecasting or other specialist areas are included within the degree programme, whether delivered by academic staff or in partnership with the NMHS, such a programme would not prepare a graduate to take up a forecasting role without further training.

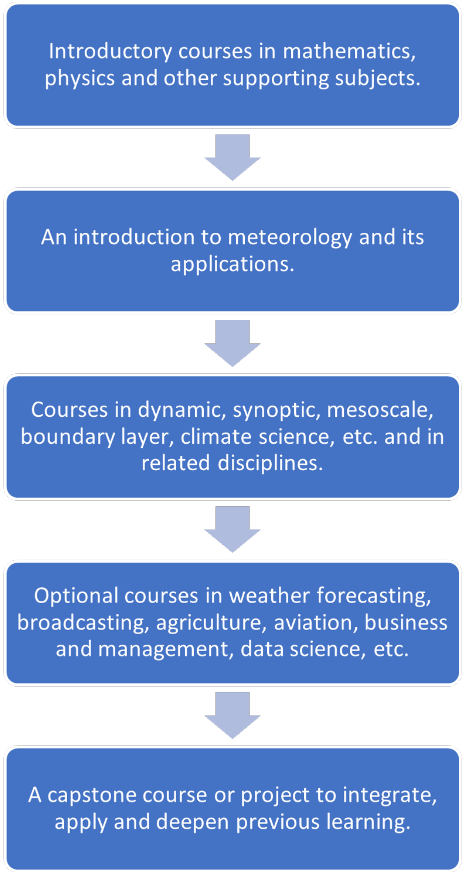

Figure 4. Schematic of an undergraduate programme in meteorology

Case 2 – Postgraduate programme in meteorology

Another common way of implementing BIP-M is by placing it at the core of a masters-level postgraduate programme in meteorology, typically over a 1-year period. An outline example of such a programme is illustrated below. In this example, it is assumed that students have a first degree in a subject that, among other benefits, will have given them the necessary education in mathematics and physics and the maturity to enable them to progress to this level and intensity of study.

Unless specific courses in weather forecasting or other specialist areas are included within the degree programme, whether delivered by academic staff or in partnership with the NMHS, such a programme would not prepare a graduate to take up a forecasting role without further training.

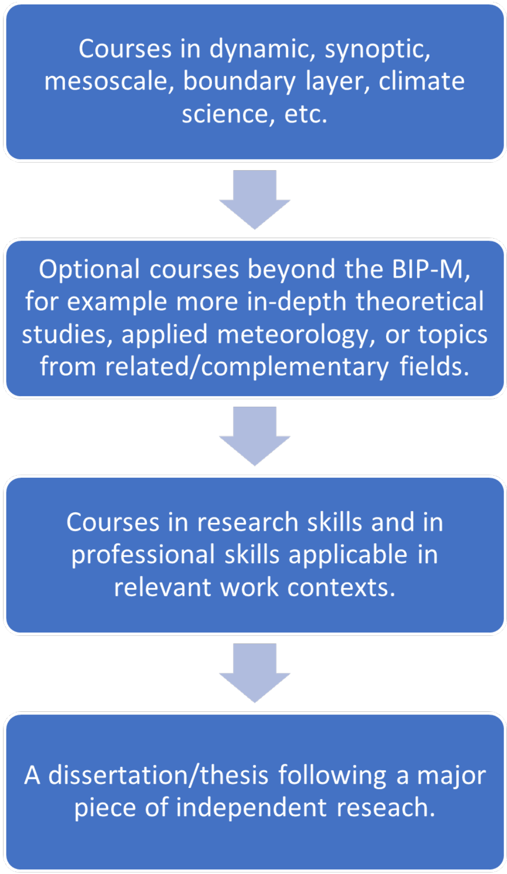

Figure 5. Schematic of a postgraduate programme in meteorology

Case 3 – NMHS graduate or in-service forecasting course

This example is of a course at an NMHS training centre or an RTC. It is assumed that students are either graduates in a physical science subject or staff employed as meteorological technicians or in other roles who have the pre-requisite education, possibly gained in service (for example through accredited online programmes or at local colleges).

Although the level of education needed to complete the BIP-M topics will necessarily be equivalent to undergraduate study, these programmes generally do not result in the award of academic credits or a degree.

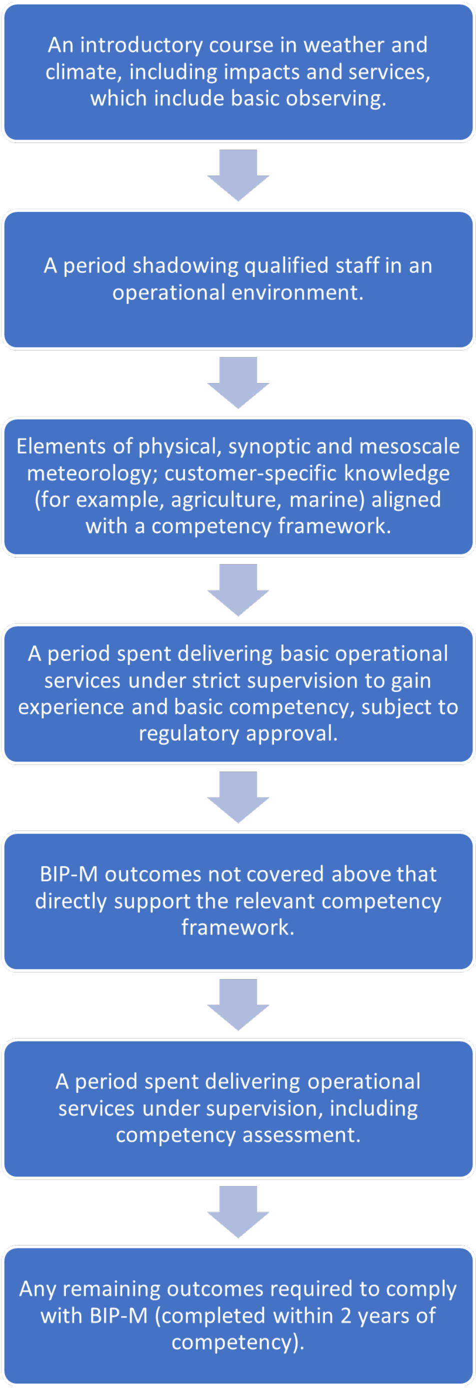

Figure 6. Schematic of an NMHS graduate or in-service forecasting course

Case 4 – Blended individual qualification route

The WMO Global Campus initiative is encouraging educational institutions to offer education and training opportunities outside of traditional academic and workplace settings. Today's technology allows a combination of learning methods –synchronous and asynchronous, self-directed and instructor-led –at a time and place that is most suited to the learners. A possible route to BIP-M qualification would be for individuals to access the necessary learning either from a single provider or from a range of different providers.

Such a route would open access to meteorological education to those traditionally excluded because of their location, employment status, care-giving duties or other reasons.

As there is no international registration system for meteorologists, providing evidence that the meteorologist has achieved the BIP-M learning outcomes remains the responsibility of the organization that employs the meteorologist. To facilitate providing evidence, institutions are encouraged to ensure that their enrolment literature and their certificates and transcripts clearly specify which BIP-M outcomes their courses achieve and to what extent.

1.10.2 *Application of BIP-MT*

Members have used various education and training approaches to train their meteorological technicians, from specific formal-education training programmes in meteorology at a technical school, RTC, college or university to vocational and on-the-job training (or a combination of the two) in meteorological observations and measurements. Whichever approach is adopted, institutions must meet the BIP-MT requirements.

The BIP-MT requirements will normally be met through the successful completion of a post-secondary programme of study at an institution such as an NMHS training institution, RTC or college of further education.

BIP-MT should be delivered in such a way that individuals successfully completing the programme of study are able:

- To demonstrate knowledge of the underlying concepts and principles associated with their field of study.
- To present, evaluate and interpret qualitative and quantitative data to make sound judgments in accordance with basic theories and concepts of their field of study.
- To evaluate different approaches to solving problems related to their field of study.
- To communicate the results of their studies accurately and reliably.
- To undertake further training and the development of new skills within a structured and managed environment.

1.11 BIPs at later stages of a career

The requirements specified by BIP-M and BIP-MT have been presented as if they are normally met by an individual taking an initial programme of study at a university or training institution. This would usually happen before or shortly after the person takes up employment at an NMHS. In practice, however, satisfying the requirements to be a meteorologist or meteorological technician might be achieved mid-career.

For example, meteorological technicians who have acquired substantial knowledge of meteorology based on their initial training, continuous professional development and operational experience may want to take a programme of study that allows them to be classified as meteorologists. In that case, many of the learning outcomes specified by BIP-M will have already been achieved. Provided that recognition of prior learning can be formally established and recorded, the programme of study need only cover those learning outcomes that have not already been achieved. Establishing and recording of prior learning may be undertaken by those responsible for training within an NMHS, when the NMHS is designated (if so required by the national educational regulator or department) as a "recognition-of-prior-learning" centre. The same approach applies to people whose initial training does not cover the entire BIP-MT, but who later in their careers decide they want to be classified as meteorological technicians.

The specific national or institutional regulations and requirements of a particular country will determine whether recategorization that takes recognition of prior learning into account is accepted in that country.

2. BASIC INSTRUCTION PACKAGE FOR METEOROLOGISTS

This part of the document contains guidance on how to implement the learning outcomes of BIP-M that are contained in the *Technical Regulations* (WMO-No. 49). It provides some narrative on the intention behind the outcomes as written and includes more detail on the topics that might be included in a programme of study to meet the learning outcomes. It must be remembered that the detail given in this chapter is neither exhaustive nor intended to constrain WMO Members in the definition of programmes. Put another way, it is the learning outcomes in the lists that define BIP-M, not the explanatory detail in the tables beneath those lists.

As professionals, meteorologists need to be able to apply high-level creative problem-solving, think critically, produce incisive analyses and carry out routine and non-routine tasks autonomously. It is these higher-order cognitive processes, and a deep understanding of atmospheric processes, that graduates of BIP-M programmes must develop.

For this reason, the lower-order thinking skills associated with the "remember" level of the taxonomy[1] (recognizing and recalling) are avoided where possible. Of course, there is a great deal of declarative knowledge – both empirical knowledge and terminology – which is important for meteorologists to know and which provides a vital foundation for the higher-order skills. In most cases, this factual knowledge is implied rather than explicitly stated here.

We have also been circumspect in using verbs associated with the "understanding" cognitive process level, such as "explain" and "describe". These verbs are often misunderstood by students and instructors alike as requiring simple recitation of an explanation, derivation, etc., when they actually mean the ability to construct cause-and-effect system models to demonstrate understanding of a concept. The definitions given in the previous chapter should be used to determine what the verbs in these outcomes mean within the context of BIP-M.

2.1 Interpretation

In this chapter, text enclosed in grey-shaded boxes, like this example, comprises excerpts for inclusion in the next edition of the *Technical Regulations* (WMO-No. 49), Volume I, Part VI. The texts will have the regulatory status of standard. practices and procedures.

The remainder of part 2 comprises narrative and suggested learning outcomes, intended to guide WMO Members on the implementation of BIP-M, but does not have regulatory status.

2.2 Overarching learning outcomes

This section describes the key attributes and skills that distinguish professional meteorologists, no matter what role they might go on to undertake. As stated above, these overarching learning outcomes are also intended to summarize the overall philosophy of BIP-M by describing how professional meteorologists think and how they use the data and tools at their disposal for their professional work.

The outcomes described here are not intended to describe any specific role and do not make any assumptions regarding the context within which an individual might eventually be employed. They are not necessarily intended to map directly to modules or units of study. Rather, they should permeate a programme of study as a whole and be used to assess the programme to ensure that individual units of study contribute to the programme's broader aim of embedding meteorological thinking and practice and establishing links between theory, the real atmosphere and the provision of scientific and professional services, to the benefit of society.

1 See section 1.6.2 ("Defining learning outcomes").

Meteorologists shall be able:

- To combine available sources of relevant observational data in a systematic way to produce coherent analyses of the state of the atmosphere at the spatial and temporal scales under consideration.
- To generate reasonable hypotheses for the evolution of the atmosphere in the region of interest in terms of relevant dynamic and physical processes and in terms of conceptual models.
- To predict the evolution of the state of the atmosphere and the degree of uncertainty in those predictions, combining relevant numerical model products with physical and dynamical thinking and empirical methods to a level of precision that is appropriate to the spatial and temporal scales under consideration and the known sources of uncertainty.
- To compare predictions with observations, using qualitative or quantitative methods to assess hypotheses and to ensure the quality of services, including through evidencing changes needed to hypotheses, products and services.
- To clearly and accurately communicate relevant information with colleagues, customers and other stakeholders using a range of media in a manner that reflects uncertainty and impacts.
- To determine the sensitivities of society to weather and climate phenomena, drawing on other disciplines where necessary, to ensure that the identification and warning of weather and climate impacts are central to the meteorologists' work.
- To evaluate their work outputs against relevant standards, take corrective action if needed, and contribute to the development of work systems and processes.
- To reflect on their learning and working practices, critically evaluate their performance and use a range of approaches to continuously develop their professional knowledge and competence.

These learning outcomes should be achieved through learning and assessment of the atmospheric science topics described later in part 2, supplemented where necessary by the professional learning outcomes and other outcomes as required to meet national needs, and supported by the advice on basic mathematics and physics also found in this part of the guidance.

2.3 Pre-requisite mathematics and physics

Meteorology, being a physical science, builds upon basic physics to describe mathematically the processes at work in the atmosphere. It is therefore necessary for meteorologists to have a solid grounding in mathematics and physics before they learn the specifics of atmospheric physics, not least because even introductory literature uses mathematical language to succinctly describe the science. At the same time, it should be borne in mind that BIP-M is not designed to educate mathematicians or pure physicists: mathematics is a means through which people can learn meteorological concepts rather than an end in itself.

For these reasons, BIP-M includes mathematics and physics learning outcomes, but only for those areas that directly support other learning outcomes. None of this precludes institutions from going beyond what is set out here in order to support their approach to teaching atmospheric science, from taking advantage of standard introductory mathematics courses as part of their offering, or from preparing students for more advanced study.

The outcomes in this section may be achieved in numerous ways, including by using any or all of the following options:

- Setting pre-requisite learning that students must achieve before embarking on the atmospheric science studies. This may be through a blend of secondary education[2] and introductory-level undergraduate modules.

[2] Many of the mathematics and physics learning outcomes needed here are part of secondary education qualifications such as A-levels, the International Baccalaureate and the Advanced Placement programme.

– Including specific introductory mathematics and physics modules into an integrated meteorology programme.

– Embedding training within the core meteorology programme (for example, by including basic electromagnetic radiative transfer in a remote-sensing module).

Meteorologists shall be able:

– To interpret and apply the mathematical language, concepts and techniques used in introductory meteorological literature and teaching materials.

– To use their mathematical knowledge to make logical and reasoned problem-solving decisions; to recognize incorrect reasoning; and to communicate their reasoning clearly using the language of mathematics.

– To apply and interpret the basic statistical measures used to summarize meteorological data and forecast output and to analyse errors.

– To represent physical and meteorological situations mathematically, understanding the relationship between the real world and the mathematical model and making reasonable interpretations of results.

– To use basic physical laws to solve problems related to mechanics, thermodynamics, wave motion and electromagnetic radiation.

The guidance in Table 2.1 and Table 2.2 should help to define instructional learning outcomes within modules of study. The guidance is not supposed to be exhaustive or limiting. Rather, it is intended to be indicative of the range and type of knowledge needed to meet the pre-requisites for studying meteorology:

Table 2.1. Suggested instructional outcomes to meet the pre-requisite mathematics requirements.

Mathematics	
Trigonometry	Solve simple geometric problems using the definitions of sine, cosine and tangent and their inverse functions, both in degrees and in radian units.
	Describe the sine, cosine and tangent functions and their graphs, symmetries and periodicity.
	Explain and apply the small angle approximation.
Logarithms and exponentials	Manipulate and interpret expressions containing logarithms and exponentials.
	Use logarithmic graphs to estimate the coefficients of exponential equations.
Algebra and functions	Manipulate polynomial equations, including by expanding brackets, by collecting like terms and by applying factorization.
	Solve simultaneous equations of two variables by elimination or substitution.
	Read and interpret graphs of functions and sketch curves defined by simple polynomials.
	Measure the slope and intercept of a linear graph.
Vectors and linear algebra	Represent vectors graphically and using vector notation and translate between the two.
	Calculate the magnitude and direction of a vector and convert between component form and magnitude/direction form.
	Add and subtract vectors and multiply vectors by a scalar. Do these both algebraically and graphically.
	Calculate the scalar (dot) product and vector (cross) product of two-dimensional vectors.

Complex numbers	Solve any quadratic equation with real coefficients, including those with complex roots.
	Explain the terms "real part" and "imaginary part".
Differential and integral calculus	Interpret the derivative of a function as the gradient of the tangent to the graph at a point and as the rate of change of that function.
	Explain the interpretation of the second derivative of a function as the rate of change of the gradient and use this to identify maxima, minima and inflection points.
	Interpret the physical meaning of ordinary and partial differential equations containing space and time derivatives.
	Interpret the integral of a function as the area under a graph and as the limit of a sum.
	Use Taylor series to approximate a function around a point of interest.
Vector calculus	Sketch representations of scalar fields of a given function and of vector fields showing translation, deformation, divergence or vorticity.
	Define the gradient, divergence and curl operators and interpret the results of these operators on scalar or vector fields.
Statistics	Interpret basic measures of the central tendency, range and spread of data.
	Interpret data plotted as a histogram.
	Explain the concepts of probability and conditional probability.
	Interpret plots of probability distribution function, probability mass function and probability density function.
	Apply regression with one or multiple variables and assess the fit of the resulting model to prediction problems.

Table 2.2. Suggested instructional outcomes to meet the pre-requisite physics requirements.

Physics	
Mechanics	Describe the concept of a force; explain and apply Newton's first law.
	Add forces graphically or algebraically to find the resultant force in a system.
	Describe and apply Newton's second law of motion to solve simple problems.
	Solve problems using the principle of conservation of (linear) momentum.
	Explain the concepts of Eulerian and Lagrangian frames of reference, when to use each and how to translate from one to the other.
	Explain the concept of centripetal acceleration and describe circular motion in a system by relating the resultant force to the centripetal acceleration.
	Apply the principle of conservation of angular momentum to rotating systems.
	Explain the concepts of work, kinetic energy, potential energy and internal energy.
	Solve simple problems using the principle of conservation of energy.
	Solve simple problems using the relationship between power, work and force.
Kinematics	Use the language of kinematics to describe physical systems: position, displacement, distance, velocity, speed and acceleration.
	Solve problems using equations describing the relationship between distance, speed, acceleration and time for uniformly accelerated motion in a straight line.
	Use vectors and differential calculus to describe motion in one and two dimensions.

Fluid mechanics	Explain the concept of hydrostatic pressure, transmission of pressure in a fluid and Pascal's law; explain why pressure decreases with height in the atmosphere.
	Explain the principle of buoyancy and Archimedes' principle.
	Describe the concept of viscosity.
	Describe a wind field or other vector field in terms of translation, deformation, divergence and vorticity.
	Describe and apply the concepts of stream function and velocity potential.
	Explain the relationship between streamlines and trajectories.
Heat transfer	Explain the physical basis of heat transfer via conduction, convection and radiation.
Basic thermodynamics	Describe the kinetic theory of gases and explain the physical basis of temperature.
	Apply the fundamentals of thermodynamics to gaseous systems, including the gas laws for dry and moist air, the first and second laws of thermodynamics and Dalton's law.
	Explain the physical basis of sensible heat, specific heat, latent heat, vapour pressure and saturation.
	Explain the physical basis of reversible and irreversible processes, entropy and enthalpy.
	Describe the phase changes of water within a gaseous system and their effects on other parts of the system.
Waves	Describe the properties of oscillations and waves and explain simple harmonic motion; solve problems using the relationship between speed, frequency and wavelength for waves.
	Explain the difference between longitudinal and transverse waves.
	Explain the fundamentals of wave motion, including the concepts of reflection, refraction, diffraction, interference phase and group velocities, wave dispersion and wave breaking.
Optics	Explain the concepts of reflection, refraction, diffraction and scattering of light.
Electromagnetic radiation	Explain the fundamentals of electromagnetic radiation, including the electromagnetic spectrum, black-body radiation, Planck's law, Wien's law and the Stefan-Boltzmann law, as well as scattering, absorption and emission of radiation.

2.4 **Mandatory topics**

This section contains learning outcomes of the topics that are mandatory for BIP-M. They cover the core of meteorological science.

2.4.1 ***Physical meteorology***

Physical meteorology deals with the scientific explanation of fundamental atmospheric phenomena. It builds upon prior learning of physics, applying basic physical laws to explain the observed nature of the atmosphere. The concepts in this section include the thermodynamic structure of the atmosphere, solar and terrestrial radiation, boundary-layer processes, cloud physics and the principles of instrumentation and measurements. In some ways these concepts are building blocks that make it easier to understand larger-scale phenomena, but they are also directly applicable to solving many problems in meteorology.

Meteorologists shall be able:

- To use their knowledge of atmospheric composition and radiative transfer to explain the structure of the atmosphere, global energy balance and the greenhouse effect, and common optical phenomena.
- To use the laws of thermodynamics to explain the stable stratification of the atmosphere and the effects of adiabatic and non-adiabatic processes, including the effects of water; to use a thermodynamic diagram to assess the properties and stability of the atmosphere.
- To summarize the micro-physical processes involved in the formation of clouds, precipitation and electrical phenomena and use a thermodynamic diagram to diagnose and predict these phenomena.
- To use knowledge of turbulence and surface fluxes to explain the structure and characteristics of atmospheric boundary layers and the behaviour of contaminants.
- To select instruments to observe surface and upper-air atmospheric phenomena, considering their physical principles of operation, sources and characteristics of error and uncertainty, and quality-control practices in use.
- To use relevant Earth- and space-based remote sensing to observe atmospheric and surface phenomena qualitatively and quantitively; to explain how radiation measurements are made, how they are turned into atmospheric data, and what the uses and limitations of these data are.

The guidance in Table 2.3 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in physical meteorology, rather than being either exhaustive or limiting.

Table 2.3. Suggested instructional outcomes in physical meteorology

Atmospheric composition, radiation and optical phenomena	
Atmospheric structure and composition	Summarize the characteristics of those atmospheric regions (troposphere, tropopause, stratosphere) of most relevance to meteorologists with reference to their major constituents, temperature and moisture content.
	Summarize the composition of the atmosphere, including trace gases, aerosols, mineral dust, volcanic ash and pollutants, including the effects of these constituents.
Radiation in the atmosphere	Explain the effects of variance in the distribution of atmospheric constituents (including aerosols, water vapour, clouds, greenhouse gases and reactive gases) and of surface conditions (moisture, vegetation, snow cover) on incoming and outgoing radiation.
Global energy balance	Explain the latitudinal and seasonal variations in climate due to the global radiational energy balance, variation in solar flux and the orbital characteristics of the Earth.
Optical phenomena	Explain the transparency of the atmosphere and the physics of common optical phenomena (for example, rainbows, haloes, coronas, sky colour, cloud colour) and describe the meteorological conditions that favour the occurrence of these phenomena.
Thermodynamics and cloud physics	
Applied thermodynamics	Apply the laws of thermodynamics to solve basic problems based on an understanding of the concept of an air parcel, including describing adiabatic and diabatic processes, dry and saturated adiabatic motions, and the associated conserved quantities.
Atmospheric moisture	Explain the physical basis for and applications of the common parameters used to represent the amount of moisture in the atmosphere; describe how these quantities are measured and the relationships between them.
	Use knowledge of thermodynamics to describe the phase-change processes of water, including the effects these phase changes have on both a hypothetical air parcel and on larger-scale processes.

Atmospheric stability	Summarize the characteristics of statically stable, neutral and unstable regions in terms of variation in density and behaviour of a perturbed parcel.
	Use knowledge of thermodynamics to describe and apply the concepts of conditional, latent and potential/convective instability.
	Select the most relevant thermodynamic parameters to assess measures of stability in data, using knowledge of the physical basis of those parameters.
	Predict how measures of static stability might change as a result of diabatic and adiabatic processes (for example, insolation, latent heat release and inclined flow).
Thermodynamic diagrams	Use a thermodynamic diagram to determine or calculate common parameters used to describe the thermodynamic state of the atmosphere, including stability, from a sounding.
	Infer information about atmospheric structure (such as the presence of cloud and precipitation) and synoptic-scale processes from thermodynamic diagrams.
Clouds and precipitation	Describe the microphysical processes leading to the formation, growth and dissipation of atmospheric hydrometeors, including both warm and cold cloud droplets and precipitation-sized particles.
	Describe the macroscopic structure and essential dynamics of the main types of cold and warm clouds.
	Given an analysis of the synoptic and mesoscale conditions, predict the likelihood of the development of the various cloud types, precipitation types, dew, icing, frost and the various types of fog; explain how local conditions may aid or hinder development of these phenomena.
Electrical phenomena	Describe the mechanisms that cause electrical phenomena in the atmosphere and assess the likelihood of these phenomena in a given synoptic and mesoscale situation.
Boundary-layer meteorology and micrometeorology	
Turbulent processes	Describe how the nature of turbulent flows differs from that of laminar flows; describe the mechanisms for the generation and dissipation of turbulence; describe the role of viscosity in providing a lower boundary condition constraining boundary-layer flows.
	Explain why statistical measures are used to describe turbulent flows, the common averaging schemes used, and the physical basis for decomposing flow variables into mean and fluctuating parts.
	Explain qualitatively how turbulent fluxes of mass, heat, moisture and momentum arise and how they act to redistribute these quantities.
	Predict the evolution of the boundary layer in terms of mass, heat, moisture and momentum based on fluxes of these quantities being a function of the vertical distribution of their mean values.
Boundary-layer energy exchanges	Describe the energy budget near the Earth's surface and the energy (thermal and kinetic) exchange processes with the surface layer.
	Describe the energy and mass budget at the top of cloudy and cloud-free boundary layers, including the role of turbulence, entrainment and radiative transfer.
Boundary-layer structure and variation	Use knowledge of turbulence, surface processes and top of boundary-layer processes to explain the structure and diurnal variation of stable, neutral and unstable boundary layers.
Local winds	Explain the impact of the terrain, coastline and urban areas on boundary-layer flows, including thermally induced circulations (for example, sea and land breezes, lake effects and valley winds); predict the occurrence of these effects for a location in a given synoptic and mesoscale situation.
	Explain the origin, significance and limitations of the Ekman spiral and the mixing-length hypothesis and use the latter to estimate the vertical structure of the wind in the surface layer, given a relevant observation.

Air contaminants	Use knowledge of common contaminants and their sources, sinks, behaviour and effects to predict how contaminants may be dispersed according to the meteorological conditions, including stability, and how this may affect air quality and visibility.
In situ observations and instrumentation	
In situ surface measurements	Explain the physical principles used in instruments to make surface measurements of temperature, moisture, pressure, precipitation, wind, cloud height, visibility, sunshine and radiation, and wave height, as well as the limitations and sensitivities of those instruments.
	Describe the way clouds, visibility and weather types are classified and observed and the uses and limitations of the data.
Upper-air measurements	Explain the physical principles used in instruments to record upper-air measurements of geographical position, pressure, temperature, moisture and wind, ozone, and other atmospheric constituents (such as dust and volcanic ash).
	Assess the utility of balloon- and aircraft-borne instruments in providing information for a given location, given the flight characteristics and reporting frequency of these platforms.
Characteristics of instruments	Use knowledge of the characteristics of surface and upper-air instruments to select the best source of data to observe parameters or phenomena of interest.
Instrument errors and uncertainty	Use knowledge of the common sources of error and uncertainty in standard instruments and observing techniques to estimate the confidence in a particular measurement, including assessment of local effects that influence the representativeness of an observation.
Use and limitation of observations	Describe the uses and limitations of conventional observations in monitoring weather and climate and in making forecasts.
Global standards for instrumentation and collaboration	Explain the importance of national and international standards of measurement and compliance with best practice for the accurate calibration of instruments.
	Describe the role of international collaboration in making and sharing observations, with emphasis on the component systems of the WMO Integrated Global Observing System.
Remote sensing	
These learning outcomes are intended to give a meteorologist essential knowledge of common remote-sensing systems and the ability to intelligently use these data in a range of situations. Further learning will be required to use remote-sensing data in the workplace. Courses built around BIP-M, especially those attracting students entering the forecasting profession, should take into account the knowledge and skills frameworks for satellite and radar meteorology contained in the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), which build on those given here.	
Principles of remote sensing	Use remote-sensed data from radar, satellites and other systems together with in situ observations, numerical weather prediction (NWP) and guidance to synthesize an overall picture of the state of the atmosphere and identify errors introduced by using a single data source in isolation.
	Select relevant remote-sensed data, taking into account the characteristics of the different systems, the geographical area of interest and the meteorological problem being considered.
	Choose display formats to maximize the benefits of remote-sensed data, including suitable projections, colour schemes and animations.
Active sensing	Explain how active sensing systems such as radar, lidar and sound detecting and ranging (SODAR) are used to provide quantitative and qualitative data about atmospheric parameters (for example, precipitation rate and type, wind speed and direction, cloud, humidity, temperature, turbulence and aerosol loading) and phenomena (such as thunderstorms, microbursts and tornadoes).

Passive sensing	Explain how passive sensing systems are used to provide digital data from received radiation (for example, in the visible, infrared or microwave parts of the spectrum).
	Describe how data from passive sensors are used to derive information such as temperature, humidity, atmospheric composition, lightning, wave heights and soil moisture.
Meteorological satellites	Describe the orbital characteristics of geostationary and low-earth orbit satellites used for meteorology, including the benefits, limitations and applications of data derived from these platforms.
	Describe the characteristics, limitations and applications of common channels available from satellite sensors, including visible, near-infrared, water vapour and infrared.
	Explain the reasons for combining channels, including by creating RGB images, the applications of this imagery, and the advantages over single-channel imagery.
	Select single- or multiple-channel imagery to observe common features of interest, including synoptic-scale and mesoscale weather systems and natural hazards.
Radar	Use knowledge of the physical principles of weather radar to explain limitations due to precipitation size, phase changes and the attenuation effects of meteorological conditions and non-meteorological targets.
	Describe how radar data may be processed to mitigate attenuation, produce composite data from a network of radars and create quantitative estimates of precipitation rate and type, wind, etc.
	Select the most relevant radar-derived imagery (including dual-polarized imagery if available) to supplement other forms of data in the given synoptic and mesoscale situation and the meteorological problem under consideration.

2.4.2 *Dynamic meteorology*

If meteorologists are to have insight into the evolution of the atmosphere and the ability to infer the consequences of that evolution in terms of errors between models and observations, they need to possess a thorough understanding of the physics of atmospheric motions, including the interactions and feedbacks between features at different levels in the atmosphere (Carroll, 1997). The development of numerical models, which are now the foundation of the majority of research and operational meteorology, is entirely dependent on atmospheric dynamics. Thus, a study of basic dynamics and of numerical modelling is included as an important part of these learning outcomes.

Care must be taken by institutions to ensure that dynamics and numerical modelling are taught in a way that meets students' needs. A mathematics-led approach will be common, and is more powerful when accompanied by the practical application of dynamical ideas and NWP to real-world data.

Meteorologists shall be able:

- To outline the application of the concepts of force, acceleration and frames of reference to a physics of atmospheric dynamics, as exemplified in the equations of motion.
- To apply conceptual models derived from dynamic meteorology to explain and predict the evolution of the atmosphere in the area of interest.
- To evaluate the extent to which conceptual models resemble reality.
- To use numerical model outputs to represent phenomena of interest based on knowledge of the characteristics of the modelling system, the spatial and temporal scales under consideration and the need to represent uncertainty.

The guidance in Table 2.4 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in dynamic meteorology, rather than being either exhaustive or limiting.

Table 2.4. Suggested instructional outcomes in dynamic meteorology

Atmospheric dynamics	
Equations of motion	Use Newton’s second law of motion and a consideration of the forces acting on a fluid parcel to outline the derivation of the horizontal and vertical equations of motion (momentum equations) in an inertial frame of reference.
	Explain the physical basis for, and the effects of, the additional terms representing the apparent forces acting in a rotating frame of reference.
	Explain the concept of geopotential and the reasons why geopotential height is used rather than geometric height.
	Explain why pressure is often used as the vertical co-ordinate in the primitive equations when considering synoptic-scale atmospheric flows.
Scales of motion	Categorize atmospheric phenomena according to their length and timescales as micro-, meso-, synoptic- or planetary-scale phenomena.
	Use the concept of scale analysis to describe simplifications to the equations of motion appropriate for each of these scales of motion.
Balanced flows	Describe the simplifications made in deriving the main classes of balanced flows (including geostrophic, gradient, cyclostrophic and inertial flows); describe the nature of these balanced flows and recognize real-world examples of them.
	Explain the concepts of thickness and thermal wind balance.
Hydrostatic equilibrium	List the simplifications made in deriving the hydrostatic equation, identify phenomena where the atmosphere is not in hydrostatic equilibrium and explain how vertical motion can be determined under the hydrostatic assumption.
Ageostrophic motion	Use the equations of motion to explain the causes and implications of ageostrophic motions, including the effect of friction.
Vorticity and divergence	Explain the concepts of divergence and vorticity and describe the mechanisms for generating changes in these parameters.
	Describe the relationship between divergence in the horizontal wind and vertical motion.
Potential vorticity	Explain the concept of potential vorticity, including the properties of conservation and invertibility.
Quasi-geostrophic flow[3]	Explain the approximations and assumptions in the quasi-geostrophic system of equations and identify situations where these assumptions may not hold.
	Outline the derivation of the geopotential tendency and omega equations.
	Provide a physical interpretation of the forcing and response terms in these equations.
	Use the geopotential tendency equation qualitatively to diagnose the evolution of upper-air features such as troughs and ridges.
	Use the omega equation qualitatively to diagnose the distribution of vertical motion associated with idealized jet streaks, troughs and ridges.
Waves in the atmosphere	Describe the physical and dynamical basis for wave motions of different scales in the atmosphere and the characteristics thereof, including sound waves, gravity waves and Rossby waves.
Baroclinic and barotropic instability	Describe wave growth through the baroclinic instability mechanism, with emphasis on the development of mid-latitude cyclones.
	Describe how barotropic instability leads to the growth of disturbances in horizontally sheared flows.
Numerical modelling[4]	

[3] See related outcomes in weather systems and services on the application of quasi-geostrophic theory.
[4] See the suggested outcomes in the application of NWP in section 2.4.3.

Data assimilation	Explain how information from observing networks and systems is obtained and prepared for use in an NWP model.
	Explain the principles behind objective analysis, data assimilation (including three-dimensional and four-dimensional variational data assimilation and hybrid schemes including the use of ensembles) and initialization.
NWP forecast models	Describe the components of an NWP model, including dynamical core, the parameterization of physical processes and boundary-condition issues, including interaction with ocean or land-surface models.
	Explain the difference between types of model (for example, spectral versus grid-point and hydrostatic versus non-hydrostatic).
Strengths and weaknesses of NWP	Describe the key sources of uncertainty or error in atmospheric numerical models and how these contribute to a limit of predictive skill.
	Describe the typical skill of global, regional and convective-scale models in terms of the spatial and temporal scale of features likely to be forecast more or less well at a given lead time.
Ensembles	Explain the principles and benefits of an ensemble modelling approach.
	Explain how the probability information is derived from ensembles, the effect of ensemble size and the usefulness and limitation of ensembles in the forecasting of extremes.
	Describe applications of ensemble model output across the range of temporal and spatial scales.
	Interpret a range of standard ensemble-derived outputs, for example, the probability of exceeding thresholds plotted on maps, probability distribution functions and statistical data plotted on a meteogram.
Subseasonal to seasonal (S2S) predictions	Explain the scientific basis of monthly/subseasonal, seasonal and intraannual forecasting.
	Access and use S2S forecast output to produce guidance on the likely impacts of the weather regimes that are forecast to be dominant and on the degree of inherent predictability and the performance of the forecast system.
Downscaling	Describe the techniques used to provide detailed regional atmospheric information based on the output from global models.
Post-processing and applications	Describe the techniques used for post-processing NWP output (for example, Kalman filtering or machine learning) and the benefits of using such techniques.
	Describe some of the applications driven by NWP output (such as wave, hydrological and crop yield models).

2.4.3 ***Weather systems and services***

The learning outcomes in this section are intended to give students the ability to apply their knowledge of physical and dynamical meteorology to real-world weather systems, including the ability to analyse, diagnose and forecast them using observational data and NWP. This will allow all meteorologists to make connections between their area of specialty and the effects of weather on people and society

The first two subsections cover mid-latitude/polar and tropical systems, respectively. Full coverage of the outcomes in one or the other of these sections is sufficient to satisfy the requirements of BIP-M. Similarly, the subsection on mesoscale meteorology should be applied with regard to the area of responsibility and the mesoscale phenomena likely to be encountered in those areas. This is intended to give institutions and students who will work exclusively in either the tropics or mid-latitudes the flexibility to study only those outcomes relevant to their future careers and is aligned with the requirements of the WMO competency frameworks in this regard.

It is recommended that, even for courses that focus exclusively on either the mid-latitudes or the tropics, students should at least be exposed to an introductory study of the other so that they understand the nature and language of global meteorology and so that they can use it as a platform for future studies.

The final two subsections cover basic knowledge of how weather is observed, analysed and forecast. However, achievement of these learning outcomes alone does not qualify a student as a weather forecaster, and that is not the intention. The *Compendium of WMO Competency Frameworks* (WMO-No. 1209) should be referred to by institutions required to educate and train weather forecasters.

Meteorologists shall be able:

- To apply conceptual models of synoptic, mesoscale and convective-scale phenomena to integrate observed and forecast data into coherent structures; to explain the formation, evolution and characteristics of these phenomena using knowledge of physical and dynamical meteorology.
- To detect situations where real-world weather systems deviate from the conceptual models using knowledge of the models' limitations and suggest reasons for the deviations.
- To predict occurrences of extreme or hazardous weather conditions associated with synoptic, mesoscale or convective-scale phenomena and monitor observed data to verify the predictions.
- To generate analyses and basic forecasts using observed and forecast real-time or historical data, including the monitoring and observing of the weather.
- To summarize the role of national meteorological services and other providers using knowledge of society's needs, the impacts of severe weather, the products and services used to meet users' needs and the processes used to manage quality.

The guidance in Table 2.5 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in weather systems and services, rather than being exhaustive or limiting.

Table 2.5. Suggested instructional outcomes in weather systems and services

Mid-latitude and polar synoptic-scale weather systems	
Weather systems	Describe the mean state and major patterns of atmospheric variability in mid-latitude and polar regions and explain these dynamically and physically, including the effects of topography.
	Summarize the key differences between tropical weather systems on the one hand and mid-latitude and polar weather systems on the other; explain the reasons for those differences.
Air masses	Explain how air masses are characterized and formed and how their temperature, moisture and stability are modified as the air masses move away from their source regions.
	Apply the concepts of air-mass characteristics and modification to predict the evolution of local weather, taking into account geographical, diurnal and seasonal factors.
Fronts	Describe the structure and characteristics of synoptic-scale cold, warm, occluded and quasi-stationary fronts.
	Generate an analysis of frontal position and motion by selecting relevant information contained in observations (in situ and remote-sensed) and model output.
	Apply physical and dynamical reasoning to explain why observed fronts differ from idealized conceptual models.
	Describe the kinematic and dynamic processes leading to frontogenesis and frontolysis and the processes causing upper-level frontogenesis.

Mid-latitude depressions	Apply physical and dynamical reasoning to explain the life cycle of mid-latitude depressions in terms of the Norwegian cyclone model, including the three-dimensional structure of a developing depression and the air flow through the depression.
	Identify warm and cold conveyor belts associated with a mid-latitude depression in the system-relative frame of reference.
	Describe weaknesses of the basic cyclone model and recognize situations where deviations from the model or use of other models such as Shapiro-Keyser or hybrid models may be more applicable.
	Apply knowledge of dynamical processes to explain cyclogenesis and the factors contributing to explosive cyclogenesis.
Polar weather systems	Explain the characteristics, formation and effects of polar weather systems, including phenomena such as katabatic winds, barrier winds, cold-air damming and polar lows.
Jet stream and jet streaks	Apply physical and dynamical reasoning to explain the development, structure and impact of jet streaks using a simple four quadrant model to explain the relationship between the jet stream and the development or persistence of mid-latitude flow patterns.
Synoptic-scale vertical motion[5]	Explain the role of vertical motion in the nature and evolution of synoptic-scale weather systems.
	Diagnose synoptic-scale vertical motion in mid-latitude weather systems using an appropriate technique (for example, by considering ageostrophic motion, using the Petterssen or Sutcliffe development theory, applying the quasi-geostrophic omega equation in its traditional or Q-vector form or using "PV-thinking"), noting the strengths and weaknesses of the technique employed.
Weather impacts	Describe the weather, with emphasis on extreme or hazardous conditions (such as windstorms, high precipitation accumulation and outbreaks of cold or heat) that might be associated with mid-latitude and polar weather systems.
	Describe the likely impacts of such conditions, including the non-meteorological factors that need to be considered when assessing those impacts and the advantages of taking an impact-based approach to communicating hazards.
Limitation of conceptual models	Analyse current and/or historical weather events to evaluate the extent to which theories and conceptual models of mid-latitude and polar weather systems resemble reality.
Tropical and subtropical weather systems	
General circulation in the tropics	Describe, using physical and dynamical reasoning, the mean state and major patterns of atmospheric variability in the tropics in terms of relevant variables and how and why these differ from those in higher latitudes.
Main tropical disturbances	Describe the main tropical disturbances and their temporal variability, including the Inter-Tropical Convergence Zone, tropical waves, trade inversions, trade winds, tropical/subtropical jetstreams, cloud clusters, squall lines, tropical depressions, subtropical ridges and upper-level anticyclones.
Analysis of tropical flows	Describe the techniques used to analyse tropical flows, including the depiction of streamlines and isotachs and the identification of areas of convergence/divergence.
Tropical waves	Describe the various types of tropical wave (including Kelvin waves, equatorial Rossby waves and Madden–Julian Oscillation) and their relationship to organized convection and cyclogenesis.
Tropical cyclones	Explain the development, structure, characteristics and impacts of tropical cyclones using physical and dynamical reasoning.
	Describe the global system in place for forecasting and warning of tropical cyclones and their impacts.

5 See related outcomes in dynamic meteorology on the theoretical aspects of some of these topics. The intent in this section is to promote links between the two sections through outcomes here on the application of theory to mid-latitude weather systems.

Monsoons	Describe the nature, characteristics and impacts of the major monsoon circulations.
	Apply physical and dynamical reasoning to explain the structure and characteristics of monsoons and the main dynamical processes involved in their development.
Ocean-atmosphere coupling	Describe the role of ocean–atmosphere coupling, including its theoretical basis, with emphasis on the El Niño-Southern Oscillation.
Weather impacts	Describe the weather, with emphasis on any extreme or hazardous conditions that might be associated with tropical weather systems (including tropical cyclones and monsoons).
	Describe the likely impacts of such conditions, including the non-meteorological factors that need to be considered when assessing those impacts and the advantages of taking an impact-based approach to communicating hazards.
Limitation of conceptual models	Analyse current, recent or historical weather events to assess the extent to which theories and conceptual models of tropical systems resemble reality.
Mesoscale weather systems	
Mesoscale systems	Describe the space and timescales associated with mesoscale phenomena and the differences in the dynamical processes that drive mesoscale and synoptic-scale systems.
Mesoscale features associated with depressions	Describe the mesoscale features associated with depressions (rainbands, drylines, gust fronts, squall lines, etc.).
Gravity waves	Apply physical and dynamical reasoning to explain the structure and formation of mesoscale gravity waves.
Convective systems	Apply physical and dynamical reasoning to explain the structure, characteristics and formation of isolated convection, including single-cell, multicell and supercell storms and meso-cyclones.
Mesoscale convective systems	Apply physical and dynamical reasoning to explain the structure and formation of mesoscale convective systems.
Orographic mesoscale phenomena	Apply physical and dynamical reasoning to explain the structure and formation of orographic mesoscale phenomena (lee waves, rotors, upslope and downslope winds, valley winds, gap flows, lee cyclones, etc.).
Extreme weather	Describe the weather, emphasizing any extreme or hazardous conditions associated with convective and mesoscale phenomena in the region of interest and the likely impact of such conditions.
Limitation of conceptual models	Analyse recent and/or historical weather events to assess the extent to which theories and conceptual models of convective and mesoscale phenomena resemble reality.
Weather observation, analysis and diagnosis	
Weather monitoring and observation	Monitor the weather, including by making basic surface observations using instruments and visual assessments (including identifying cloud types, cloud amount, visibility and weather type) and explain the reasons for conducting such assessments.
	Describe the underlying physical causes of weather phenomena that are observable from the Earth's surface.
Processing observations	Describe how and why observations are quality-controlled, coded and distributed.
Synoptic analysis and interpretation	Analyse and interpret synoptic charts and soundings plotted on thermodynamic diagrams.
	Describe the limitations of the observations used in synoptic analyses and of the global and regional analyses produced by operational data-assimilation systems.
Interpretation of radar data	Interpret common radar displays, including the use of enhancements and animated imagery, to identify features associated with convective and mesoscale processes.

Interpretation of satellite imagery	Interpret satellite images, including the use of common wavelengths, enhancements and animated imagery, to identify cloud types and patterns, synoptic and mesoscale systems and other phenomena (such as fog, volcanic ash, dust and fires).
Integration of conventional and remote-sensing data	Integrate remote-sensing data with conventional observations to identify synoptic and mesoscale systems and diagnose the weather situation by relating features found in the individual data sources.
Weather forecasting	
Local weather	Describe factors affecting local weather (for example, the effect of orography and large bodies of water on cloud and precipitation or the effect of land surface types).
Forecast process	Describe the main components of the forecast process, including observation, analysis, diagnosis, prognosis, product preparation, communication and verification.
Types of forecasting method	Explain the advantages and disadvantages of preparing forecasts based on persistence, climatology, extrapolation, empirical techniques and NWP.
	Describe the role of the forecaster and how it has evolved through NWP and other innovations.
Nowcasting	Apply high spatial- and temporal-resolution observation data, and remote-sensing systems in particular, together with conceptual models, for the detection and nowcasting of high-impact weather phenomena.[6]
Conceptual models	Apply conceptual models in making short-range forecasts and interpreting longer-range forecasts, noting when real-world systems do not always conform to these models.
Practical forecasting	Combine information from various sources to explain the current weather conditions; use basic forecasting techniques, including the interpretation of NWP output, to forecast atmospheric variables (for example, maximum and minimum temperature, wind and precipitation type and intensity) at a specific location.
	Determine the key sources of uncertainty in a given forecast and how these may change as more data becomes available at shorter lead-times.
	Combine forecast data with knowledge of users' vulnerabilities to determine potential impacts and estimate the magnitude and likelihood of those impacts.
Service delivery	
Service providers	Describe the role of NMHSs in monitoring, forecasting and communicating the weather and its impacts.
	Describe the role of other providers, including private-sector and international organizations.
Service provision	Communicate weather information in a way that meets the needs of users with different levels of meteorological knowledge.
	Decide whether to use deterministic or probabilistic approaches based on the timescales, the uncertainty of the situation, and users' needs.
Key products and services	Describe key products and services (including warnings of hazardous weather conditions) based on current and forecast weather information provided to the public and other users.
	Describe the range of communication channels or media used to disseminate weather information, including the potential weaknesses of these methods.
	Describe how the products and services are used by the public, governments, businesses and other end users (for example, for decision-making and risk management).

[6] The *Guidelines for Nowcasting Techniques* (WMO-No. 1198) expand on the knowledge and training requirements needed for nowcasting and should be consulted when designing programmes intended to train weather forecasters.

Hazardous weather	Describe the extent to which hazardous weather systems affecting the region of responsibility can be forecast with sufficient lead-times for action to be taken.
	Explain the importance of assessing the risk of hazardous weather, including interactions between weather and other natural hazards, and the importance of issuing prompt and accurate warnings.
	Explain the benefits of issuing warnings based on the potential impacts of hazardous weather rather than purely on the intensity of the weather phenomena.
	Describe the potential impacts of hazardous weather on society.
Quality management systems[7]	Explain the role and importance of the quality management system (QMS) in service delivery.
	Describe basic techniques used within QMSs to assess the quality of products and services and to rectify quality-related problems.
Benefits and costs of meteorological services	Identify the economic and social impacts of meteorological services on a country and their key user sectors.

2.4.4 ***Climate science and services***

Climate change is the defining challenge of our time and is a subject that professional meteorologists of all types will find themselves addressing to a greater or lesser extent. In addition, the role of weather forecasters continues to expand to include providing longer-range forecasts, including monthly and seasonal predictions.

The learning outcomes in this section of BIP-M are not intended to give learners all the knowledge and skills required to be a professional climatologist or climate researcher. The separate BIP-CS under preparation should be consulted when preparing courses in this area. These outcomes are intended to ensure all meteorologists have a basic grounding in the Earth's climate system, its variability and climate change so they can speak credibly about climate, use longer-range forecast products intelligently and communicate these clearly to customers.

Meteorologists shall be able:

- To apply conceptual models of the Earth's global circulation, climate system and the interactions between the land, ocean, atmosphere and cryosphere to explain the mean state of the climate.
- To interpret products and service based on climate information, taking into account their inherent uncertainty.
- To describe the observed variability in the climate system and the causes and impacts of that variability; to use this knowledge to interpret products such as climate predictions and monthly to seasonal forecasts.
- To communicate the results of monthly, seasonal and climate predictions based on an understanding of probability, uncertainty and predictability at different scales and the sensitivities of the audience.
- To explain the long-term changes occurring in the climate system using knowledge on how these changes are observed, what the drivers for change are, including feedbacks within the system, what the potential impacts of climate change are, and what adaptation and mitigation strategies are possible.

The guidance in Table 2.6 should help to define instructional learning outcomes within study modules. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in climate science and services, rather than being exhaustive or limiting.

[7] For further information on training to help maintain a QMS, see *Guide to the Implementation of Quality Management Systems for National Meteorological and Hydrological Services and Other Relevant Service Providers* (WMO-No. 1100).

Table 2.6. Suggested instructional outcomes in climate science and services

The Earth-atmosphere system and the general circulation	
Components of the Earth system	Describe the key components of the Earth system (the atmosphere, oceans, land, the cryosphere and solid Earth).
Climate and weather	Describe climate and how it differs from weather.
Climate data	Describe how climate is estimated and the inherent uncertainty of climate data; explain how climate data are analysed using statistics and how climate can be measured using remote-sensing data.
Climate system components	Describe the main features of the energy cycle, hydrological cycle, carbon cycle and nitrogen cycle.
Features of global circulation	Explain the main features of the global circulation of the atmosphere and oceans based on an understanding of the physical and dynamical process involved.
	Describe the global energy balance and the role of the atmosphere and oceans in balancing the radiative heating differences between the Equator and the poles.
Regional and local climates	Assess the factors that determine regional and local climates.
Classification and description of climates	Describe the techniques used for classifying climates, the principles behind the techniques, and the meaning and use of standard statistical variables describing the climate.
Local climate	Describe the climatology and seasonal changes of the region of responsibility and the way climatological information can be obtained and displayed.
	Extract information from tables and from charts of basic climate data and interpret this to formulate a description of a local climatology in terms of mean/average, deviation and extremes.
Key products and services	Describe the key products and services based on climate information provided to the public and other users.
	Describe the inherent uncertainties of such products and services and how they are used (for example, for decision-making and risk management).
Climate variability and climate change	
Data to assess climate variations	Describe the source and processing of data used to reconstruct past climates and assess changes in climate and atmospheric composition.
Observed climate variations	Describe how the climate has changed in the recent past in the context of changes that have occurred more generally in the past and the techniques used for attributing the causes.
Atmosphere ocean interaction	Describe the various ways the atmosphere and the oceans influence each other.
Climate variability	Apply physical and dynamical reasoning to explain the causes of internally generated climate variability (including examples of teleconnections, anomalies and the climatic effects of major drivers such as the Madden–Julian Oscillation, the North Atlantic Oscillation and the El Niño-Southern Oscillation).
Climate change	Apply physical and dynamical reasoning to explain the causes of externally forced climate change (including the influence of human activity) and the source of uncertainty in understanding these causes.
Impact, adaptation and mitigation	Assess the major impacts of climate variability and change and outline the adaptation and mitigation strategies that are applied in response to current and projected changes in the climate.
Climate models	Explain the differences between climate models and those used for weather prediction; explain why there are uncertainties in climate predictions.
	Describe how climate predictions can be verified; explain why there are differences between statistical intra-annual forecasts and climate model predictions.

2.5 Professional learning outcomes

This section contains suggestions for learning outcomes to support the achievement of several of the overarching learning outcomes and thus give meteorologists the fundamental professional skills they will need at the outset of their careers. The outcomes given below are not an exhaustive list, and institutions will be guided by national and regional human resource needs. Neither are the outcomes in this section mandatory; rather, they are intended to act as a guide to some of the knowledge that might be needed now or in the future.

2.5.1 *Management skills*

Institutions are encouraged to provide opportunities for general business and management education as part of an overall meteorology programme. Suggestions of topics that would be useful to include in such courses can be found in *A Compendium of Topics to Support Management Development in National Meteorological and Hydrological Services* (ETR-24) (World Meteorological Organization, 2018a).

2.5.2 *Communication and teamwork skills*

The ability to communicate forecasts, impacts and research findings to a range of audiences is included in several learning outcomes within the BIP-M sections on weather systems and climate. The outcomes below expand on those outcomes and provide the basis for the learning and assessment of communication and teamwork skills.

An individual achieving the learning outcomes for communication skills should be able:

– To communicate meteorological information in the form of forecast policy discussions and handover briefings that are impact-focused and that utilize the forecast funnel.

– To identify the key weather and climate sensitivities of customers and deliver tailored briefings that focus on impacts, uncertainties, confidence and support for decision-making.

– To prepare and provide media interviews and community outreach activities using plain language, talking points and documents that communicate key messages.[8]

– To engage customers and colleagues by using the right tone and body language and showing empathy.

– To produce clear and concise written documents.

– To share knowledge and work constructively with others in a team.

The guidance in Table 2.7 should help to define instructional learning outcomes within study modules.

Table 2.7. Suggested communication learning outcomes that would be useful for operational meteorology roles

Impact-based weather briefings	
Summarize weather observations	Summarize significant past and present weather phenomena and their impacts.
Explain the current situation	Present a coherent narrative of past and present weather conditions, utilizing the forecast funnel and atmospheric conceptual models.
Summarize current products	Accurately and concisely summarize the content of current forecast policy, forecast products and warnings.

[8] WMO has published details of the competencies for broadcasters and communicators in the *Compendium of WMO Competency Frameworks* (WMO-No. 1209).

Deliver a prognosis	Summarize future hazardous and high-impact weather, including required warnings.
	Present a coherent weather narrative of the future evolution of the atmosphere, utilizing the forecast funnel and conceptual models.
	Discuss uncertainties, confidence and alternative scenarios.
Delivery style	Be timely and concise.
	Vary tone and voice to engage colleagues.
	Employ active listening to ensure that information has been effectively communicated and that staff are aware of their responsibilities.
Customer briefings and customer-decision support	
Assess customer needs	Acquire knowledge of customer needs through interactive dialogue.
	Research customer operations, including operational standards and procedures, weather and climate sensitivities and key decision thresholds.
Deliver tailored forecast briefings	Deliver an impacts-based weather briefing that supports customer decision-making by employing knowledge of customer needs.
	Use language and conceptual models of weather suited to the customer's meteorological knowledge and the duration of the briefing.
	Deliver briefings using voice, tone and empathy to engage customers and meet their needs.
Add value to current products	Explain current forecast policy, warnings and forecasts to customers based on their needs.
	Explain forecast uncertainty and alternative scenarios based on an understanding of conceptual models and customer sensitivities.
Media briefings and community outreach	
Preparation	Identify the angle of the story being sought or the purpose of the outreach activity.
	Employ the inverted pyramid to focus the media briefing on the most important information and address the key concerns or interests of the target audience.
	Identify and prepare for tough questions, avoiding controversial topics where appropriate.
	Use or develop talking points to deliver a tailored media interview.
Language skills	Express meteorological terminology in plain language.
	Use tone/voice to express empathy and engage listeners.
Body language	Use eye contact and body language to express empathy and engage listeners.
Writing skills	
Forecast and warning documents	Construct written products, including forecasts, warnings, briefings and talking points.
	Use technical or plain language to suit customers' and colleagues' needs.
	Modify text generated graphically and automatically to ensure it is clear and accurate.
Social media	Compose short impact-based posts using clear and concise plain language, images and links to warnings and forecasts.
	Compose responses to comments, maintaining an emphasis on the weather narrative, avoiding controversial topics and adhering to NMHS values and the code of conduct.

2.5.3 ***Information technology***

The ability to extract and present meaningful, valuable information from meteorological data has always been a core competence for meteorologists. In recent years, the volumes of observational and forecast data produced have increased dramatically, and this presents challenges as well as opportunities. To exploit these data, many meteorologists now need skills in computer programming, data manipulation and visualization and knowledge of applying machine-learning techniques.

The aims of these outcomes are for the student to be able:

– To access, manipulate and view meteorological data held in diverse formats.

– To use statistical tools to extract useful information from data.

– To understand how machine-learning techniques are used to build simple predictive models of weather, climate and their impacts.

Table 2.8 lists suggested learning outcomes in using information technology.

Table 2.8. Suggested learning outcomes in using information technology

Basic IT skills	Write simple shell scripts to automate processes and combine the functionality of several programs to complete a task.
	Use the command line to interact with the operating system, including running programs and managing files and processes.
	Use word-processing, spreadsheet and presentation software.
Programming	Write simple programs in a high-level programming language, including the use of variables, loops, flow control, input/output from files and the command line.
	Use language features such as functions to structure code in an efficient way through re-use.
	Use functionality provided by standard language libraries or imported from specialized libraries.
	Utilize arrays and array operators from standard mathematical libraries and explain the benefits of using array operators versus looping over data sets.
	Check for and handle errors and exceptions using standard language features.
	Utilize the software-development life cycle to ensure the requirements are captured and the code is well designed and implemented, documented, peer reviewed and tested.
	Use a version control system to maintain the integrity of the code and facilitate collaborative working.
Meteorological data	Describe and compare the common file formats for storing meteorological data, including text-based and binary formats.
	Explain the importance of maintaining metadata and of understanding the provenance, validity and units of data.
	Use standard libraries for loading, navigating and manipulating structured meteorological data.
Visualization	Plot data using chart types that clearly and unambiguously present the information in the data, including line charts, scatter plots and histograms.
	Include titles, axes, data labels and other standard features to ensure the data are comprehended.
	Take into account accessibility and users' needs when designing visual communications, for example by choosing perceptually uniform colour scales.
	Plot geospatial data using symbols, contours or a colour mesh with a suitable map projection, scale and colour scale.
Statistical computing	Use programming tools such as mathematical libraries to calculate standard statistical parameters and analyses to summarize and compare data.
	Apply techniques including Fourier transforms and empirical orthogonal functions to reduce the dimensionality of data sets and discover temporal signals in time-series data.

Machine learning	Describe any necessary steps to transform raw data in order to analyse it, including cleaning, transformation of units, normalization and categorization.
	Divide data into training and testing sets and explain the reasons for doing so.
	Explain supervised and unsupervised machine-learning algorithms and choose an appropriate scheme for a given problem.
	Explain the principles behind supervised linear regression and classification schemes and apply these to data to produce simple predictive models.
	Describe how simple unsupervised machine-learning algorithms such as k-nearest neighbours can be used to classify data.
	Describe how algorithms such as neural networks can be used to build non-linear models.
	Explain why the problems of bias and variance arise, what strategies exist to minimize these, and what the possible implications are for weather and climate forecasting applications.
	Describe potential ethical or legal issues arising from using machine-learning techniques, including the use of personal data and not being able to explain the decisions made by the algorithms.

2.5.4 *Research skills*

Many undergraduate programmes include a capstone module during which students undertake some independent research, which is often presented in the form of a dissertation. This experience is clearly a useful foundation for more thorough education in research methodologies during postgraduate study. For other students, having the skills to carry out basic independent research can still prove to be useful through their careers, since it can support their continuous professional development and help them to prepare case studies or training material.

Table 2.9 lists suggested learning outcomes in basic research and science communication.

Table 2.9. Suggested learning outcomes in basic research and science communication

Planning and designing research	
Literature searches and reading scientific literature	Plan and carry out a literature search using a range of sources. Use library services to aid in the literature search process. Use different types of resources, such as review articles, opinion pieces, original research and books.
	Assess context, reliability, bias, conflicts of opinion and validity in conclusions of literature.
	Summarize and critically evaluate arguments, results and conclusions.
	Identify underdeveloped aspects of existing research or areas where further research might be fruitful.
Research design and execution	Develop a research question.
	Form a hypothesis.
	Identify the appropriate form of experimental or non-experimental research.
	Develop research methodologies that minimize biases and other invalid results.
	Carry out the research plan, adjusting when problems or opportunities arise, but being mindful of deviating from the original research question or hypothesis.
	Interpret results, using appropriate statistical measures to ensure the results are significant and determine whether the hypothesis is supported.
Scientific communication[9]	

[9] For more details on scientific communication, see, for example, Schultz (2009).

Paper writing	Utilize a strategy to develop a structure or outline of a paper that impactfully presents the research findings while incorporating the standard structural components expected in a paper.
	Produce clear, readable and impactful text, tables, figures and associated captions.
	Cite all works referenced or quoted using an approved scheme.
Peer-review process	Prepare for peer review by understanding the process, using colleagues, editors, etc. to ensure the paper is of the standard required.
	Engage with reviewer comments positively and develop a plan to make any corrections or incorporate any suggested improvements.
Scientific presentations	Identify opportunities to talk about scientific work through informal or more formal events such as internal seminars and conferences.
	Produce clear visual aids to help the audience view and understand a presentation, rather than distract them with too much text or clutter.
	Practise delivering oral presentations to develop clarity, volume, pace, timing and the ability to deal with questions and unforeseen events.
	Produce a poster summarizing the key parts of research in a clear and accessible way.

2.5.5 *The historical and scientific context of meteorology*

To aid continuous learning throughout a meteorologist's career and to enable the integration of meteorology with related sciences, it is recommended that the topics listed below be incorporated into a programme of study:

– The history of advances in science, technology and service delivery that have contributed to the development of meteorology and its application.

– Contemporary challenges in meteorology and emerging scientific and technological innovations that might influence how research or operations need to evolve.

– Developments in related fields that may bring opportunities for interdisciplinary efforts to solve problems that benefit society.

2.6 Selective specializations

As indicated in section 1.6 ("Structure of BIP-M and BIP-MT"), the underlying knowledge and skills upon which meteorologists can develop the skills and competencies needed for selective specializations are drawn from the learning outcomes covered earlier in part 2 and from the competency frameworks for each specialization. Many of these competencies are described in the Compendium of WMO Competency Frameworks (WMO-No. 1209).

Individuals wishing to work in areas such as weather forecasting, broadcast meteorology and meteorological education will need to undertake further education and training to obtain the specialized job competencies in these areas. In addition, individuals are expected to continue enhancing their knowledge and skills by participating in continuous professional development throughout their careers.

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3. BASIC INSTRUCTION PACKAGE FOR METEOROLOGICAL TECHNICIANS

This part of the document contains guidance on how to implement the learning outcomes of BIP-MT contained in the *Technical Regulations* (WMO-No. 49). It starts with an outline of the aims of BIP-MT and then specifies the learning outcomes associated with foundation topics. The rest of part 3 deals with the learning outcomes for the mandatory general meteorology topics and the underlying knowledge and skills that meteorological technicians can use to develop the skills and competencies needed for selective specializations.

The overall aim of BIP-MT is to provide participants with basic knowledge of atmospheric phenomena and processes, as well as skills related to that knowledge.

To satisfy the requirements of BIP-MT, participants must achieve the learning outcomes that cover:

– Basic geography and oceanography, basic hydrology, basic physical and dynamic meteorology, basic synoptic and mesoscale meteorology, global and local climatology, cloud formation, communication (oral and written), IT skills (basic computer knowledge and meteorological information uses), meteorological parameters and climate-data quality control, and meteorological instruments and methods of observation.

– The application of basic knowledge to observe and monitor the atmosphere and interpret commonly used meteorological diagrams and products.

– The acquisition of at least one selective specialization topic.

The BIP-MT requirements are intended to provide participants with the knowledge, skills and confidence to carry on developing their expertise and to further specialize.

Individuals wishing to work in areas such as weather observation, climate monitoring, network management and the provision of meteorological information and products to users will need to undertake further education and training to obtain the specialized job competencies in these areas. In addition, individuals are expected to continue enhancing their knowledge and skills by participating in continuous professional development throughout their careers.

3.1 Interpretation

> In this chapter, text enclosed in grey-shaded boxes, like this example, are excerpts proposed for Volume I, Part VI of the next edition of the *Technical Regulations* (WMO-No. 49) and will have the regulatory status of standard practices and procedures.

The remainder of part 3 comprises narrative and suggested learning outcomes. The outcomes are intended to guide WMO Members on the implementation of BIP-MT, but do not have regulatory status.

3.2 Overarching learning outcomes

This section describes the key attributes and skills that mark out a professional meteorological technician, no matter what role they end up taking on. These overarching learning outcomes are also intended to summarize the overall philosophy of BIP-MT by describing how meteorological technicians think and use the data and tools at their disposal to carry out their professional work.

The outcomes described here are not intended to describe any specific role, nor do they assume the context within which an individual might eventually be employed. The outcomes are not necessarily intended to map directly to modules or units of study. Rather, they should permeate and be used to assess an overall programme of study to ensure that individual units of study contribute to the broader aims of the programme, that is, embedding meteorological thinking and practice and making links between theory, the real atmosphere and the provision of scientific and professional services to the benefit of society.

Meteorological technicians shall be able:

- To apply basic knowledge of meteorology, geography and related sciences to observe and monitor the atmosphere.
- To interpret available sources of observational data and commonly used meteorological diagrams and products to produce coherent descriptions of the state of the atmosphere at the spatial and temporal scales under consideration.
- To identify, analyse and resolve the issues involved in setting up and maintaining meteorological instrumentation in the area of responsibility.
- To communicate with colleagues, customers and other stakeholders using a range of media with relevance, clarity and precision.
- To determine the sensitivities of society to weather and climate phenomena, drawing on other disciplines where necessary, to ensure that the impacts of weather and climate on people and society are central to their work.
- To evaluate their work outputs against relevant standards, take corrective action if needed and contribute to the development of work systems and processes.
- To reflect on their learning and working practices, critically evaluate their performance and use a range of approaches to continuously develop their professional knowledge and competence.

These learning outcomes should be achieved through learning and assessment of the atmospheric science topics described later in this part, supplemented where necessary by the professional learning outcomes and other outcomes as required to meet national needs, and supported by the advice on foundation topics also contained in this part of the guidance.

3.3 Pre-requisite mathematics and physics

It is expected that the supporting knowledge could be acquired using any one of the following approaches, or a combination of them:

- Completing a programme of study in the foundation or pre-requisite topics at a school or college before attending an institution to study the topics in atmospheric science.
- Completing an introductory programme of study in the foundation or pre-requisite subjects at the same institution where the general meteorology topics are to be studied.
- Integrating the acquisition of the supporting knowledge associated with the foundation or pre-requisite topics into the mandatory topics studied in general meteorology.

The guidance in Tables 3.1 and 3.2 should help to define instructional learning outcomes in modules of study. It is intended to be indicative of the range and type of knowledge needed to meet the pre-requisites and thus access the study of meteorology, rather than being either exhaustive or limiting.

Meteorological technicians shall be able:

To demonstrate the knowledge of mathematics and physics required to successfully complete the meteorological components of the BIP-MT.

Table 3.1. Suggested instructional outcomes to meet the pre-requisite mathematics requirements

Mathematics	
Trigonometry	Define sine, cosine and tangent, describe their relationship with their inverse functions and manipulate basic trigonometrical equations.
Logarithms and exponentials	Manipulate logarithms and exponentials.
Vectors	Add and subtract vectors and multiply a vector by a scalar.
Algebra	Manipulate polynomial equations and solve basic algebraic equations, including quadratic equations.
Geometry	Calculate the area of right-angled and isosceles triangles, the circumference and area of circles, and the area and volume of rectangular blocks, cylinders and spheres; describe the relationship between radians and degrees.
Co-ordinate geometry	Interpret the slope and intercept of a linear graph; recognize standard curves such as the parabola, ellipse and hyperbola; convert between Cartesian and polar co-ordinate systems.
Statistics	Select suitable ways of displaying statistical data and interpret the results; use different measures of central tendency (mean, median and mode) and variation (range, interquartile range and standard deviation); explain the concepts of sampling, linear regression by least squares, correlation, normal distribution, percentiles and hypothesis testing.

Table 3.2. Suggested instructional outcomes to meet the pre-requisite physics requirements

Physics	
Kinematics	Solve problems using the equations that describe the relationship between distance, speed, acceleration and time for uniformly accelerated motion in a straight line.
Dynamics	Solve basic problems when a system is in equilibrium, using Newton’s second law of motion and the principle of conservation of momentum.
Work, energy and power	Explain the concepts of work, kinetic energy, potential energy and internal energy and solve problems using the principle of conservation of energy and the relationship between power, work and force.
Motion in a circle	Explain the concept of centripetal acceleration and describe circular orbits by relating the gravitational force to the centripetal acceleration.
Phases of matter	Describe the physical differences between solids, liquids and gases; explain the concept of latent heat associated with a phase change; describe the processes associated with phase changes, with emphasis on condensation and evaporation.
Temperature and heat	Explain the concepts of temperature and heat; describe how the physical properties of a substance that varies with temperature can be used to measure temperature; explain how heat is transferred by conduction, convection and radiation.
Thermodynamics and kinetic theory of gases	Solve problems using the equation of state for an ideal gas; give a qualitative description of the first law of thermodynamics; explain what is meant by an adiabatic process, with emphasis on the adiabatic expansion of a gas; describe the concepts behind the kinetic theory of gases.
Oscillations and waves	Describe the properties of oscillations and waves and explain simple harmonic motion; solve problems using the relationship between speed, frequency and wavelength for waves; explain the difference between longitudinal and transverse waves and the concepts of reflection, refraction, diffraction and interference.
Electromagnetic radiation	Describe the characteristics of electromagnetic radiation and the key features of the electromagnetic spectrum; describe the processes of reflection, absorption and scattering of radiation (including reflection and refraction of light); explain what is meant by a black body; outline the implications of the Stefan-Boltzmann law and Wien’s law.

Electricity and electromagnetic induction	Describe the physical basis of current, voltage and resistance and how they are measured; solve circuit problems (including those with two or more resistors) using Ohm's law and Kirchhoff's laws; describe the process of electromagnetic induction.

3.4 Mandatory topics

This section contains learning outcomes for topics that are mandatory for BIP-MT. The outcomes cover the core aspects of meteorology and related sciences.

3.4.1 *Basic geography, oceanography and hydrology*

Meteorological technicians shall be able:

To describe the basic geographical, oceanographical, and hydrological features of the region of responsibility.

Table 3.3 should help to define instructional learning outcomes to meet the basic requirements in geography, oceanography and hydrology. It is intended to be indicative of the range and type of knowledge needed, rather than being either exhaustive or limiting.

Table 3.3. Instructional outcomes to meet the basic geography, oceanography and hydrology requirements

Basic geography, oceanography and hydrology	
Basic geography and oceanography	Describe the topographical features and the location of stations in the region of responsibility.
	Describe the local terrain.
	Describe the general circulation and thermal structure of the oceans.
	Explain how temperature, salinity and sea-state measurements are taken.
Basic hydrology	Describe the hydrological cycle, identifying the key factors that determine run-off, groundwater and surface-water resources and the water balance.
	Explain how hydrological measurements (precipitation, evaporation, soil moisture, river flow, groundwater, etc.) are made.

3.4.2 *Basic physical and dynamic meteorology*

Meteorological technicians shall be able:

- To explain the basic physical and dynamical processes that take place in the atmosphere.
- To explain the physical principles used in instruments to measure atmospheric parameters.

The guidance in Table 3.4 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in basic physical and dynamic meteorology, rather than being either exhaustive or limiting.

Table 3.4. Instructional outcomes to meet the basic physical and dynamic meteorology requirements

Basic physical and dynamic meteorology

Atmospheric composition and structure	Describe the composition of the atmosphere and explain its vertical structure.
Radiation	Explain the diurnal, latitudinal and seasonal variations in the radiation reaching the Earth's surface; describe the differences between short-wave (solar) and long-wave (terrestrial) radiation; describe the processes affecting short- and long-wave radiation (that is, reflection, scattering and absorption of radiation); outline the heat budget of the Earth's atmosphere; explain the greenhouse effect and the effect of ozone on ultraviolet radiation; describe the heat balance at the Earth's surface and how it varies with latitude.
Atmospheric pressure	Explain why pressure varies with height, what effect temperature and humidity have on the variation of pressure with height and why pressure is often reduced to mean sea level.
Atmospheric temperature	Describe the heating and cooling effect of convection, advection, turbulence and evaporation/condensation; explain the effect of water vapour, cloud and wind on surface air temperature; explain the diurnal variation in surface air temperature; describe the main factors that affect the global distribution of surface air temperature.
Atmospheric humidity	Explain why humidity is important; define vapour pressure, saturated vapour pressure, wet-bulb temperature, dew point and relative humidity; describe the factors that affect the rate of evaporation.
Atmospheric stability	Describe the causes of variations in atmospheric stability; explain the concepts of dry adiabatic lapse rate, saturated adiabatic lapse rate and environmental lapse rate; describe various types of stability (for example, absolute, conditional and neutral); explain the role of temperature inversions and how stability and instability develop.
Wind	Explain why winds occur; describe the pressure gradient force and Coriolis force and explain concepts related to geostrophic and gradient winds; describe the effect of friction on the wind and explain the causes of common local winds caused by topography (for example, sea/land breezes, Foehn winds and katabatic/anabatic winds).
Dew, frost and fog	Describe the factors that affect visibility; explain the formation of dew and frost and the causes of fog, with emphasis on radiation and advection fog.
Atmospheric optics and electricity	Explain the formation of rainbows, haloes, blue skies and lightning.

3.4.3 ***Basic synoptic and mesoscale meteorology***

Meteorological technicians shall be able:

- To describe the formation, evolution and characteristics of synoptic-scale and mesoscale tropical, mid-latitude and polar weather systems; to analyse weather observations.
- To describe the forecast process and the use made of the associated products and services.

The guidance below should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in basic synoptic and mesoscale meteorology, rather than being exhaustive or limiting:

Table 3.5. Instructional outcomes to meet the basic synoptic and mesoscale meteorology requirements

Basic synoptic and mesoscale meteorology	
Weather at a specific location	Explain how the weather experienced at a specific location is a combination of effects acting on different time and space scales.
Bodies of air	Describe and explain the origin, characteristics, movement and modification of bodies of air.

Mid-latitude and polar weather systems	Describe the characteristics of depressions, anticyclones, troughs and ridges and their associated weather, with emphasis on those affecting the region of responsibility; describe the characteristics of warm, cold and occluded fronts and the weather associated with their passage; describe the relationship between jet streams and weather systems.
Main tropical disturbances	Describe the main tropical disturbances and their associated weather, including the Inter-Tropical Convergence Zone, tropical depressions, monsoons and the El Niño-Southern Oscillation.
Mesoscale systems	Describe the formation and characteristics of important mesoscale features affecting the region of responsibility.
Hazardous weather	Describe the formation and characteristics of hazardous weather systems (for example, thunderstorms and tropical cyclones) affecting the region of responsibility, the extent to which they can be forecast and their impact on society.
Surface pressure diagrams	Identify the main synoptic features on surface pressure diagrams and the associated satellite and radar imagery and describe the typical weather associated with those features.
Upper-air diagrams	Describe different types of upper-air diagrams, including height charts on constant pressure surfaces; identify the main synoptic features on the diagram and the associated satellite and radar imagery; describe the typical weather associated with those features.
Aerological diagrams	Describe the physical ideas that form the basis of aerological diagrams and perform basic operations on the diagram.
Display and mapping systems	Discuss the common systems used within meteorological services to display and map data along with the benefits and shortcomings of the systems, and prepare products and services for users.
Forecast process	Describe the forecasting process and the principles behind NWP and interpret basic operational NWP output.
Key products and services	Describe the key products and services (including warnings of hazardous weather conditions) based on current and forecast weather information provided to the public and other users.
Function of NMHSs	Describe the function of NMHSs in monitoring and forecasting the weather and the role of other service providers.

3.4.4 *Global and local climatology*

Meteorological technicians shall be able:

– To describe the global circulation of the atmosphere, the climates in the region of responsibility, and key climate products and services.

– To outline the basic concepts behind climate variability and climate change.

The guidance in Table 3.6 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in global and local climatology, rather than being exhaustive or limiting.

Table 3.6. Instructional outcomes to meet the global and local climatology requirements

Global and local climatology	
Features of global circulation	Explain the main features of the global circulation of the atmosphere and oceans and their temporal (diurnal, seasonal, annual) variability.
Regional and local climates	Explain the factors that determine regional and local climates.
Classification and description of climates	Describe the techniques for classifying the climate, including the Köppen method.

Local climate	Describe the climatology and seasonal changes of the region of responsibility and the climatic trend in that region.
Climate variability and climate change	State the difference between climate variability and climate change; describe the basic concepts behind the greenhouse effect; describe the effect and the basic science involved in human-induced climate change; outline the basis for climate predictions.
Seasonal forecasts	Outline the process and scientific basis for making seasonal forecasts.
Climate data	Describe how climate data are captured, collected and quality-controlled in the region of responsibility.
Climate statistics	Describe how climate data are analysed in terms of their distribution (for example, frequency and cumulative frequency), central tendency and variation.
Key products and services	Describe the key products and services based on climate information provided to the public and other users.

3.4.5 ***Cloud formation***

Meteorological technicians shall be able:

To describe the formation and characteristics of the main cloud and precipitation types.

The guidance in Table 3.7 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in cloud formation, rather than being exhaustive or limiting.

Table 3.7. Instructional outcomes to meet the cloud formation requirements

Cloud formation	
Cloud identification	Describe the main cloud types and cloud species; describe their characteristics; describe their usual height range; describe the associated weather phenomena.
Hydrometeors	Describe the various hydrometeors and how they are observed.
Cloud formation	Explain why rising motion leads to the formation of clouds; describe the main mechanisms for the formation of clouds; describe the different cloud types; describe the geographical locations where cloud types are most likely to form.
Precipitation and thunderstorms	Describe the processes that produce precipitation, the triggering processes for thunderstorms and their life cycle.

3.4.6 ***Meteorological parameters, instruments and methods of observation***

Meteorological technicians shall be able:

- To describe how weather phenomena are measured from ground, air and space-based instruments.
- To make a basic weather observation based on the evaluation and interpretation of data from ground, air and space-based instruments.

The guidance in Table 3.8 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in meteorological parameters, instruments and methods of observation, rather than being exhaustive or limiting.

Table 3.8. Instructional outcomes to meet the meteorological parameters, instruments and methods of observation requirements

Meteorological parameters, instruments and methods of observation	
Weather phenomena	Describe the various weather phenomena considered when taking a visual surface observation; specify their characteristics and explain their formation.
Weather monitoring and observation	Monitor the weather; make surface observations using remote and directly read instruments and visual assessments (including identification of cloud types, cloud amount and weather type) and explain the reasons for such assessments.
Temperature	Discuss different methods of temperature measurement and how they relate to the use and limitations of the instruments/sensors.
Humidity	Discuss different methods of humidity measurement and how they relate to the use and limitations of the instruments/sensors.
Wind direction and speed	Discuss different methods of wind direction and speed measurement and how they relate to the use and limitations of the instruments/sensors.
Rainfall	Discuss different methods of rainfall measurement and how they relate to the use and limitations of the instruments/sensors.
Direct and indirect radiation	Discuss different methods of direct and indirect radiation measurement and how they relate to the use and limitations of the instruments/sensors.
Pressure	Discuss different methods of pressure measurement and how they relate to the use and limitations of the instruments/sensors.
Sunshine recorder	Discuss different methods of sunshine measurement and how they relate to the use and limitations of the instruments/sensors.
Evaporation	Discuss different methods of evaporation measurement and how they relate to the use and limitations of the instruments/sensors.

3.4.7 *Basic climate-data quality control*

Meteorological technicians shall be able:

To describe and apply climate-data quality control procedures.

The guidance in Table 3.9 should help to define instructional learning outcomes within modules of study. It is intended to be indicative of the range and type of knowledge needed to achieve the learning outcomes in climate-data quality control, rather than being exhaustive or limiting.

Table 3.9. Instructional outcomes to meet the climate-data quality-control requirements

Climate-data quality control	
Climate-data sets	Conduct climate-data preservation and rescue procedures; assess the location and characteristics of the observation sites against the requirements for a climate-observation reference network; collect and store climate data and metadata in relational databases; apply quality-control processes to climate data and resulting time seriesβassess climate-data homogeneity and adjust inhomogeneous time series; create, archive and document climate data sets; apply spatial and temporal interpolation to ensure data continuity.
Quality of climate information and services	Define and apply quality management procedures for climate services; monitor the functions of climate services, including validation of data, products and services; evaluate the impact and benefits of climate services for customers by gathering customers' comments, suggestions and complaints.
Communication of climate information to users	Establish effective communication channels with users of climate services and build outreach capacities, such as Regional Climate Outlook Forums, that comply with the interfacing requirements of the Global Framework for Climate Services (GFCS) and integration within the WMO Information System (WIS).

Quality control of climate data	Monitor all observations to check for errors and inconsistencies, correct errors or flag data in accordance with prescribed procedures and take follow-up action; record corrections, flags and follow-up actions in metadata repository; check observational messages for format and content before issuance and make corrections if required; ensure all observations are sent and received successfully.

3.5 Professional learning outcomes

This section contains learning outcomes to support the achievement of several of the overarching learning outcomes and thus give meteorological technicians the fundamental professional skills they will need at the outset of their careers. The outcomes given in Tables 3.10 and 3.11 are not exhaustive lists of these skills; institutions will be guided by national and regional human resource needs.

Table 3.10. Communication of useful learning outcomes for meteorological technician roles

Communication and teamwork skills	
Written communication	Use word-processing software to prepare well-written text; use presentation software to prepare good-quality displays or graphics; prepare written communications within specified time limits in a concise, accurate and comprehensible way and for different customers or clients.
	Communicate meteorological information in the form of forecast policy discussions and handover briefings that are impact-focused and that utilize the forecast funnel; identify the key weather and climate sensitivities of customers and deliver tailored briefings that focus on impacts, uncertainties, confidence and support for decision-making.
	Prepare and provide media interviews and community outreach activities using plain language that communicates key messages; engage customers and colleagues by using the right tone and body language and showing empathy.
Oral presentation	Make presentations within stated time limits in which the content and style of delivery accurately convey information in a way that can be understood by the audience; use different communication styles and techniques.
Teamwork	Share knowledge and work constructively with others in a team.

Table 3.11. Learning outcomes in using information technology

Information technology	
Basic computer knowledge	Use word-processing software to edit and format written documents; use presentation software to edit and format displays or graphics.
Material for publishing	Create, publish and update a basic web page; understand features of a web page (tables and images) using CSS and HTML.
Accessing and obtaining information	Find meteorological information using libraries, databases and Internet searches; create material for publishing.
Meteorological information uses	Describe how meteorological information is used, such as for air-traffic management and control, flight crew members and disaster risk managers.

3.6 Selective specializations

The guidance in Table 3.12 should help to define instructional learning outcomes and performance criteria within modules of study and training courses based on BIP-MT. It is intended to be indicative of the range and type of knowledge and skills needed in each selective specialization, rather than being exhaustive or limiting.

Table 3.12. Learning outcomes and performance criteria for general meteorological technician roles

General meteorological technician	
Monitoring the meteorological situation	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 1: Monitor the meteorological situation.
Coding (*Manual on Codes* (WMO-No. 306))	Outline how observations are coded.
	Outline how observations are transmitted.
	Describe differences between different types of messages (SYNOP, SHIP, CLIMAT, METAR, etc).
Cloud identification	Identify various cloud types according to their characteristics and height.
	Identify the various cloud types with associated weather phenomena (see *International Cloud Atlas: Manual on the Observation of Clouds and Other Meteors* (WMO-No. 407).
Surface observation	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 2: Perform a surface observation.
	Observe other parameters as required, such as solar radiation, evaporation, soil temperature, state of the ground, soil moisture, sea state, atmospheric composition, wind shear, leaf wetness and phenology.
Quality of observational information	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 6: Maintain the quality of observational information.
	List the interfacing requirements of GFCS and integration within WIS.
Performance of instruments and systems	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 5: Monitor the performance of instruments and systems.
	Monitor the functionality of automatic weather observing systems and make staff familiar with steps to be taken when components malfunction.
Use of remote sensing (when available) in making observations	Interpret information derived from remote-sensing technology in making observations (for example, ceilometer for cloud base height in synoptic observations and meteorological aerodrome reports).
	Cross-check observations obtained using alternative observing techniques (for example, remote sensing versus in situ measurements) to ensure consistency (for example, compare visibility information recorded by visibility meters with satellite imagery (fog, sandstorms) and manual observations).
	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 4: Utilize remote-sensing technology in making observations.
Balloon-borne upper-air observations	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 3: Perform a balloon-borne upper-air observation.
Maintain a safe work environment	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 7: Maintain a safe work environment.

For the outcomes and criteria listed in Table 3.13, reference should be made to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209) for competency standards and related background material relevant to aeronautical meteorological observers.

Table 3.13. Learning outcomes and performance criteria for aeronautical meteorological observer roles

Aeronautical meteorological observer	
Monitoring the meteorological situation	Outline how observations are coded and transmitted.
	Describe differences between different types of messages (METAR and SPECI).
Cloud identification for aviation	Describe the main cloud types, their characteristics, their usual height range and associated weather phenomena.
Quality of system performance and meteorological information	List the interfacing requirements of GFCS and integration within WIS.
Use of remote sensing (when available) in making observations	Interpret information derived from remote-sensing technology in making observations (for example, ceilometer for cloud base height in synoptic observations and meteorological aerodrome reports).
	Cross-check observations obtained using alternative observing techniques (for example, remote sensing versus in situ measurements) to ensure consistency (for example, compare visibility information recorded by visibility meters with satellite imagery (fog, sandstorms) and manual observations).
Safe work environment	Perform safely in the proximity of electrical hazards.
	Perform all observing tasks safely while minimizing exposure to hazardous environmental conditions (severe weather, lightning, flooding, hurricanes, fires, etc.).
	Maintain a register of hazards and perform hazard management.

For the outcomes and criteria listed in Tables 3.14–3.17, reference should be made to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209) for competency standards and related background material relevant to instrumentation, calibration, meteorological observations and observing programme and network management.

Table 3.14. Learning outcomes and performance criteria for meteorological instrument technician roles

Meteorological instrument technician	
WMO Integrated Global Observing System	Describe the main components of the WMO Global Observing System and WIS (including the Global Telecommunication System) that are used for making and transmitting meteorological and other environmental observations on a global scale using surface-based and space-based systems.
Siting of instruments	Describe the factors that need to be considered when siting surface instrumentation.
Surface instrumentation	Explain the physical principles used in instruments to make surface measurements of temperature, moisture, pressure, precipitation, wind, cloud height, visibility, sunshine and radiation (including instruments used in automatic weather stations); describe how these instruments operate and outline the kinds of errors that might occur.
Automatic weather station instrumentation and basic electronics	Identify automatic weather station instrumentation.
	Identify the individual components of the automatic weather station instruments.
Installation of instruments and communications	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 1: Install instruments and communications systems.
Instrument maintenance and system performance	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 2: Maintain instrument and system performance.

Fault diagnosis	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 3: Diagnose faults.
Monitoring performance of instruments and systems	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 5: Monitor the performance of instruments and systems.
Repair of faulty instruments and systems	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 4: Repair faulty instruments and systems.
Lightning detection network and radar maintenance (both optional)	Maintain instrument and system performance.
	Diagnose faults.
	Maintain a safe working environment.
Safety	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 5: Maintain a safe work environment.

Table 3.15. Learning outcomes and performance criteria for air-quality instrument technician roles

Air-quality instrument technician	
Air-quality theory	Describe the types of air pollution, their characteristics and their influence on climate change.
	Describe the components of air-quality monitoring stations.
	Maintain an air-quality monitoring station.
	Describe the measurement principle and basic maintenance requirements of nitric oxide (NO), carbon monoxide (CO), ozone (O_3), and promethium (Pm).
	Describe logging technologies.
Instrument performance	Prepare the standards to be used for checking instrument performance.
	Handle standards and items appropriately.
	Compare the instrument with standards and evaluate its functionality.
	Record and analyse the measurement errors.
	Prepare instrument performance reports as required.
Installation of instruments and communications	Assemble and test instruments before transport to site.
	Transport instruments to site.
	Install instruments and communication systems (including simple site preparation).
	Train observing and technical staff to operate and maintain instruments (including the provision of standard operating procedures, standard operating instructions, system manuals, wiring diagrams, etc.).
	Test on-site instrument and communications performance thoroughly prior to operational cutover.
	Complete site classification for any variable concerned, prepare instrument and variable metadata and submit them to the WMO Integrated Global Observing System via the Observing Systems Capability Analysis and Review Tool.
	Switch instrument(s) to operational mode.
Instrument maintenance and system performance	Refer to the *Compendium of WMO Competency Frameworks*(WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 2: Maintain instrument and system performance.
Fault diagnosis	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 3: Diagnose faults.

Monitoring performance of instruments and systems	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 5: Monitor the performance of instruments and systems.
Safety	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel installing and maintaining instrumentation, Competency 5: Maintain a safe work environment.

Table 3.16. Learning outcomes and performance criteria for marine meteorological observer roles

Marine meteorological observer	
Monitoring the marine meteorological situation	Assess the evolving local meteorological situation.
	Explain the potential influence of the evolving meteorological situation on subsequent observations.
	Identify meteorological symptoms that may lead to the onset of significant weather.
Marine coding (*Manual on Codes* (WMO-No. 306))	Outline how observations are coded and transmitted; describe the SHIP format, sea state (swell and wind waves), sea ice and vessel ice.
Cloud identification for marine observations	Identify the various cloud types according to their characteristics and height.
	Relate cloud types with associated weather phenomena.
Surface observation	Observe and accurately record atmospheric pressure, temperature, humidity, wind, cloud, present and past weather, visibility, sea state, swell heights and periods.
	Encode and transmit surface observations using prescribed codes and methods.
Quality of observational information	Monitor all observations to check for errors and inconsistencies, correct errors or flag data in accordance with prescribed procedures and take follow-up action.
	Record corrections, flags and follow-up actions in a metadata repository.
	Assess observational messages for format and content before they are issued and make corrections if required.
	Ensure all observations are sent and received successfully.
Monitoring the performance of instruments and systems	Regularly inspect meteorological instruments (such as rain gauges and wet-bulb thermometers), automated observing systems (such as automatic weather stations and the weather-radar fault status), communications systems and backup systems (for example, power).
	Conduct routine maintenance tasks as prescribed (for example, change the wet-bulb wick).
	Conduct first-in fault diagnosis and alert technical staff.
	Undertake action under guidance from remote technical staff.
	Record interventions and irregularities in a maintenance log or metadata repository.
Balloon-borne upper-air observations	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 3: Perform a balloon-borne upper-air observation.
Safety	Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), Competency framework for personnel performing meteorological observations, Competency 7: Maintain a safe work environment.

Table 3.17. Learning outcomes and performance criteria for specialist climate-data controller roles

Specialist climate-data controller	
Climate-data control	Refer to the *Compendium of WMO Competency Framewor*k (WMO-No. 1209), Competency framework for the provision of climate services, Competency 4: Ensure the quality of climate information and services

Guidance on the remaining roles of meteorological technicians may be obtained from the WMO publications listed below.

Hydrometeorological technician

Refer to the *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology* (WMO-No. 258), Volume II: Hydrology, Fourth Edition.

Agrometeorological technician

Refer to the *Guide to Agricultural Meteorological Practices* (WMO-No. 134), Chapter 2: Agricultural meteorological variables and their observations.

Public/marine forecasting technician

Refer to the *Compendium of WMO Competency Frameworks* (WMO-No. 1209).

As stated in the *Compendium of WMO Competency Frameworks* (WMO-No. 1209), it is recommended that forecasters working for public weather services and marine weather forecasters should have successfully completed BIP-M (or parts thereof) as defined in the *Technical Regulations* (WMO-No. 49), Volume I, Part V, and in Appendix A: “Basic Instruction Packages”.

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