World Meteorological Organization

Initial formation and specialisation of meteorological personnel:

Detailed Syllabus Examples

Supplementing Chapters 3 and 4 of the *Guidelines for the Education and Training of Personnel in Meteorology and Operational Hydrology,* WMO-No. 258, Vol. I - Meteorology

I. F. Drãghici
G. V. Necco
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Continuing Education and Training in Meteorology and Hydrology

CET-MH-No. 1

December 2001

WMO/TD-No. 1101

Secretariat of the World Meteorological Organization
Geneva - Switzerland

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Preface

The WMO Education and Training Programme (ETRP) was established to assist its Members, particularly from developing regions, in obtaining adequately educated and trained personnel. Competent, skilled and knowledgeable staff is essential for the continued development of Meteorological and Hydrological Services so as to enable them to discharge their operational responsibilities, as well as meet the challenges of new functions.

The past few decades have brought enormous and rapid changes in practically all areas of human activity. The economical, social and political patterns now evolving in a globalized world are giving rise not only to new demands but also to far-reaching changes in many aspects of the meteorological profession. These rapid changes also affect the educational processes. Technology is moving so fast that the educational systems are now being required not only to transfer knowledge, or at least the necessary information, but also to create new learning attitudes.

In recent years the ETRP has developed a new approach to the classification of meteorological and hydrological personnel, more appropriate to the needs of the present Century. This simpler and more flexible new classification scheme, approved by the WMO Executive Council at its fiftieth session (Geneva, 1998) and endorsed by the thirteenth World Meteorological Congress (Geneva, 1999), is common to both meteorological and hydrological personnel, put more emphasis on job-competency requirements, treats meteorological disciplines and sub-disciplines in a much simpler and structured approach and emphasises the concepts of continuing professional development, lifelong learning culture and learning organization.

The new, fourth edition of the WMO Publication N° 258*, "Guidelines for the Education and Training of Personnel In Meteorology and Operational Hydrology"*, describes the major elements of the new classification. It includes guidance aiming at assisting educators (and managers) in designing and implementing programmes for human resources development, particularly in national Meteorological and Hydrological Services from developing countries. The Guidelines are also aimed at facilitating common understanding and a certain degree of uniformity and stability in an international context.

The continuing education and training (CET) of personnel at all levels underpins career progression and is an essential element in the new classification. The importance of CET in the ETRP was underscored by the last WMO Congress which, through its resolution on this programme, decided that "special emphasis should be placed on developing and maintaining the continuing education of staff in all field of activities of the Organization …". This emphasis is reflected in one the overall objectives of the ETRP for the Fifth WMO Long-term Plan. Moreover CET was the theme of the last quadrennial WMO Symposium on Education and Training (Tehran, 1999), an event that attracted educators and instructors from all regions and produced a series of recommendations which were later endorsed by the WMO Executive Council.

To satisfy these CET needs the EC Panel of Experts on Education and Training agreed upon the initiation of a new ETR TD series, *"Continuing Education and Training in Meteorology and Hydrology" (CET-MH).* This series aims at promoting CET in meteorology and operational hydrology and to assist trainers (and trainees), particularly from developing countries, in constantly up-dating their knowledge and teaching skills.

This first issue supplements Chapters 3 and 4 of the recently released WMO N° 258, Volume I, Meteorology, by providing detailed syllabus examples of the major topics required under the Basic Instruction Packages for Meteorologists and Meteorological Technicians (BIP-M and BIP-MT). Many other alternative syllabus formulations could be designed for the same BIP curricula from WMO N° 258 : the

a possible option in designing his/her own specific syllabus.

BASIC INSTRUCTION PACKAGE FOR METEOROLOGISTS - BIP-M

Chapter 3, WMO-No. 258 Vol. I - Meteorology

Requisite topics in mathematics and physical sciences

Compulsory topics in atmospheric sciences

Elective fields of specialization in meteorology

Other fields of specialization

3.1 Requisite topics in mathematics and physical sciences

Mathematics

(a) *Linear algebra and vector calculus.* Matrices, systems of linear equations, inverses, determinants. Vector spaces, orthonormal bases and orthogonal projections, eigen-values and eigen-vectors; diagonalisation. Applications of vector and tensor analysis to the study of fluid flow; e.g. the Green, Gauss, Stokes and transport theorems; solenoidal and irrotational vector fields, potential function; relation between material and Eulerian derivatives; vector operators in curvilinear coordinates.

(b) *Differential and integral calculus.* Fundamental concepts and methods in mathematical analysis, functions, limits, continuity, derivatives, integration, infinite series, Taylor expansion, partial derivatives; multiple integrals, curvilinear integrals, surface and volume integrals; integral calculus theorems; complex variable functions.

(c) *Ordinary and partial differential equations.* Ordinary differential equations, Laplace transforms, Fourier series and integral; harmonic analysis; applications. Special functions, Legendre functions and spherical harmonics, generalised integrals, gamma and beta functions; elliptical integrals. Partial differential equations: linear equations of first and second order; the wave equation, vibrating string, normal modes of vibration, and heat equation applications; initial-value and boundary-value problems.

(d) *Probability theory and statistics*. Population and samples; frequency distributions; statistical descriptors and sample moments; elementary probability theory; conditional probability; independence; random variables and distributions; moments; two-dimensional distributions; marginal and conditional distributions; statistical hypotheses; error types; significance levels; tests of significance: univariate and multivariate time series.

(e) *Information and communication technology*. Basics of computers and network technology; local and wide area networks; internet; operating system and application software; basics of UNIX (Linux) and MS-Windows; software instruction, standard tools; database management systems; basic skills in homepage development and maintenance. Programming and data exchange between different applications; multiple platforms; graphical user interface; analysis and visualisation interfaces; display software;

(f) *Numerical methods*. Numerical differentiation and integration; differential versus difference equations; methods for the numerical solution of ordinary differential equations; simultaneous linear equations; methods for the numerical solution of non-linear algebraic equations; stability criteria; standard transcendental equations to include effects of initial and boundary conditions.

Physics

(a) *Fundamentals of mechanics*. Force and inertia; velocity and acceleration, momentum and kinetic energy, work and potential energy; gravitation; Newton's laws of motion; rotating systems, centripetal acceleration, Coriolis and centrifugal

effects; orbital mechanics, Kepler's laws, trajectories, orbits; Newtonian mechanics; stability and instability of mechanical systems.

(b) *Basic thermodynamics*. Thermodynamic system; variables of state; Clapeyron diagram; temperature and pressure; thermal energy; laws of Boyle-Mariotte, Gay-Lussac, Avogadro, Dalton; ideal gas and Van der Waal's gas; First law of thermodynamics; various forms of energy - work, heat, electrical and chemical energy; conservation of energy. Second law; entropy, reversible and irreversible energy transformations, heat engines and cyclic processes; changes of phase; mixtures of gases - partial pressures; thermal boundary layer; Newton's law of cooling.

(c) *Wave theory*. Waves - description, propagation, transmission, refraction, diffraction; simple water waves; wave theory application; electromagnetism, geometric optics, and acoustics; the electromagnetic spectrum.

(d) *Fluid motion*. Nature of fluids; pressure and density; streamlines, streak lines, and trajectories; Bernoulli's theorem; circulation and vorticity; rotation - Rossby number; stratification - buoyancy, Richardson number; combined effects of rotation and stratification - Burger number; flow near a boundary - surface boundary layer, surface stress, momentum flux, power-law profiles; Ekman number; Lagrangean-Eulerian relations.

(e) *Turbulence in fluids*. Viscosity, Navier-Stokes equations, Reynolds number, transition to turbulent flow; turbulent diffusion of heat and momentum, eddy conductivity and eddy viscosity; empirical and statistical representation of turbulent flow.

(f) *Electromagnetic radiation; electromagnetism.* Basic theory of electromagnetic radiation; physical concepts; the spectral energy density of blackbody radiation; Plank's law; radiative transfer equation; basics of molecular spectroscopy; the infrared and ultraviolet absorption by atmospheric gases. Electrostatics and magnetostatics; electromagnetism; geometric and wave optics; applications.

Chemistry

(a) *Basic physical chemistry*. The elements and the periodic table; compounds; bonding; valence; bonds. Chemical reactions and reaction rates, chemical equilibria; equilibria constants; ionic and molecular species and their general properties; chemical nomenclature.

(b) *Chemical thermodynamics.* The first law, enthalpy; the second law, entropy; the third law; Gibbs free energy; free energy change; chemical potential. Reaction mechanisms; collision theory of gaseous reactions; the effect of temperature on reaction rates; catalysis; residence and renewal time.

(c) *Aqueous solutions.* Solution concentrations; solubility; aqueous equilibria; electrolytes. Acids and bases: ionisation; hydrogen ion concentrations of dilute solutions; the pH scale; hydrolysis reaction; rain-water pH. Oxidation-reduction reactions; electrochemical cell; electrolyte; Nernst equation; redox potentials.

(d) *Introductory photochemistry*. Electromagnetic radiation; absorption; unstable atoms; interactions of photons with molecules; photochemical reactions and

photolysis process; photostationary states. Major and minor gases in the Earth's atmosphere; trace constituents - oxygen hydrogen nitrogen, carbon, sulfur and halogen species; noble gases; water as a unique compound. Ultra-violet radiation and the protective effect of stratospheric ozone.

Complementary requirements

(a) *Communication and presentation techniques:* Written and oral communication; presentation skills; writing reports, projects, scientific articles, etc. Communication theory: information and communication technology; signal processing; noise-signal ratio; optimal receivers. Technical report writing; development strategies; forming an outline, building a case; scan reading and literature study; basic features of a report; skill in writing; paragraph writing; topic statements and patterns; production; editing for emphasis; punctuation. Scientific, professional literature; types of publications; citations and references; search in data base and library catalogue literature.

(b) *International communication languages*: To the extent possible, students should be conversant with one of the common international communication languages.

3.2. Compulsory topics in atmospheric sciences

Physical meteorology

(a) *Radiation in the atmosphere*: The spectrum of electromagnetic radiation; molecular absorption and emission of radiation; radiant flux and irradiance; diffuse and parallel beam; radiation measurement. Blackbody radiation, Stefan-Boltzman law; wavelength of the maximum radiant flux, Wien displacement law; absorptivity and emissivity, Kirchoff's law. Atmospheric absorption of solar radiation; photon extinction by absorption and scattering, Beer's law; solar radiation incident on the top of the atmosphere; solar constant; vertical profile of the absorption. Atmospheric absorption and emission of infrared radiation; the diffuse radiation; Schwarzschild's equation. Aerosols origin and composition; scattering of solar radiation from aerosols; Rayleigh-Mie theory.

(b) *Atmospheric acoustics, optics and electricity:* Regions and extensions of the atmosphere; troposphere, stratosphere, mesosphere, thermosphere; ionosphere; exosphere; magnetosphere. Geometric optics of reflection, refraction and diffraction; applications to aurora, rainbow, halo, glory, corona, mirages; transparency of the atmosphere; the visual range; turbidity and its measures. The fair-weather electric field and space charge; atmospheric ions and ionising radiation; conductivity; thunderstorm electrification - observation and theory; lightning discharge.

(c) *The global energy balance.* Radiative transfer; globally averaged atmospheric energy balance; sources and sinks; balance at the earth's surface; global energy balance for the earth-atmosphere system. Energy balance in the troposphere; role of radiative transfer, fluxes of latent and sensible heat. Time variations in the energy balance; diurnal cycle, seasonal variations. Energy balance of the upper atmosphere; photoionization; photodissociation of oxygen; ozone layer.

(d) *Cloud and precipitation; water cycle.* Evaporation, condensation, and sublimation; saturation vapour pressures over liquid and solid; relative and specific humidity; suspended particles. Formation of fog, mist and cloud; cloud condensation nuclei; growth of a drop by condensation; cloud droplets; growth by collision and coalescence; warm rain; ice formation; snow, hail and rain by ice processes; ice precipitation; precipitation types and classification; snow cover, melting and evaporation. Hydrological cycle: processes of precipitation and direct condensation; evaporation and transpiration from natural surfaces; area and time statistics of precipitation; streams and rivers; hydrometry.

(e) *Atmospheric thermodynamics*: Atmospheric systems; first and second law of thermodynamics as applied to air and cloud; reversible transformations; adiabatic and non-adiabatic processes; potential temperature; hydrostatic balance, standard atmosphere. Changes of phase of water, latent heats of fusion and evaporation, Clausius-Clapeyron equation; adiabatic transformations of dry and moist air; horizontal and vertical mixing. Principles and application of aerological diagrams; parcel and slice methods; vertical stability; conditional and latent instability; potential or convective instability.

(f) *Boundary layer and turbulence; micrometeorology:* Laminar flow; viscosity; viscous stresses; laminar boundary layer; flow over a plane surface. Turbulent flow; basic mathematical theory of turbulent motion; mean values and

fluctuations; Reynolds stresses; analogy with molecular processes; exchange coefficients; well-mixed boundary layer; flux-gradient theory. Mixing length theory; the laminar Ekman layer; surface layer; secondary circulations; vorticity-transfer. Introduction to statistical theories of turbulence; Kolmogoroff similarity hypotheses. Heat transfer and diffusion; laminar thermal boundary layer; exchange of heat, moisture, momentum, and trace constituents between the surface and the atmosphere; urban heat island effect. Boundary layers over ocean and sea.

(g) *Satellite systems.* Orbital mechanics; principles of instruments used for the measurement of meteorological parameters. Basic image interpretation; application of satellite measurements to Earth's radiation balance and albedo; surface temperature; atmospheric temperature profile; cloud heights and types; cloud-drift winds; minor atmospheric constituents; aerosols and precipitation; circulation systems; tropical cyclones.

(h) *Weather radar.* Principles of measuring the backscatter of pulses of radio waves; transmitter, antenna, and receiver; peak power, pulse length, scanning modes, polarisation; propagation and attenuation of microwaves; radar equation; reflectivity factor. Converting radar echo intensity to rainfall rate; convective and stratiform precipitation; hail and tornadoes; rain versus snow; non-precipitating clouds; interpretation techniques. Doppler radar equation, frequency shifts.

(i) *Introduction to atmospheric chemistry; urban pollution.* Photochemistry principles. Environmentally important atmospheric species; reactive gas species; photochemical oxidants; ozone - total column, vertical profile, and near the surface; greenhouse gases; atmospheric aerosols; water vapour. Urban emissions of primary pollutants; emission sources; production of secondary pollutants. Global environmental issues associated with the changing of the chemical and physical characteristics of the atmosphere.

(j) *Suggestions for laboratory work and practical exercises:* principles of atmospheric measurement (temperature, humidity, wind, pressure, radiation, rainfall) including the understanding of accuracy, response, sensitivity, lag, analysis of errors, calibration. Surface energy balance including measurement of solar radiation balance, net and long-wave radiation balance, turbulent transfers by the profile method; turbulent heat transfer by the eddy correlation method. Surface layer processes including measurement of turbulent vector wind field fluctuations, sensible heat transfer by the eddy correlation method, momentum and sensible heat flux by the profile method and of the surface energy budget by the Penman method. Heat transfer experiments including diurnal temperature waves in sand and heat loss from heated cylinder in a wind tunnel.

Dynamic meteorology

(a) *Basic fluid dynamics*. Scalar and vector fields; Gauss and Stokes theorems; kinematics of flow fields; material derivative; Eulerian and Lagrangean rates of change; conservation of mass, momentum and energy. Navier-Stokes equations. Rotating frames of reference; equations of motion in coordinate form: spherical coordinates; preliminary approximations to the equations in spherical coordinate form; Coriolis parameter; tangent-plane geometry; f- and β-plane approximations.

(b) *The hydrostatic and geostrophic approximation.* Scale analysis for the mid-latitude large-scale weather systems. Rossby number; hydrostatic and geostrophic balance; inertial flow; cyclostrophic flow; gradient flow and the gradient-wind balance for a steady circular vortex. Vertical shear of the geostrophic wind; thermal wind; pressure co-ordinates and geopotential height.

(c) *The vorticity and the thermodynamic energy equations.* Bjerknes' circulation theorem; stream function and velocity potential; Helmholtz theorem; trajectories and streamlines; natural coordinates. Vorticity and vorticity equation; relation between absolute vorticity and relative vorticity; principal mechanisms for vorticity generation and change. First law of thermodynamics, meteorological formulation; diabatic forcing in the lower and middle atmosphere; adiabatic motion: potential temperature conservation.

(d) *Quasi-geostrophic motion.* Boussinesq approximation; Brunt-Väisäla (buoyancy) frequency; Taylor-Proudman theorem; quasi-geostrophic approximation. Geopotential tendency equation. Omega equation; vertical motion; cancellation between the forcing terms; alternative interpretation; Q-vectors diagnosis of vertical motion. Conservation of quasi-geostrophic potential vorticity for frictionless and adiabatic flow. General potential vorticity equation of Ertel-Rossby; anomalies of potential vorticity in the cyclogenesis process; non-linear interactions; initial value approach, invertibility principle, use of the gradient-wind equation as balance condition to find the wind and mass field from the potential vorticity distribution;

(e) *Atmospheric waves; baroclinic and barotropic instability*: Quasi-linear behaviour of atmospheric motions; small perturbation theory; classical wave equation; dispersion relations; phase and group velocity. Simple wave types: acoustic and sound waves; shallow water gravity waves; internal gravity (buoyancy) waves; inertial gravity waves, inertial oscillations. Barotropic (Rossby) waves; westward propagation; beta effect; strong dispersion. Baroclinic instability; Eady and Charney models; stabilising influence of the beta effect on the long waves and of the static stability on short waves. Barotropic instability; Rayleigh-Kuo criterion for a basic zonal current with horizontal meridional shear; stable and unstable distribution of the absolute vorticity field.

(f) *General circulation energetics.* Kinetic, potential and internal energy; relationship between potential and internal energy in quasi-static flow; available potential energy; conservation theorems. Energy equations for an atmosphere confined to a zonal channel on an f-plane, with rigid lateral walls. Conversion of available potential energy to kinetic energy; generation of available potential energy. Treatment of the available potential energy and kinetic energy in their zonal and eddy forms, and their interaction. Momentum budget; dynamics of zonally symmetric circulations. Selective role of various scales of atmospheric motions; the generation, conversion and transfer of energy as a function of wave number. Introduction to weather and climate predictability; non-linearity, complexity, and chaos, strange attractors.

(g) *Stratospheric dynamics; physics and chemistry.* Dynamical interactions between the stratosphere and troposphere, ultra-long quasi-stationary planetary scale waves; vertically propagating planetary waves. Energetics of the lower stratosphere; sudden stratospheric warming; waves in the equatorial stratosphere; Kelvin waves and mixed Rossby-gravity waves; quasi-biennial oscillation; ozone layer; stratospheric heat balance. Transport of chemicals; Brewer-Dobson troposphere-stratosphere circulation (equator-poles), and the

solstitial stratosphere-mesosphere circulation (summer-winter poles). Antarctic "polar stratospheric clouds"; photolysis of the man-made chloroflourocarbons (CFCs) by the ultra-violet radiation; blend of chemical, dynamical and transport processes leading to the stratospheric ozone hole(s).

(h) *Numerical weather prediction*: Finite differences and truncation errors, accuracy, consistency, stability, convergence, time and space differencing. Numerical solution of Laplace, Poisson and Helmholtz equations by iterative methods; relaxation techniques. Introduction to spectral methods, spherical harmonics, transform method, semi-Lagrangian approach. Primitive equation models: model variables; inclusion of moisture and radiation effects; boundary and initial conditions. Objective analysis and data assimilation; optimum interpolation method, variational methods; dynamic initialisation, non-linear normal mode initialisation; 4-D data assimilation. Current operational models: global, regional, and local models; model equations; co-ordinate systems and numerical formulation; parameterisation of physical processes. Ensemble forecasts; unpredictable internal variations. Application of model products to the prediction of routine parameters and specific events; shortcomings and sources of error in the models; role of the human forecaster.

(i) *Suggestions for laboratory work and practical exercises:* Physical demonstration of dynamical concepts: Bernoulli's theorem, vorticity, Reynolds, Rossby, Richardson and Burger numbers. Waves and turbulence. Density currents, convective thermals and plumes, cellular convection in a stable layer of fluid, spin-up of a rotating fluid, baroclinic waves in a heated rotating annulus, surface gravity waves and barotropic Rossby waves. Information and communication technology and data processing systems; computer architecture, visualisation, and networking; programming techniques and languages. Numerical methods, round-off errors, finite difference formulas, trapezoidal rule for integration, tridiagonal linear systems; 1-D diffusion and 1-D advection equation. Quasi-geostrophic potential vorticity conservation, quasi-geostrophic omega equation, Q-vectors approach to vertical motion field, baroclinic instability and Eady model. Numerical solution of the barotropic vorticity equation. Eulerian, Lagrangean and spectral methods, vector and parallel processing; application in data assimilation, numerical weather prediction; other computer simulations.

Synoptic meteorology

(a) *Overview of meteorological observations and measurements*: Physical principles used in instruments to measure temperature, moisture, pressure, precipitation, wind, sunshine and radiation. Cloud observations and classification; estimating visibility; meteors (non-astronomical). Measuring basic meteorological variables; classical instrumentation for surface observations; upper-air sounding systems. Ship observations: fixed and drifting buoys; measurements of current, salinity, and temperature; measurement of surface characteristics; wave height. Common sources of error in standard instruments and observing techniques; techniques for estimating the confidence to be placed in a particular measurement. Synoptic data - surface, upper-air and special observations; coding and decoding, representation and analysis of meteorological data; quality control. Global observing system; World Weather Watch programme; global meteorological telecommunications network;

(b) *Relationships between wind, pressure, and temperature fields:* Kinematics of horizontal motion; representation of horizontal motion by zonal and meridional components; features of the field of flow. Gradient, cyclostrophic and friction wind; change of wind with height (thermal wind); vertical structure of pressure systems as a function of temperature field; relationships with the temperature advection (hodograph); barotropic and baroclinic stratification; effects of the diabatic heating and cooling, friction, and boundary layer pumping.

(c) *Mid-latitude synoptic systems*. Air-mass concept: source areas; formation processes for air masses. Air-mass modification; thermodynamic and dynamic changes; secondary air masses; boundary/interface between two adjacent air masses; the slope of steady-state frontal zones; frontal-wave depression. Classical wave cyclone model; cyclone families; Sutcliffe's "development theory" of cyclogenesis; affect of surface friction, exchange of sensible heat, orography. Non-frontal lows; lee depression, heat low, polar low; mid-troposphere cut-off low. Conceptual models. Conveyor belts.

(d) Cyclogenesis and frontogenesis. Conditions for baroclinic instability using a two-level linearised quasi-geostrophic model. Small perturbations superposed on an unstable zonal current; wave-type solution; phase speeds; stability criteria; characteristics of the wave of maximum instability; pattern of vertical motion; energetic interpretation. Alternative view of cyclogenesis using the concept of potential vorticity; advection of a pre-existing upper-level positive anomaly of potential vorticity over a lower-level baroclinic region; creation of a warm surface anomaly and its positive feedback to upper-levels. Frontogenesis kinematics, thermodynamics, and dynamics; discontinuities of zero, first and second order; mechanisms for changing horizontal temperature gradients. Theories of frontogenesis in linear fields of motion; effects of horizontal confluence and vertical motions; quasi-geostrophic frontogenesis; refinements by the semi-geostrophic approximation.

(e) *Tropical weather systems*. Trade inversions, trade winds, tropical/sub-tropical jet streams, and other broad wind systems; rainfall, tropical cyclones, monsoons. Characteristic patterns of cloud associated with easterly waves, seasonal evolution of the tropical wind systems, and the inter-tropical convergence zone; annual cycles. Synoptic analysis of the disturbance patterns at the surface and their relation to high-altitude features; kinematic analysis depicting streamlines and isotachs; identification of areas of wind speed convergence and horizontal wind shear; low-level jets. Tropical storms, squall lines, and convective regional processes, as seen in satellite imagery; structure of the rain-bands and eye-wall of hurricanes/typhoons. Ocean-atmosphere coupling; tropical regions as a major heat source for other regions; other tropical/extra-tropical interactions.

(f) *Mesoscale atmospheric circulations.* Mechanically forced circulations; thermally induced circulations; non-convective circulations; convective circulations. Mesoscale structures and circulations in cyclones, in particular in the vicinity of frontal systems; characteristic patterns of the associated clouds and precipitation, as observed in satellite and radar imagery.

(g) *Near real time monitoring of weather, nowcasting*: Plotting, display and interpretation of synoptic observations. Monitoring the evolution of meteorological parameters and atmospheric systems (especially those causing severe and hazardous weather). Preparation, display, interpretation of basic meteorological products (e.g., surface charts, satellite imagery, upper-air mappings, vertical

cross-sections) and overlay meteorological data and NWP products over satellite imagery.

(h) *Weather forecasting*: Basic principles of weather forecasting; application of the wave cyclone model, and other conceptual models. Forecasting methods; persistence, extrapolation, and analogue schemes; numerical weather prediction scheme. Post-processing and interpretation of numerical model outputs; "model output statistics" and "perfect prog" type methods; stochastic models; Monte Carlo methods; forecast probability statements. Public weather services; elaboration and dissemination of general and local weather forecasts; severe weather warning; nowcasting. Special services to aviation, agriculture, water sector, shipping, industry, commerce, etc. The role of National Meteorological Services in weather and climate monitoring and forecasting; role of the private sector.

(i) *Suggestions for laboratory work and practical exercises:* Analysing surface and upper-air observations; isobaric and isallobaric analyses. Movement and development of weather systems, fronts, and air masses. Use of thermodynamic diagrams, frontal cross-sections, analysis of frontogenesis; streamline analysis; iterative calculation of trajectories. Scalar and vector field derivatives by objective analysis of station data; thermal wind calculation and checking of the consistency between the temperature and wind data; estimation of thermal and vorticity advection, application of quasi-geostrophic analysis to a developing cyclone; interpretation of NWP diagnostic fields and of satellite and radar imagery. Basic synoptic analysis and weather monitoring; interpretation of numerical weather products for various case studies, such as: split cold front, orographic enhancement, explosive cyclogenesis, and severe storms.

Climatology

(a) *Introduction to earth system science:* Formation of the Sun, Earth and Moon, and their evolution over geological time; structure of the geosphere; formation and evolution of the atmosphere and the ocean; plate tectonics, volcanoes, processes of wind and water that shaped surface features. Appearance and evolution of life on Earth. Natural records of past climates; ice core in glaciers, polar ice sheets, ocean cores; radiocarbon dating, tree ring analysis, pollen analysis, oxygen isotope analysis, distribution of land and sea, changing patterns of snow and ice cover. Theories of climatic change over the last 250,000 years; evolution of continents and mountains; Earth-Sun geometry - Milankovitch cycles; glacial and interglacial periods; changing Sunspot activity and atmospheric composition.

(b) *Climatic data:* Climatic elements and their space-time variability. Instruments and methods of observation for the climatic elements; collection, processing, storage and retrieval of climatological data; quality assurance and quality control; internal, temporal and spatial consistency checks.

(c) *Descriptive climatology; statistics and probability theory.* Data display and interpretation: univariate measures of location, scale, asymmetry and shape; graphical summaries. Probability: main rules, conditional probability, Bayes theorem. Distribution and density functions for common discrete and continuous distributions. Estimation methods; hypothesis testing; difference of means of independent samples; types of errors; levels of significance. Relationships: correlation and regression; significance testing; multivariate analysis; multiple

regression; multiple and partial correlation; discriminant analysis; factor analysis; covariance; non-parametric tests; contingency tables. Time series: stochastic processes; stationarity; spectrum analysis; autoregressive models. Fourier analysis; harmonic analysis; Markov processes; tests for randomness, trends, autocorrelation analysis, and persistence. Spatial series: spatial coherence; spatial correlation and regression analysis; orthogonal polynomial surfaces; spatial Fourier and spectral analysis; empirical orthogonal functions.

(d) *Climate classification.* General classification related to plant growth or vegetation; Köppen's temperature and aridity criteria. Energy and moisture budget classification; Thornthwaite's potential evapotranspiration and moisture budget; Budyko's radiation index of dryness. Genetic classification; Flohn's categories based on the global wind belts and precipitation characteristics. Strahler's climatic regions. Classification of climatic comfort; estimates of comfort.

(e) *The physics and chemistry of the climate system:* Earth's radiation budget; geometry of insolation; greenhouse effect. Composition and vertical structure of the oceans; major circulation features and their relation to the atmospheric winds; transportation of energy by ocean currents; internal redistribution of heat. Air-sea interaction; sea surface temperature anomalies; differences between the two hemispheres. Surface land and water, planetary albedo, hydrological cycle.

(f) *Climate dynamics*: Climate system - the (non-linearly) coupled atmosphere-ocean-land weather system averaged over an appropriate time period. Influence of the geodetic parameters; meridional transport of heat, moisture, and momentum; Hadley and Walker circulations; monsoons. Climate variability and change; seasonal, inter-annual, decadal and centennial variability; equatorial temperature changes and interactions; mid-latitude temperature changes and interactions; tropics/mid-latitudes teleconnections; El Niño and Southern Oscillation (ENSO) and possible mechanisms.

(g) *Climate change*. Changes in the climate over the last century; possible causes. Fundamentals of modelling the general circulation of the atmosphere; evolution to coupled atmosphere-ocean general circulation models. Feedback in the radiative forcing of climate due to anthropogenic enhancing of greenhouse effect and changing of aerosol content; response of terrestrial and marine systems to climate change and their positive and negative feedback.

(h) *Climatology and seasons of the country*. Weather regimes in seasons; circulation types; anomaly patterns; frequency and tracks of pressure systems; long waves; blocking; index cycles; tropical disturbances. Operation of climate monitoring databases; and scientific statistics packages. Climatic diagrams, graphs and maps; interpolation and spatial averaging; climatic maps for applied purposes.

(i) *Suggestions for laboratory work and practical exercises:* Basic formulae for radiation calculations: energy received from the Sun, height of the Sun in the sky, azimuth of the Sun, length of day and direction of sunrise and sunset. Calculating the short-wave radiation income of a slope; energy balance of local surfaces; the albedo of various surfaces to short-wave radiation; emissivity of selected surfaces; factors in the transfer of heat and moisture at a given site - latent heat and sensible heat flux; soil heat flux, Bowen ratio. Methods to evaluate potential evapotranspiration: Penman equation and the "equilibrium" model; Makkink, Budyko-Davies, Thornthwaite formulas. Descriptive statistics - mean values and frequency distribution, central tendency and fractiles; mean deviation; sampling

and standard error; distributions and probability; recurrence estimates, extreme events, trends, statistical inference; fitting models to data; time series analysis.

3.3. Elective fields of specialization in meteorology

Aeronautical meteorology

(Based on an extract from WMO-No. 258, third edition, as revised by N. Gordon, President of the WMO Commission for Aeronautical Meteorology and T. Fox, Chief of Aeronautical Meteorology for the International Civil Aviation Organization, ICAO)

The basic education and training of meteorologists engaged in the provision of meteorological forecasts for aeronautical purposes should be programmed in a similar manner to that of meteorologists engaged in operational weather forecasting in a National Meteorological Service. This instruction should be supplemented by special courses in aviation knowledge and procedures for meteorological service to international air navigation. Syllabi for these subjects are given below: items (a-d) concern meteorological knowledge; items (e-k) aviation knowledge; and items (l-m) refer certain regulatory documents and publications by WMO and ICAO. The BIP-M compulsory topics constitute the essential prerequisite requirement.

(a) *Aircraft Icing:* Theory of formation of icing; processes and dependence upon temperature; drop size; liquid water content; airframe configuration and aircraft speed. Types of icing; clear ice; rime ice and hoar frost. Ice accretion rates; association with cloud types (stratiform and cumuliform clouds); thunderstorms; freezing precipitation; orographic and frontal lifting effects. ICAO criteria for reporting icing. Methods of forecasting the risk of ice formation and means of avoiding icing areas. Formation and effects of in-flight structural icing on different types of aircraft, e.g., on wing and tail surfaces, propellers, rotor blades, Pitot tube, antennas and windshield; formation or deposition of structural icing, including frost, on parked aircraft. Formation of in-flight icing in engine systems for piston, turbo-prop and turbo-jet engines.

(b) *Turbulence:* Turbulence near the ground; mechanical turbulence as a function of wind speed, wind shear and terrain roughness; convective turbulence as related to hydrostatic instability; effects of boundary-layer turbulence on take-offs and landings of aircraft; turbulence related to clouds, fronts and thunderstorms. High-level turbulence (CAT); association with horizontal and vertical wind shear, jet stream, stability and tropopause inversion. Mountain wave turbulence applied to both boundary layer and high-level. Gravity waves. Wake vortex. ICAO criteria for reporting turbulence and mountain waves. Methods of forecasting the risk of the existence of turbulence; means of avoiding turbulence areas.

(c) *Other hazardous phenomena:* Reduced surface visibility; fog - fog types and their manner of formation and dissipation; the relationship of visibility to fog type and duration, other weather phenomena causing reduced surface visibility: mist, sandstorms and duststorms, to precipitation (e.g., rain, drizzle, snow, blowing snow) and various lithometeors (e.g., smoke, haze and volcanic ash). Thunderstorms; association with in-flight turbulence, hail, icing and lightning; surface conditions related to thunderstorms such as strong, gusty winds, windshear, poor visibility; frontal and airmass thunderstorms; squall-line thunderstorms. Volcanic ash at flight levels and international airways volcano watch (IAVW). Low-level wind shear associated with marked inversions and/or low-level jet streams. Specific knowledge in the interpretation of weather radar information towards making short-term forecasts for the terminal area. Wind shear in the approach and landing phases of flight.

(d) *Meteorological aspects of flight planning:* Meteorological basis for pressure-pattern flying; definitions of great circle and composite tracks; wind components. Least-time tracks; use of D-value; determination of drift angle. Requirements for en-route wind, temperature and significant weather forecasts and aerodrome forecasts (in the TAF code form) for pre-flight planning and in-flight re-planning; use of flight documentation from the world area forecast system (WAFS); direct supply of information to operators for centralised operational control. Preparation of area and route forecasts. Special emphasis on the importance and techniques of briefing of flight crews and operational personnel.

(e) *Definitions.* Aeronautical meteorologists should be familiar with the ICAO definitions of terms which have conventionally limited meaning when used for international aviation purposes. In particular they should be aware of the meaning of, and distinctions between the following terms: Routine air-report, special air-report, meteorological report, briefing, forecast, aerodrome forecast, landing forecast, observation, GAMET area forecast, SIGMET and AIRMET information, visibility (for aeronautical purposes), runway visual range. Altitude, elevation, height, density altitude, pressure altitude, flight level, cruising level, transition altitude, transition level, transition layer. Operator, operator's local representative, pilot-in-command. Flight information region, terminal area, controlled airspace, advisory airspace, controlled area, control zone, ATS route, airway, advisory route, air traffic control service, air traffic advisory service, flight information service, alerting service; aerodrome control tower, area control centre, approach control office. Aerodrome, instrument runway, landing area, movement area, obstacle free zone, approach, final approach, circling approach, initial visual approach and missed approach areas; take-off and climb-out directions. "Service"; "provide", "issue", "make available", "supply" (used in connection with meteorological information required by users); "designated meteorological authority", "meteorological service provider".

(f) *Procedures for meteorological services for international air navigation.* Aeronautical meteorologists should have a good knowledge of the following, together with the corresponding regional procedures and plans contained in regional basic air navigation plans (ANPs) and the associated facilities and implementation document (FASID). World Area Forecast System (WAFS); World Area Forecast Centres (WAFCs) and their functions. International Airways Volcano Watch (IAVW) and Volcanic Ash Advisory Centres (VAACs) and their functions. Tropical Cyclone Advisory Centres (TCACs) and their functions. Meteorological offices and meteorological watch offices, and their respective functions. Aeronautical meteorological stations and their functions; local routine and special reports, reports in the METAR and SPECI code forms. Trend-type landing forecasts; period of validity, format. Aerodrome forecasts in the TAF code form; period of validity, amendment criteria, obtaining aerodrome forecasts from other aerodromes. Wind shear warnings; aerodrome warnings. Information for operators or operator's local representatives; pre-flight planning; briefing and display of meteorological information required by operators; information required from operators. Information for pilots-in-command prior to departure; briefing, documentation, route forecast, aerodrome forecasts. Information for pilots-in-command during flight, scope and responsibility of area meteorological watch; SIGMET and AIRMET information, VOLMET broadcasts and D-VOLMET. Information for and from air traffic services; types of meteorological information required by aerodrome control towers, approach control offices and area control/flight information centres; transmission of aircraft meteorological reports. Forms of meteorological messages; routine and special reports in code or plain language; forecasts and amendments to forecasts; trend-type landing forecasts;

route and area forecasts (including GAMET); SIGMET and AIRMET information message; tropical cyclone and volcanic ash advisory messages; units of measurements. Information for search and rescue according to local procedures. Aeronautical climatological information. Forms used; publication of climatological information.

(g) *Air traffic services:* Visual and Instrument Flight Rules; the meanings of and distinction between VFR, VMC, IFR and IMC; scope of Flight Information Service, including the provision of Automatic Terminal Information Service (ATIS); the objectives of, and the criteria for, the provision of Air Traffic Control Service; rules governing terrain clearance; cruising level system; vertical separation minima and methods of effecting horizontal separation. Functions and distinction between Area Control Centre, Approach Control Office, Aerodrome Control Tower and Flight Information Centre. Holding and Approach Procedures; Alerting and Search and Rescue Services; methods of aerial search. CNS/ATM systems. Requirements for aircraft position reporting and meteorological reporting procedures, automatic dependent surveillance (ADS) report. Procedures for co-ordination between ATS units and the meteorological service; meteorological observations performed by ATC personnel in aerodrome control towers. Computation and use of transition levels, layers and altitudes and of the lowest usable flight level en-route that will ensure adequate terrain clearance. Special requirements relating to Category II and III operations particularly runway visual range and cloud base.

(h) *Aerodromes:* Design of aerodromes in so far as meteorological factors are concerned; specific knowledge of the physical design of the aerodrome with which they are concerned; purpose and operation of aerodrome lighting, particularly as it relates to operations in lower visibility conditions and its relation to RVR assessment; effect upon aerodrome ground services of changing weather conditions such as the requirement for snow clearing operations and the effect of wet runways on braking action. Determination of aerodrome reference temperatures and methods used by aerodrome services for measuring runway surface conditions related to meteorological aspects such as snow depth and runway braking action; awareness of local climatological conditions and their effects on environmental aspects such as noise and atmospheric emissions caused by aircraft landing, taking-off and taxiing.

(i) *Operation of aircraft:* Significance of aerodrome operating minima,* and awareness of the minima applicable to the regular and alternate international aerodromes with which they are concerned. Knowledge of approach systems - visual and instrument, categories of operations; altimeter setting procedures; the ICAO Standard Atmosphere. Basic flight navigation, the principal aids to navigation and methods of determining winds in flight. Effects of air density, humidity, icing, low-level wind shear, turbulence and wind on aircraft performance and the meteorological factors influencing fuel consumption. Special requirements of general aviation (IGA) and aerial work, and of SST aircraft (including sonic boom questions).

(j) *Aeronautical information services:* Meteorological elements required for publication in the Aeronautical Information Publication (AIP), and of the specifications for AIP. General specifications for NOTAMs/ASHTAMs, their origin

* Aerodrome operating minima are defined in ICAO Annex 6, Part 1, and are the subject of a number of Standards and Recommended Practices in ICAO Annex 6, Part I, Chapter 4.4.1

and distribution. ICAO Abbreviations and Codes used in messages on the Aeronautical Fixed Service (AFS) and in Aeronautical Information Services documents. Information concerning the meteorological service which is required to be depicted on Instrument Approach, Landing and Aerodrome Charts.

(k) Aeronautical telecommunications: Understanding of the general organization of aeronautical telecommunications; a thorough knowledge of the procedures applicable to the preparation of meteorological messages which they or their assistants will normally originate. Operation of the Aeronautical Fixed Service, including particularly the Aeronautical Fixed Telecommunication Network (AFTN), Aeronautical Telecommunications Network (ATN); message headings, addressing of messages, priorities of messages; regional aeronautical MET telecommunication procedures (AMBEX, ROBEX); satellite distribution system for information relating to air navigation (SADIS) and international satellite communications system (ISCS).

(l) WMO documentation: Technical Regulations, (WMO-No. 49), Vol. II — Meteorological Service for International Air Navigation. Manual on Codes (WMO-No. 306). Guide on meteorological observation and information distribution systems at aerodromes (WMO-No. 731). Guide to practices for meteorological offices serving aviation (WMO-No. 732). Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8). Weather Reporting (WMO-No. 9).

(m) ICAO documentation: Annex 3 — Meteorological Service for International Air Navigation. Regional Supplementary Procedures* (Doc. 7030). Procedures for Air Navigation Services — ICAO Abbreviations and Codes (PANS-ABC, Doc 8400). Location indicators (Doc 7910). Manual of Aeronautical Meteorological Practice (Doc 8896). Manual on Co-ordination between Air Traffic Services and Aeronautical Meteorological Services (Doc 9377). Manual of Runway Visual Range Observing and Reporting Practices (Doc 9328). ICAO/WMO Manual on the Provision of MET Service for International Helicopter Operations (Doc 9680). Relevant Air Navigation Plans (ANPs and FASID)*.

Agricultural meteorology

(a) Plant physiology. Plants and crop microclimate; the core of plant interaction with the atmospheric environment: photosynthesis, respiration and transpiration. The gross equations for photosynthesis and respiration; diurnal cycle; "light and dark reactions"; photochemical processes in the light reactions; impact of low temperatures or low concentrations of CO_2 on the rate of dark reaction; reduction of the total photosynthesis by low light intensities; light saturation. Transpiration; the driving force for liquid flow through the plant, and for water vapour flow between plant and the bulk air; equation for the transpiration rate. Soil-plant relations; soil role as: nutrient reservoir; water reservoir; heat reservoir; source of oxygen-containing air for root respiration. Effects of the physical and chemical environment and of meteorological factors on the growth and development of plants; distinction between growth and development; phenology and tolerance; the heat units concept.

(b) Bio-meteorological interrelationships. Plant pathology; weather factors conducive to infection of plants; farm animals (livestock); zoology, anatomy and physiology;

* All regional supplementary procedures in the MET field except those governing air reporting are included in Part VI of the ANPs and FASID.

diseases and pests of crops and animals. Soil cultivation and treatment; crop management and layout; farm buildings, equipment and operations. Effect of various climatic factors on the rate of growth processes in a plant's life and on the crop - quantitatively and qualitatively; effects of weather and climate extremes on physiological processes in vegetation. Livestock; the effects of atmospheric factors on livestock production, acclimatisation, animal protection in an unfavourable climate, effect of climate on population size, diseases, evaluation methods and techniques. Meteorological factors influencing the aerial movement and dispersal of spores, pollen, insects, birds, and other air-biota.

(c) *Surface energy balance.* Review of basic concepts in planetary boundary layer. Air temperature, heat exchange at the Earth's surface; soil temperature, transmission of heat in soil, heat budget; soil freezing, and the role of snow cover. Humidity and wind relations near the ground surface; the effect of surface conditions on the boundary layer; diurnal and annual variations of soil temperature and moisture; the influence of plant cover in micrometeorology; importance of the air layer near the ground for agriculture. Artificial control of plants environment; energy budget; controlling the heat load - heat trapping and shading; protection from cold - supplementary heat and reduction in sensible and latent heat flux; controlling the soil heat budget.

(d) *Water balance.* Determination of water loss from land surfaces; evaporation - fundamental processes, methods to determine evaporation and estimation of its energy balance; model methods of Penman, Priestley-Taylor, Penman-Monteith. Soil-moisture content and potential: moisture-energy relations, movement of water in the soil, the influence of soil-moisture content and potential on plant growth. Estimation of local soil water budget and of hydrological catchment yields from climatic data; controlling the soil moisture - reducing the transpiration cooling and irrigation; efficiency of water use by various irrigation techniques.

(e) *Observations and measurements; data processing.* Weather data networks and requirements; in situ and remote observations; instruments and methods of observation; quality assurance and quality control. Air temperature, grass-minimum temperature, radiative surface temperature, soil temperature and soil heat flux, wind, radiation and sunshine, humidity, dew and leaf wetness, evaporation and evapo-transpiration, state of the ground and soil moisture. Techniques for making measurements of the state of a crop, and of the flow processes within and around the plants. Vegetation surveillance by remote sensing; introduction to Geographic Information Systems; Data processing; statistical and mathematical methods; procedures for evaluating and presenting the results, statistics of biological and phenological observations.

(f) *Operational forecasts.* Knowledge of seasonal to inter-annual climate forecasts, and their application in agriculture and forestry. Utilisation of weather forecasts for agriculture (e.g. the use of real-time and forecast information in pest management on farms, scheduling irrigation and other farm operations), special weather warnings, and specific agricultural meteorology forecasts; operational modelling for short-term management; crop-weather modelling.

(g) *Assistance for planning;* Assistance for improving agricultural methods and operations; assessing weather risks for agriculture; last spring freeze, dry weather and drought risk in terms of the demand for water by a particular agricultural system. Alternative forms of agricultural meteorology decision-supporting activity; application of multi-criteria analysis techniques.

(h) *Preventing the impact of adverse weather conditions.* Irrigation scheduling; windbreaks and shelter-belts; protection from extreme temperature; frost protection; radiation and advective frosts; physiological processes involved in frost protection; active and passive methods; glass-houses and stables; protection from excess temperatures; protection of harvested products in transport and storage. Artificial stimulation of precipitation; hail and active suppression of hail; fire in vegetation.

Atmospheric chemistry

(a) *Evolution of the Earth's atmosphere; chemical composition and vertical structure.* Primitive atmosphere; pre-biotic evolution; the advent of biological activity - photosynthesis; rise of oxygen and ozone; oxygen-carbon budgets. Contemporary chemical composition of the atmosphere: constituents and their lifetime; units for the chemical abundance; air composition near the ground; changes with height.

(b) *Attenuation of solar radiation by atmospheric gases and aerosols*. Review of radiation basic concepts and principles: radiant flux and irradiance; blackbody. Heating of the atmosphere due to the absorption of solar radiation by trace gases. Scattering of solar radiation by aerosols (e.g. soil dust, sulfates, organics); absorption of solar radiation by aerosols, even less important than in the case of trace gases.

(c) *Absorption and emission of long-wave terrestrial radiation*. Infrared emission of the radiant energy from the Earth's surface and from the atmosphere. "Greenhouse effect"; anthropogenic changes in the concentrations of greenhouse gases and aerosols; and perturbation of the approximate thermal equilibrium of the Earth. Radiative forcing of the Earth-atmosphere system; the globally averaged radiative forcing due to the well-mixed greenhouse gases (CO_2, CH_4, N_2O, halocarbons); (negative) radiative forcing due to aerosols; indirect impacts.

(d) *Chemicals in the troposphere.* Sources: biological, solid Earth, oceanic, in situ formation in the atmosphere. Transformations: the hydroxyl and nitrate radicals, ozone, chemical families, other homogeneous, gas-phase chemical reactions. Importance of photochemical reactions; and of the chemical reaction cycles; key role of the free radicals. Transport: within the planetary boundary layer; diurnal variations over the land; migration of chemicals with long residence time into the free troposphere; possible passage into stratosphere, mainly in the tropical regions. Sinks: transformations into other chemical species, conversion gas-to-particle; wet and dry deposition onto the Earth's surface and the oceans.

(e) *Atmospheric aerosols.* Aerosol concentration and size distribution; total number and concentrations; size spectra; characteristics of aerosol number distribution in urban polluted, rural continental and marine air. Sources of aerosols: solid earth, oceans, anthropogenic, in situ formation. Transformation of aerosols: enrichment, gas-to-particle conversion, coagulation. Chemical composition, transport and sink of aerosols; dry removal by coagulation, sedimentation and impaction; wet removal by cloud condensation nuclei, liquid water and ice particles in clouds, and by the precipitation elements. Residence times; geographical distribution.

(f) *Cloud and precipitation chemistry.* Cloud condensation nuclei and nucleation scavenging; dissolution of gases, aqueous-phase chemical reactions;

precipitation scavenging. Chemical composition of rainwater; acid rain; production of aerosol particles by clouds: homogeneous-bimolecular nucleation.

(g) *Tropospheric chemical cycles.* Earth System biogeochemical cycles. Carbon cycle: CO_2 as the primary carbon-containing gas in the atmosphere; its photosynthesis and dissolution into the ocean; role of CH_4, HCHO and CO; slow exchange of carbon between the surface of the ocean and the deep ocean; "greenhouse" warming caused by increasing CO_2 concentrations. Nitrogen cycle: biological fixation and denitrification; biogenic emissions from the Earth and the oceans (NH_3, N_2O and NO_x), decomposition of proteins and urea from animals (NH3), biomass burning and fossil fuel consumption (NO_x, NH_3 and N_2) and lightning (NO_x). Sulfur cycle: natural emissions - biogenic reactions in soils, marshland, and plants; also in the ocean; anthropogenic emissions.

(h) *Stratospheric chemistry.* Ozone "layer" overview: absorption of the UV radiation; Chapman theory; catalytic chemical cycles. Ozone column abundance; maximum production in the tropical stratosphere; peaks in concentrations at polar and mid-latitudes;. Anthropogenic perturbation to ozone: catalytic action of chlorine from man-made chloroflourcarbons (CFCs) and the role of stratospheric ice particles; Montreal protocol and subsequent agreements. Stratospheric sulfate aerosols; impact of volcanic eruption.

(i) *Air quality and human health.* Sources of anthropogenic pollutants; fossil-fuel combustion; effects of carbon monoxide on human health; photochemical smog; visibility reduction; mixing of pollutants on local, regional and global scale. Natural cleansing processes. Tools and techniques for monitoring and sampling pollutants; storage and extraction of information from databases; permissible levels of pollutants; Air quality monitoring and human health; policy, legal, and regulatory matters for air pollution control.

Climate monitoring and prediction

(a) The climate system: Internal interactive components: atmosphere, oceans, sea ice, land (including the vegetation, albedo, biomass; and ecosystems), snow cover, land ice and hydrology “External” components: Sun and its output, Earth's rotation, Sun-Earth geometry and the slowly changing orbit; distribution of land and ocean; geographic features on the land, ocean bottom topography and basin configuration; mass and basic composition of the atmosphere and ocean.

(b) Climate monitoring; networks; principles. The Global Climate Observing System (GCOS). World Weather Watch, WWW-component and the CLIMAT records; Tropical Atmosphere-Ocean, TAO-component. Other ocean observations: merchant ships, tide gauge stations and satellite-based data. Changes in instrumentation, observing practices and location; climate record homogeneity. Observing system priorities; network design; new observation system development; data management. Observations for basic forcing factors: solar radiation, greenhouse gases and aerosols. Observations for feedback from climate system components: clouds, oceans, surface hydrology and land cover. Observations for climate responses: surface temperature and precipitation.

(c) General circulation of the atmosphere: Statistics of the general circulation of the atmosphere; description of the mean state and its variation with the seasons; world distribution of mean sea-level temperatures; mean annual range of

temperature; mean annual precipitation. Distributions of the zonal wind and the zonal temperature field; latitudinal, vertical and seasonal variation of the intensity of atmospheric disturbances. Definition of zonal and eddy quantities; algebra of average values and associated fluctuations; distinction between stationary and transient disturbances. Momentum, heat and water balance; time variation of angular momentum; its meridional transport by atmospheric disturbances. Maintenance of the mean temperature field; meridional transport of sensible and latent heat; temperature changes caused by zonal heat sources and sinks.

(d) *Air-sea interaction, hydrological cycle, and the impact of land characteristics.* Observations and theories of the seasonal changes in the ocean circulation and temperature, and interactions with the atmosphere; transfer of sensible and latent heat from the ocean; wind-driven circulation; mixed layer; mid-latitude and equatorial waves; seasonal budgets of momentum, fresh water and heat. Role of equatorial oceanic up-welling and of the SST gradients in modulating the meridional (Hadley) and zonal (Walker) atmospheric circulations; inter-annual variability. Energy and momentum exchanges between the land surface and the atmosphere; earth's bio-geo-chemical cycles and their influence on the hydrological cycle; role of the land and ocean biota. Global energy balance.

(e) *Sources of climate predictability.* Typical time-scales characterising the variability of the atmosphere, land and ocean; non-linear processes and predictability. Sources of predictability. ENSO predictability; influence of other ocean basins (e.g. Atlantic and Indian); teleconnections.

(f) *Statistical forecasting methods.* Forecasting SST, particularly in connection with the ENSO phenomena. Statistical methods: linear deterministic relationship between the predictor and a single predictand index. Linear multivariate methods; autoregression through Markov modelling, or through the linear inverse methods optimised to fixed lead-times. Covariance or correlation between multiple fields at fixed lead-time: canonical correlation analysis, singular value decomposition, and combined empirical orthogonal functions. Probabilistic methods, discriminant analysis. Instabilities in precursor-predictand relationship in the linear statistical prediction schemes. Non-linear methods.

(g) *Dynamical forecasting methods*. Atmosphere-only general circulation models (AGCM) and coupled atmosphere-ocean general circulation models (CGCM). Formulation and limitation of models. Use of ensembles of numerical integration for seasonal predictions; separation between the repeatable portion of the anomalous climate signal due to boundary layer forcing, and the portion that is due to internal variability or chaos in the atmosphere.

(h) *Climate change and human affairs:* Role of living things in maintaining the global climate system; adverse impact of humankind on the planetary albedo and on the atmospheric composition. Projections of global mean temperature and of continental/regional scale climate change. Potential global warming and sea level rise; impact of climate change on energy use, air pollution, crop yields, water quality and availability, frequency of severe weather events, and spread of infectious diseases.

(i) *Uncertainties of the current climate projections:* Insufficiency of long-term instrumental observations of climate system variables. Limitations in the representation of climate processes in models, especially feedback processes. Uncertainties in the estimation of future emissions (also sources and sinks) and

bio-geo-chemical cycling of greenhouse gases, aerosols and aerosol precursors; uncertainties in projections of future concentrations and radiative properties.

(j) *Seasonal forecasting*. Developments in seasonal weather forecasting up to say three to six months in advance; better insight into the causes of climate variations on a seasonal time frame and at a finer geographical resolution. Improvement of computer models by the inclusion of the significant effect of the SST anomalies over seasonal time-scales. Capability to estimate the probability of the prevalence of certain weather conditions. Downscaling of seasonal to inter-annual climate prediction; forecast probabilities for shorter time frames and smaller geographical areas. Use of predictions in a probabilistic format with typically three-category qualifications versus deterministic forecasts of absolute value. Nature, limitations and opportunities of probabilistic forecast data for the successful use of seasonal predictions in business decisions.

Mesoscale meteorology and weather forecasting

(a) *Overview of mesoscale and the role of forecaster.* Definition of mesoscale; free and forced mesoscale circulations. Conventional and upper-air observations; use of radar and satellite imagery, wind profilers and acoustic sounders; 3-D and 4-D data assimilation systems from the operational numerical weather prediction suite. Typical mesoscale, local-scale circulations and associated severe weather. Role of weather forecaster; ensemble forecasting; collaboration with end users.

(b) *Mesoscale features of mid-latitude cyclones.* Conceptual models of the extra-tropical cyclone. Fronts and frontogenesis; rain-bands; conditional symmetric instability; mesoscale aspects of explosive cyclogenesis; interaction with complex terrain; gravity currents, gust fronts and arc/rope clouds. Severe thunderstorms and squall lines. Meso-synoptic environment associated with excessive rains; specific cloud-scale and cloud microphysics processes favouring flash floods; particularities of radar and satellite pattern.

(c) *"Non-convective" mesoscale circulations and phenomena.* Mechanically forced circulations (e.g. lee waves and gravity waves, up-slope and down-slope winds; mesoscale lee lows and vortices); orographic precipitation enhancement. Thermally induced circulations (e.g. sea-land breeze, coastal fronts, lake effect, valley wind circulation). Mesoscale travelling gravity waves; low-level jets.

(d) *Convective mesoscale circulations and phenomena.* Synoptic environment for convection and its basic dynamics. Surface features. Type and structure of thunderstorms, relationship to instability and vertical wind shear, multi-cell and super-cell thunderstorms; mesoscale convective complexes (MCC). Phenomena attending thunderstorms: tornado, microburst, and lightning, heavy convective precipitation, hail, flash flooding.

(e) *Cloud and precipitation in operational numerical models.* Representation of the condensation and precipitation of water in numerical prediction models. Generation of unstable stratification in the free atmosphere. Convective adjustment schemes; other parameterisations for large-scale cloud and precipitation; cumulus parameterisation schemes.

(f) *Operational numerical weather prediction suite.* Collection and checking of observations; assimilation of observations with forecasts to produce weather

analyses. Running of global and mesoscale models to produce forecasts; producing verification data. Use of ensemble prediction technique; operational application of model output, both diagnostic and forecast fields; Perfect Prog method and Model Output Statistics.

(g) *Weather monitoring; nowcasting.* Monitoring of the weather, particularly for detecting unexpected weather changes and onset of hazardous phenomena; interpretation and use of the latest radar and satellite information. Special appraisal of NWP output and satellite and radar imagery for possible severe weather evolutions.

(h) *Forecasting specific weather phenomena; public weather services.* Forecasting temperatures, cloud, precipitation, surface wind and visibility. Forecasting thunderstorms, super-cells and organised convection; deep convection and hail; areas of aircraft icing and turbulence. Forecasting low-level significant weather for non-professional aviators. Conditions favouring fire formation. Forecasting potentially high pollution days.

(i) *Large-scale and medium range forecasts.* Global ocean waves models to forecast wave and swell for marine and offshore purposes; forecasting extra high and low tides. Ocean model forecasts for the deep thermal and saline structure of the ocean (not the surface waves). Trajectory and dispersion forecasts for environmental emergencies. Medium range weather forecasting; use of ensemble prediction to detect changes of "weather regimes"; forecasting upper winds, temperature and tropopause height; surface weather events.

(j) *Verification of forecasts.* Sources of uncertainty. Evaluation techniques, skill scores and other measures of merit for site-specific categorical (yes/no) and probabilistic forecasts.

Radar meteorology

(a) *The principles of weather radar*. Electromagnetic waves; polarisation; normal and anomalous propagation; pulsed-Doppler radar; signals received from point and distributed scatterers; attenuation due to stormy and fair weather; back scatter and attenuation cross sections; hydrometeor size distributions; radar equation; representations of echoes from moving and stationary scatterers; radar limitations (e.g., range and velocity ambiguities);

(b) *Weather signals*. Signal statistics; echo coherency; weather radar equation; angular and range weighting functions; resolution volume; reflectivity factor; correlation of echoes in range and time;

(c) *Doppler spectra of weather signals.* Discrete Fourier transform and window functions; Doppler spectra of weather echoes; relation between wind, reflectivity and the Doppler spectrum; examples of Doppler spectra associated with various weather phenomena (e.g., thunderstorms, tornadoes);

(d) *Weather signal processing.* Spectral moments; estimation of reflectivity using range and time averaging; auto covariance and spectral processing to estimate mean Doppler velocity and spectrum width; signal processing for coherent polarimetric radar; performance of the estimators; examples of two-dimensional fields of reflectivity factors, radial velocity, and turbulence;

(e) *Weather observation.* Spectrum width; wind shear and turbulence; antenna side-lobes; ground and sea clutter; techniques to extend unambiguous range and velocity; effective width of a scanning beam; thunderstorm structure; wind estimation with two Doppler radars; server local storms, mesoscale convective systems, hurricanes;

(f) *Precipitation measurements.* Single parameter techniques (e.g., using reflectivity factor Z of specific differential phase KDP) to estimate rain rate R; relations between Z, R, and liquid water content; accuracy of rain measurements; two-parameter techniques to estimate rainfall; principles of radar polarimetry; improvements of rain measurements and identification of hail with polarimetric radar; observation of hydrometeors type and behaviour through dual-polarisation technique;

(g) *Observation of winds, storms, and related phenomena*. Visual depiction of storm phenomena (e.g., tornadoes, microbursts) and their radar signatures; wind field estimation using single Doppler radar; weather hazards to aviation.

(h) *Observation of fair weather*. Bragg scatter from irregularities in temperature and humidity; observations of wind, buoyancy waves (i.e., undular bores, solitary waves, etc), and turbulence in clear air;

(i) *Applications; examples of displays and products.* Technical specifications of the actual radar; modes of operations, standard applications, examples of displays and products, automatic detection of hazardous weather; case studies.

Satellite meteorology

(a) *Evolution of satellite meteorology*. Evolution of polar orbiting satellites; geostationary satellites; data processing capability.

(b) *Nature of radiation:* Remote sensing of radiation; basic units, definitions of radiation; Planck's radiation law; related derivations; Wien's displacement law; Rayleigh-Jeans radiation law; Stefan-Boltzmann law; brightness temperature.

(c) *Absorption, emission, reflection, and scattering.* Absorption and emission; conservation of energy; planetary albedo; selective absorption and emission; line formation; vibrational and rotational spectra; interactions between radiation and matter; Beer's law; Schwarzchild's equation; atmospheric scattering; solar spectrum. Composition of the Earth's atmosphere; atmospheric absorption and emission of solar radiation and of thermal radiation; atmospheric absorption bands in the infrared and in the microwave spectrum; remote sensing region.

(d) *The radiation budget:* The mean global energy balance; the first satellite experiment to measure the net radiation; radiation budget; distribution of solar energy intercepted by Earth; solar heating rates; infrared cooling rates; radiative equilibrium in a grey atmosphere.

(e) *The radiative transfer equation (RTE):* Derivation of RTE; temperature profile inversion; transmittance determinations; Fredholm form of RTE and the direct linear inversion method; constrained linear inversion of RTE. Statistical least squares regression; linearization of RTE; statistical regularization; minimum

information solution; empirical orthogonal functions. Numerical iteration solution by Chahine relaxation method; Smith's numerical iteration solution; comparison of the Chahine and Smith solutions; problem solving linear RTE directly; direct physical solution; microwave form of RTE; RTE in cloudy conditions.

(f) Surface temperature. Sea surface temperature (SST) determination; slope method; three-point method; least squares method; cloud clearing for SST determinations. Water vapour correction for SST determinations; accounting for the surface emissivity. Estimating fire size and temperature.

(g) Detecting clouds. Introduction; threshold tests for finding cloud; IR window temperature threshold and difference tests; CO_2 channel test for high clouds; near infrared thin cirrus test; shortwave infrared window reflectance threshold test; reflectance threshold test; reflectance ratio test; low cloud test; microwave tests; resultant cloud mask; spatial uniformity tests to find cloud. Infrared window 1-D histogram tests; infrared window radiance spatial uniformity; visible reflectance uniformity test; 2-D infrared and visible histogram analysis. Practical applications of the cloud tests; ancillary data requirements; implementation of the cloud mask algorithms; short-term and long-term clear sky radiance composite maps; Ongoing climatologies; ISCCP; CLAVR; CO_2 slicing; spatial coherence.

(h) Techniques for determining atmospheric parameters. Techniques for detecting atmospheric composition; total water vapour estimation; split window method; split window variance ratio; split window and perturbation of RET; water vapour profile solution; total ozone determination; cloud height determination; geopotential height determination; microwave estimation of tropical cyclone intensity; satellite measure of atmospheric stability.

(i) Techniques for determining atmospheric motions. Atmospheric motion; gradient wind, geostrophic and thermal wind; inferring winds from cloud tracking.

(j) Satellite orbits. Orbital mechanics; the geostationary orbit; orbital elements; gravitational attraction of non-spherical Earth; Sun synchronous polar orbit.

Tropical weather and climate

(a) Tropical weather overview. Briefing on the main characteristics of the tropical weather and climate. Special features, which distinguish tropical meteorology from extra-tropical meteorology: non-validity of simple geostrophic approximation, non-applicability of frontal models, tropical heat sources, seasonality of weather and dominance of diurnal cycle. Critical dependency of tropical systems on convection, which is particularly sensitive to the sea-surface temperature and the heat balance of the land areas. Types of observational data available; their accuracy and relevance; typical forecasting problems and techniques.

(b) Large-scale circulations. Hadley and Ferrel circulations; trade wind regimes, trade inversion; ITCZ; tropical upper-tropospheric trough; upper-level jets; hypothesis of "critical" latitudes; cumulonimbus "hot tower" hypothesis; Walker cells; structure of the east-west circulation cells; monsoons. Basic ocean properties; budgets of moisture, energy and momentum; the role of ocean as a major energy input to the general circulation of the atmosphere, etc.

(c) *Synoptic-scale circulations.* Cyclones, surface and upper-level cyclones; wave-type disturbances. Easterly waves, structure and energetics. Tropical dynamics and vertical structure: basic scaling, tropical waves, Gill model, vertical structure, balanced vortex model, geostrophic adjustment.

(d) *Monsoon meteorology.* Physical mechanisms leading to monsoon circulation formation; areas of monsoon circulation. Monsoon-Hadley-east-west circulation relationship. Asian monsoon characteristic features; effects of the Tibetan Plateau on the onset of the summer monsoon. East Asian and Australian summer monsoon; African monsoon; West Africa Monsoon Trough and its regular migration with the seasons; irregular year-to-year variations.

(e) *The ENSO.* Standing wave in atmospheric mass and pressure; high-pressure cell over eastern South Pacific and the low-pressure region over western Pacific and Indonesia; their control over the strength of the Pacific trade winds. The ocean as an enormous heat energy source; atmosphere-ocean coupling; Walker circulation and its phases; negative correlation between the strengths of Walker and Hadley circulations; Southern Oscillation Index. Seasonal and inter-annual variability of the heat sources; excitation mechanism of equatorially trapped waves; structure of the intra-seasonal (30-60 day) oscillation. ENSO teleconnections in the tropical and extra-tropical regions, effects over the central and eastern Atlantic sub-tropical high-pressure cell, and on the general trade wind flow in the Atlantic.

(f) *Convection and mesoscale convective systems.* Tropical clouds; physics and dynamics of convective regimes; diurnal variations; impacts of organised cumulus convection on the large-scale motion. Shallow and deep convection; equation systems; approximations of shallow and deep convection; Rayleigh-Bénard convection; Rayleigh number; its typical values; parameterisation of convection in large-scale atmospheric models.

(g) *Tropical cyclones (TCs).* TCs general structure and evolution; eye and eye wall; trajectories; hurricanes and typhoons. TC genesis, theories of formation and motion, seasonal genesis potential; equation system, physical mechanisms for development and intensity change; energetics, eddy fluxes. Convection in TCs; mesoscale convective systems; boundary layer processes and their role in the evolution of TCs; positive and negative feedback in the TC-ocean system; comparison with a Carnot heat engine; beta-gyres. Mathematical modelling of TCs; forecasting methods. Hurricanes and typhoons; impact of storms on society.

Urban meteorology and air pollution

(a) *Overview of urban atmosphere.* Mesoscale and local scale circulations. Urban versus rural environment. Urban energy fluxes; solar radiation, other flux parameters, anthropogenic factors in the urban heat balance; structure, development and growth of the heat island; urban wind field and its influence on the heat island; urban moisture, clouds, hydrometeors, precipitation. Pollutant-weather interactions; weather conditions relevant for air pollution dispersion.

(b) *Monitoring urban weather and climate.* Parameters and phenomena to be monitored.. Design of monitoring network; setting priority locations for observations; observational techniques and procedures; frequency of observations; the format for recording urban climatic data. Equipment required for the monitoring; autographic or manual; instruments' sensitivity and accuracy.

(c) *Thermal radiation*. Radiation concepts; Kirchoff's law; energy emitted by a blackbody, and its spectral intensity; Plank's function; Stefan-Boltzman law. Equation of radiative transfer; absorbing-emitting species of the unpolluted atmosphere, particularly CO_2, H_2O, O_3, N_2O, CH_4, O_2, and CO. Photochemical reactions in the atmosphere; Lambert-Beer law for the emergent spectral intensity for a given path length. Earth's radiation budget; the "greenhouse effect"; radiative inversions; subsidence; formation of dew or hoarfrost and the rapid development of moderate/high pollution concentrations in populated areas.

(d) *Atmospheric boundary layer.* Viscosity and the shear stress; turbulence; time-averages and fluctuations; Reynolds equations for atmospheric flows; the turbulent stresses; correlation coefficients. Momentum and heat transport in a turbulent boundary layer; the mixing length; the velocity distribution near a surface in the absence of buoyancy effects; von Karman constant; shear stress near the surface; friction velocity; the logarithmic velocity profile; Reynolds number. Enhancement of turbulence by buoyancy effects; Richardson number; Monin-Obukhov length scale. Neutral boundary layer; the closure problem of turbulence; Ekman solution; Prandtl number; Ekman layer pumping and subsidence; similarity theory for the neutral boundary layer. Convective boundary layers; potential temperature and heat flux profile. Diurnal cycle of the boundary layer.

(e) *Buoyant plumes; dispersion of air pollutants.* Effluent forms of buoyant plumes from large power plants or other factories; stack gases concentrations; the heat flux of the stack; buoyancy flux and length scale. Theory for the plume rise in a neutral atmosphere; effect of stable stratification; "effective" stack height. Dispersion of air pollutants; mass conservation in the presence of molecular diffusion and chemical reactions; diffusion equation; diffusion from an instantaneous point source. Eulerian and Lagrangean description of turbulent dispersion; Gaussian plume model for the turbulent diffusion from isolated and multiple point sources; plume model applications; Gaussian puff model for instantaneous releases. Atmospheric dispersion equation, K-theory; gradient-transport hypothesis; turbulent diffusivity; solutions to simplified atmospheric diffusion equation; comparison of predictions of the Gaussian plume model and the atmospheric dispersion equation. Other methods of analysis for pollutant concentrations. Brief introduction to time dependent Eulerian models; process modelling reliability, sensitivity, efficiency and applicability of models; algorithms and mathematical techniques for handling a very large parameter space.

(f) *Application concepts in boundary layer meteorology*. Power law form of the velocity profile in the vertical. Mixing height and its relationship with: the base of a high inversion (if any), height of the mixed layer (for convective boundary layers) and height of the Ekman layer (for neutral or stable boundary layers). Transport wind - the wind speeds averaged within the mixing layer. Ventilation factor as a measure of adverse conditions for dispersal of pollutants. Air pollution potential as a measure of the conditions that are unfavourable to the dilution and dispersion of pollutants. Stagnation index criteria.

(g) *Urban pollution forecasts.* Simple urban air quality models based essentially on operational meteorological data; climatological dispersion models; applications for potentially high pollution days, forecasts implying atmospheric stability, stagnation conditions, low winds and temperature inversions; diffusion parameters; forecasting the assimilative capacity of the atmosphere; issuance of air pollution alerts.

(h) *Health effects of pollutants.* Physiological reactions of human beings, animals, and vegetation. Chemistry of principal air pollutants: carbon monoxide, sulfur oxides in combination with particulate material, hydrocarbons, oxides of nitrogen, photochemical oxidants, particulate lead compounds; photochemical smog reactions. Ambient air quality standards. Other aspects of urban climate; urban hydrology and drainage; water management in urban areas; corrosion and deterioration, noise, plants in the cities; natural hazards in the cities; impact of urban atmosphere on socio-economic activities; urban planning and design.

3.4 Other fields of specialization

Biometeorology and human health

(a) *Human biometeorology (HBM) scope*. Relationships between the weather and climate, and the life and health of humans. Quantitative HBM - measurable changes in human health caused by measurable environmental elements. Qualitative HBM - observed medical symptoms obviously triggered or exacerbated by atmospheric conditions or agents. Statistical HBM - searches for correlation between weather/climate elements and human actions, reactions and health; statistical meteorotropisms; seasonal relationship; temperature extremes; mortality and morbidity. Methods in HBM based on physical science principles; process-response system of energy and matter flows within the biosphere; investigative methods; morbidity and mortality records; methodology assumptions; sampling properties of climatological and epidemiological data.

(b) *Biophysical adaptation; the body-environment energy budget.* Human body thermo-regulatory mechanisms; determination of body's thermal equilibrium by: metabolic rate, heat storage in body tissues, radiative and convective exchanges with the surroundings, and evaporative heat loss by sweating. Physics of the conductive-convective heat exchanges body-environment; thermal conductivity of the body; body size effects, energy budget equation; equation for the rate of temperature change in the body in relation to the body-environment temperature difference. Interpretation of physiological responses, particularly the temperature responsiveness of metabolic rate; "emergency" responses to thermal stress: secretory, vascular and circulatory.

(c) *Biophysical adaptation; clothing and housing*. Indoor heat loss by radiation and evaporation; outdoors loss of additional heat by convective transfer facilitated by the wind. Energy budget equation for a body in thermal equilibrium with its environment; the "operative temperature" concept; the range of physiological responses to various combinations of radiation, wind, air temperature and humidity. Role of closing, energy budget equation for the outer surface of clothing, and for the interface between the skin and the inner surface of clothing; the combined "resistance" of the body and clothing to heat conduction; specific interpretations for hot-dry, hot-moist and cold climates. Role of housing; the "heating degree-days" concept; limits of tolerance.

(d) *Epidemiology and environmental human physiology*. Individual health and disease; aetiology of human health; disease and longevity; public health; climate-related diseases; demographic aspects of disease; sources of epidemiological data; infectious and respiratory diseases; circulatory afflictions; pathological effects of heat, cold climates, and high altitudes; short-term reactions; acclimatisation and adaptation. Climatic determinism; nutrition and climate, sociological and psychological effects; climate stress.

(e) *Climatic comfort; windchill and heat discomfort.* Human comfort dependence on: air temperature, relative humidity and wind. Comfort indices, especially for windchill and heat stress. *Windchill:* the cooling effect of low temperature and wind on bare skin; windchill equivalent temperature; nomograms; formulae that include the protective effect of clothing. *Heat discomfort*: temperature and relative humidity; "apparent temperature" parameter depending on midday temperature, vapour pressure and wind speed; the "clo" measure for the thermal insulation

provided by clothing at 21°C, 50% relative humidity, and 10 m/s wind speed; the heat index and other more elaborate comfort indices.

(f) *Monitoring bioclimatic resources*. Climatic parameters affecting the life and health of humans. Atmospheric conditions' relationship with mortality and morbidity, including heat-wave and cold-wave mortality and seasonal variations; respiratory diseases associations, especially allergies; other health effects of air pollution and of weather systems. Bioclimatic mapping for human comfort, discomfort and danger (heat stroke, frostbite); areas which need both central heating and air conditioning; classifying, zoning and estimating conditions for productive and tourist activities in diverse climate zones of the world. Empirical studies associating non-severe weather and various physiological and psychological responses, including medical-meteorological forecasting.

Boundary layer meteorology

(a) *Physics of the boundary layer*. Review the main types of boundary layers: Stokes boundary layer - balance between pressure gradient and frictional forces; Ekman boundary layer - balance among Coriolis, pressure gradient and frictional forces; advective boundary layer - balance between the pressure gradient and frictional forces and the advective accelerations. Conventional and non-conventional circulations; mixed layer physics and internal boundary layers. Diurnal evolution of the planetary boundary layer; vertical profiles for the fields of heat, moisture, momentum and trace constituents; soil temperature profile and its diurnal variations. Numerical models for the diurnal cycle of meteorological parameters in the boundary layer; introduction to parameterisation schemes - the "closure" problem.

(b) *Atmospheric turbulence.* Review of the turbulence theory; statistical description of turbulent flow, spectral representation, overall shape and scale of the spectrum; turbulent (eddy) transport of momentum, heat and water vapour; measurement of turbulent quantities; heat flux equation; Richardson criterion; Monin-Obukhov length scale; semi-empirical and similarity theories. Techniques for determining the surface energy budget for different surfaces and estimating the fluxes of momentum, energy, and moisture; boundary layer stability under a variety of conditions; relationship between boundary layer stability and the transportation and mixing of pollutants. Diffusion model applications to air pollution.

(c) *Parameterisations of the planetary boundary layer.* Viscous sub-layer; surface layer; transition layer; internal boundary layers. Parameterisation of the sub-grid scale correlation terms; first-order closure representations - drag coefficient (bulk aerodynamic formulation), local exchange coefficients, exchange coefficients derived from profile-functions; second-order closure - explicit equations for the sub-grid scale fluxes. Use of boundary layer parameterisations to estimate transport and diffusion of atmospheric pollutants. Diffusion modelling techniques - box models, Gaussian models - plume and puff models; time-dependent 3-D advection-diffusion models.

(d) *Bulk transport of pollutants; modelling by primitive equation models:* Synoptic scale transport of pollutants; acid precipitation and sulfate transport; long-distance transport of tropospheric ozone. Challenges: availability and quality of observational data from the pollution sources, parameterisation of turbulent mixing in the boundary layer, correct representation of mass fluxes of pollutants

associated with convective clouds; simulation of the aerosol population dynamics. Sub-grid scale variability of chemical fields and scale-interactions on systems with complex chemical reactions. Integrated regional modelling: local effects, mesoscale phenomena, one and two way nesting, models with chemistry, and their application. Evaluating the accuracy of air pollution models, and their credibility for environmental assessment applications and regulatory purposes, including in policy and abatement strategies.

Clouds and precipitation; weather modification

(a) *Atmospheric aerosols.* Aerosols; definition and principal characteristics; concentration and size distribution; fall speeds; Brownian motion and diffusion; coagulation. Turbulent mixing of aerosols; vertical distribution and sedimentation; removal of aerosol particles by washout. Cloud condensation nuclei (CCN); their origins, volcanoes, meteor trails, forest fires, industrial smoke stacks and other anthropogenic sources; origins of natural ice nuclei; modes of activation; number of active ice nuclei as a function of temperature; concentrations.

(b) *Formation of clouds.* Review of the thermodynamics of dry air and of unsaturated moist air; ways of reaching saturation, pseudo-adiabatic process; static stability and parcel buoyancy; mixing and convection. Formation of a cloud droplet, release of excess water vapour by cooling; the surface tension effect; role of dissolved solute; growth rate equation; evaporation of droplets. Formation of water clouds; simple numerical simulation of the competition for available water vapour; observational facts; continental versus maritime clouds. Formation and growth of ice crystals; growth rate equation for ice crystals; condensation and accretion; multiplication of ice particles by fragmentation; electrification of clouds.

(c) *Precipitation process.* Formation of rain by coalescence; continuous collection; terminal speeds of water drops; precipitation embryos; evolution of cloud droplet spectrum by coalescence of liquid droplets; evolution of raindrop spectra. Bergeron, Wegener, Findeisen process; the rapid growth of ice particles in a supercooled water cloud; the riming efficiency of crystals; rain formation by melting snow. Hailstone growth; hydrometeors growing by accreation in strong updrafts; supercooled cloud water or rain-water.

(d) *Cumulonimbus convection*. Severe local storms; cumulonimbus dynamics; lightning, and hail; the radar reflectivity in relation to the presence of hail. Joint radar and satellite data use for near real time storm monitoring and nowcasting, including through interactive numerical cloud simulations.

(e) *Hail suppression.* Cloud seeding and its direct impact on the microphysics processes of precipitation formation; indirect effects on the dynamics of weather disturbances and on the water budget - initial vertical tower growth; horizontal cloud expansion, secondary growth; interaction with neighbouring clouds; increased area rainfall. Cloud modification by: changes of particle concentrations (supply of cloud condensation nuclei, ice nuclei, water droplets); changes of particle growth processes (enhancement of nucleation, condensation, sublimation, collision/collection, and breakup); changes of bulk properties of clouds or air (buoyancy increase by heating, drag, electrical fields).

(f) *Fog clearing; precipitation management.* Supercooled fogs - ice-phase seeding; warm fogs - adding heat, mixing with clear air by helicopters, hygroscopic

treatments, tree rows to sweep out fog as it passes through them. Clearing or creating clouds; opening holes in supercooled stratus; creating cloud cover; frost protection. Enhancement of rain and snow; seeding with giant nuclei, spraying of droplets, increasing buoyancy; dynamic seeding of convective clouds with ice nuclei; redistribution of precipitation.

(g) *Technology of weather modification*. Observation systems and techniques: radar, mesoscale and local networks; aircraft platforms for dynamic and microphysics measurements. Instruments: nucleus counters, liquid water content measuring devices; droplet and drop size measuring devices, ice particle counters, temperature and pressure sondes, inertial platforms electrical field mills, charge sensors, etc. Technology: nuclei generators, dry ice crushers, propane nozzles, other systems for nucleating or drag creating devices - rockets, shells, flares. Evaluation statistical techniques in artificial stimulation of rain and snow, fog dispersal, cloud dissipation, hail suppression. Practical and legal aspects.

Economic meteorology; marketing and management

(a) *Meteorological information, products and services.* National and international context in which producers and users of meteorological information operate;; role of private sector meteorology. Characteristics of meteorological information; range of services; range of products. Classification of services and products as indivisible (multiple user availability) or non-exclusive; range of techniques for the services' provision.

(b) *Users and beneficiaries of meteorological information.* Range of users of meteorological products. Potential beneficiaries of meteorological services. Sensitivity of users to meteorological conditions. Indices showing the impact of meteorological conditions on the economy and individual. Factors inhibiting the use of meteorological information

(c) *Introductory econometric statistics.* Probability measures for natural conditions statistics. Elements of theory of games: queuing models; linear programming; Monte Carlo techniques; random numbers generators. Selection of optimal decisions under conditions of total and partial uncertainty. Efficiency function; optimum criteria; Bayes' mean loss estimation and its application to the selection of optimal decision; loss nomograms; parametric criteria for selecting the optimal strategy.

(d) *Verification of forecasts*; *conceptual framework*. Purposes of forecast verification. Reasons for imperfect forecasts. Basic concepts in forecast verification; types of variables; types of forecasts; joint distribution of forecasts and observations; forecast quality, bias, accuracy and skill.

(e) *Verification methods.* Techniques for verifying categorical forecasts of continuous quantities. Techniques for verifying categorical forecasts for binary events. Techniques for verifying probability forecasts of dichotomous events and the extension of these verification measures to forecasts of multi-category events.

(f) *Estimation of economic benefits using decision models*. Decision analysis; basic requirements of a decision model. Non-probabilistic decision criteria (e.g. maximin payoff and maximax payoff; maximin loss; neglect of the likelihood of the events occurrence). Probabilistic decision criteria (e.g. maximising expected

payoff, expected monetary value; minimising expected opportunity loss; risk-neutral behaviour; maximisation of expected utility). Expected value. Strengths and weaknesses of decision models. Sequential decision-making problem; dynamic (i.e. sequential) versus static (i.e. a decision does not affect subsequent decisions) models. Sensitivity analysis.

(g) *Basis of standard cost-loss models; the economic value of forecasts.* Standard model; basic assumptions about costs and loss. Value of forecasts using the standard cost-loss model; optimal strategy based on minimising losses over a large number of cases. Optimal course of action when only climatological information is available; mean expense when taking optimal action based on climatology; mean expense when using perfect forecasts; economic value of a forecast. Interpretation results from cost-loss models.

(h) *Extension of the standard cost-loss model; applications of decision models.* Extension of the standard model. Use of standard cost-loss model to determine the threshold probability for which action should be taken.

(i) *Techniques for the estimation of economic benefits.* Market prices; estimating the economic value of specialised forecasts for particular users; limitations of using market prices. Behavioural studies; user surveys; decision experiments; observing the economic impact of a change in the provision of meteorological services; regression models, to assess the impact of the volume of meteorological services on measures of economic performance. Limitations of descriptive behavioural response studies. Contingent valuation technique and its application; limitations of contingent valuation technique.

(j) *Marketing meteorological products and services.* Understanding the functioning of a commercial unit and the users' sensitivity to weather-climate conditions; preparing indicators of economic usefulness of meteorological information; mastering commercial negotiation techniques; knowing juridical procedures; providing consulting services and technical support.

General hydrology and hydrometeorology

(a) *Development of hydrology.* Definitions, and relations of hydrology to other sciences; the hydrological cycle; physical characteristics of the watershed; variability and randomness of hydrological phenomena; catchments; water balance; influence of man on the hydrological cycle; hydrological data.

(b) *Precipitation.* Formation of precipitation, measuring devices and accuracy, determination of amounts, rainfall depth, duration and intensity, spatial and temporal distribution, rainfall data screening; depth duration frequency curves; analysis of extreme rainfall events; mixed distributions; probable maximum precipitation; analysis of dry spells.

(c) *Evaporation and evapotranspiration*. Evaporation from open water, intercepted water and bare soil; transpiration; actual and potential evapotranspiration; factors affecting evapotranspiration; empirical formulae and physically-based theories to estimate evapotranspiration; methods to estimate potential evapotranspiration; evaporation measurement.

(d) *Groundwater resources.* Occurrence of subsurface water; infiltration; factors governing infiltration; measuring techniques; formulae for estimating infiltration; water in the unsaturated soil; readily available soil moisture; occurrence of water in the saturated zone; types of aquifers; ground water flow and storage.

(e) *Surface water resources.* Determination of surface run-off; equation of Manning; rating curves; flood surveys; hydrograph analysis; factors affecting hydrograph shape; flow duration curves; flood frequency analysis; missing data. Hydrometric networks; methods of measuring water levels, velocities, and solid and liquid discharges; storage and processing of data.

(f) *Water balance*. Rainfall-runoff relations; short duration peak runoff; long duration catchment yield; deterministic catchment models; water balance of lakes, swamps, watersheds and regions. River flood forecasting; flash flooding; flood control techniques; low flows; irrigation; water resources monitoring.

(g) *The hydrological cycle; hydrometeorology.* Movement and changes in the state of water substance in the atmosphere, in particular above the continental surfaces; time trends in meteorological data. Water cycle; climate and the flow regime; impact of global climate change; possible sea level rise; droughts; severe storms.

General oceanography and marine meteorology

(a) *Physical oceanography overview.* The ocean as a component of the Earth's system; formation of the seas; plate tectonics; dynamics of the ocean bottom; morphology; ocean basins; continental shelf; production of ocean sediment. Physical and chemical properties of sea water. Vertical structure of the ocean temperature and its variation; the permanent thermocline. Range of pressure and density; thermometric determination of depth; dependence of density on temperature and salinity; potential density. Temperature-salinity relationships; mixing; T-S diagram. Currents and water masses; water masses and circulation of the individual oceans.

(b) *Introduction to ocean dynamics.* Typical spatial and temporal scales of variability. Water-mass boundaries; mixed layer depth; halocline and upper zone; upwelling; deep and bottom water masses; intermediate and central water masses. Marine currents; upwelling; oceanic circulation; major oceanic currents; west-coast and east-coast oceanography. Equations of motion; gravity and gravity equation; geopotential; hydrostatic pressure; gravitational stability; Coriolis acceleration; horizontal and vertical components. Currents in a homogeneous ocean; currents in a two-layer ocean and in a stratified ocean; relative currents; volume transport; frictionless ocean currents; geostrophic flow.

(c) *Wind-driven currents; turbulence transfer; thermohaline circulation.* Transfer phenomena and turbulence; viscosity and shear stresses; laminar flow; evaluation of exchange coefficients by the kinetic theory of gases. Real fluids exchange phenomena; turbulent viscosity, conductivity and diffusivity. Statistical consideration of turbulent exchange; mean values; momentum transfer, Reynolds stresses; the turbulent coefficient of viscosity in the vertical; diffusion of salt. Prandtl's assumption, mixing length theory; application to boundary layer flow; von Kármán constant; friction velocity; the laminar sub-layer; the drag coefficient; wind stress on the ocean surface. Wind driven currents; wind drift; Ekman spiral;

frictional depth; mass transport in the wind drift currents. Vertically integrated vorticity equation; beta-effect; torques by surface winds and by viscous stresses; simplified solutions by Sverdrup, Stommel, and Munk. Inertial motion; Rossby waves; Stommel's application to the Gulf Stream; inertial current study by potential vorticity and energy conservation. Thermohaline circulations; deep ocean waters and the apparent stability of the permanent thermocline; relatively high values of dissolved oxygen; role of the thermohaline circulations along with the wind-driven circulation; effects of upwelling; circulation patterns in the deep water; western and eastern boundary currents.

(d) *Surface waves; oscillations of air-sea interface*. Sea waves, swells, tsunamits, storm surges; generation, development and propagation. Basic wave concepts: elevation; spectrum of surface waves; phase speed; group speed; wind waves; sea state; significant wave height; tides; storm tides. Basic theory of gravity waves; plane waves of permanent form; harmonic wave solution; deep water waves; pressure anomaly; orbits, orbital velocities and streamlines in deep water waves; group speed; dispersion. Relation of waves to winds; shallow water waves; wave refraction; waves of finite amplitude; waves potential and kinetic energy; energy propagation; standing waves. Internal waves on a surface of density discontinuity.

(e) *Tides.* High and low waters; the range of the tide; tidal stream; "slack waters"; "Lunar day" and the mean tidal interval; diurnal inequality; mean sea level; "lowest low water springs". Equilibrium and dynamical theory of the tides; harmonic analysis; movements of the Sun and Moon; declination; Moon's phases; new and full moon; revolution of the axis of the Moon's orbit; nutation; the generating potential; types of tides: synodic, anomalistic, declinational, mixed.

(f) *The heat budget of the ocean*. Radiation from the Sun and atmosphere; standard zenith optical path length; incoming radiation under cloudy conditions; albedo. Blackbody radiation; Stephan-Boltzman law; Wien's displacement law; efficient absorption of radiation by carbon dioxide and water vapour in the atmosphere; decrease of the effective back radiation with increasing temperature (for constant relative humidity). Sea surface heat loss by radiation and evaporation; "skin temperature"; poleward heat transport. Conduction of sensible heat; relationship with air temperature and other variables; exchange coefficient; atmospheric stability role; condensation; evaporation; heat budget equation. Diurnal variation of oceanic elements; seasonal characteristics.

(g) *Air-sea interaction*. Interdependence of ocean and atmosphere, air-mass and water-mass modification; water-mass mixing. Exchange of energy: turbulent fluxes of sensible and latent heat; turbulent fluxes of momentum; radiative fluxes of net incoming and outgoing radiation; radiative sea surface heat budget; energy transport by marine currents. Exchange of matter. Ice formation and breakup, fast ice and pack ice, icebergs.

(h) *Measurement platforms and instruments*. Ocean observations using in situ instrumentation and remote sensing; principles of sub-surface temperature-reversing thermometers; currentmeters, bathythermographs, thermographs and other devices; salinity, current, chemical, and opacity measurements. Buoy observations, tide gauge stations, satellite-based data for sea surface temperature, winds, sea-level topography, and sea ice; infrared radiometry; observations from merchant ships. Sound propagation in the water; attenuation of sound; echo-sounding; sub-bottom recordings; refraction; light in the see; the

spectral density of energy flux; light attenuation; reflection and refraction; refractive index; application to marine measurements.

(i) *Meteorological applications.* Organic resources of the ocean; main types of ocean food; biological relationships; environmental influence on fish behaviour. Introduction to numerical modelling of the ocean circulation; coupled atmosphere-ocean models; operational marine forecasting. Provision of standard services and warnings.(e.g. coastal construction, coastal estuary engineering and maintenance). Forecasts for sea waves and sea ice. Forecasts for tropical cyclones and typhoons: areas of formation, season, track, and conditions for formation; mature stage: clouds, winds, temperature, pressure and swell, storm surge; tracking the movement and the decay stage.

Middle-upper atmosphere

(a) *Upper atmosphere sub-regions.* Vertical structure and composition of the upper atmosphere; variation of mean molecular weight with height; scale height; molecular-scale temperature; geopotential; some standard atmospheres; nomenclature; stratosphere, mesosphere and thermosphere. Observed lower stratosphere; tropopause; temperature and pressure; winds; water vapour and dust; climatology of the lower stratosphere, large scale features of the temperature variations; winds; inter-annual variations; the tropical stratosphere particularities; disturbed circulation of the lower stratosphere; winter and summer circulations; southern hemisphere conditions. Structure and circulation of upper stratosphere and mesosphere; the anomalous propagation of sound; noctilucent clouds; meteor trails; temperature and wind measurements; boundary between the lower and upper stratosphere.

(b) *The Sun's radiation in the upper atmosphere; space "weather".* Recall of basic concepts and definitions of spectroscopy, quantum mechanics, photochemistry and radiative transfer. Atomic energy levels; hydrogen, helium, nitrogen, oxygen; molecular energy levels; nitrogen, oxygen; energy exchange by collision; blackbody radiation; radiative transfer; absorption of solar radiation by an exponential atmosphere. Physical and optical features of the Sun; solar wind, solar flares, sunspots, and solar cycles; surface-based and satellite-based solar monitoring systems. Electromagnetic energy from the Sun; ultraviolet radiation; absorption by the upper atmosphere; absorption by atomic and molecular nitrogen and oxygen; absorption by other constituents.

(c) *Chemistry of the upper atmosphere; stratospheric ozone*. Flux of solar radiation reaching the earth's surface; Dobson, infrared, optical, chemical, and chemiluminescent methods of determining the vertical distribution of ozone. Photochemical and meteorological processes affecting ozone; seasonal variations; Antarctic ozone hole. Composition of the mesosphere; an oxygen atmosphere; a nitrogen-oxygen atmosphere; a hydrogen-oxygen atmosphere; sodium in the upper atmosphere; noctilucet clouds. Composition and structure of the thermosphere; photochemical processes; critics of the photochemical equilibrium assumption for the oxygen; vertical distribution of molecular oxygen; diffusion level; mass-spectrometer measurements; pressure and density measurements; density variations and solar activity; vertical distribution of temperature and molecular mass.

(d) *Radiative transfer from the infrared radiation*. Radiative processes and heat transfer from the minor polyatomic constituents water vapour, carbon dioxide, and ozone; inapplicability of Kirchhoff's law in the upper mesosphere; other mechanisms of radiative heat loss in the lower thermosphere; downward molecular conduction at higher levels. Formal procedure to solve the equation of transfer; the use of transmission function; spectral models; the problem of carbon dioxide radiation in the vicinity of mesopause; radiation by other thermosphere constituents. Observed high temperature of the high-latitude winter mesopause region and the observed low temperature of the high-latitude summer mesopause region; heat conduction and thermosphere models.

(e) *Atmospheric tides; geomagnetic phenomena; the ionosphere.* Observation of atmospheric tides and winds in the lower thermosphere; Theory; gravitational forces and resonance, Laplace tidal equation; thermal forces, the effect of surface heating and the role of the absorption of solar radiation by the stratospheric ozone. Small-scale wind variations in the lower thermosphere; Hines' theory. Geomagnetism; Maxwell's equations, magnetic dipole, the Earth's dipole field, geomagnetism theories; the airglow and aurora; lights of the night sky; the airglow spectrum. Ionosphere; electron production and loss processes; production of ions, day- and night-time; D, E and F region chemistry; impact of solar storms on power grids, satellites and communications systems.

(f) *The dynamics of the stratosphere and mesosphere*. Review the observational basis; zonally averaged circulation, energetics of the stratosphere and mesosphere; extra-tropical planetary waves and the sudden stratospheric warmings; equatorial stratospheric waves; the quasi-biennial and the semi-annual oscillations. Development of dynamical models; basic equations, scale analysis, dynamical simplifications; beta-plane approximation, geometrical simplifications; linear waves in a motionless basic state; radiative heating, sources and sinks. Baroclinic instability in the stratosphere; Charney-Stern theorem; baroclinic instability in the mesosphere. Numerical modelling of the upper atmosphere by quasi-geostrophic and primitive equation models; transport of chemical species; transport through the tropopause; meridional and vertical transport in the stratosphere; transport in the mesosphere.

Numerical methods for mathematical modelling in meteorology

(a) *Basic finite-difference methods.* Accuracy and consistency; stability and convergence; the energy method, Von Neumann's method, the Courant-Frederics-Lewy condition. Time-differencing: the oscillation equation, phase-speed and amplitude error; two- and three-level schemes; leapfrog computational mode. Space-differencing; differential-difference equations and wave dispersion; dissipation and dispersion; artificial dissipation. Combined time- and space-differencing; the discrete-dispersion relation; the Lax-Wendroff method.

(b) *Systems of equations.* Staggered meshes, split schemes; diffusion, sources and sinks; linear equations with variable coefficients, aliasing error, conservation and stability; non-linear instability in barotropic vorticity equation.

(c) *Spectral and other methods.* The spectral method; comparison with finite-difference methods, the transform method, conservation properties. The pseudo-spectral method. Spherical harmonics, truncating the expansion, elimination of

the pole problem, Gaussian quadrature and transform method, non-linear shallow water equations. Finite-element method.

(d) *Semi-Lagrangian methods.* The scalar advection equation with constant/variable velocity; systems of equations, comparison with the method of characteristics; the semi-implicit semi-Lagrangian approach to shallow-water wave equation, comparison with the Eulerian approach.

(e) *Boundary conditions.* Well-posed initial/boundary-value problems, radiation condition, time-dependent boundary data, reflections at an artificial boundary, stability in the presence of boundaries. Two-dimensional shallow-water flow and stratified flow; lateral and upper boundary conditions, radiation upper boundary condition. Use of wave absorbing layers.

BASIC INSTRUCTION PACKAGE FOR METEOROLOGICAL TECHNICIANS - BIP-MT

Chapter 4, WMO-No. 258 Vol. I - Meteorology

Requisite topics in basic sciences

Compulsory topics in general meteorology

Elective options in operational meteorology

4.1 Requisite topics in basic sciences

Mathematics

(a) *Review of elementary algebra, geometry and trigonometry.* Algebra; natural logarithms, radicals, and quadratic equations; real and imaginary roots; operation with double radicals. Simple plane geometry; polygons; length of a circumference and of an arc of circle; the angle between a straight line and a plane; prisms; pyramid; cylinder; cone; sphere. Trigonometry; arcs and measurement of angles, circular functions, reduction to the first quadrant, trigonometric tables; simple trigonometric equations. Plane analytical geometry, cartesian, rectangular and polar coordinates; geometric locus; equation of a straight line; simple standard curves like parabola, ellipse, and hyperbola.

(b) *Introductory differential and integral calculus*. Elementary knowledge of functions, their continuity and limit; graphical representation; derivatives; simple applications; tangent to a curve; slope of a curve; gradient of a scalar; minimum and maximum of a function. Integrals of common functions; applications; area defined by the arc of a curve; lateral area and volume of a body of revolution.

(c) *Elementary statistics*. Simple frequency distribution; tabulation and graphical representation of statistical data; the mean, median, mode, variance, percentile; measures of dispersion: mean and standard deviation; simple linear regression by least squares; correlation; measures of uncertainty and confidence.

(d) *Introduction to information technology*. Basics of computer and network technology; Internet. Introduction to operating systems; use of standard tools and applications; data storage, analysis, and display software; telecommunications. Basic skills in worksheet environment: course work and practical activities to develop skills in data management through commercial software or equivalent; basic programming skills in worksheet environment; introduction to homepage development and maintenance.

Physics

(a) *Basic mechanics*. Properties of matter; kinematics of a material point; rectilinear motion of a particle; velocity and acceleration; force and inertia. Newton's laws of motion; circular motion; centripetal force; centrifugal acceleration; simple harmonic motion; work and energy; equilibrium of systems of co-planar forces; motion of rotation; moment of inertia. Rotating systems, Coriolis effects.

(b) *Nature of fluids; heat*

(d) Electricity and magnetism. Static electricity; electric currents; induction; electrical units; electric potential; Ohm's and Kirchhoff's laws; thermoelectric effects; chemical action of a current; electrolysis; electromagnetic induction; magnetic potential; terrestrial magnetism.

Chemistry

(a) *Basic chemical concepts*. Structure of the atom; chemical elements and the periodic table; compounds; valence; bonds; acids and bases; inert gases; metals and non-metals; reactions and reaction rates.

(b) *Elements of bio-geo-chemistry*: Chemical composition of the atmosphere; key elements in the earth system: oxygen, silicon, iron, hydrogen, carbon; water as a unique compound. Bio-genic elements: oxygen, carbon, etc.; properties of macro- and micro-nutrients; atmospheric photo-chemistry; chlorophyll, ozone.

Communication skills

(a) *Expression and communication skills:* Course work and practical activities to develop oral and written presentation and communication skills.

4.2 Compulsory topics in general meteorology

Introductory physical and dynamical meteorology

(a) *The Sun, Earth and electromagnetic radiation.* Features of the Sun; motions of the Earth; seasons; duration and intensity of sunshine; solar radiation; types of heat transfer; radiant energy and light; blackbody radiation; emissivity, absorptivity and transmissivity. Qualitative discussion of radiation laws: Kirchhoff, Plank, Stefan-Bolzmann, Wien; scattering; absorption of the radiant energy in the atmosphere; albedo of natural surfaces: upper surface of clouds, land surfaces, water; greenhouse effect. The heat balance of the atmosphere; terrestrial radiation; the free atmosphere radiation; radiation flux; the Earth heat balance.

(b) *Introductory atmospheric thermodynamics.* Vertical structure of the atmosphere; distribution of temperature and pressure; troposphere, stratosphere, tropopause; upper atmosphere. Thermodynamics and statics; laws of Boyle, Gay-Lussac, and Avogadro; equation of state; effects of water vapour; first law of thermodynamics; internal energy; work done by external forces; changes in internal energy; applications to the atmosphere; adiabatic process; hydrostatic balance; geopotential. The lapse rate; vertical stability.

(c) *Atmospheric moisture; condensation process.* Water vapour; change of phase; vapour pressure; saturation; absolute and specific humidity; relative humidity; temperature of the dew point. Change of phase; adiabatic process at saturation; reversible adiabatic and pseudoadiabatic condensation process; formation of clouds and precipitation; wet-bulb temperature; thermodynamic diagrams; tephigram; conditional and convective instability.

(d) *Atmospheric motion; geostrophic flow.* Atmospheric pressure; gravity; pressure gradient force; hydrostatic balance; Coriolis force; geostrophic wind; variation of wind and temperature with height; upper winds; frictional force. General circulation of the atmosphere; global distributions of temperature, pressure, moisture, wind; major climatic zones. Orographic effects; local winds; boundary layer; urban effects; elements of atmospheric turbulence.

(e) *Elements of atmospheric optics and electricity*. Atmospheric refraction, rainbow, halo, corona, blue of the sky; transparency of the atmosphere and visibility; application of notions of static electricity to the electric field of the atmosphere; air conductivity, lightning discharge and thunderstorms.

Elements of synoptic meteorology and climatology

(a) *Observing the Earth's atmosphere and oceans*. The meteorological network concept; representative value of a meteorological element; surface and upper air observations. Remote sensing of atmospheric phenomena using radar and satellite sensors; buoys, ships and planes. Establishment of the global observing system and its growth over time; the WMO's World Weather Watch and other international programmes.

(b) *Information technology; operational data processing.* Operating standard information and communication technology software to prepare operational data sets; constant updating of real time databases; quality control. Displaying

observational data on surface and upper air charts; preparing standard analysis charts and aerological diagrams; Use of specific weather analysis software.

(c) *Air-masses; cyclones and anticyclones.* Formation and modification of air masses; ocean heat exchange and evaporation; vertical fluxes; air-mass modification. Frontal waves; characteristics of extra-tropical cyclones and anticyclones; warm, cold and occluded fronts; relationship between surface and upper-air features.

(d) *Introduction to synoptic analysis.* Displaying and analysing surface pressure and upper-air charts to identify centres of high and low pressure, frontal boundaries, weather patterns, etc. General familiarisation with operational NWP output; understanding guidance forecasts, satellite and radar imagery; preparing forecast verification data. Assisting the forecaster in preparing weather briefings; monitoring the receipt of operational forecasts and warnings from the main centre. Communicating forecasts and warnings to the public, authorities and individual customers; customer services and relations.

(e) *General climatology; routine applications.* Definition of climate; climatic elements: temperature, precipitation, humidity, wind speed and direction, visibility, sky cover, sunshine, radiation, etc. Climatic controls; natural influences: latitude, relief, water, ice and snow; anthropogenic effects. Statistical methods: means, normals, departures, deviation; climatological data processing; maintaining climatological records; monthly record of extreme values; the CLIMAT message; preparation and dissemination of routine climatological information.

(f) *Climatological measurements.* Requirements for the installation of climatological stations and instrument shelter; principal and ordinary climatological stations, precipitation stations, and stations for specific purposes. Precipitation gages; siting and exposure of precipitation gages; pluviographs. Other climate-related measurements: soil temperature; soil moisture; humidity. Psychrometers, hygro-thermographs; heated electrical hygrometers for dew point measurement. Sunshine and solar radiation; sunshine recorder; actinographs.

(g) *Organisation of meteorology.* Roles of National Meteorological Services; weather and climate monitoring and forecast services; warning services for hazardous weather. Specific meteorological services to aviation, agriculture, shipping, offshore petroleum industry, utilities, industry, commerce; air pollution sources; atmospheric concentrations; removal processes; effects; other environmental issues. Private meteorology services.

Meteorological instruments and methods of observation

(a) *Overview of meteorological observation and instrumentation.* Basic principles of meteorological measurement; synoptic scale mesoscale and local scale; choice of site for instrument enclosure; procedures for installation; standardisation; methods and procedures of calibration; operation; maintenance and checking of instruments; quality assurance and quality control procedures. Errors; distinction from related concepts of precision, sensitivity and accuracy; kinds of errors due to: observer, instrument, relationship between the instrument and the measured element, sampling. Elements that are measured and/or estimated. Hours of observation. Meteorological codes for synoptic observations; code tables.

(b) *Making an observation*: Procedure for producing routine observations; non-routine observations (special reports); identifying cloud types and various meteors; estimating cloud cover (total and layers); estimating and measuring cloud height; estimating visibility. Reading thermometers; calculation of relative humidity; measuring wind speed and direction; assessing mean and gust wind speeds and direction. Recognising weather types and intensities for current and past weather observations; reading barometers and calculating QFF, QFE and QNH; calculating the three-hour pressure tendency; measuring rainfall and snow depth; measuring sunshine; assessing state of ground.

(c) *Quality control, coding, and transmission of observations*: Avoidance of errors; recognising normal and anomalous readings; quality control; recording observations in a register; completing messages in standard codes - SYNOP, METAR and SPECI, PILOT and TEMP, other codes; transmitting observations using telephone or IT links.

(d) *Operating, and maintaining instruments*. Resetting thermometers; time marking recording instruments and changing charts and pens; adjusting recording instruments; familiarity with methods of cleaning instruments; carrying out simple repairs to instruments; maintaining the enclosure and instrument screen to the operationally acceptable standard.

(e) *Automatic observing stations*: Remote stations on land and over the water; various sensors - temperature, humidity, wind, pressure, short- and long-wave radiation, rain gages; microprocessors producing meteorological messages from raw data. Operating display functions; entering manually certain observed data; quality control of completed message, transmitting the message. Maintaining IT equipment; complying with health and safety, and security regulations associated with the use of IT equipment.

4.3 Elective options in operational meteorology

Synoptic observations and measurements

(a) *Surface temperature; pressure; humidity; wind.* Air and ground temperature, and their measurement; dry bulb and wet bulb thermometers; maximum and minimum thermometers; grass and ground minimum thermometers; soil thermometers; thermographs. Atmospheric pressure measurement; mercury barometer; primary and secondary standards; corrections and reductions to mean sea level; aneroid barographs and microbarographs; barometric tendency. Humidity measurement; psychrometric tables. Wind speed and direction measurement; cup anemometer and vane; standard exposure requirements; definition of the surface wind for synoptic purposes; gustiness; squalls. Coding.

(b) *Precipitation; evaporation; visibility; clouds; fog.* Precipitation measurement; dew measurement; rain gauges; sampling for determining the chemical composition of precipitation. Evaporation measurements; evaporation pans. Horizontal visibility estimation; turbidity measurement. Clouds observation: type, amount, height, speed and direction; cloud base recorders; cloud systems. Fog formation, and types. Coding.

(c) *Sunshine and radiation*. Sunshine and its measurement; instruments for measuring solar and terrestrial radiation; radiometers and photometers. Intensity of direct solar radiation at normal incidence, pyrheliometers; solar radiation received from the whole hemisphere, pyranometers; brightness of visible or luminous energy, photometers.

(d) *Hydro-, litho-, photo-, electro-meteors; past and present weather*. Hydrometeors: rain, drizzle; snow, ice crystals, hail, fog, mist, drifting snow, dew; hoarfrost. Lithometeors: haze, smoke, blowing dust or sand, dust storm or sandstorm, dust whirl or sand whirl. Photometeors: halo phenomena, corona, mirage, rainbow. Electrometeors: thunderstorms, aurora. Past and present weather. Coding.

(e) *Upper-air observations*[(#)]. Pilot balloon observations of winds aloft using single and double theodolites; wind vector errors and random errors of observation; accuracy and correctness; constant-level balloons. Measurement of upper-air pressure-height, temperature, humidity and wind by radio-sounding techniques; principle of radiosonde; telemetring system; radiosonde types; calibration; testing and preparation of instruments prior to launch. Errors; quality assurance of received data; verification methods; displaying sounding data on aerological diagrams; data analysis and checking for self-consistency. Coding and transmission of aerological data; maintenance of upper-air observing equipment.

Other specialised observations and measurements

(a) *Marine observations and measurements.* Types of surface and sub-surface observations at sea; meteorological and oceanographic elements; equipment required. Sea surface temperature measurements; wave observations and measuring devices; ice nomenclature and observations; ice accretion at sea and on ships; surface currents; current measurement. Ship codes for surface and

[(#)] This paragraph concerns only personnel responsible for taking radiosonde/rawinsonde observations.

upper-air weather reports. Buoy observations at sea; types of buoys for measuring surface and sub-surface parameters; sources of errors.

(b) *Agrometeorological and biological observations.* Radiation measurements;, devices for measuring distribution of solar radiation within crop canopies; estimation of radiation using sunshine, cloudiness and haze data. Soil moisture and temperature; devices and methods for determining soil moisture content; absorption; heat fluxes. Evaporation and evapotranspiration; estimating evaporation from empirical formulae; aerodynamic, and energy balance approaches; actual and potential evaporation. Phenological observations; growth phases of plants; germination; emergence; shooting; flowering; ripening; harvesting; defoliation. Measurement of plant-growth, leaf-size, length of stalks, thickness of tubers. Observations of birds, insects and diseases; migration, appearance; outbreak of diseases and epidemics.

(c) *Atmospheric chemistry measurements.* Natural and anthropogenic pollutants and normal atmospheric cleansing processes; pollutant sources; formation of smog and tropospheric ozone; acid precipitation. Tools and techniques for measuring pollutants; surveying and sampling techniques; legal levels of pollutants. WMO Global Atmosphere Watch (GAW) system; "core" measurement programme at GAW stations: surface ozone, precipitation chemistry, radiation (visible and UV), CH_4, CO, chemical composition of aerosols, black carbon, total ozone, and meteorological parameters. Data quality assurance and quality control for GAW.

Remote sounding of the atmosphere

(a) *Meteorological satellites.* Polar orbiting and geo-synchronous satellites; characteristics and physical principles; absorption, emission, reflection, and scattering of electromagnetic radiation. Operational radiometers; footprints; sensing water vapour and mapping its flow through the atmosphere; retrieving vertical profiles of temperature and humidity; time-space evolution of cloud systems; retrieving cloud-motion winds. Estimating sea surface temperature and the height of the ocean surface; soil moisture and vegetation cover; albedo; radiation budgets; radiation balance of the Earth-atmosphere system. Sensing stratospheric ozone measurements; its vertical profile and global distribution. Advanced Very High-Resolution Radiometer (AVHRR) scanner sensing in the visible, near-infrared, and thermal infrared portions of the electromagnetic spectrum; deriving operationally sea surface temperatures, normalised difference vegetation index, atmospheric aerosols over the oceans; also monitoring volcanic eruptions, cloud patterns, and other applications.

(b) *Weather radar.* Absorption, refraction and reflection of electromagnetic radiation by meteorological and other atmospheric targets; microwave band; radar equation; radar signal fluctuations; radar back-scatter from small water drops and ice crystals; atmospheric attenuation; radar calibration. Weather radar applications in hydrology; echo characteristics; severe storms; Doppler effect and its applicability to meteorological measurements; Doppler weather radar; wind profiling; multiple retrievals; storm dynamics; clear air echoes; airborne Doppler radar; "hurricane hunting".

(c) *Lidar and sodar.* Lidar (Light Detection and Ranging); optical radar principles: atmospheric absorption and scattering from molecules and aerosols; micrometer range; lidar equation; back-scattering coefficients; atmospheric attenuation;

application to the study of stratospheric particulates and cloud physics. Doppler lidar: detection of turbulence in clear air; measurement of atmospheric motion; the transport and diffusion of plumes from particulate sources. Sodar (acoustic radar); sodar equation; applications; Doppler wind sensing, vertical profiles of wind; wind shear regions; atmospheric turbulence; detection of layered surfaces, thermal inversions, frontal zones, air pollution. The high temporal resolution of wind profilers and acoustic sounders compared to conventional upper-level data.

(d) *Ozone spectrophotometer.* Physical principles; downward spectral radiance; zenith angle; spectral radiance at the ground ignoring scattering and variations of extinction coefficients; the optical path between the ground and the space, the total mass of absorber in a vertical column. Dobson technique for measuring the column ozone and profiles of ozone; Umkeher method - intensities of reflected rather than direct, UV light; Total Ozone Mapping Spectrometer. Lidar measurements of the atmospheric ozone based on absorption of laser light by ozone; profile of ozone concentrations versus altitude (10-50 km).

(e) *Special soundings; meteorological rockets*. Measurement of short- and long-wave radiative fluxes by radiometric sondes; total radioactivity of the air, radioactivity sondes; vertical distribution of atmospheric electricity parameters; sondes for measurements of the potential gradient, atmospheric conductivity, air-ground currents; ozone sondes; electrochemical concentration cells, chemical with luminescence, and optical sondes. Typical errors associated with various radiosondes. Rocket measurements of pressure, density, temperature, wind speed, turbulence; also measurements of atmospheric composition, and solar radiation; rockets measure profiles of ozone levels from the ground up to about 75 km using photo-spectroscopy.

Aeronautical meteorology for technicians

(a) *Observing techniques.* Surface wind direction and speed, including changes and variations. Visibility and runway visual range, including spatial and temporal variations in RVR observations, by visual means or by use of automatic instruments such as the transmissometer and forward-scatter meter. Cloud amount, height and type and spatial and temporal variations; vertical visibility, observations using automatic instruments such as a ceilometer. Pressure measurements for the purpose of determining QFE and QNH.

(b) *Hazardous phenomena.* Aircraft icing; elementary knowledge of icing types; formation, accretion rates and association of icing with clouds, freezing precipitation, orographic and frontal lifting. Turbulence: elementary knowledge of turbulence near the ground as related to topography, air-mass stability, clouds, fronts and thunderstorms. Elementary knowledge of high-level turbulence (CAT) and its association with jet streams. Wind shear. Volcanic ash.

(c) *Meteorological aspects of flight planning.* Meteorological basis for pressure-pattern flying; meteorological requirements for en-route winds and temperatures; weather and aerodrome forecasts. Interpretation of area, route and terminal forecasts and preparation of material for briefing of flight crews.

(d) *Reporting, coding and dissemination of weather information.* Complete knowledge of international meteorological codes related to observations, such as METAR, SPECI, SYNOP, PILOT, and TEMP, and aeronautical forecasts, such

as TAF and ROFOR. Knowledge of procedures for dissemination of weather information at the aerodrome, including the special needs of ATC units. Knowledge of the procedures for the preparation of the plain language forms of meteorological messages.

(e) Definitions. Meteorological report, observation. Visibility, runway visual range. Altitude, elevation, height, aerodrome elevation, flight level, transition level. Aerodrome meteorological minima, instrument runway, landing area. Landing forecast, aerodrome forecast, forecast, GAMET area forecast, SIGMET and AIRMET (information), briefing, routine and special air-report. Operator, operator's local representative, pilot-in-command.

(f) Procedures for meteorological services for international aviation. Organization of the meteorological service and particularly the functions of the various types of meteorological offices. Aeronautical meteorological stations and their functions, local routine and special observations and reports, reports in METAR and SPECI code forms. Meteorological watch. Observations required from aircraft and the procedures related to the ground-to-ground dissemination of these observations. Introduction to the responsibilities of ICAO and WMO in aeronautical meteorology.

(g) Air traffic services. Demands for meteorological services, including the types of meteorological information required by the various air traffic services units and the updating of this information by means of duplicate displays in ATS units or by prompt data transmission originated by the meteorological office or station. Familiarity with special requirements relating to Category II and III operations particularly in respect of runway visual range and cloud base information and any other specific local requirements by aeronautical users for meteorological information.

(h) Operation of aircraft. Flight planning. Duties of flight operations officers when exercising operational control. Navigation and landing aids. Effects of air density, icing, turbulence, wind, wind shear and volcanic ash on aircraft performance. Altimeter setting procedures, standard atmosphere. Performance characteristics, including fuel consumption of civil aviation aircraft; characteristics of propeller type, turbo-prop and turbo-jet, and, where applicable, supersonic aircraft. Effects of various weather phenomena on aeronautical operations and on aerodrome ground services.

(i) Aeronautical telecommunications. Elementary understanding of the general organization of aeronautical telecommunications, but they should have a good working knowledge of the operation of the aeronautical fixed service (particularly AFTN and ATN) and any special broadcasts and/or regional telecommunications networks applicable to the region concerned - e.g., AMBEX and ROBEX. Such knowledge should include: message headings, addressing of messages, priorities of messages and any appropriate regional procedures. Meteorological technicians should be acquainted with the ICAO abbreviations used in messages on the aeronautical fixed services (AFS). The more frequently used abbreviations should be known by heart.

(j) WMO documents. Technical Regulations, (WMO-No. 49), Vol. II — Meteorological Service for International Air Navigation. Manual on Codes (WMO-No. 306). Guide to Meteorological Instruments and Methods of Observation (WMO-No. 8). Weather Reporting (WMO-No. 9).

(k) ICAO documents. Annex 3 — Meteorological Service for International Air Navigation. Regional Supplementary Procedures (Doc. 7030). Procedures for Air Navigation Services — ICAO Abbreviations and Codes (PANS-ABC, Doc 8400). Location indicators (Doc. 7910). Manual of Aeronautical Meteorological Practice (Doc. 8896). Manual of Runway Visual Range Observing and Reporting Practices (Doc 9328). Manual on Co-ordination between Air Traffic Services, Aeronautical Information Service (AIS) and Aeronautical Meteorological Services (Doc 9377) and Relevant Air Navigation Plans (ANPs and FASID;)

Note: Some civil aviation administrations in specific circumstances authorize air traffic services personnel to make meteorological observations at an aerodrome. As indicated in ICAO Annex 1— Personnel Licensing*, the training syllabi for the ATS personnel concerned should be supplemented by relevant parts of the syllabus of the Aeronautical Meteorological Technician given under items (a) to (d) above.*

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