APPENDIX - 5

India Meteorological Department

Central Training Institute

Syllabus for Forecaster's Training Course
In
General Meteorology

Six Months Duration

Sr.No	Subject	Hour
1	Dynamic Meteorology/Geophysical fluid dynamics(Theory + Practical)	60+20=80
2	Numerical weather prediction (Theory + Practical)	
3a	Physical Meteorology(Theory + Practical)	40+20=60
3b	Physical Oceanography	30
4a	Synoptic Meteorology (Theory and Practicals)	
4b	Aviation (Theory and Practicals)	
5a	Climate Science	60
5b	Statistics (Theory+Practical)	20+30=50
6	Hydrometeorology	20
7	Satellite Meteorology(Theory + Practical)	30+25=55
8	Radar Meteorology	20
9	Computer Programming and applications	40+35=75
	Total	700

Paper -1: Dynamic Meteorology/Geophysical fluid dynamics

Theory (Total Hours: 60 Hrs)

- **Circulation and vorticity (12 hours):** Definition & Mathematical expression of Circulation. Absolute and relative circulation. Circulation theorems. Interpretation of terms in the circulation theorem. Application of circulation theorems.Definition of vorticity along with its mathematical expression. Physical meaning of Curl of any vector. Components of vorticity vector. Relation between circulation and vorticity. Relative vorticity in natural co-ordinate. Explanation of curvature and shear vorticity with specific examples. Concept of potential vorticity. Conservation of potential vorticity (conceptual) and its application.Voriticity equation in different Co-ordinates (No derivation). Physical interpretation of different terms. Scale analysis of vorticity equation. Application of vorticity equation. Geostrophic vorticity.
- **Pressure tendency and mechanism of pressure change (2 hours):** Pressure tendency equation (No derivation): physical interpretation, in detail, of each term, representing different mechanisms of pressure change. Different isobaric patterns and their movement.
- **Perturbation theory (1 hours):** Why perturbation method has been proposed? Hypothesis in Perturbation method. To show that perturbation method can remove non-linearity from governing equation.
- **Atmospheric Waves (9 hours):** General definition of wave. Wave- amplitude, frequency, wave length, wave number. Definition & concept of Phase velocity, group velocity, Dispersion relation, dispersive wave, non- dispersive wave. Atmospheric waves: Rossby wave, Gravity wave (External, Internal & Inertia), Kelvin wave. Detail discussion about their dispersion relation (No derivation), Phase speed & group velocity. Physical interpretations of above. Forced flow across a mountain, critical flow, sub critical flow, super critical flow, Froud number and its application.
- **Hydro-dynamic instability (6 hours):** General definition of hydrodynamic instability. Categorization of hydrodynamic instability in different ways.Barotropic & Baroclinic instability, their definition, analysis, criteria and examples. Brunt-Vaisalla instability: Definition & its analysis.Inertial instability: Method of analysis and instability condition. CISK: Definition and explanation.
- **Planetary boundary layer (15 hours):** A brief introduction to PBL: Definition of PBL. Importance of PBL. Characteristics of PBL: the turbulent motion. Types of turbulent motion: Convective turbulence and Mechanical turbulence. Conditions, favourable for Convective turbulence and Mechanical turbulence. Depth of PBL and its diurnal and seasonal variation at a place. Different sub layers in PBL.Boussinesq approximation and its physical interpretation. Governing equations in the PBL using Boussinesq approximation. Reynolds averaging technique. Concepts of eddy flux, eddy flux divergence in detail and their importance. Governing equations for mean motion in PBL. Definition of a closed system and an open system of equation. Assumptions to make the system of governing equations, closed. Turbulent kinetic energy equation (No-derivation) and the physical interpretation of different terms of it. Concept of Flux Richardson number. K-Theory/ Flux-gradient theory/ Similarity theory. Mixing length theory. Logarithmic vertical profile of horizontal wind in viscous sub layer using similarity theory. Concept of roughness length and Von-Kerman constant. Vertical profile of mean

horizontal wind in atmospheric/ oceanic Ekmann layer. Depth of Ekmann layer. Concept of Ekmann layer pumping. Secondary circulation. Spin down. Relation between mass transport in oceanic Ekmann layer and surface wind stress. A dynamical explanation for El-Nino and La-Nino. Convective boundary layer (CBL) or well mixed boundary layer.

- **Dynamical aspects of general circulation (15 hours):** Energetics aspects of General circulation: Definition of Atmospheric energetics. Different form of atmospheric energies, viz., internal energy, potential energy and kinetic energy. Expressions for internal energy. Global internal energy, global potential energy and global kinetic energy equation (Derivation not required).Detail physical interpretations of generation of potential energy, global internal energy and its conversion into kinetic energy. Detail physical interpretation for generation mechanism of global kinetic energy, its conversion into potential and internal energy and the dissipation of kinetic energy. Belt of sub tropical anticyclone, the source region for global kinetic energy. Global energy equation. Dynamical explanation for the sun to be source of atmospheric energy.Equivalence of internal and potential energy in a stably stratified hydrostatic atmosphere. Physical explanation for the proportionality of I.E and P.E in hydrostatic and stably stratified atmosphere.Introduction to total potential energy (TPE). Concept of available potential energy (APE). Qualitatively comparison of APE in a region based on day-to-day charts.Concept of zonal APE, KE, PE and eddy APE, KE, PE. Global angular momentum balance equation. Interpretation of mountain torque, frictional torque and meridional transport of zonal angular momentum. Different mechanisms for meridional transport of zonal angular momentum.

Dynamic Meteorology/Geophysical fluid dynamics :Practicals

Total hour =20

- Computation of horizontal divergence and vorticity using curvature method (4 hours).
- Computation of geostrophic wind and geostrophic vorticity at a point using model wind data (4 hours).
- Computation of thermal wind and thermal advection (4 hours).
- Solving Poison's equation by relaxation method (4 hours).
- Computation of vertical velocity using kinematic method from model wind data (4 hours)

Paper -2 Numerical weather prediction
Theory

Numerical Weather Prediction (Theory)

1. Theoretical aspects of NWP:
History of NWP, with special reference to Indian context. Hierarchy of NWP models. What is broadly understood by the term 'NWP model'? Different components of a NWP model (basic concept only). Introduction to different vertical coordinate systems. Map factor (m).

2. **Numerical Methods**: Different methods for solving model equations: Finite difference method. Implicit & semi implicit scheme. Numerical stability criterion (CFL). Spectral method. Basic concepts about spherical harmonics, Spectral representation of fields, Triangular and Rhomboidal truncation.

3. **Data Assimilation:** Basic concept of data assimilation. Different stages of data assimilation-objective analysis and initialization. What is objective analysis and salient features of different objective analysis ,viz., Cressman techniques, OI scheme (Optimum interpolation), Statistical spectral interpolation schemes and their comparison. What is initialization and salient features of different initialization schemes viz., Static, Dynamic, Normal mode, & Physical and their comparison. Concept of Variational data assimilation.

4. **Parameterization of physical processes (10 hours): Basic concepts of sub grid scale physical processes and their parameterization. Salient features of different parameterization schemes and their comparison for** Planetary boundary layer, Convection (Deep cumulus and shallow convection), Large scale condensation, Radiation (short wave & long wave parameterization), Cloud Radiation interaction, Dry and moist convective adjustment processes, Hydrology (Bucket method).

5. Basics of Operational Numerical Models: Mesoscale model, Regional Model (LAM), Global Model (mainly Medium Range Forecasting), Climate Model Ensemble model & Super ensemble model.

6. NWP Products: Different NWP products and their interpretation. Post processing of model output. Forecast verification technique and different Forecast skill scores. Forecast errors, Systematic errors. Interpretation & application of model output. Model Output Statistics (MOS) and their use in Short Range (1 - 3 day) forecasting of weather elements

Basic concepts on Storm Surge modeling , Ocean State Modeling, Crop Weather Model, Pollution Model, Aviation Hazard Modeling, Hydrological Cycles.

Practical: Numerical form of Laplacian of a scalar. Computation of Laplacian of a scalar field. Numerical method of solving Poisson equation. Graphical packages for illustration

of NWP products. Stream function, velocity potential and vertical velocity. Numerical experiments with NWP models (WRF & AGCM).

Paper-3 Physical Meteorology & Physical Oceanography
(Total Hours = 90)
Section- A: Physical Meteorology
Theory (Total Hours = 40)

- **Thermal structure of the atmosphere**; troposphere, stratosphere, mesosphere, thermosphere, and explanation of these. Basic ideas and concepts of QBO, and stratospheric warming. Tropopause breaks. (7 hours).
- **Theory of atmospheric visibility** by day and night, atmospheric optics (basic ideas). Effect of air pollution on visibility. Meteorological Optical Range (MOR); concept and application.(5 hours).
- **Cloud Physics** – initial stage of condensation; curvature effect; condensation nuclei; growth of cloud droplets by diffusion and by coalescence; collection efficiency; freezing nuclei; formation of ice and snow; Precipitation, rain making experiments, weather modification. Theories of generation of hail in thunderstorms. (8 hours).
- **Fair weather electrical field of the atmosphere**, electrical conductivity and ionization in the atmosphere, thunderstorm electrification, lightning discharge. (7 hours).
- **Air pollution**: Basic ideas and concept of air pollution; sources, causes, Impact of air pollution on health, acid rain meteorological factors affecting air pollution, wind rose diagram.(7 hours).
- **Ozone**; Ozone hole, CFC and awareness of Montreal protocol.Radar Meteorology :- Doppler Radar; basic principal and application.(6 hours).

Practical (Total Hour = 20)

- Study of stability conditions for given sounding data.(6 hours).
- Determining the perceptible water vapour amount.(4 hours).
- Computation of various stability Indices for prediction of thunderstorms (10 hours)

Section – B: Physical Oceanography

(Total hours =30)

- Geographical data relating to oceans and their importance (2 hours).
- Physical properties of sea water; T – S diagram (3 hours)
- Absorption of solar radiation (2 hours)
- Extinction coefficient in the sea (2 hours)

- Air sea interaction; surface wind and current, waves, upwelling, Ekman current (4 hours)
- Formation of subtropical anticyclones, ENSO & Monsoon brief ideas.(4 hours)
- Heat budget of the oceans (4 hours)
- observation and collections at sea; water sampling devices, temperature measurement (4 hours)
- Marine pollution to be taught; its sources, causes and its impact on marine environment briefly. (2 hours).
- Global warming and sea level rise and its importance for coastal areas, small island and marine ecosystem, in brief. (2 hours)
- Tides and Tidal energy (1 hour)

Paper- 4 : Synoptic Meteorology Theory & Aviation

Synoptic Meteorology (Theory)

1. Air masses and fronts; Production and transformation of air masses; conservational properties, the exchange properties and formation of air masses; air masses sources in winter and summer; Classification of air masses; types of transformation
2. Fronts and frontogenesis – surfaces of discontinuity, typical structure of fronts, slope of frontal surfaces, classification of fronts, kinematic and dynamic boundary conditions, frontogenesis and frontolisis, frontogenetical fields; Principal frontal zones.
3. The structure of extratropical cyclones and anticyclones – cyclone model; life cycle of cyclones; Fronts and weather; Occlusions; thermal structure of cyclones; cyclone family; theory of cyclone development; a forecasting guides; example of cyclone development; anticyclones; cut off cyclones and anticyclones; Blocking; index cycle.
4. Tropical Cyclones – life cycle; surface and upper air structure; pressure; temperature, wind, humidity and cloud fields; Energy aspects, formation of tropical storms, theories of formation, intensification and movement of tropical storms
5. The Jet –streams – polar front jet stream – subtropical jet stream, polar night jet stream, Easterly jet stream, Characteristics features of the various Jet Streams, theories of formation, weather development, cloud and clear air turbulence.
6. Winter season – Western disturbances, cold waves, fog and jet streams, disturbance from the east, fronts in the Indian region

7 Hot weather season – Norwesters; Dust storms and dust raising winds, thunderstorms, hail storms, tornadoes, heat waves, Jet streams, cyclonic depression and storms in the Indian seas

8 The southwest monsoon season: - Monsoon onset, strong monsoon, weak monsoon, revival of the monsoon, monsoon depressions, heavy rainfall, easterly jet stream, influence of extra tropical systems, Chinese weather systems, effect of typhoons and other systems from the east, withdrawal of the monsoon

9 The northeast monsoon season – strong and weak northeast monsoon, depressions and storms in the Indian seas, forecasting their information, movement, recurvature, jet streams.

10 Double equatorial troughs – depiction of synoptic features in the equatorial regions in different seasons for the year.

- **Aviation:**
- Organization of the IMD; World Meteorological Organization; and International Civil Aviation Organization.
- Aviation Procedures: Meteorological organization for aviation in India; Altimeter setting procedures; briefing and documentation, procedures; Meteorological services provided to airlines; Area Meteorological Watch; Aviation Climatological Publications; Meteorological requirements of turbine engine aircraft; Elements of air navigation and pressure pattern flying.
- Decoding of flight, root and aerodrome forecasts on relevant forms.
- Issue of routine aviation forecasts such as area forecast, Route forecast, Flight forecast, Terminal forecast, Airfield warnings etc.
    - Meteorological broadcasts for aeronautical purposes. Air traffic services; altimeter setting procedures; Metrological Organization for Aviation in India:
    - Display in Meteorological Offices; Aviation Climatological publications. Different types of aircraft (Pistonprop: turboprop; Jet etc.) and their meteorological requirements; Publications of Civil Aviation Department. Elements of Air Navigation
    - Effects of weather on aircraft flights; Air accidents and their Investigations VVIP/VIP flights.

- ❖ Study of analyzed weather central charts for issue of TAF, Trend, Flight / Route forecasts, SIGMET etc.
- ❖ Preparation of Significant weather charts
- ❖ Familiarization with numerical model output products and their use
- ❖ Writing of aviation forecasts such as area forecast, Route forecast, Flight forecast, Terminal forecast, Airfield warnings etc.

- Preparation of flight forecast, two for each season. Preparation of TREND forecast for deterioration and improvement in respect of each element. Formats and elements in different types of forecasts/warning (both aviation and non-aviation), Decoding of flight, route, and aerodrome forecast on relevant forms.

Practical:

Synoptic Meteorology

1. Analysis and issue of inference and forecasts for a chart sequence for tropical cyclone, Satellite and RADAR pictures should also be used along with the chart sequence.
2. Analysis and issue of inference and forecasts for a chart sequence for a monsoon depression
3. Analysis and issue of inference and forecasts of a widespread thunderstorm activity case
4. Analysis and issue of inference and forecasts for a chart sequence in a western disturbance case
5. Analysis and issue of inference and forecasts in an onset and advance of monsoon case
6. Analysis of extended charts – surface and upper air of January and July cases and their 24 hours prognosis

Aviation Meteorology

1. Study of analyzed weather central charts for issue of TAF, Trend, Flight / Route forecasts, SIGMET etc.
2. Preparation of Significant weather charts
3. Familiarization with numerical model output products and their use
4. Preparation of significant weather charts
5. Familiarization with Numerical Model output products and their use in Aviation.

Paper-5 : Climate Science & Statistics

Theory (Total: 110 hours)

Part-A: Climate Science (Total Hour = 60)

Synoptic Climatology (5 hours)

- Extra-tropical – Air mass climatology - January and July; Geographical distribution of Fronts, Frontal zones - Extra-tropical cyclones – frequency, regions of blocking and cyclogenesis.
- **Climates of other regions in brief** (3 hours)
  Asia, Africa, North America, South America, Europe, Australia, Arctic and Antarctic.
- Angular momentum cycle (3 hours)
- Water Cycle (4 hours)
- Energetics and the Ocean-Atmosphere Heat Engine (6 hours)
- Variability in the climate system (13hours)
  - Interannual and interdecadal variability (1 hours)
  - Monsoon (southwest and northeast) Variability, diurnal, intraseasonal, Interannual, decadal, long term trends, Teleconnection patterns (5 hours)
  - El Nino/ Southern Oscillation, Climatology, Dynamics and prediction, links with global climate (5 hours)
  - North Atlantic Oscillation, North Pacific Oscillations, NH Teleconnection Patterns (1hours)
  - Indian Ocean Dipole, statistics, dynamics and links with global climate (1hours)
- Climate modeling and prediction : Mathematical simulation of climate, model simulations of mean climate, Fundamentals and methods of long range forecasting, IMD's long range forecast models, Dynamical models for long range forecasts, Skill of long range forecasts (7 hours)
- Science of Climate Change : Basics of Climate Change (science), Climate Feedbacks (water vapour, cloud, oceans, snow and ice), Observed climate change over India and globe, Future climate projections, IPCC report results (8 hours)

- Basic ideas of Agricultural meteorology including energy and water budget of crops, and crop yield relationship with weather elements, crop weather calendar (3hours)
- Micrometeorology - Definition and generation of microclimates, elements of microclimatology (2hours)
- Basic ideas on Bioclimatology and Applied Climatology (2 hours)
- Paleo-climatalogy (4 hours)

Part-B: Statistics
Theory (Total hours = 20)

- Elements of sampling, tests of significance; Null Hypothesis; Students 't' test; contingency tables Chi-square test
- Time series and harmonic analysis
- Analysis of variance ANOVA/ MANOVA)
- Multivariate Regression Analysis
- Cluster and Factor Analysis

Practical (Total Hour = 30)

- Testing of null hypothesis
- Time series analysis
- Trend analysis
- Cross correlation & Auto correlation with different lag
- Harmonic analysis
- Multivariate regression analysis

Paper -6: Hydrometeorology (Total Hours = 20)

- Network design for a river basin (1 hour)
- Estimation of average rainfall in a basin (2 hours)
- QPF(1 HOUR)
- Hydrological cycle (1 hour)
- Estimation of Design Storm (2 hours)
- Hydro met Disasters , Flood and Drought (4 hours)
- Rainfall Runoff Relation (3 hours)
- Mountain Meteorology (2 hours)

- Snow Hydrology (2 hours)
- Developments in Water Resources (2 hours)

Paper-7 Satellite Meteorology

Theory: Total Hours = 30

- Remote Sensing, Principles of Remote Sensing, Application in Meteorology, Introduction to Satellite Meteorology including Orbital Mechanics. (4 Hours).

- Meteorological Satellites, Polar Orbiting, Geostationary satellites, Current and future meteorological satellites of the world. Payloads on Meteorological Satellites, NOAA, INSAT -3D, Metop. (3 Hours).

- Processing of data from Imagers, INSAT Meteorological Data Processing System (IMDPS). Generation of images in various channels. Retrievals of meteorological products from the imager data including water vapor. Atmospheric motion vectors, Sea Surface Temperature and Upper Troposphere Humidity (UTH), Outgoing Long wave Radiation (OLR), Quantitative Precipitation Estimates (QPE), Rainfall, Fog, Minor atmospheric constituents/aerosols/ Fire /smoke, Enhancement techniques, Gray scales, Pseudo Color Images. (6 Hours).

- Principles of Sounding, Processing of data from Infrared and Microwave Sounders. Retrieval of products from sounder, Vertical temperature, humidity and ozone profiles. (5 Hours).

- Interpretation of Satellite images of various channels and identification of typical clouds and weather systems from cloud imageries, use of various satellite derived products, satellite Bulletin and its interpretation. Tropical cyclone, its identification and grading using Dvorak's technique. (6 Hours).

- Automatic Weather Stations (AWS), full technical details Digital Cyclone Warning Dissemination System (DCWDS), Digital Meteorological Data Dissemination (DMDD). (3 Hours).

- Hardware details of INSAT Meteorological Data Processing System (IMDPS) including Earth Station. GPS technique for Integrated Precipitable Water Vapor (IPWV) measurement. (3 Hours)

Practical :Total Hours =25

- Study of typical satellite pictures from both geostationary and polar orbiting satellites. Identification of different types of clouds and weather systems from Satellite images. (8 Hours).

- Issue of Satellite bulletins. (2 Hours).

- Assessment of T-number of Cyclone from satellite images using Dvorak's technique (form to be filled up by the trainees). (8 Hours).

- Practical Exercises on Use of Satellite derived products for weather analysis and forecasting, generation of products and posting on website. (7Hours)

Paper -8 Radar Meteorology
Total Hours = 20

Radar principles.

Doppler Radar, Wind profiler, MST Radar, LIDARS

Scattering of microwaves by precipitation / precipitating particles. Scattering by a sphere, Scattering by rain and ice crystals.

Minimum detectable power, receiver noise, radar equation for a point target, part played by various parameters in the radar equation. Radar equation for an extended target. Practical importance of radar set constants and the radar cross section. Effect of wave-length, wave lengths commonly used. Types of scans used in weather radar, their merits.

Classification of radar echoes.

Convective and stratiform types, bright band echo from lightening, tornadoes, squall lines.

Study of severe storms and cyclones, quantitative measurement of ZR & M and their co-relation. Measurement of rate and amount of precipitation, effect of circular polarization, use of circular polarization in weather radar research, non-precipitating / precipitation echoes, super-refraction, limitations of weather radar.

Elementary ideas of cloud physics. Drop size distribution in various types of rain. Relation between drop size, terminal velocity, rate of rain fall and radar echo intensity. Study of Disdrometer and its application.

Doppler radar

Doppler radar principles and its limitations. Doppler principle of velocity measurement, unambiguous velocity and range. Doppler dilemma. Spectrum width. Introduction to DWR (Physical visualisation/inspection), RAINBOW workstation.

Principles of dual polarized doppler radar. Advantages over conventional doppler radar techniques.

Doppler radar base products and derived products.

1. Introduction to reflectivity products and their utilization. PPI, RHI, CAPPI, PCAPPI, MAX, VIL, HHW, EBASE, ETOP, VCUT.

2. Hydrological products SRI, VIL, PAC, PRT.

3. Velocity products, PPI_V, VVP-2, UWT_2, Max_V and their utility in weather forecasting. Horizontal shear, vertical shear, AZ shear, EL shear.

4. Spectrum width products.

Visit to Doppler weather radar installation.
Products generation using raw data of a doppler radar.

Application of doppler radar in weather forecasting.
Nowcasting techniques using DWR.
Use of DWR products in ACWC forecasting, aviation safety.
Experience of some recorded weather events using DWR.

Paper -9 Computer Programming and applications

(Total : 40 hours)

Computer Programming / Applications (including practicals)

- Fortran-77/90 Programming
- Introduction to Numerical Analysis - Successive approximations – Taylor series - Propagation of Errors - Solution of Algebraic / Transcendental equations (Regular-Falsi. Newton-Raphson methods etc.) - Interpolation (Newton’s Lagrange's schemes) - Numerical integration (Simpson's. Weddle's formulae, etc.)
- Matrices - Solution of Simultaneous Equations (Matrix Inversion. Iterative and Relaxation methods, etc.) - Numerical solution of ordinary differential equations (Euler, Predictor – Corrector, Runge Kutta methods) - Numerical solution of partial differential equations (Iterative and Relaxation methods) - Finite differencing schemes - Computational stability / instability in meteorological problems.
- Numerical Analysis: Practicals, Fortran
- Statistical Package (SPSS /SYSTAT/ R Software) for advanced statistical applications

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