National Meteorological Agency of Ethiopia (NMA)

Meteorological Education and Training Directorate

Curriculum

for

General Meteorology Post Graduate Diploma (PGD) Training Course

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Phase I

DYNAMICAL METEOROLOGY
Theory (Total Hours= 110)

Mathematical Preliminaries (8 hours)

- Introduction to vector differential opertor $\nabla\rho$, divergence of a vector, gradientof a scalar, curl of a vector and their properties. Stoke's theorem & Gaussdivergence theorem (No derivation, statement and interpretation only).
- Ordinary & Partial differential equations with examples, order & degree of differential equation, General form of a 2_{nd} order partial differential equation, Conditions for parabolic, elliptic and hyperbolic equation, Types of partial differential equation- linear and non-linear, simple example of linear &nonlinear differential equation (ordinary & partial both). Laplacian equation, Poisson equation, Helmholtz's equation. Harmonic function, cylindrical harmonic and spherical harmonic, examples. Basic concepts of initial & boundary value problem (IVP & BVP). Well posed and ill posed problem.

Introduction (1 hour)

- Scopes of Dynamic Meteorology. Concept of continuum. Basic conservation laws governing the atmospheric motion.

Equation of Motion (12 hours)

- Frame of reference: Time rate of change of a vector in an inertial and in a rotating frame of reference & their relation.
- Vector equation of motion in an inertial & non-inertial frame of reference.
- Forces, their categorization and property.
- Local change of a field, advection of a field variable, local (Eulerian) derivative & total (Lagrangian) derivative of a field variable.
- Introduction to local tangential co-ordinate. Equation of motion in local tangential co-ordinate.
- Introduction to spherical polar co-ordinate. Equation of motion in spherical polar co-ordinate. Curvature terms.

Scale Analysis (8 hours)

- Concept of order of magnitude. Dimensional analysis of different field variable

- Definition of scale of a weather system. Scale analysis of momentum equation for mid-latitude/tropical synoptic scale / mesoscale system.

- **Geostrophic Approximation (5 hours)**
- Definition and properties of geostrophic wind. Vectorial expression for geostrophic wind. Schematic diagram to show how geostrophic balance is achieved.

- Rossby number. Use of Rossby number as a tool to test the validity of geostrophic approximation
- Ageostrophic wind, its definition and property. Vectorial expression for ageostrophic wind. Its relation with acceleration.

Hydrostatic Approximation (6 hours)

- Simplification of vertical momentum equation for mid latitude synoptic scale system following scale analysis leading to hydrostatic approximation. Discussion on the validity of this approximation.
- Using above approximation, definition of atmospheric pressure at any point.
- Definition of geopotential and geopotential height of a point andcorresponding units.
- Hypsometric equation and its use in computing thickness of a layer of atmosphere.

Kinematics of Wind Field (3 hours)

- Stream lines and trajectory, their definition and differential equation, streamfunction, Blatons equation.
- Resolution of horizontal wind into pure translation, divergence, rotation, deformation. Invariance of divergence and vorticity under co-ordinate transformation. Equation and patterns of streamline for pure translation, divergence, rotation, deformation

Natural Coordinate and balanced flow (7 hours)

- Introduction to natural co-ordinate. Horizontal equation of motion in natural co-ordinate. Gradient balance and gradient wind. Physically possible different gradient flow. Examples. Sub & super – geostrophic flow. Special cases of gradient balance: - geostrophic balance, inertial balance, and cyclostrophic balance. Examples.

Vertical Variation of Wind (9 hours)

- Concept of vertical wind shear. Schematic explanation for horizontal temperature gradient leading to vertical shear of geostrophic wind.
- Different vertical co-ordintes, pressure (p), potential temperature (θ) etc. Pressure gradient force in p & θ co-ordinates.Horizontal equation of motion with p as vertical co-ordinate.
- Thermal wind: Definition, Thermal wind equation and properties of thermal wind.
- Application of the concept of thermal wind in explaining Sub tropical westerly jet, Tropical easterly jet, intensification of cold (warm) core low (high) with height, tilt of axis of low (high) towards cold (warm), cold and warm advection associated with veering/backing of geostrophic wind.
- Analysis of the shear hodograph and stability conditions.
- Concept of barotropic and baroclinic atmosphere.

Continuity Equation and Convergence (9 hours)

- Equation of continuity with different vertical co-ordinates: Importance of 'p' as a vertical co-ordinate. Application of continuity equation: Dines compensation principle. Concept & importance of level of non-divergence (LND). Kinematical method of computing ω. Scale analysis of continuity equation. Concepts of incompressible fluid, homogeneous fluid and isotropic fluid.
- Moisture continuity equation.
- Divergence of an arbitrary vector field. Physical concept. 2-D (or 3-D) divergence as a fractional rate of change of area (or volume). Horizontal divergence in natural co-ordinate system & in other (Spherical polar orcylindrical) co-ordinate system.

Kinematics of Pressure Field (4 hours)

- Mathematical definition of center of low, high & COL. Mathematical equation of trough & ridge. Expression for the velocity of an isobaric pattern. Mathematical equation for the slope of axis of low/high.

Circulation and Vorticity (16 bours)

- Definition and mathematical expression of circulation. Circulation theorems, their detailed derivation, detail discussions on their application aspects. Detailed discussions about solenoidal vector.
- Concept of vorticity of an arbitrary vector field. Definition of atmospheric vorticity along with its mathematical expression. Physical meaning of Curl of any vector. Components of vorticity vector. Relation between circulation and vorticity.
- Vorticity for solid body rotation. Concept of planetary vorticity. Relative vorticity in natural co-ordinate. Explanation of curvature and shear vorticity with specific examples. Concept of potential vorticity.
- Vorticity equation in different co-ordinates. Physical interpretations for individual terms. Scale analysis of vorticity equation. Application of vorticity equation. Conservation laws for Barotropic (Rossby) potential vorcity & Baroclinic (Ertel) potential vorcity and their application.

Theoretical Aspects of NWP (10 hours)

- History of NWP, with special reference to Indian context, basics of NWP, governing Equation, Spatial and temporal scales of atmospheric motion. Scale analysis of governing equations and especially for tropical atmospheric motions.
- Introduction to different vertical coordinate systems (Sigma, Eta, Theta coordinates, Log pressure, Terrain following co-ordinates Hybrid coordinate (+P) etc Map factor (m)
- Hierarchy of NWP models

Perturbation Theory (1 hour)

- Why perturbation method has been proposed? Hypothesis in Perturbation method. To show that perturbation method can remove non- linearity from governing equation.

Pressure Tendency and Mechanism of Pressure Change (3 hours)

- Pressure tendency equation: Its derivation and physical interpretation, in detail, of each term, representing different mechanisms of pressure change. Importance of net divergence in an atmospheric column. Different isobaric patterns and their movement

Basics of Planetary Boundary Layer (8 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. A general idea about depth of PBL and its diurnal and seasonal variation at a place.
- Description of different sub layers in PBL.
- Boussinesq approximation and its physical interpretation. Governing equations in the PBL using Boussinesq approximation.
- Concepts of Reynolds average. It's difference from the mean part in perturbation theory. Precaution to be taken while Reynold averaging.
- Concepts of eddy flux, eddy flux divergence in detail and their importance.
- Derivations of governing equations for mean motion in PBL.

Dynamic Meteorology (Practical) Total hour =20

- Computation of divergence & vorticity using curvature method (6 Hours)
- Computation of geostrophic wind,vorticity (4 Hours)
- Computation of thermal wind and thermal advection (4 hours)
- Computation of vertical velocity using kinematic method (6 hours)

Physical & Environmental Meteorology a) Physical Meteorology (Theory)

(Total hours = 75)

- The Gas Laws, Moisture in the atmosphere, Moisture parameters; Latent heat; Molecular weight of dry air, virtual temperature, work, energy and specific heats of gas; First law of thermodynamics, enthalpy; adiabatic process, potential temperature (10 hours)
- Second law of thermodynamics: enthalpy, Clausius – Clapeyron equation; Thermodynamic diagrams; Normand's theorem; Saturated adiabatic and pseudo-adiabatic processes; Equivalent potential temperature, Dry and Moist static energy, Stability and instability by parcel and slice methods, conditional, convective and latent instabilities, convection and entrainment (10 hours)
- Hydrostatic equation: Geopotential, thickness and heights of constant pressure surfaces, Homogeneous, isothermal and constant lapse rate atmospheres; Standard atmospheres; Barometric altimetry. Precipitable water vapor: Rate of precipitation (10 hours)
- Electromagnetic spectrum: quantitative description of radiation; Kirchoff's Law, Planck's Law, Stefan-Boltzman's Law, Wien's displacement law, and Beer's Law; Scattering, Rayleigh, Mie and non dimensional scattering, absorption, and emission of radiation; Schwarzchild's equation, Refractive index variations discontinuities, refractivity turbulence (10 hours)
- Solar radiation, direct and diffuse, and global radiation and their measurements; Solar constant and its measurements; Albedo of Earth, Details of aerosol scattering and their

impact on direct and diffuse radiation, Atmospheric Aerosols turbidity and its impact of solar radiation. (4 hours)

- Terrestrial radiation: Absorption of terrestrial radiation by atmosphere; Greenhouse effect, Simpson and Elsasser's diagram; Radiative cooling of the atmosphere; Heat balance of the earth and atmosphere, Anthropogenic green house gases, green house effect, its role and examples from atmosphere of Venus, "Runaway green house effect" Sources of green house gases, linked with anthropogenic activities. (6 hours)
- Refraction, scattering and diffraction of solar, IR and radio waves: Impact of dust and turbidity (5 hours)

- Theory of Atmospheric visibility; visibility meters; Measurement of visibility during day and night. Impact of hydrometeors and Lithometeors on visibility, impact of air pollution and photochemical processes in the Atmospheric boundary layer on visibility **(10 hours)**
- Basics of Cloud Physics **(5 hours)**
- Radar equation (with derivation): RADAR depiction of various phenomenon; RADAR reports; Interpretation of RADAR echoes; Anomalous propagation, radar estimation of precipitation, identification of convective and startiform precipitation, melting band. (5 hours)

b) Physical Meteorology Practicals Total Hours = 30

- Analysis of Radiosonde data using tephigrams: Computation of virtual temperature & other thermodynamic parameters. (10 Hours)
- Advanced analysis of radiosonde data for weather predictions: Study of stability conditions for given sounding data. Computation of the precipitible water vapour amount.
- Computation of various stability Indices for prediction of thunderstorms. Energy computations like CAPE. (15 Hours).
- Computation of optical depth for use in radiation balance Studies. (5 hours).

c) Environmental and Applied Meteorology (Total Hours = 35)

- Air pollution: Basic ideas about Air pollution; Air quality and anthropogenic activities, Sources of air pollution and important pollutants – gaseous and particulate matter. (15 hours)
- Basic ideas of Agricultural meteorology including energy and water budget of crops, and crop yield relationship with weather elements, crop weather calendar (5 hours)
- Micrometeorology - Definition and generation of microclimates, elements of microclimatology (2hours)
- Basic ideas on Bioclimatology and Applied Climatology (3 hours)

SYNOPTIC AND AVIATION METEOROLOGY

a) SYNOPTIC METEOROLOGY (THEORY) (Total Hours = 80 hours)

- • Scales of weather systems (Meso, Synoptic and Planetary scales) - Network ofobservatories - Surface, upper air and special observations (satellite, radar,aircraft etc.) - Map projections - Representation and analysis of fields ofmeteorological elements on synoptic charts - Vertical time/cross sections and their analysis. **(6 hours)**

- • Wind and pressure analysis - Isobars on level surface and contours on constant pressure surface - Isotherms, thickness field - Geostrophic, gradient and thermal winds – Jet streams - Slope of pressure systems - Streamline and isotach analysis. **(6 hours)**
- • Ordinary thunderstorm - Severe thunderstorm (Squall-line, Multi-cell, Super-cell) – Role of CAPE, CINE and Vertical Wind Shear – Synoptic conditions favorable for thunderstorm - Norwesters, Dust-storm (Andhl), Hail storm, Tornado, Squall, Meso-high, Gust front , Down-burst and Micro-burst, **(10 hours)**
- • Tropical cyclone - Life cycle - Surface wind – Vertical structure in wind, temperature and angular momentum – Eye, Wall Cloud and Spiral cloud bands - Cyclone Genesis - Intensification of Cyclones – T-number - Movement of cyclones – Land fall - Interaction with nearby cyclones - Storm surge **(10hours)**
- Asian summer monsoon - Monsoon onset over Kerala - Active and Break monsoon phases – Monsoon trough – Cross equatorial Low Level Jetstream –Tibetan Anticyclone - Tropical Easterly Jetstream - Monsoon depression – Mid Tropospheric Cyclone - Offshore troughs/vortices – Influence of northern hemisphere mid-latitude westerly troughs - Monsoon and typhoons –Monsoon and orography - Intra-seasonal variability of Monsoon (15 and 40 day modes) - Withdrawal of monsoon – Monsoon and the Indian ocean - Summer monsoons of Africa and Australia **(12 hours)**
- Air masses and fronts – Fronto-genesis - Slope of frontal surface – Extra tropical cyclone and its structure and life cycle - Fronts and associated weather - Development of cyclones and anticyclones - Application of pressure tendency equation - Importance of vorticlty advection, temperature advection and diabatic heating **(8 hours)**
- Waves in middle latitude westerlies – Cut-off lows - Western Disturbance and Its structure and associated weather - Easterly wave and its structure and associated weather. **(6 hours)**
- Diurnal and local effects - Sea and land breezes - Slope and valley winds - Fog - Mountain wave - Clear Air Turbulence - Nowcasting - Meso-network - Use of radar and satellite in meso-scale analysis and forecasting. **(8 hours)**
- Nowcasting and Short range weather forecasting - Persistence, climatology and steering methods - Movement and development of synoptic scale systems - Analogue techniques - Prediction of individual weather elements – Prediction of visibility, surface and upper level winds, sea and swell - Interpretation and use of numerical model outputs in weather forecasting - Forecast verification techniques **(10 hours)**

b) SYNOPTIC METEOROLOGY (Practical) (Duration 30 hours)

General (12 hours, 2 hours each)

a) Weather Codes - Plotting of Charts- Chart reading
b) Surface chart analysis
c) Streamline and isotach analysis
d) Analysis of constant pressure charts
e) Analysis of thickness charts and thermal wind
f) Vertical time/cross section analysis

Analysis of tropical weather systems-surface and upper air (one case each)

a)*Tropical Cyclone*
b)Monsoon Depression
c)Active and Break Monsoon

d)Western Disturbance
e)North-east Monsoon/Easterly wave

(14 hours – 2 hours each, except for tropical cyclone and monsoon depression)

Analysis of frontal depression surface and upper air (2 hours)

Rossby waves and their prognosis (2 hours)

Sub tropical Jet stream (2 hours)

C) AVIATION METEOROLOGY THEORY (20 hours)

- Meteorological organization for aviation in Ethiopia; International Civil Aviation organization, Meteorological broadcasts for aeronautical purposes, Meteorological support for Air traffic services;
- Pilot briefing and flight documentation, Aviation weather forecast and warning services, Aviation weather codes and practices
- Elements of air navigation and pressure pattern flying, Altimeter setting procedures
- Effects of weather on aircraft flights: Aircraft accidents and their investigations.
- Different types of aircraft and their meteorological requirements
- Detection of Low Level Wind Shear, Microburst, Gust front, Turbulence (eddy dissipation rate) and Icing probability

D) Aviation Meteorology PRACTICAL (10 hours)

- Preparation of meteorological documentation for a flight
- Preparation of METAR, and TREND, TAF and SIGMET forecasts
- Interpretation of meteorological Radar data for aviation applications
- Interpretation of weather satellite data for use aviation applications
- Preparation of a Significant weather chart from numerical model forecast outputs received on internet

Climate Science & Statistics (Total hour 100)

A: Climate Science (65 hrs)

Basics (5 hours)

- Earth Sun relationship, Ecliptic and equatorial plane, Rotation and revolution of the earth Equinoxes, Solstices, Perihelion and Aphelion, Causes of seasons, Seasonal and latitudinal variation of insolation, Definition of climate , radiative forcing (2 hours)
- Climatic classification: Geographical, genetic classification etc. Koppen, Thornthwaite, Penman (3 hours)

Ethiopian Climatology (25 hours)

- Three seasons - (Pressure and wind distribution for mid- season months) (3 hours):
- Bega - Western disturbances, fog, thunderstorms, hail, cold waves, sub-tropical jet stream; Northeast monsoon - Interaction of low and high latitude disturbances, easterly waves (4 hours)
- Belg: Cyclonic storms, tracks, Frequency, western disturbances, fog, dust storms, thunderstorms, Norwesters, heat waves, pre-monsoon thunderstorms, dustraising winds, equatorial trough (4hours)
- Kiremt – Onset definition, criteria to declare monsoon onset, Monsoon active and break spells, Heavy rainfall and floods and droughts, break monsoon and droughts; monsoon trough, monsoon depression - frequency rainfall, Tropical Easterly Jet Stream, Westerly troughs and influence on monsoon, meridional circulation (10 hours).

- Post-Kiremt: Withdrawal of Kiremt ; cyclonic storms – Tracks, frequency, Long term trends, easterly waves, Northeast monsoon rainfall (4 hours)

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.
- Zonal index & Index cycle

Mean State of the global Atmosphere (15 hours)

- Mean temperature structure (global distribution and vertical structure)
- Mean Geopotential Height structure
- Mean Atmospheric Circulation (global distribution, vertical structure, variability of the circulation)
- Precipitation, evaporation, runoff and cloudiness

Mean State of the Oceans (10 hours)

- Mean and vertical temperature, density and salinity structure
- Mean Ocean circulation
- SST anomalies and Asian summer monsoon (interannual variability of date of monsoon onset and quantum of Indian summer monsoon rainfall) - Tropical Biennial Oscillation – Role of ocean in the Active – Break cycle of monsoon – Relation between tropical deep Convection and SST, El Nino
- Climate Change and sea level rise - Ocean in relation to long term changes in Monsoon, tropical cyclones and Climate , Land use changes and climate

Mean state of the cryosphere & Biosphere (5 hours)

- Role of the cryosphere in the climate, General features of the cryosphere, effect of biota on climate (deforestation)

B: Statistics for Meteorology (35 hrs)

- Introduction: statistical variables, continuous and discontinuous variables, sample and population; dispersion; mean, median, mode, quartile deviation, inter-quartile range, deciles and percentiles. (2 hours)
- Graphical representation of a distribution; histograms; frequency polygon; cumulative frequency distribution; ogive. (2 hours)
- Binomial distribution; Poisson's distribution; Gamma Distribution, normal (Gaussian) distribution with application to meteorology; moments of a distribution; skewness and kurtosis; mean deviation; standard error of the mean; probable error. (4 hours)
- Basics of probability analysis, Bayesian theorem (3 hours)
- Elements of sampling, tests of significance; Null Hypothesis; Contingency Table, Students 't' test; Chi-square test (8 hours)
- Linear correlation and regression analysis (8 hours)
- Time series and harmonic analysis (5 hours)
- Analysis of variance ANOVA/ MANOVA (3 hours)
- Statistical Methods – 5 weeks

Computer Programming and applications (50 hours)
(Theory- 30, Practical- 20)

• Introduction of Computers, Basic computer architecture, operating systems, high level languages (1 hour)

- Different data formats (ASCII, Binary, HDF, NetCDF, Conversions) (4 hours)
- Basics of Fortran-77/90 Programming (25 hours)
- Introduction to Fortran Programming: Concept of Compiler, object programme; source programme etc.
- constants, variables and expressions, logical operations, statement functions
- Input, output statement, blank field specification etc. - solved examples.
- Mathematical function built in with computer software - solved examples; Control statements, conditional and unconditional statement - If statement - GO TO statement - solved examples,
- Expressions and arithmetic statement of operations, use of parentheses etc.
- DO' statement - their necessity and application in details - general form of DO statement, CONTINUE statement, nested DO loops entrance and exit from DO loops, Uses of conditional statement - solved examples.
- Functions, subroutine and sub-programme, uses of common and equivalence block data.

Practical

- EXCEL (2 hours)
- Grads (10 hours)
- Statistical Package (SPSS /SYSTAT) (8 hours)

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Phase II

Stream: General Meteorology

Geophysical fluid dynamics (Total Hours= 40)

- **Quasi-geostrophic theory (7 Hours) :** Quasi-geostrophic approximations, Betaplane approximation. Governing equations in isobaric co-ordinates using quasigeostrophic approximation. Quasi-geostrophic vorticity equation: Thermodynamic energy equation, Geopotential tendendency (χ) equation: Conservation of quasigeostrophic potential vorticity. Diagnostic ω (omega) equation (With and without diabatic heating term)

- **Advanced Planetary boundary layer (7 hours):** K-Theory/ Flux-gradient theory/ Similarity theory. Its limitation. Mixing length theory. Derivation of logarithmic vertical profile of horizontal wind in viscous sub layer using similarity theory.
- Concept of roughness length and Von-Karman constant. Ekmann layer: Derivation of vertical profile of mean horizontal wind in atmospheric/ oceanic Ekmann layer.
- Derivation of depth of Ekmann layer. Concept of Ekmann layer pumping. Secondary circulation. Spin down. Derivation of the 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. The turbulent kinetic energy equation.. Physical interpretation, in detail, of the Buoyancy production or loss (BPL) term and mechanical production (MP) term in association with convective and mechanical turbulence, concept of Flux Richardson number.
- **Atmospheric waves (8 hours):** Basic concepts: Wave number, Frequency, Phase speed and group velocity. Sound wave, Rossby wave, Kelvin wave, Gravity wave (external, internal and inertia), Mixed Rossby Gravity wave- dispersion relation and physical interpretation. Eliassen-Palm flux and its conservation law.
- **Hydrodynamic instability (8 hours):** General definition of Hydrodynamic instability. Classification of Hydrodynamic instabilities. Static instability: Derivation of the criterion for Brunt-Vaisalla instability. Dynamic instabilities: Inertial instability, barotropic instability and baroclinic instability. Derivation of the criteria for above instabilities. Energetics and mechanism of above instabilities.
- **Dynamical aspects of general circulation (10 hours):** Energetics aspects of General circulation: Definition of Atmospheric energetics. Different form of atmospheric energies, viz., internal energy, potential energy and kinetic energy. Derivation of global internal energy, global potential energy and global kinetic energy equation.
- Detailed physical interpretations of generation of potential energy, internal energy and its conversion into kinetic energy. Detailed 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 sourceregion 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), derivation of its expression. Concept of available potential energy (APE) and the derivation of the expression for it.

- Qualitative comparison of APE in a region based on day-to-day charts. Concept ofzonal APE, KE, PE and eddy APE, KE, PE.

Numerical Weather Prediction (Theory)

Total Hour = 120

- **Data Assimilation (40 hours):** Assimilation of available GTS data:Allconventional/non-conventional/Remote Sensing/Doppler Radar Data. Qualitycontrol. Data assimilation: Objective analysis & Initialization. Differentobjective analysis schemes, function fitting, Cressman techniques, OI scheme(Optimum interpolation), Univariate and multivariate, one, two and multipleobservation problems, algorithms. Statistical spectral interpolation, Initialization: Static Dynamic, Normal mode, Dynamic normal mode &Physical, Nudging, Synthetic data generation/vortex initialization. Three/ Fourdimensional data assimilation, 3D & 4 D variational data assimilation (discreteand continuous: both synoptic and asynoptic). Procedure for Global Data Assimilation (GDAS) and mesoscale data assimilation. sensitivity analysis invariational assimilation, estimation theory, Kalman filtering. Atmospheric data assimilation: development of a variational assimilation scheme, applications with shallow water model and its adjoint model, Oceanic dataassimilation: data assimialtion at mesoscale, assimilation of altimetry data.

- **Numerical Methods (10 hours):** Different methods for solving model equations: Finite difference method & Spectral method. Initial and boundary conditions. Finite difference method: space & time differencing technique, Truncation error. Implicit & semi implicit schemes, Numerical stability analysis-CFL criteria. Spectral method: Spectral representation, spectral coefficient, Triangular and Rhomboidal truncation, Spectral transform , aliasing. Relaxation (Sequential & successive relaxation) method for solving Poisson's equation. Discretisation techniques used for basic governing equations, Discretisation of horizontal and vertical mixing processes.

- **Parameterization of physical processes (35 hours):** Dry and moist adiabatic adjustment, saturation point (LCL).Cumulus parameterization.Surface forcing, shallow and deep convection, verification methods for convection schemes. Parameterization of PBL. Radiation. Principle of
- radiative transfer. Gravity wave drag and its parameterization Biosphere and Land surface processes. Parameterisation of air-sea interaction processes.

- **Dynamical models (10 hours):** Non-divergent barotropic model: Derivation of governing equation for geopotential tendency and algorithm for prediction of geopotential using this model. Equivalent Barotropic model: Derivation of the governing equation. Determination of Equivalent level.Two-layer baroclinic model: Derivation of

governing equation, algorithm for predictionof mean and thermal vorticity. Primitive equation model in σ- coordinate.

- **Operational Numerical Models (15 hours**): Mesoscale model (WRF/MM5/ARPS). Regional Model (LAM). Global Model (mainly Medium Range Forecasting). Non-Hydrostatic Model. Ensemble model. Super ensemble model.

- **NWP Products (10 hours):** Different products: Direct and Derived, Post processing of model output: Local, Regional, Global products, Availability of NWP products on internet. Model output verification: Forecast skills, Forecast errors, Systematic errors. Model output applications: Comfort Index, Down scaling of model output like location specific forecast, Statistical interpretation (model output statistic (MOS) & perfect prognostic method (PPM), Processes Modeling: Basic concepts on Storm Surge, Ocean State Modeling, Crop Weather Model, Pollution Model, Aviation Hazard Modeling, Hydrological Cycles.

Numerical Weather Prediction (Practical)

Total Hour = 60

- Numerical method of solving Poisson equation. Computation of stream function (Ψ) and velocity potential (χ) from model output wind data. (2 hours)

- Subjective analysis, objective analysis, spatial analysis, function fitting, Statistical Interpolation. Initialization of numerical models. Development of an operational variational assimilation scheme, applications in numerical weather prediction (shallow water model).Assimilation of
- altimetry data, use of adjoint in the oceanic component of coupled models, an ocean assimilation system. (24 hours)

- Estimation of apparent heat source and moisture sink in deep cumulus parameterization. Moist adiabatic processes and criteria for convective instability. Column model for simple convection schemes. Estimation of long wave-radiation. Estimation of short-wave radiation flux and cloud radiation interaction. Surface fluxes computation over land and ocean.1-D PBL model for parameterization of boundary layer. Simple land surface processes parameterization (20 hours).

- Graphical packages for illustration of NWP products. One dimension column model: Physical processes, Boundary layer, Heat and moisture sources, RS/RW. Simple programmes on Cressman technique. WRF model. (14 hours)

Advanced Physical Meteorology a) Theory (Total hours = 50)

- Atmospheric Electricity: Basic concepts regarding fair weather field (Mathematical derivations) and its maintenance and thunderstorm electricity (excluding detailed mathematical derivations, instrumental measurements etc) (5 hours)

- Upper Atmosphere and Ozone: Different techniques of exploration of upper atmosphere; thermal structure of tropopause stratosphere, mesosphere and thermosphere and their physical explanation, QBO and stratospheric warming; Formation and destruction of ozone temporal and spatial variations; measurements of ozone; Umkher effect. Ozone hole, CFC and related concepts.(10 hours)
- Cloud Physics and Weather Modification : Atmospheric aerosols and condensation nuclei, initial stage of condensation, curvature and solute effects, growth of cloud droplets by diffusion and by collision and coalescence; collection efficiency; ice nuclei, mechanism of growth of precipitation from clouds in tropics and extra-tropics, rain making experiments, fog dissipation, hail suppression, weather modification:
- Thunderstorm and hail. Simple cloud models. Cloud Physics measurements: Surface, airborne and satellite (like MODIS) (20 hours)

- Advanced concept of Air pollution; Role of meteorological parameters in dispersal of pollutants in the boundary layer. Wind roses, acid rain, smog and impact of air pollution on human health and structures. Boundary layer structure in urban areas. Indoor pollution.

b) Practicals (10 hours)

- Ventilation co-efficient.
- Study of surface wind data at a station.
- Computation for preparing windroses
- Graphical preparation of typical wind roses

Physical Oceanography & Ocean – Atmosphere Interaction (Total Hours = 50)

- Physical properties of sea water, temperature, salinity and density and theirspace – time variations - Bowen's ratio - Formation and classification of water masses.- T-S diagram -. Water masses of the ocean with special reference to Indian Ocean - Acoustical and optical characteristics of seawater**.(10 hours)**

- Atmospheric Boundary Layer over Ocean:- Variations of wind, temperature and moisture in the vertical – Air sea temperature differences – Wind stress and wind stress curl – Lapse rate -Temperature Inversions – Clouds **(6 hours)**

- Oceanic boundary layer : Sea surface temperature – Temperature variation in the vertical - Mixed layer – inversions - Thermocline – Balance of forces and transport in the Ekman layer - Upwelling / downwelling – Wind driven gyres and western boundary currents - Penetration of Solar Radiation – Turbidity – Fresh water flux - Salinity variation in the vertical - Barrier layer **(10 hours)**

- Energy balance at the ocean surface - : Evaporative flux, Sensible heat flux, Short wave, long wave and net radiation fluxes – ocean heat budget and transport – Mechanism of heat transport and partition of heat transport between the atmosphere and ocean **(10 hours)**

- Ocean waves and Swell, their generation and propagation, Tsunamis and Tides in the ocean – Oceanic Kelvin and Rossby waves (**8 hours)**
- Acquisition and communication of ocean data **(2 hours)**
- Marine Pollution and its impact on Coastal and Marine ecosystem **(2 hours)**
- Deep ocean circulation **(2 hours)**

MODEL OUTPUT DIAGNOSTICS THEORY (Total 80 hours)

- Nowcasting for the next few hours (for TREND forecast and SIGMET in aviation and for severe weather warning) – objective extrapolation techniques using radar and satellite data – use of mesoscale models for nowcasting weather and weather elements including visibility, ceiling etc and development and movement of mesoscale weather systems incorporating data from mesonets, Doppler radar, vertical soundings of the atmosphere and boundary layer measurements

- Very Short Range (up to 24 hours) forecasting using mesoscale models of genesis and intensification of meso-scale and synoptic scale weather systems and weather elements including rainfall and precipitation rate – their use in Terminal Area Forecast (aviation), Heavy Rainfall Warning, Severe Thunderstorm Warning (dust-storms, hail-storm, squalls) - storm surge models and storm surge prediction

- Short Range (1 to 3 days) forecasting using regional and global models of the movement and development of (a) waves in westerlies, (b) easterly waves, (c) jet streams, (d) monsoon depressions, (e) tropical cyclones, (f) other synoptic weather systems Numerical model downscaling techniques Model Output Statistics (MOS) and their use in Short Range (1 - 3 day) forecasting of weather elements

- Techniques for forecast verification – skill scores for circulation characteristics andmagnitude (intensity) of weather elements.

- Quantitative Precipitation Forecasting in the different seasons and in situations with (a) monsoon depressions (b) tropical cyclone (c) western disturbance (d) active monsoon with strong Low Level Jetstream etc

- Use of coupled Atmosphere – Ocean – Land models – use of SST and soil moisture anomalies to extend the length of the forecast period

- Forecast of Air Pollution parameters, construction of trajectory (forecast and hindcast) of contaminated air parcels

- Numerical Model Forecast outputs routinely available on the World Wide Web – Indian model output products available on the web – near real time atmospheric and oceanic data (analysed and in maps or as grid point data) routinely available on the web

- Human intervention in model output forecasts before dissemination as forecasts and warnings to users (massaging or forecaster intervention)

- Medium, Extended and Long range NWP forecast outputs – Ensemble, Super Ensemble and Multi Model Ensemble forecasts

- Numerical model forecast – verification techniques

MODEL OUTPUT DIAGNOSTICS (PRACTICALS) (30 hours)

- Exercises using reanalyzed global data and GrADS software
  - 850 and 200 hPa winds and jetstreams of Jan, Apr, Jul and Oct (JAJO)
  - Hadley circulation using mean meridional winds 0E-180E and 180E-0E (JAJO)
  - Walker circulation using mean zonal winds 05S-05N
  - 850 and 200 hPa Stream function of Jan-April-July-Oct (JAJ0)
  - 850 and 200 hPa Velocity Potential of JAJO
  - Vertical velocity at 500 hPa of JAJO
  - Vorticity/divergence at 850/700 hPa levels
- Construction of air parcel trajectory using 06 hourly reanalyzed / forecast wind data
- Exercises using grid point data sets and GrADS software
  - Sea Surface Temperature JAJO
  - GPI rainfall rate JAJO
  - Outgoing Longwave Radiation JAJO
  - Vertically Integrated Moisture (TMI) JAJO
  - QuickScat winds JAJO of tropics
- Extrapolation using Doppler Radar and Satellite Pixel data for Nowcasting weather (1 to 4 hour forecasting)
- Use of Meso-scale model outputs for short range prediction of weather elements (1 to 24 hour forecasting)
- Use of Regional and Global model outputs for 1 to 3 day forecasting of ○ Thunderstorm areas
  - Tropical cyclone tracks
  - Monsoon rain (area and intensity)
  - Rossby waves
  - Jet streams
  - Monsoon onset, Active – Break monsoon
  - Monsoon depressions
  - Western disturbance
- Use of Model Output Statistics in weather prediction for 1 to 3 days

Climate Science (Total: 65 hours)

- **Climates of other regions in brief** (3 hours)

- Asia, Africa, North America, South America, Europe, Australia, Arctic and Antarctic.
- Angular momentum cycle (5 hours)
- Water Cycle (5 hours) , Energetics and the Ocean-Atmosphere Heat Engine (5 hours)
- Variability in the climate system (15 hours)
  - Interannual and interdecadal variability
  - 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, Coupling of Ocean and Atmosphere in ENSO – Indian Ocean Dipole and

EQUINOO – Relation between ENSO.IOD-EQUINOO and Indian monsoon, Indian Ocean Dipole, statistics, dynamics and links

- with global climate.
  - North Atlantic Oscillation, North Pacific Oscillations, NH Teleconnection Patterns (1 hours).
- Climate modeling and prediction : Mathematical simulation of climate, model simulations of mean climate, Contended range prediction : Scope and different methods : Fundamentals and methods of long range forecasting, IMD's long range forecast models, Dynamical models for long range & extended range forecasts, Skill of long & extended range forecasts (15 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 (12 hours)

- Paleo-climatalogy (5 hours)

• Advanced Statistics (Total 30 hours)

- Multivariate Regression Analysis
- Principal Component Analysis/ Empirical Orthogonal Functions
- Cluster and Factor Analysis
- Canonical Correlation Analysis
- Discriminant Analysis, Log Linear Analysis
- Advanced Time series Analysis including Wavelet analysis
- Artificial Natural Network, weather Generators

• Computer Programming and applications (Total: 80 hours)

- **Computer Programming / Applications (including practicals)**

  Fortran-90 Programming and MATHLAB including numerical analysis
  - Additional features in Fortran 90 and features in C,C+ & C++ .(20 hours)
  - MATHLAB (5 hours)

- Numerical Analysis: Theory (20 hours)
- 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: (25 hrs) Practicals, Fortran and MATH LAB Statistical Package (SPSS /SYSTAT/ R Software) for advanced statistical applications (10 hours)

Hydrometeorology (Total: 20 hours)

- **Hydrological cycle, Estimation of Design Storm:** Characteristics of rainfall in India**, Rainfall Analysis, Estimation of Standard Project Storm, Probable maximum Precipitation, Return Period Analysis, Temporal Distribution of Rainfall, Practical (7 hours)**

- **Hydrometeorological Disasters** : Definition of flood, Types of floods (seasonal ,flash, urban) Causes of flood, **Various methods of Quantitative Precipitation Forecast (Synoptic Analog , Use of NWP outputs)**, Satellite applications ** (Quantitative Precipitation Estimate, Delineation of flood inundation from remote sensing satellite),
- Radar Applications ** related to rainfall estimates (intensity and total rainfall) , Droughts, Rainfall Monitoring (**4 Hours)**

- **Rainfall Runoff Relations**: Concept of Hydrograph, Rainfall Runoff Models (Lumped Model: Unit Hydrograph, Distributive model: MIKE 11) (**5 Hours)**

- **Snow Hydrology**: Variation in characteristics of Snow (size, shapes of snow crystals, density) with age, estimation of snow cover from satellite imageries**, **Snow Melt Model (degree day method), (2 Hours)**

- **Developments in Water Resources**: Water Demands of Future, Water Scarcity, River Linking, Rain Water Harvesting, Impact of Climate Change on Water Resources., any other current topic of importance.
  (**2 Hours**)
  Note: 1 The topics in **Bold letters** are to be **covered in details** while the introduction to concepts is expected for other topics.

SATELLITE and Radar METEOROLOGY a) Satellite Meteorology Theory (Total Hours = 35)

- Remote Sensing, Principles of Remote Sensing, Application in Meteorology, Introduction to Satellite Meteorology including Orbital Mechanics. (2 Hours).

- Meteorological Satellites, Polar Orbiting, Geostationary satellites, Current and future meteorological satellites of the world. Payloads on Meteorological Satellites, NOAA, INSAT - 3D, Metop. (2 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 motionvectors, 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. (4 Hours).

- Principles of Sounding, Processing of data from Infrared and Microwave Sounders. Retrieval of products from sounder, Vertical temperature, humidity and ozone profiles. (4 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. (4 Hours).

- Automatic Weather Stations (AWS), full technical details Digital Cyclone Warning Dissemination System (DCWDS), Digital Meteorological Data Dissemination (DMDD). (2 Hours).
- Hardware details of INSAT Meteorological Data Processing System (IMDPS) including Earth Station. GPS technique for Integrated Precipitable Water Vapor (IPWV) measurement. (2 Hours)

Practical (Total Hours =10)

- Study of typical satellite pictures from both geostationary and polar orbiting satellites. Identification of different types of clouds and weather systems from Satellite images. (3 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). (2 Hours).
- Practical Exercises on Use of Satellite derived products for weather analysis and forecasting, generation of products and posting on website. (3 Hours)

b) Radar Meteorology Theory (Total Hours = 25)

Radar principles

- Scattering of microwaves by precipitation / precipitating particles.Scattering by a sphere, scattering by rain and ice crystals. Rayleigh and Mie scattering – applicability at various operating frequencies.
- Attenuation by atmospheric gases, water vapour, rain, snow etc

- 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.
- Propagation of microwaves in the atmosphere, Effect of meteorological factors, effects on radar beam height, abnormal and subnormal propagation

- **Classification of radar echoes**
- Convective and stratiform types, bright band echo from lightening, tornadoes, squall lines. bright band, echo from lightning • Mesocyclones, gust front, downbust, vortex detection, non-precipitation
- and non-meteorological echoes. flare echo • Study of severe storms and cyclones, (Local severe storms (including various types,e.g. single-cell, multiple-cell super-cell, squall line, andhi) and tropical cyclones may be separately dealt with in detail). Quantitative measurements of ZR & M and their correlations.
- Non-precipitating / precipitation echoes, super-refraction, clutter and anomalous propagation, corrections to height and beam width errors, corrections for attenuation, limitations of weather radar.
- Doppler Radar, Wind profiler, MST Radar, LIDARS, RASS, SODAR and LIDARS

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 operation/inspection), RAINBOW workstation.

- Principles of dual polarized and mulitparametric radars Doppler radar. Advantages over conventional Doppler radar techniques.

Doppler radar base products and derived products

- Introduction to reflectivity products and their utilization. PPI, RHI, CAPPI, PCAPPI, MAX, VIL, HHW, EBASE, ETOP, VCUT.
- Hydrological products SRI, VIL, PAC, PRT.
- Velocity products, PPI_V, VVP-2, UWT_2, Max V and their utility in weather forecasting. Horizontal shear, vertical shear, AZ shear, EL shear.
- Spectrum width products.
- Radar Applications, Detection of turbulence, shear, gust front,microburst, mesocyclone and tornado, severe weather probability, icingprobability, hail probability and hail size, tropical cyclone centre determination and tracking, TC structure, intensity, rainfall distributionand other parameters, inputs for storm surge prediction
- Transmission of radar information, Networking of radars,

Practical (Total Hours = 10)

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 cyclone forecasting, aviation forecasts.
- Experience of some recorded weather events using DWR.