Course Content

S. No.	Course No	Course Name	Credits
		I-Semester	
1.	OA-401	Fundamentals of Earth System Science	2
2.	OA-402	Physics of the Atmosphere	4
3.	OA-403	Physics of the Ocean	4
4.	OA-404	Dynamics of the Atmosphere and Ocean	4
5.	OA-405	Mathematical Physics	3
6.	OA-406	Statistical and Numerical Analysis in Geosciences	3
7.	OA-407	Practical-1: Statistical and Numerical Computing	2
8.	OA-408	Practical-2: Weather Data Analysis and Forecasting	1
		Total credits	**23**
		II-Semester	
1.	OA-451	Geological, Chemical and Biological Oceanography	3
2.	OA-452	Advanced Geophysical Fluid Dynamics	4
3.	OA-453	Tropical Meteorology and Climatology	4
4.	OA-454	Climate Change and Its Impacts	3
5.	OA-455	Modeling of the Atmosphere and the Oceanic Processes	4
6.	OA-456	Practical-3: Observational Techniques in Oceanography	1
7.	OA-457	Practical-4: Meteorological and Oceanographic Computations	2
8.	OA-471	Elective-I	3
		Total credits	**24**
		III-Semester	
1.	OA-501	General Circulation of the Atmosphere and Ocean	4
2.	OA-502	Numerical Weather Prediction	4
3.	OA-503	Atmosphere and Marine Boundary Layer Processes	4
4.	OA-504	Remote sensing and GIS in Ocean and Atmospheric Sciences	3
5.	OA-505	Practical-5: Remote Sensing and GIS Laboratory	1
6.	OA-506	Practical-6: Model Simulations and Diagnostics	2
7.	OA-521	Elective-II	3
8.	OA-522	Elective-III	3
		Total credits	**24**
		IV-Semester	
1.	OA-551	Project Dissertation (Report, Presentation and Viva-voce)	16
2.	OA-552	Seminar on breakthrough papers	1
3.	OA-553	Summer Internship (Report and Presentation)	1
		Total credits	**18**
		Cumulative credits (I-IV Semester)	**89**

List of Elective Courses

1. Cloud Physics and Atmospheric Electricity
2. Diagnostic Studies of Atmospheric and Oceanic Processes
3. Satellite Meteorology
4. Satellite Oceanography
5. Aerosols and Atmospheric Chemistry
6. Ocean Acoustics
7. Marine Pollution
8. Ocean Optics
9. Agricultural Meteorology
10. High Performance Computing in Atmosphere and Ocean Sciences
11. Ocean State Forecasting
12. Mesoscale modelling
13. Air Pollution Studies
14. Coastal Oceanography
15. Glaciers and Climate
16. Climate and Energy
17. Mountain Meteorology
18. Climate and Water resources
19. Middle Atmosphere Meteorology
20. General Geology

(More electives can be added depending on demands from the industry and expertise of the available faculty, subject to the rules of the UoH)

SEMESTER- I

OA-401 Fundamentals of Earth System Science

Basic concepts for Earth System Science : The origin and early evolution of the Earth; Evolution of Geosphere and Biosphere; Earth as a system of interacting components- Geosphere, Biosphere, Atmosphere and Hydrosphere.

Life on Earth; chemosynthetic and photosynthetic processes; marine productivity; organic/inorganic carbon; warm/cold waters herbivores

Ecosystems: Biological pump; biomass; biodiversity; trophic dynamics; stability; interactions with the environment.

Biogeochemical Cycles such as Carbon cycle; Nitrogen cycle; Sulfur cycle; Phosphorus cycle; trace metals; Coupling of biogeochemical cycles and climate- Forcings, feedbacks and responses.

Ocean carbon cycle; distribution and storage of carbon in the Ocean; Reservoir of carbon; role of biology; ocean carbon exchange with the atmosphere in the present climate; variability and trends of air-sea carbon exchange and its projected changes in the future climate.

Global change on short and long time-scales: Natural versus anthropogenic changes; global warming and greenhouse effect; role of long-term variability of solar luminosity; human modifications of the Earth system;sustainability

Reference Books:

1. Lenton, T., Earth System Science: A Very Short Introduction, 1st edition, Oxford University Press, 2016.
2. Ehlers, E., and T. Kraft, Earth System Science in the Anthropocene: Emerging Issues and Problems, Springer.
3. Jacobson, M. C., R. J. Charlson, H. Rodhe, and G. H. Orians, Earth System Science: From Biogeochemical Cycles to Global Changes, Elsevier Academic Press, 2006.
4. Flechtner, F., N. Sneeus, and W.D. Schuh, Observation of the System Earth from Space - CHAMP, GRACE, GOCE and future missions, Springer, 2014.
5. Kump, L. R., J. F. Kasting, and R. G. Crane, Earth System Science, 3rd edition, Pearson Education, 2010.

OA-402: Physics of the Atmosphere

Elementary concepts of atmospheric sciences; vertical thermal structure and composition of the atmosphere hydrostatics of the atmosphere; geopotential; equipotential surface; hydrostatic equation; hydrostatic equilibrium; standard atmosphere; altimetry.

Gas laws and their application to the atmosphere; equation of state for dry and moist air; humidity parameters; virtual temperature; First and second laws of thermodynamics; specific heats of gases; internal energy; adiabatic processes; potential temperature; revisiting entropy; reversible and irreversible processes; Carnot's cycle; thermodynamics of water vapour; latent heat; the Clausius-Clapeyron equation; thermodynamics of the atmosphere; dry adiabatic lapse rate; case of unsaturated moist air;saturated adiabatic lapse rate; pseudo-adiabatic cases; equivalent potential temperature; wet-bulb temperature; wet-bulb potential temperature and saturation potential temperature; Normand's propositions and Normand point..

Atmospheric instability and convection-stability criteria; parcel method; Brunt-Vaisala oscillations; lifting; mixing and convective condensation levels; potential instability and latent instability; stability indices; slice method of stability analysis; cloud formation and types.

Principles of thermodynamic diagrams and various thermodynamic diagrams

Radiation: Laws of black body radiation; radiation transfer; solar radiation; latitudinal and seasonal variation; passage through the atmosphere – absorption, scattering and reflection; mean disposition of solar radiation; terrestrial radiation; absorption in the atmosphere; Raleigh and Mie scattering; atmospheric window

Reference Books:

1. Wallace, J. M., and P. V. Hobbs, Atmospheric Science: An Introductory Survey, 2nd edition, Elsevier Academic Press, 2006.
2. Marshall J., and R. A. Plumb, Atmosphere Ocean and Climate Dynamics: An Introductory Text, Elsevier Academic Press, 2008.
3. Hess, L. S., Introduction to Theoretical Meteorology, Wiley Online Library.
4. Andrews, D. G., An Introduction to Atmospheric Physics, 2nd edition, Cambridge University Press, 2010.
5. Houghton, J. T., Physics of the Atmosphere, Cambridge University Press, 2002.

OA-403: Physics of the Ocean

General introduction: History of oceanography and major expeditions; physical properties of sea water; distribution of temperature, salinity, density and oxygen in space and time; acoustical and optical characteristics of seawater.

Heat budget of ocean: Insolation; long wave radiation; effect of clouds; sensible and latent heat transfer; Bowen's ratio; ocean heat transport; spatio-temporal variability of heat budget terms and net heat balance.

Water type and masses: Formation and classification; identification of water masses; Temperature/Potential-Salinity (T/θ-S) diagrams; water masses of the Atlantic, Pacific, and Indian Ocean with special reference to Arabian Sea and Bay of Bengal.

Surface gravity waves: Characteristics, shallow water transformation and breaking; long-shore and cross-shore currents; rip currents

Tides: Tide generation and propagation; characteristics of tides; spring and neap tides; diurnal and semi-diurnal tides; tidal current; tidal flushing; tides in estuaries

Circulation: General circulation of the atmosphere; wind-driven currents in the oceans; wind stress; Ekman spiral and transport; subtropical and polar gyres; major currents of the world oceans; thermohaline circulation; Ocean conveyor belt.

Indian Ocean Circulation: Northeast and Southwest monsoon winds; ocean surface circulation; equatorial current systems; under currents; circulation in Arabian Sea and Bay of Bengal; somali current; Indonesian Through Flow and Pacific-Indian Ocean exchange; Agulhas current and Indian Ocean-Atlantic exchange.

Ocean processes: Upwelling and sinking; mesoscale eddies; winter cooling and convection; Indo-Pacific Ocean warm pool; Seyshells-Chagos Thermocline Ridge (SCTR); tropical cyclones and upper ocean response; El-Nino and Southern Oscillation (ENSO); Indian Ocean Dipole.

Reference Books:

1. Stewart, R. L., Introduction to Physical Oceanography.
2. Waves, Tides and Shallow Water Processes: Open University Course Team and Butterworth-Heinemann Publications, Oxford, UK, 1999.
3. Williams, F. J., and S. Elder, Fluid Physics for Oceanographers and Physics: An Introduction to Incompressible, US Naval Academy, Paragon Press.

4. Talley, L. D., G. L. Pickard, W. J. Emery and J. H. Swift, Descriptive Physical Oceanography, 6th edition, Elsevier, 2011.

Additional Reading Material

1. Pond, S. and G. L. Pickard, Introductory Dynamic Oceanography, 2nd edition, Butterworth-Heinemann, 1983.
2. Marshall J., and R. A. Plumb, Atmosphere Ocean and Climate Dynamics: An Introductory Text, Elsevier Academic Press, 2008
3. Defant, A., Physical Oceanography Vol.1, Pergamon Press, 1961.
4. Neumann, G., and W. J. Pierson, Principles of Physical Oceanography, Prentice-Hall, 1966.

OA-404: Dynamics of the Atmosphere and Ocean

Introduction: Objective, importance of geophysical fluid dynamics; distinguishing attributes of geophysical flows; scales of motions; importance of rotation; importance of stratification; distinction between the atmosphere and ocean; data acquisition; the emergence of numerical simulations; scales analysis and finite differences; higher-order methods; aliasing.

The Coriolis force: Rotating framework of reference; unimportance of the centrifugal force; free motion on a rotating plane; analogy and physical interpretation; acceleration on a three-dimensional rotating planet.

Equations of fluid motion in different coordinate systems: Cartesian, spherical and natural vertical-pressure and potential temperature

Geostrophic flows: Homogeneous geostrophic flows; homogeneous geostrophic flows over an irregular bottom; generalization to nongeostrophic flows; inertial motion and cyclostrophic flow; gradient wind and thermal wind Currents without friction: Hydrostatic equilibrium; geopotential, isobaric and isopycnal surfaces, Geostrophic equation; inertial motion; level of no motion and absolute currents; quasi-geostrophic dynamics; simplifying assumptions and governing equations.

Currents with friction: Ekman's solution to the equation of motion with friction; drag co-efficient; Ekman transport and upwelling; bottom friction and shallow water effect; Sverdrup's equation and its application; equatorial undercurrent; Stommel's and Munk's theorem; westward intensification of ocean currents.

Reference Books:

1. Holton J. R., and G. J. Hakim, Introduction to Dynamic Meteorology, 5th edition, Academic Press, 2012.
2. Hess, L. S., Introduction to Theoretical Meteorology, Wiley Online Library.
3. Roisin, B. C. and J. M. Beckers, Introduction to Geophysical Fluid Dynamics, Academic Press, 2009.
4. Pond, S. and G. L. Pickard, Introductory Dynamic Oceanography, 2nd edition, Butterworth-Heinemann, 1983.
5. Olbers, D., J. Willebrand and C. Eden, Ocean Dynamics, Springer, 2012.

Additional Reading Material

1. Proudman, J., Dynamical Oceanography, Methuen & Co Ltd, 1963.
2. Haltiner, J. G., and F. L. Martin, Dynamical and Physical and Meteorology, McGraw-Hill, 1957.
3. Fomin, L. M., The Dynamic Method in Oceanography, Elsevier, 1964
4. Roisin, B. C. and J. M. Beckers, Introduction to Geophysical Fluid Dynamics: Physical and Numerical Aspects, Academic Press, 2009.
5. Dietrich, G., General Oceanography, John Wiley and Sons Inc, 1963.
6. Sverdrup, H. U., M. W. Johnson and R. H. Fleming, The Oceans: Their Physics, Chemistry and General Biology, Prentice Hall Inc, 1942.

OA-405: Mathematical Physics

Vector calculus: Differentiation and integration of vectors; scalar and vector fields; vector operators; cylindrical and spherical polar coordinates.

Linear vector spaces: Vector spaces and representations; linear operators; matrices and their properties; special matrices; eigenvalues and eigenvectors; change of basis and similarity transformation; matrix diagonalization and its geometric interpretation; simultaneous linear equations.

Complex variables: Functions of complex variable: analyticity and Cauchy-Reimann relations; power series in a complex variable; elementary functions.

Fourier analysis: Periodic functions and Dirichlet conditions; Fourier representation-real and complex series; symmetry properties; non-periodic functions-Fourier transform; properties; Parseval's theorem; Laplace transform and region of convergence; applications to differential equations.

Ordinary differential equations: First and second order equations; linear equations with constant and variable coefficients; series solutions; special functions; Legendre, Bessel and Hermite functions; introduction to linear vector space of functions with special functions as basis vectors.

Partial differential equations: Wave and diffusion equations as examples; general and particular solutions; separation of variables; integral transform methods.

Reference Books:

1. Riley, K. F., M. P. Hobson, & S. J. Bence, Mathematical methods for physics and engineering, Cambridge University Press, 2006.
2. Hassani, S., Mathematical physics, Springer, 2002.
3. Greenberg, M. D., Advanced engineering mathematics, Pearson Education, 2002.
4. Croft, A., R. Davidson and M. Hargreaves, Engineering Mathematics, Pearson education, 2001.
5. Spiegel, M. R., et al., Complex Variables (Schaum's series), McGraw-Hill education, 2009
6. Brown, J. W. and R. V. Churchill, Fourier series and Boundary Value Problems, McGraw-Hill Education, 2015.

Additional Reading Material

1. Kalpan, W., Advanced Calculus, 5th edition, Pearson, 2002.
2. Arfken, B., and H. Weber, Mathematical Methods for Physicists, Elsevier, 2005, 1182p.
3. Pipes, L. A., and L. R. Harvill, Applied Mathematics for Engineers and Physicists, Dover publications, 2014.

OA-406: Statistical and Numerical Analysis in Geosciences

Introduction to Statistics: Mean, mode, median, variance, standard deviation, correlation coefficient, skewness and Kurtosis; linear, non-linear and multiple regression; least squares curve fitting

Probability: Probability distribution functions (PDFs); Binomial, Poisson, Gaussian, Log-normal, and Chi-square distributions; moments of distribution.

Sampling and methods of sampling: Population, sample mean and standard deviation; central limit theorem; Monte Carlo methods; Bayes's theorem; one and two way analyses of variance; design of experiments; testing hypotheses; Student's t test; F-test; Chi-square test; principal component analysis

Linear system of simultaneous matrix: Jacobi and Gauss Seidel method

Applications of empirical orthogonal functions; Fourier transforms; wavelet transforms; and filtering

Interpolation: Forward, backward and centered difference; Newton's formula for interpolation

Numerical solution of algebraic and transcendental equations: Iterative algorithm; Bisection method and Newton Raphson method.

Numerical differentiation and integration: Numerical differentiation; finite difference approximation of derivatives; Numerical integration; Trapezoidal and Simpson's rule.

Numerical integration of ordinary differential equations (ODEs): Euler and Runge Kutta methods

Numerical solution of partial differential equation: Explicit and Crank-Nicolson method

Reference Books:

1. Hamming, R. W., Numerical Methods for Scientists and Engineers, 2nd edition, McGraw Hill, 1973
2. Sastry, S. S., Introductory Methods of Numerical Analysis, 5th edition, PHI learning private limited-New Delhi, 2012.
3. Isaacson, E., and H. Keller., Analysis of Numerical Methods, John Wiley & Sons 1966.
4. Pipes, L. A. and L. R. Harvill, Applied Mathematics for Engineers and Physicists, 3rd edition, Dover publications, 2014.
5. Spiegel, M. R., and L. J. Stephens., Schaum's Outline of Statistics, 6th edition, McGraw Hill education, 2018.
6. Chapman, S. J., Fortran 90/95 for Science and Engineering McGraw Hill Education, 2nd edition, 2013.
7. Press, W. H., S. A. Teukolsky, W. T. Vetterling and B. P. Flannery., Numerical Recipes in FORTRAN, Cambridge University Press, 2000.

OA-407: Practical-1: Statistical and Numerical Computing

Fundamentals of programming logic and algorithm development

In this course, students will study and solve various numerical and statistical problems, by developing algorithms in FORTRAN (Force 2 compiler in Window OS/GFortran in Unix) and MATLAB, and executing them on computer using datasets provided (or to be downloaded as instructed).

OA-408: Practical-2: Weather Data Analysis and Forecasting

General measurement system: Principles; measurement of surface meteorological parameters-rainfall, wind, temperature, humidity, pressure, radiation, soil moisture and soil temperature;. Aerosol and its size distribution and chemical compositions; trace gases; Ship-based and buoys observations..

Upper air observations: Pilot balloon; radiosonde/GPSsonde;.,

Data analysis and forecasting: Surface and upper air data analysis; T-Phigram; use of weather chart and T-Phigram for weather forecasting.

Visit to India Meteorological Department (IMD).

Reference Books:

1. Handbook of Meteorological Instruments : H.M.S.O., LONDON,1965
2. Middleton, W. E. K. and A. F. Spilhaus, Meteorological Instruments, 3rd edition, University of Toronto Press, 1960.
3. Pictorial guide to maintenance of meteorological Instruments: H.M.S.O., London, 1963
4. Guide to Meteorological Instruments and observing practices :2014 edition WMO Publications, May 2017

SEMESTER-II

OA-451: Geological, Chemical & Biological Oceanography

Geological Oceanography: Basics of Marine Geology; seafloor spreading; plate tectonics; evolution of ocean basins; Bathymetry and Physiography of the ocean floor; coastal water bodies – estuaries, lagoons, beaches, barrier islands, mudflats and wetlands.

Marine sediments – sources; sediment transport; mass gravity flows; turbidites; sediment dispersal and accumulation patterns; accretion and erosion; Sediments of Indian, Pacific and Atlantic Oceans. Earthquakes and Tsunami origination in Oceans.

Geochemical cycling of elements: Hydrothermal vents and hydrothermal alterations; factors affecting distribution of calcareous and siliceous deposits on the seafloor; mechanism of formation of different types of mineral and chemical deposits - Polymetallic nodules and sulphide deposits.

Sediment samplers - Grabs and corers; sediment samples processing and analytical techniques; sedimentation rates using radiocarbon dating techniques (C-14 methods), AMS and U-Th dating.

Ice ages and their causes; stable isotopes and their applications in paleoclimate reconstruction; oxygen isotopes in planktic and benthic forams; corals; marine sediment cores; paleo sea-level; paleo temperatures and productivity.

Chemical Oceanography: Chemical reactions: their basis and types; thermodynamic and kinetic considerations; concentration-activity difference; activity coefficient; chemical interactions and equilibria relevant to the Ocean; acid-base; ion-exchange; adsorption-desorption; dissolution-precipitation; reduction-oxidation; dissolution-colloid formation-precipitation; chemical speciation of important seawater systems; carbonate, phosphate and nitrate.

Concentrations and cycles: Major and minor ions; major sources and sinks of elements; geochemical balance and residence time; nutrients and nutrient-type elements; bio-limiting and bio-intermediate elements; phosphorus, nitrogen and silicon cycles; nitrification; denitrification and anammox; iron limitation in HNLC waters

Gases and Fluxes: Non-reactive and reactive gases; fluxes of gases across sea surface; oxygen and apparent oxygen utilization (AOU); oxygen minimum zones (OMZ) and anoxia; carbon dioxide and solubility pump; ocean acidification and its impact on the CO_2 system; lysocline; $CACO_3$ compensation depth (CCD).

Biological Oceanography: Photosynthesis and respiration - Basic aspects of calvin cycle; carbon isotopic differentiation in C_3 and C_4 plants; chlorophyll-a primary productivity and the abiotic and biotic factors affecting it; vertical structure of chlorophyll and productivity; deep chlorophyll maxima; compensation depth; penetration depth; critical depth; regenerated production, new production biological pump and F-Ratio; eutrophication.

Major groups of algae; their characteristics and importance; harmful algal blooms; biomagnification and shellfish poisoning; characteristic algal pigments and their absorption characteristicsDissolved organic carbon (DOC) and coloured dissolved organic matter (CDOM); allochthonous and autochthonous inputs; ectocrines; particulate organic matter (POM); marine snow; bacteria and viruses; microbial loop; primary to bacterial production ratio; biological oxygen demand; food chain; foodweb and trophic dynamics; deep scattering layer; ecological efficiency; species succession; species richness and diversity indices.

Mangroves and corals and their ecology and biology.

Major zooplankton groups and higher organisms: Radiolarians; Pteropods; crustaceans; corals; fishery resource and its forecast.

Marine biology of Arabian Sea and Bay of Bengal

Reference Books:

1. Lalli, M. C., and T. R. Parsol, Biological Oceanography: An Introduction, Open University Set Book
2. Riley, P. J., and R. Chester, Chemical Oceanography, Elsevier, 1983.
3. Wright, J., and A. Colling Seawater and its composition, properties and behavior, Open University, Elsevier, 1989.
4. K K Turekian – Chemical Oceanography
5. Pilson, M. E. Q., An Introduction to the Chemistry of the Sea, Prentice Hall, New Jersey, 431 pp, 1998.
6. Lecture Notes in Chemical Oceanography of Stanford University.
7. Lalli, C., and T. R. Parsons,. Biological Oceanography: An Introduction, Elsevier, 320 pp, 1997.

OA-452: Advanced Geophysical Fluid Dynamics

Circulation and Vorticity: Kelvin's circulation theorem; Bjerknes circulation theorem; vorticity equation in cartesian and isobaric coordinates; divergence and vorticity of the geostrophic wind; scale analysis of the vorticity equation; potential vorticity conservation; Rigid-Lid approximation.

Waves in the atmosphere and Oceans: Concept of wave motion, acoustic waves, gravity waves, shallow water waves, Tsunami waves, Kelvin and Rossby wave

Budgets: Mass budget; momentum budget; energy budget; salt and moisture budgets; Boussinesq approximation; flux formulation and conservative form

Ekman Layer: Shear turbulence; friction and rotation; the bottom Ekman layer; generalization to nonuniform currents; Ekman layer over uneven terrain; surface Ekman layer; Ekman layer in real geophysical flows; Reynolds-averaged equations; Eddy coefficients; important dimensionless numbers.

Hydrodynamic instabilities: Barotropic instability and applications; introduction to baroclinic instability; Kelvin-Helmholtz instability

Reference Books:

1. Roisin, B. C. and J. M. Beckers, Introduction to Geophysical Fluid Dynamics: Physical and Numerical Aspects, Academic Press, 2012.
2. Pedlosky J., Geophysical Fluid Dynamics, Springer, 1987.
3. Holton J. R., and G. J. Hakim, Introduction to Dynamic Meteorology, 5th edition, Academic Press, 2012
4. Gill A. E., Atmosphere-Ocean Dynamics, Academic Press, 1982

OA-453: Tropical Meteorology and Climatology

Weather and climate; Components of the climate system and feedbacks to climate.

Radiation climatology of the earth's atmosphere; geographical and seasonal distribution of incoming solar radiation; outgoing radiation; net radiation; terrestrial heat balance.

Geographical and seasonal distributions of temperature, pressure, wind, precipitation, vertical distribution of temperature and winds.

Climatology of air masses: Origin, movement and modification of air masses; fronts and convergence zones; weather associated with frontal zones.

Classification of climates: Koeppen and Thornthwaite's schemes

Large scale planetary systems: Trade wind and ITCZ; Hadley and Walker circulation; Jet streams; Madden Julian oscillation

Synoptic scale weather systems: Low and high pressure systems; easterly waves

Tropical cyclones: Grey-Sikka conditions; life cycle; structure in wind; temperature; introduction to various theories; cyclone movement; storm surges.

Monsoons: climatological features and seasonal evolution of Indian summer monsoon; principal rain bearing systems including monsoon depressions, lows; mid-tropospheric cyclones; intraseasonal variability of summer monsoon including active and break cycles; monsoon variability on interannual and decadal time scales; impacts from tropical oceanic drivers such as the ENSO and IOD; northeast monsoon

Mesoscale systems: Thunderstorm; dust storm; hail storm; tornado; sea and land breeze.

Reference Books:

1. Monsoon monographs Vol-I and Vol-II, 2010 : India Meteorological Department
2. Rao, Y. P., South West Monsoon, IMD, 1976.
3. Pant, G. B., and K. Rupakumar, Climates of South Asia, J.Wiley and Sons: Chichester, 1997.
4. Chang, C. P. and T. N. Krishnmoorthy, Monsoon Meteorology, Oxford University Press, 1987.
5. Anthes, R. A., Tropical Cyclones, their evolution structure and effect, American Meteorological Society, 1982.
6. Asnani, G. C., Tropical Meteorology.
7. Trewartha, G. T., An Introduction to climate, McGraw-Hill.

Additional Reference

1. Pandharinath, N., Aviation Meteorology, B.S. Publications, 2012
2. Atkinson, B. W., Mesoscale atmospheric circulations.
3. Shaw, D. B., Meteorology over the Tropical Oceans, Royal Meteorological Society publication 1979.
4. Sellers, W. D., Physical Climatology, University of Chicago Press, 1965.
5. Neelin, J, D., Climate Change and Climate Modelling, Cambridge University Press, 2011.
6. Barrry, R. G., and R. J. Chorley, Atmosphere Weather and Climate, 9th edition, Routledge publishers, 2010.

OA-454: Climate Change and Its Impacts

Overview of the climatic history of the earth; theories of climatic changes

Climatic change and climatic variability: local and planetary influences; Milankovitch cycles-eccentricity, tilt and precision cycles; internal feed backs; Dansgaard-Oeshger cycles; Thermohaline circulation and its effect on climate.

Paleoclimate archives: micro fossils; dendrochronology; sclerochronology; lake and ocean varve sediments; foraminifera; oxygen isotope stratigraphy; loess deposits; Ice cores - polar and tropical ice cores; speleothems; pollen grains.

Paleoclimate Methods: Stable isotopes - oxygen; carbon; calcium-magnesium ratios and their application in paleoclimate studies

Greenhouse effect in Earth's current climate; climate sensitivity; climate feedback parameter; water vapour feedback; snow & ice feedback; cloud feedback; climate response time in transient climate change; transient climate change versus equilibrium response experiments; example of a doubled-CO_2 equilibrium response experiment; the role of the oceans in slowing warming; climate sensitivity in transient climate change.

Global warming: Relevance of greenhouse gases and aerosols; other climate forcings; climate change scenarios

IPCC AR5* SPM report: Recent climate change and detection; future projection; mitigation; adaptation.

Sea level change: modelling and predicting climate change.

[*to be replaced by the latest IPCC SPM report as and when it gets released]

Reference Books:

1. Paleoclimates: Understanding Climate Change Past and Present : Thomas Cronin
2. Climate and Evolution: William Diller Matthew
3. Principles of Paleoclimatology : Thomas Cronin
4. Climatic Changes; Their Nature and Causes: Ellsworth Huntington
5. Barrry, R. G., and R. J. Chorley, Atmosphere Weather and Climate, 9th edition, Routledge publishers, 2010.
6. Hartmann, D., Global Physical Climatology, 2nd edition, Elsevier Academic Press, 2015.
7. General Climatology : H.J. Critchfield, Prentice Hall (1964)
8. An introduction to climate : G.T. Trewartha
9. World Climatology – An Environmental Approach , 1974 edition : *J.*.G. Lockwood, Edward Arnold press, London.
10. Sellers, W. D., Physical Climatology, University of Chicago Press, 1965.
11. Neelin, J, D., Climate Change and Climate Modelling, Cambridge University Press, 2011.
12. Farmer, G. T. and J. Cook**,** Climate Change Science: A Modern Synthesis: The Physical Climate, Springer, 2013.

OA-455: Modelling of the Atmosphere and Oceanic Processes

Historical Background of atmospheric and ocean models; primitive equations and their simplification

Hierarchy of numerical models: Filtering problem, barotropic model; equivalent barotropic model; two level Baroclinic model; general circulation model

Finite difference Techniques: Taylor's expansion; forward, backward and central schemes; nonlinear instability and aliasing; arakawa grids.

Time integration schemes: Explicit and implicit schemes; semi-implicit schemes; initial conditions; surface and lateral boundary conditions.

Galerkin methods: spectral method; finite element method; spectral model.

Parameterization of physical processes in the atmosphere: Basic concepts of parameterization - boundary layer, cumulus convection, radiation and land surface processes

Ocean modeling: Hierarchy of ocean models; reduced gravity model; linear continuously stratified model; shallow water model; global ocean model; physical processes and parameterization schemes; Parameterization of physical processes in the ocean: Basic concepts of parameterization - mixing processes, air-sea fluxes, tide and waves.

Coupling-Hierarchy of coupled models; coupling strategies; spin-up problems.

Earth System model.

Reference Books:

1. Coiffier, J., Fundamentals of Numerical Weather Prediction, Cambridge University press, 2012.
2. Warner, T. T., Numerical Weather and Climate Prediction, Cambridge University press, 2011.
3. Bhaskar Rao, D. V., Numerical Weather Prediction, Published by BS publishers and India Meteorological Society.

4. Krishnamurti, T. N., & L. Bounoua, An Introduction to Numerical Weather Prediction Techniques, CRC press, 1995.
5. Randall, D., An Introduction to Numerical Modeling of the Atmosphere, 2009.
6. Kampf, J., Advanced Ocean Modelling, Springer, 2010
7. Stephen Griffies, S., Fundamentals of Ocean Climate Models, Princeton University Press, 2004

Additional Reading Material:

1. Haltiner, G. J., and R. G. Williams, Dynamic Meteorology & Numerical Weather Prediction, Wiley, 1980.
2. Muller, P., and H. V. Storch, Computer modeling in Atmospheric and Oceanic Sciences, Springer, 2004.
3. Kampf, J., Ocean Modeling for beginners, Springer, 2009.
4. Chassignet, E., and P. Verron, Ocean Modeling and Parameterization, Springer, 1988.
   Miller, R. N., Numerical Modeling of Ocean Circulation, Cambridge University Press, 2007.

OA-456: Practical-3: Observational Techniques in Oceanography

Students will participate in research expedition Cruise organized by National Institute of Ocean Technology (NIOT) or National Institute of Oceanography (NIO) or National Centre for Antarctic and Ocean Research (NCAOR) or Indian National Centre for Ocean Information Services (INCOIS) to train students in general oceanographic data collection methods, and familiarity with various on-board instruments.

OA-457: Practical-4: Meteorological and Oceanographic Computations

Computation and visualization softwares such as GraDs, NCL, Ferret and MATLAB.

Computations: of absolute vorticity; horizontal divergence; geostrophic, thermal and gradient winds; relaxation methods; stream function and velocity potential, from NCEP/NCAR or equivalent circulation datasets.

Identification of ENSO and IOD events from the gridded SST datasets.
Calculation and presentation of Walker and Hadley circulations from reanalysis products
Computation of salinity from Chlorinity and conductivity; density using temperature and salinity
Specific volume anomaly using temperature, salinity and depth
Computation of potential temperature
T/θ-S diagrams and identification of water mass
Stability characteristics of water column, Brunt-Vaisala frequency and stability parameters
Computation of geostrophic currents
Estimation of wind stress curl and computation of wind-driven current
Estimation of mixed layer, barrier layer and thermocline depths

SEMESTER- III

OA-501: General Circulation of Atmosphere and Ocean

General circulation of the atmosphere; angular momentum balance; zonal mean and time mean circulations; Walker circulation; zonally asymmetric components of the general circulation; a simple model of Hadley cell; ITCZ; maintenance of general circulation; transport of momentum, heat and moisture fluxes in the atmosphere.

Atmospheric energetics: Energy equation; internal and potential energies; frictional dissipation of kinetic energy; conversion of potential and internal energies to kinetic energy; available potential energy; Stationary and transient eddies; Lorenz energy cycle.

Atmospheric response to equatorial heating: Monsoons, ENSOs as explained by Matsuno-Gill solutions; teleconnections of tropical phenomena such as ENSO beyond tropics; Rossby wave source; introduction to decadal phenomenon such as the PDO.

The observed mean ocean circulation; inferences from geostrophic and hydrostatic balance; ocean eddies

Wind-driven ocean circulation; mixed layer of the ocean; theories of wind-driven circulation; Sverdrup solution.

Thermohaline circulation; Conveyor belt formation; Abyssal circulation; mixing; Isopycnal and diapycnal mixing; ocean heat budget and transport

Reference Books:

1. Roisin, B. C. and J. M. Beckers, Introduction to Geophysical Fluid Dynamics, Academic Press, 2009.
2. Pedlosky, J., Ocean Circulation Theory, Springer, 1998.
3. Marshall J., and R. A. Plumb, Atmosphere Ocean and Climate Dynamics: An Introductory Text, Elsevier Academic Press, 2008.
4. Lorenz, E. N., The Nature and Theory of the General Circulation of the Atmosphere, WMO, 1967.
5. Holton J. R., and G. J. Hakim, Introduction to Dynamic Meteorology, 5th edition, Academic Press, 2012
6. Corby, G. A., The Global Circulation of the Atmosphere, Royal Meteorological Society, 1969.
7. Sverdrup, H. U., M. W. Johnson and R. H. Fleming, The Oceans: Their Physics, Chemistry and General Biology, Prentice Hall Inc, 1942.
8. Neumann, G., and W. J. Pierson, Principles of Physical Oceanography, Prentice-Hall, 1966

OA-502: Numerical Weather Prediction

History of numerical weather prediction; Richardson's forecast; analysis of the initial tendencies; the causes of the forecast failure.

Hierarchy of NWP models: mesoscale, regional and global models.

Concept and steps of operational forecasting systems: Selection of the models; role of dynamics and physics; initial conditions; boundary conditions; pre-processing and post-processing; model diagnostics; determintic and probalistic forecasts; Dynamical and Statistical models; ensemble and super ensemble prediction systems; NWP model evaluation, correlation, skills, and bias correction.

Initialization and data assimilation: Relevance of observations; model spin-up; statistical framework for data assimilation; successive-correction methods; three-dimensional variational analysis; introduction to 4-D VAR and/or other advanced methodsSpecific parametrizations schemes used in NWP system: Choice of scale sensitive parametrization scheme; parametrization schemes (convection, cloud microphysics, PBL, air-sea interaction and land-surface processes), sensitivity experiments.

Issues in NWP system: Challenges in weather forecasting; Chaos theory; Lorenz's butterfly effect; predictability; seamless prediction system (weather to climate prediction); present status of NWP system in India.

Reference Books:

1. Coiffier, J., Fundamentals of Numerical Weather Prediction, Cambridge University press, 2012.
2. Warner, T. T., Numerical Weather and Climate Prediction, Cambridge University press, 2011.
3. Bhaskar Rao, D. V., Numerical Weather Prediction, Published by BS publishers and India Meteorological Society.
4. Daley, Roger, Atmospheric Data Analysis, Cambridge Atmospheric and Space Series, 1999.
5. Kalnay, E., Atmospheric modeling, Data Assimilation and predictibility, Cambridge University Press, 2003.
6. The emergence numerical weather prediction : Peter Lynch, Cambridge University Press, 2006.
7. Haltiner, G. J., and R. G. Williams, Dynamic Meteorology & Numerical Weather Prediction, Wiley, 1980.
8. Krishnamurti, T. N., & L. Bounoua, An Introduction to Numerical Weather Prediction Techniques, CRC press, 2006.
9. Randall, D., An Introduction to Numerical Modeling of the Atmosphere, 2009.
10. Muller, P., and H. V. Storch, Computer modeling in Atmospheric and Oceanic Sciences, Springer, 2004

Additional Reading material

1. Krishnamurti, T. N., H. S. Bedi and V. M. Hardiker, An Introduction to Global Spectral Modelling, Oxford University Press, 1998.

OA-503: Atmosphere and Marine Boundary Layer Processes

Introduction: definitions and background; variables; wind and flow; turbulent transports; Taylor's hypothesis and observing techniques; boundary layer depth and structure; mathematical and conceptual tools; turbulence and its spectrum; spectral gap; mean and turbulent parts; basic statistical methods; rules of averaging; turbulent kinetic energy; kinematic flux, eddy flux; stresses.

Governing equations for turbulent flow: methodology; basic equations; simplifications and approximations; equations for mean variables in a turbulent flow; mixed layer theory; mixing and entropy; governing equations; model behaviour; surface fluxes and entrainment.

Deep convection and marine boundary layer: Controls on deep convection; MABL modification by downdrafts; boundary layer recovery; boundary layer modeling and parameterizations.

Physical interaction between ocean and atmosphere; wind stress and drag coefficient with respect to wind speed; momentum transfer, atmospheric impact on oceanic circulation.

Reference Books:

1. Bigg, G. R., The Oceans and climate, Cambridge University Press, 1996.
2. Kagan, B, A., Ocean atmospheric interaction and climate modeling, Cambridge University Press, 1995.
3. Arya, S. P., Introduction to Micrometeorology, Academic Press, 2001.
4. Kraus E. B. and J. A. Businger, Atmosphere-Ocean interaction, Oxford University Press, 1995.
5. Stull R. B., Introduction to Boundary Layer Meteorology, Springer, 1988.
6. Geernaert, G. L., Air-Sea exchange: Physics, Chemistry and Dynamics, Springer, 1999.
7. Toba, Y., Ocean-Atmosphere interactions, Springer, 2003.

OA-504: Remote sensing and GIS in Oceanic and Atmospheric Sciences

Introduction to remote sensing; basic concepts; electromagnetic radiation; solar and terrestrial

radiation; atmospheric effects; absorption; transmission; scattering; spectral response of earth's surface features.

Remote sensing of atmospheric and ocean variables; atmospheric vertical and limb soundings; remote sensing platforms; satellite orbits- near polar geostationary and sun-synchronous satellites; swath; spatial, temporal, spectral and radiometric resolution; examples of Indian atmospheric and ocean satellites including INSAT; sensors-active and passive sensors; sensor calibration; visible, thermal and microwave sensors and their applications in meteorology and oceanography

Visible remote sensing: Theory of ocean colour remote sensing; optical properties of pure water; natural waters and atmosphere; reflection and refraction at the surface; scattering and absorption of light underwater; reflection from sea bed; colour of the sea; phytoplankton, yellow substance, suspended particulate matter; case 1 and case 2 waters; estimating water parameters; satellite sensors for ocean colour-I and their applications

Infrared Remote Sensing: Infrared radiometers; SST retrieval with atmospheric corrections and validation; application; skin and bulk SST; global SST data products

Microwave remote sensing: Theory and principles of microwave radiometry; passive microwave radiometers and its applications in ocean and atmosphere; active microwave sensors; principles; applications of SAR; scatterometers and altimeters for ocean and atmospheric studies.

Introduction to GIS; creation of point, line and polygon in form of shape file/Geo-database; geo-referencing of satellite data and digitized vector files using GIS software; geo-informatics; integration of attribute data; analysis using map algebra; map composition and finalization; web-GIS; application of ArcGIS and ERDAS.

Reference Books:

1. Houghton, J. T., F.W. Taylor and C.D. Rodgers, Remote sounding of atmosphere, Cambridge University Press, 1984.
2. Stewart, R. H., Methods of Satellite Oceanography, University of California, 1985.
3. Robinson, I. S., Satellite Oceanography, Ellis Horwood, 1985.
4. Barret E. C., Climatology from Satellites, 1974.
5. Kidder, S. Q., and T.H. Van der Harr, Satellite Meteorology - An introduction, Academic Press, 1995.
6. Weng,Q., Remote Sensing and GIS Integration: Theories, Methods and applications, McGaw-Hill Professional, 2009.

Additional Reading Material

1. Maul, G. A., Introduction to Satellite Oceanography, Springer, 1985.
2. Bhatta, B., Remote Sensing and GIS, Oxford University Press
3. Ikeda, M. and W. Dobson, Oceanographic Applications of Remote Sensing, CRC Press, 1985.

OA-505: Practical-5: Remote Sensing and GIS Laboratory

Satellite datasets and familiarization with open data; Satellite data processing techniques, analysis and interpretations; radiometric and geometric corrections; band ratios; retrievals of ocean color parameters and SST; interpretations of clouds systems; tropical systems; Dvork technique to estimate tropical cyclone intensity; applications of GIS; raster vector analysis; creation of shape file; layering; DEM.

OA-506: Practical-6: Model Simulations and Diagnostics

Simulation of a tropical cyclone using an axis-ymmetric tropical cyclone model (TCM); conducting sensitivity experiments with a TCM to understand the importance of various Grey-Sikka parameters;

familiarizing with the models such as the WRF and ROMS; validation of GCM simulations of tropical processes; delineation of decadal signals such as that of the pacific decadal oscillation using filtering methods; identification of dominant statistical patterns of the tropical pacific and tropical Indian ocean using EOF method; ensemble forecast system-evaluation of models performance, bias and systematic bias correction; multi-model ensemble forecast

SEMESTER IV

OA-551: Project dissertation (Report, Presentation and Viva-voce)

Students will carry out individual project dissertation preferably at National Laboratories or Institutes such as IITM-Pune, INCOIS-Hyderabad, NIO-GOA, TIFR-Hyderabad, PRL-Ahmadabad, SPL-Trivandrum, IISc, IISERs, IITs and state/central Universities.

OA-552: Seminar on breakthrough papers

Students will study breakthrough papers (3 per each student) assigned by the faculty, and deliver seminars. Students should use PowerPoint presentation.

OA-553: Summer Internship (Report and Presentation)

Students will carry out summer internship training after II Semester (mid-May – mid-July) at National Laboratories or Institutes such as IITM-Pune, INCOIS-Hyderabad, NIO-GOA, TIFR-Hyderabad, PRL-Ahmadabad, SPL-Trivandrum, IISc, IISERs, IITs and state/central Universities.

ELECTIVE Courses

1. Cloud Physics & Atmospheric Electricity

Atmospheric aerosols-sources and sinks; physical, optical and chemical properties, primary versus secondary aerosols; aerosol radiative effects; condensation nuclei – their properties and characterisation; cloud condensation nuclei; thermodynamic theory of nucleation and growth; Kelvin equation, solute effect, Kohler curve; cloud classification; size of clouds and cloud systems; cloud droplet number and size spectra, rain drop spectra;; microstructure of clouds; fog and its typesCloud physics : ; warm and cold clouds, droplet growth by condensation; Collision and coalescence processes; collection efficiency; ice nuclei, ice crystal habits; diffusional growth of ice crystals; growth by accretion; rimming, ice multiplication; Langumir chain reaction; aggregation and break up of snowflakes; Bergeron and Frendeisen process; Graupel; Hail; precipitation of warm and cold clouds; precipitation mechanisms;

Statistical growth; Bowen model; Telford model; cloud entrainment; bubble theory.

Artificial rain-making: Static and dynamic mode of seeding: artificial rain-making experiments in India; Hail formation and suppression;

Life cycle of thunderstorm cell; severe thunderstorms; hail; tornado; weather modification; Global electric circuit: Fair weather electrical structure of the atmosphere; ions and properties; sources of ionizing radiation; ionosphere and it different layers; features of atmospheric electric field; conductivity and resistance of the atmosphere; the air–earth point discharge currents; precipitation currents;the transfer of charge.

Development of thunderstorms: Global distribution of thunderstorms; theories of thunderstorm electrification; break down potential; structure of lightening flash; sequence of events in a discharge; physics of lightening stroke; mechanism of earth-atmospheric charge balance; role of thunderstorms.

Radar observation of clouds and precipitation; radar equation; rain drop spectra; radar echoes of hail storm and tornadoes; radar observation of hurricanes; measurements of rainfall by radar.

Reference Books:

1. Rodgers, R. R., and M. K. Yau, A Short Course in Cloud Physics, 3rd edition, Elsevier, 1996.
2. Pruppacher, H. R., and J. D. Klett, Microphysics of Clouds and Precipitation, Springer, 2010.
3. Mason, B. J., The Physics of Clouds, Oxford University Press, 2010.
4. Chalmers, J. A., Atmospheric Electricity, Pergamon press, 1967.
5. Mason, B. J., Clouds, Rain and Rainmaking, 2nd edition, Cambridge University Press, 2010.
6. Pruppacher, H. R., and J. D. Klett, Clouds and Electricity.
7. Chalmers, J. A., Atmospheric Electricity, 2nd revised edition, Elsevier Science Ltd

2. Diagnostic Studies of Atmospheric and Oceanic Processes

Synoptic observations; pressure and wind systems; scales of atmospheric systems; primary-secondary and tertiary circulations; kinematics of the pressure field; pressure systems-intensification, movement, frontogenesis and frontolysis; slope of fronts; kinematics and dynamics; middle and high latitude weather systems; long waves and short waves; zonal index-anticyclones; cut off lows and blocking high; western disturbances.

Synoptic analysis: map projections; basic principles; surface, upper air and derived charts; aerological diagrams-use of special observations such as radar and satellite; representation and analysis of meteorological elements and systems on charts; weather prediction-short, medium and extended range forecasts; limits of predictability; subjective and objective methods of prediction; forecasting

offices; charts prepared and services rendered to public; shipping; aviation; agriculture; storm warning.

Kinematics of the pressure field; characteristic curves; general expressions for their velocity and acceleration; movement of troughs; ridges and pressure centres; intensification and weakening; deepening and filling of surface pressure systems.

Kinematics of the wind field; relation between streamlines and trajectories; trajectories in moving cyclones and anticyclones; differential properties of the wind field; application of geostrophic, gradient, thermal winds, divergence and vertical velocity computations.

Synoptic data and collection; surface and upper air weather data transmission; code for inland, coastal and ship stations; upper air data; PILOT and TEMP codes; Sstation models; weather charts and analysis.

Ocean data analysis and visualization: Buoys, agro, satellite, model reanalysis, global ocean data assimilation systems (GODAS).

Reference Books:

1. Piettersen, B., Weather analysis and forecasting – Vol.1 & 2.
2. Riehl, H., Tropical meteorology, Mc-Graw Hill, 1954.
3. Hastenrath, S., Climate and circulation of the tropics, Springer, 1985.
4. Ramage, C. S., Monsoon meteorology, Academic Press, 1971.
5. Asnani, G. C.,Tropical Meteorology Vol. I & II.
6. Kurz, M., Synoptic Meteorology.
7. Pant, G. B., and K. Rupakumar, Climates of South Asia, J. Wiley & Sons, 1997.

3. Satellite Meteorology

Historical development; various satellites employed; TV and IR pictures of clouds; data acquisition systems; automatic picture transmission (APT); Kepler's laws of planetary motion; orbits of satellites; choice of orbits; geosynchronous satellites; concepts of radiative transfer; propagation of solar radiation through the atmosphere; theory of radiative transfer in the atmosphere; radiative transfer in clear and cloudy skies; satellite techniques; visual and infrared sensing; atmospheric window; sensors employed for various measurements.

Meteorological satellite systems; the global weather satellite system; Meteosat satellites; NOAA satellites; future programmes; retrieval of meteorological parameters; sea and land surface temperature measurements; measurement of rainfall, retrieval of cloud parameters; surface wind extraction by MW measurements; wind extraction by pattern tracking techniques; cloud motion and scales; methods for retrieval of atmospheric temperature and humidity profiles.

Interpretation of weather satellite imagery; subjective interpretation using different presentation techniques; interpretation using different channels; use of image animations; identification of cloud types using satellite imagery; large scale patterns; general circulation; Jet streams and Jet streak developments; blocking situations.

Reference Books:

1. Kidder, S. Q., and T.H. Van der Harr, Satellite Meteorology - An introduction, Academic Press, 1995.
2. Introduction to Meteorological and other Environmental satellites, WMO (Publications).
3. Deepak, A., Remote Sensing of Atmosphere & Oceans, Elsevier, 1980.
4. Training Course on Satellite Meteorology, ISRO Publications

4. Satellite Oceanography

Introduction to remote sensing; basic concepts; principles of aerial photography; electromagnetic radiation; solar and terrestrial radiation; atmospheric effects; absorption; transmission and scattering; spectral response of earth's surface features; atmospheric windows; concept of signature.

Remote sensing platforms; satellite orbits; near polar, geostationary and sun-synchronous satellites; swath; spatial, temporal, spectral and radiometric resolution; LANDSAT; SPOT; IRS; INSAT; SEASAT; ERS; JERS; MOS; RADARSAT; active and passive sensors; sensor calibration; visible, thermal and microwave sensors and their applications in oceanography; data transmission; reception; processing and dissemination; sea-truth data validation.

Visible remote sensing: Theory of ocean colour remote sensing; optical properties of pure water; natural waters and atmosphere; optical pathways in the atmosphere; reflection and refraction at the surface; scattering and absorption of light underwater; reflection from sea bed; colour of the sea; phytoplankton; yellow substance; suspended particulate matter; case 1 and case 2 waters; estimating water parameters; satellite sensors for ocean colour- CZCS, SeaWiFS, OCTS, MOS, MODIS, OCM, LISS I & II. Calibration and validation of ocean colour; applications.

Infrared remote sensing: Thermal emission; atmospheric absorption; IR sensors; SST retrieval; atmospheric correction; effect of cloud; thermal skin layer; skin and bulk SST; effect of surface films; infrared radiometers; AVHRR; ATSR; OCTS; MODIS; AATSR; TM; global SST data; NASA pathfinder; ASST-calibration and validation of SST; applications

Microwave remote sensing: Theory of microwave radiometry; microwave emission of sea surface; atmospheric effects; retrieval of salinity and wind vector; passive microwave radiometers- SMMR, SSM/I, TRMM/TMI and AMSR; active microwave radiometers; microwave interaction with the sea surface; low, intermediate and high incidence angles; wind and radar backscatter; scatterometers- SASS, AMI, NSCAT, SeaWinds; SAR; SAR imaging of wind speed and direction; ocean waves; internal waves; shallow bathemetry; altimetry- principles; atmospheric correction; sea surface height anomaly; ERS, T/P, Jason-1; observing planetary waves and eddy energy.

Reference Books:

1. Robinson, I. S., Satellite Oceanography, Ellis Horwood, 1985.
2. Ikeda, M. and W. Dobson, Oceanographic Applications of Remote Sensing, CRC Press, 1985.
3. Stewart, R. H., Methods of Satellite Oceanography, University of California, 1985.
4. Allan, T. D., Satellite Microwave Remote Sensing, Ellis-Horwood Series in Marine Science, Chichester. 1983.
5. Maul, G. A., Introduction to Satellite Oceanography, Springer, 1985.
6. Barret E. C., Climatology from Satellites, 1974.
7. Robinson, I. S., Measuring the Oceans from space: The principles and methods of satellite Oceanography: Springer, 2004.

5. Aerosols and Atmospheric Chemistry

Chemical composition of earth's atmosphere; trace gases; aerosols; clouds; the role of aerosols in climate; direct, semi-direct, and indirect effects; Cyclic processes- carbon, oxygen, nitrogen and sulphur cycles; temperature profile of the atmosphere; temperature regulation in the mesosphere, stratosphere and troposphere; photochemical processes; photo dissociation and ionization; reactions of electronically excited species; adiabatic processes and correlation rules; chemical kinetics- unimolecular, bimolecular and tri-molecular reactions; condensed-phase, surface and heterogeneous reactions.

Stratospheric chemistry: Oxygen only chemistry; reaction scheme; stratospheric ozone; Chapman reactions; influence of trace constituents; catalytic cycles; Null cycles; holding cycles and reservoirs;

natural sources and sinks of catalytic species; heterogeneous and homogenous chemistry; consequences of ozone perturbation; ozone variations and trends; Antarctica ozone hole and its history; polar stratospheric clouds.

Tropospheric chemistry:– Tropospheric constituents and oxidants sources, sinks and transport; oxidation and transformation; photochemical chain initiation; oxidation steps; tropospheric ozone production; biogenic volatile organic compounds; heterogeneous processes and cloud chemistry.

Air Pollution: Natural and anthropogenic pollution; sources of anthropogenic pollution; primary and secondary pollutants; atmospheric effects - smog, acid rain (sulphur dioxide and nitrogen dioxide), visibility; tropospheric ozone-nitrogen dioxide chemistry; ion chemistry in the atmosphere; introduction to air quality modeling; Lagrangian and Eulerian modeling concepts; Receptor modelling and source apportionment.

Reference Books:

1. Hobbs, P. V., Introduction to Atmospheric Chemistry, Cambridge University Press, 2000.
2. Jacob, D. J., Introduction to Atmospheric Chemistry, Princeton University Press, 1999.
3. Wayne, R. P., Chemistry of Atmospheres, 3rd edition, Oxford University Press.
4. Pitts, B. J, F., and Jr. J. N. Pitts, Chemistry of the Upper and Lower Atmosphere, Academic Press, 2000.
5. Seinfeld, J. H., and S. N. Pandis, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, Wiley, 2016.
6. Ya, K., Kondratyev, L. S. Ivlev, V. F. Krapivin, and C. A. Varotsos, Atmospheric Aerosol properties: Formation, Processes, Impacts:, Springer, 2006.
7. Lewis, E. R. and S. E. Schwartz, Sea Salt Aerosol Production: Mechanisms, Methods, Measurements and Models – A Critical Review, American Geophysical Union, 2004.

6. Ocean Acoustics

Introduction to Ocean acoustics; acoustic plane; spherical and cylindrical wave equations and their solutions; sound velocity in fluids; energy density; acoustic intensity; acoustic standards; the decibel scale.

Reflection and transmission of plane waves: Normal incidence; fluid-fluid interface; fluid-solid interface; standing wave patterns; transmission through three media; oblique incidence; fluid-fluid interface; angle of intromission; fluid-solid interface.

Absorption of sound waves in fluids; sound transmission loss in sea water; sound velocity structure of the sea; ray tracing; refraction phenomenon; sound channels; surface and bottom reflections; sound transmission in shallow water; ray and normal mode solutions; attenuation in inhomogeneous fluids; scattering from non-resonant bodies and bubbles; bubble resonance; scattering characteristics of marine life; non-resonant bodies; resonant swim bladder of fish.

Piezoelectric and magnetostrictive sonar transmitting and receiving transducers; hydrophones; radiation pattern of sonar transducers; array of discrete and continuously distributed source elements; transmitting and receiving directivity factor and directivity index; beam shaping for arrays.

Active sonar signals; resolution and bandwidth; source level; echo level; masking by noise and reverberation; improving signal-to-noise ratio; additional parameters significant in active sonar; echo sounding and sub bottom profiling; diffraction of impulsive signal at rough surfaces; average reflection coefficient for rough surfaces; doppler effect of moving objects; doppler navigation; passive sonar; acoustic output of ships; passive detection range; passive detection hydrophones; array steering; ocean acoustic tomography.

Reference Books:

1. Kinsler, L.E., A.R. Frey, A. B. Coppens, and J. V. Sanders, Fundamentals of Acoustics, 4th edition, John Wiley & Sons Inc, 2000. :
2. Medwin, H., and C. Clay, Acoustical Oceanography, Academic Press, 1997.
3. Tucker, D. G., Underwater Observation Using Sonar, Fishing News Ltd, 1966.
4. Tolstoy, I., and C. Clay, Ocean Acoustics, Acoustical Society of America, 1987.
5. Theory and Experiments in Underwater Sound : N.N. Rao

7. Marine Pollution

Pollution of the oceans; kinds of pollution; marine pollutants and their sources; types of pollutants-physical, chemical, biological, thermal, radioactive and non-point; oil and micro-plastic pollution; effects of pollution.

Oceanographic factors involved in dispersing pollutants; the transport phenomenon; advective and diffusion aspects; dispersal of pollutants in estuaries and near shore areas; physical oceanographic factors affecting marine pollution.

Control and abatement of marine pollution; effluent outfalls; radioactive waste disposal; containment of oil at sea; oil slicks and their management; chemical dispersants; water quality parameters and standards; procedure and instrumentation

Monitoring strategies; global waste management and the oceans; hazardous material transport; carrying capacity; open ocean dumping and incineration; monitoring and control; general laws on prevention on marine pollution.

Reference Books:

1. Massin, J. M., Remote Sensing for the control of Marine Pollution, Vol. 6, Springer, 1984.
2. Geyer R. A., Marine Environment Pollution, Elsevier, 1980
3. Gross, M. G., Ocean Dumping and Marine Pollution
   Duedall, I. W., J. M. Capuzzo and D. R. Kester, Oceanic Processes in Marine Pollution,1988

8. Ocean Optics

Characterization of light field in water; radiance; irradiance; diffuse attenuation coefficient; water leaving radiance; inherent and apparent optical properties of sea water; Light scattering by water molecules; raman scattering by water; Rayleigh scattering and Mie scattering.

Absorption characteristics of water constituents; backscattering characteristics of water constituents; fluorescence by phytoplankton and dissolved organic matter; impact of bottom refection on upwelling radiance and volume reflectance in water; colour of the sea.

Optical properties of Case I and Case II waters; refractive index of sea water; remote sensing reflectance, reflectance albedo, photosynthetically active radiation.

Hydro-optical models; Bio-optical models; composition of natural water and its relation to hydro-optics; Ocean colour remote sensing; ocean colour sensors; algorithms for ocean colour data processing; ocean colour application studies; underwater photography and imaging instruments.

Reference Books:

1. Jerlov, N. G., Marine Optics, 2nd edition, Elsevier Science, 1976.
2. Shifrin, K. S., Physical Optics of Ocean waters, Springer, 1988.
3. Pozdnyakov, D., and H. Graßl, Colour of Inland and Coastal waters:A methodology for its interpretation, Springer, 2003.

9. Agricultural Meteorology

Agricultural meteorology-meaning and scope; components of agricultural meteorology; importance of weather and climate for agricultural production; role and responsibilities of agricultural meteorologists.

Agrometeorological observations; agromet observatories; soil climate; radiation; soil temperature; soil moisture; evaporation and evapotranspiration; lysimeters; open pan evaporimeters; phenological observations and measurements; automatic weather stations.

Weather and climate in relation to plants and crops; principles of crop production; evaluation of crop responses to weather elements; impact of variability of climate on crop production; insects and plant diseases; climate classification; agro-climatic zones and agro-ecological regions of India.

Crop weather calendars; weather forecasts for agriculture at short, medium and long range levels; agromet advisories, forecasts and warning for agriculture and forestry; benefits of weather services to agriculture.

Weather hazards in agriculture: droughts, types of drought and their causes; prediction of drought; floods, hail, dew, frost and protection against them; windbreaks and shelterbelts; hail suppression, dissipation of fog, modification of frost intensity and severe storms; mulches and anti-transpirants; meteorological conditions in artificial and controlled climates; green, plastic, glass and animal houses.

Crop weather models: Empirical and statistical crop weather models; regression models; growth and yield prediction models; crop simulation models, e. g. CERES, WOFOST, SPAW, RESCAP, WTGROW; forecasting of pests and diseases; verification, calibration and validation of models.

Climate change: green house effect; CO_2 increase; global warming and its impact on agriculture; future scenario; global and Indian contexts

Reference Books:

1. Venkskevitch, G. Z., Agro meteorology , Israel Program for Scientific Transition, IPST press, Jerusalem, 300 pp., 1961.
2. Guide to Agricultural Meteorological Practices by WMO No.134, 1981. 4.
3. Lecture Notes for training Class IV Agricultural Meteorological personnel by WMO No.593, 1982. 5.
4. Reddy, S. J., Agroclimatic/Agrometeorological Techniques, Jeevan Charitable Trust, ICRISAT Colony, Secunderabad, 1993.

10. High Performance Computing in Atmosphere and Ocean Sciences

Introduction to multitasking and massively parallel processing; various architectures; application of HPC in global and regional models; parallelism in weather and climate models; domain decomposition method; 1D, 2D and 3D parallelization of GCMs; MPI, PVM, SHMEM, message passing libraries; high performance compilers; load balancing; interprocessor communication; network communication; graphical user interface; data formats; local and wide area networking; data flow and data mining.

Reference Books:

1. Røed, L. P., Atmospheres and Oceans on Computers-Fundamentals, Springer, 2019.
2. Yang, L. T., and M. Guo, High-Performance Computing: Paradigm and Infrastructure, Wiley interscience, 2005.

11. Ocean State Forecasting

Numerical techniques used in marine forecasting; forecasting of tides and currents in the North Indian Ocean; real time forecasting of storm surges in India and its neighborhood; prediction of coastal upwelling; fronts and vertical thermal structure in the Bay of Bengal and the Arabian Sea; wave prediction in the North Indian Ocean; forecasting of salinity and flow structure in the Indian estuaries.

Reference Books:

1. .Schott, F. A. and J. P. McCreary, The Monsoon Circulation of the Indian Ocean, Progress in Oceanography, 2001.
2. Emery, W. J. and R. E. Thomson. Data Analysis Methods in Physical Oceanography, Elsevier Science, 2014. .
3. Miller, R. N., Numerical Modeling of Ocean Circulation, Cambridge University Press, 2006.
4. Kantha, L. H. & C. A. Clayson, NumericalModels of Oceans and Oceanic Processes, Academic Press, 2000.

12. Mesoscale modeling

Mesoscale processes; scaling; observations and analysis; wave fundamentals; Lee waves and windstorms; orographically forced flows; orographic precipitation; differential heating; gravity currents and convective initiation; isolated convective storms; tornadoes; MCS -squall lines; heavy rainfall; internal structure of cyclones; rain bands - observations and theory; Hydrostatic approximation and nonhydrostatic dynamics, basics of mesoscalemodeling; mesoscale data assimilation; details of some community mesoscale models (MM5 and WRF), mesoscale simulation of intense convective events.

Reference Books:

1. Pielke, R. A., Mesoscale Meteorological Modelling, Academic Press, 2013.
2. Atkinson, B. W., Mesoscale Atmospheric Circulation, Academic Press
3. Ray, P. S., Mesoscale Meteorology and Forecasting, American Meteorological Society, 1986.

13. Air Pollution Studies

Various sources and types of pollutants in the atmospheric environment; Reynolds averaging; closure problem; atmospheric diffusion; types of boundary conditions for modeling dispersion; solution of diffusion equation for instantaneous and continuous sources; dispersion from a ground/ elevated sources; long and short range dispersion, removal mechanism; dry and wet deposition; chemical removal; atmospheric surface boundary layer; similarity theory; wind rose, dispersion parameters and plume rise; Gaussian and box models; optical stack height; case studies for the dispersion of pollutants.

Reference Books:

1. Seinfeld, J. H., and S. N. Pandis, Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, Wiley, 2016.
2. Arya, S. P., Air Pollution Meteorology and Dispersion, Oxford University, 1988.
3. Arya, S. P., Introduction to Micrometeorology, Academic Press, 2001
4. Hinds, W. C., Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles, Wiley-Interscience, 1999.

14. Coastal Oceanography

Wave generating and restoring forces; shallow water waves; coastally trapped long waves; influence of sea-bed friction; wave spectra; refraction and shoaling of waves; seiches; waves-current

interaction; wave transformation in shallow waters; Tsunamis; breaking waves; phenomenon of wave reflection; refraction and diffraction; surf zone hydrodynamics; shoreline setup; swash and runup heights; wave generated alongshore currents; Rip currents; Storm surges; theory of tides; tides in rivers and coastal lagoons; general characteristics of estuaries; classification of estuaries; stratification; estuarine circulation and mixing; shear instability at an interface; entrainment and sedimentation in estuaries; dispersion processes:-Advective and turbulent diffusion; river-estuary-near-shore systems; sediment characteristics; sediment transport mechanisms; bedform dynamics; suspended particles in wave flows and vortices; morpho-dynamics- Beach profiles; tide range influence on beach morphology; lee side erosionl beach realignment due to climate change; interaction of an estuary with the near-shore bay.

Reference Books:

1. Holthuijsen, L.H., Waves in Oceanic and Coastal Waters, Cambridge, 2009.
2. Svendsen, I.A., Introduction to Nearshore Hydrodynamics, World Scientific, 2006.
3. Janssen, P., The Interaction of Ocean Waves and Wind, Cambridge, 2009.
4. Mani, J.S., Coastal Hydrodynamics, PHI, 2012.
5. Dean, G.R. and R.A. Dalrymple, Coastal Processes with Engineering Applications, Cambridge, 2002.
6. Nielsen, P., Coastal and Estuarine Processes, World Scientific, 2009

15. Glaciers and Climate

Introduction to Glacial Environments; Glacier Mass Balance; Supraglacial, Englacial, and Basal Hydrology; Glacier Dynamics I - Internal Deformation; Glacier Dynamics II - Basal Sliding; Glacier Dynamics III - the Role of Deformable Sediments; Glacier Surging; Ice Cores: Glaciological Aspects and the Climate Record, applications of remote sensing techniques for glacial change monitoring w.r.t climate change.

Reference Books:

1. Cronin, T. M., Paleoclimates: Understanding Climate Change Past and Present, Columbia University Press, 2009.
2. Bradley, R. S., Paleoclimatology, Volume 68, Second Edition: Reconstructing Climates of the Quaternary, Academic Press, 1999.
3. Cuffey, K. M., and W. S. B. Paterson: The physics of Glaciers, 4th edition, Academic Press, 2010.
4. Van der veen, C. J., Fundamentals of Glacier Dynamics, 2nd edition, CRC Press, 2017.

16. Climate and Energy

Introduction to the atmosphere: weather and climate processes; Solar radiation and surface energy balance: Solar constant, solar geometry, atmospheric radiative transfer, clouds and aerosols, surface energy budget, urban energy use, sensors and observations; Meteorological considerations for solar power: solar resource assessment, solar forecasting for different timescales, uncertainty estimation, types of solar systems; Wind in the atmospheric boundary layer: boundary layer structure and evolution, surface layer, stability, log and power laws, flow over complex terrain, low-level jets, offshore winds, sensors and observations; Meteorological considerations for wind power: wind resource assessment, wind forecasting for different timescales using statistical and numerical methods, uncertainty estimation, types of turbines, turbine wakes, wake interactions in wind farms, turbine and wake models, LES and mesoscale models of wind farms; Solar-wind coupling: resource variability, power demand, optimization. Wave energy, tidal energy, ocean thermal energy conversation (OTEC), geothermal energy

Reference Books:

1. Ahrens, D., Meteorology Today, 11th Edition, Cengage, 2015.

2. Emeis, S., Wind Energy Meteorology, 1st Edition, Springer, 2013.
3. Garratt, J. R., The Atmospheric Boundary Layer, 1st Edition, Cambridge University Press, 1994.
4. Kaimal, J.C. and J. J. Finnigan, Atmospheric Boundary Layer Flows, 1st Edition, Oxford, 1994.
5. Kalogirou, S., Solar Energy Engineering, 1st Edition, Elsevier, 2009.
6. Stull, R., Introduction to Boundary Layer Meteorology, 1st Edition, Kluwer Academic, 1999.
7. Stull, R., Meteorology for Scientists and Engineers, 2nd Edition, Cengage, 1999.

17. Mountain Meteorology

Latitudinal, altitude and topographical effects of mountain on meteorological elements; Circulation systems related to orography, mountain and valley winds; Climatic characteristics of mountains, energy budgets, cloudiness, precipitation, evaporation, fog, lightening, snow avalanches and valley air pollution; some case studies, the equatorials mountains of New Guina, the Himalayas, sub- tropical desert mountains, the Rocky and the Alps. General properties of mountain perturbations, adiabatic meso-scale perturbations in a straight atmospheric flow, adiabatic synoptic scale perturbations, computation, of the dissipation of mechanical energy resulting from a mountain perturbation, modelling aspects of mountain waves, mountain generated momentum fluxes, theory of linear gravity waves, orographic gravity-wave drag, its parameterisation and influence in general circulation models.

Reference Books:

1. C David Whiteman, C. D., Mountain Meteorology: Fundamentals and Applications, Oxford University Press, USA.
2. Chow, F. K., S. F.J. De Wekker and B. J. Snyder, Mountain Weather Research and Forecasting: Recent Progress and Current Challenges; Springer Atmospheric Sciences, 2012.

18. Climate and Water resources

The climate system: climate, climate change, drivers of climate change, characteristics of climate system components, greenhouse effect, carbon cycle, general circulation of wind, ozone hole in the stratosphere, ENSO and its teleconnections.

Impacts of climate in the Indian and Global context; observed and projected changes of IPCC, impacts on water resources, need for vulnerability assessment, water-related adaptation to climate change in the fields of ecosystems and biodiversity, agriculture and food security, land use and forestry, human health, water supply and sanitation, infrastructure and economy (insurance, tourism, industry and transportation); adaptation, vulnerability and sustainable development sector-specific mitigation, carbon dioxide capture and storage (CCS); cropland management, afforestation and reforestation; potential water resource conflicts between adaptation and mitigation; implications for policy and sustainable development

Water resources assessment case studies; Ganga Damodar Project; Himalayan glacier studies; Ganga valley project; adaptation strategies in assessment of water resources; operation policies for water resources projects; flood management strategies; drought management strategies; temporal & spatial assessment of water for irrigation; land use & cropping pattern; coastal zone management strategies.

Reference Books:

1. IPCC Report AR5
2. Shukla, P R, Subobh K Sarma, NH Ravindranath, Amit Garg and Sumana Bhattacharya, Climate Change and India: Vulnerability assessment and adaptation, University Press (India) Pvt Ltd, Hyderabad.
3. Preliminary consolidated Report on Effect of climate change on Water Resources, GOI, CWC, MOWR, 2008.

19. Middle Atmosphere Meteorology

Composition and structure of stratosphere, mesosphere and thermosphere; changes in chemical composition - homosphere, heterosphere, ozonosphere; standard upper atmosphere; the ionosphere - composition morphology and general properties; general climatology of the middle atmosphere, wind and temperature distribution; zonally averaged circulation energetics of the middle atmosphere; vertically propagating planetary waves; sudden stratospheric warming; waves in the Equatorial stratosphere; quasi biennial oscillation (QBO); troposphere-stratosphere coupling; energetics of lower stratosphere; stratospheric warming, blocking situations in the troposphere.

Reference Books:

1. Andrews, C.G, J.R Holton & C. Leovy, Middle Atmosphere Dynamics
2. Brasseur, G. and S. Simon, Aeronomy of the Middle Atmosphere
3. Holton, J. R., R.A. Craig, Introduction to Dynamic Meteorology : The Upper Atmosphere
4. Holton, J. R., Dynamic Meteorology of the Stratosphere
5. Mesosphere Physics of the Earth's Upper Atmosphere : C.O. Hines, I. Paghis, T.R. Hatz. & J.A. Fejer
   Stratosphere-Troposphere interaction : K. Mohan Kumar

20. General Geology

Dimensions of earth, structure, composition and origin of earth; crust, mantle and core.

Internal dynamic process: Plate tectonics, continental drift, Earthquake and volcanoes.

External dynamic process: Weathering, erosion and deposition.

Fundamental concepts in Geomorphology: Geomorphic processes distribution of landforms drainage patterns; landforms in relation to rocks typesl paleochannelsl buried channels.

Origin of igneous, sedimentary and metamorphic rocks; sedimentary structures-petrographic character of conglomerate, sandstone, shale, limestones; introduction to sedimentary basins and deltaic systems; topographic maps; thematic maps; topographic and thematic profiles.

Palaeontology: Introduction to Palaeontology; fossils and fossilization; micropaleontology; Palynology: distribution of microfossils-foraminifera, radiolaria, conodonts, ostracodes, diatoms; importance of micro fossils in oil exploration.

Earth resources and environment.

Reference Books:

1. Carlson, Richard W; The Mantle and core: Treatise on geochemistry;v.2 Amsterdam: Elsevier, 2005
2. Robert L. Rudnick; The Crust Treatise on geochemistry;v.2 Amsterdam: Elsevier, 2005
3. William Lowrie ; Fundamentals of geophysics Cambridge University Press, 2007.
4. Thronbury, William D., Principles of geomorphology 2nd Edition New Delhi: CBS Publishers and Distributors, 2004.
5. Clifford Embleton and John Thornes; Process in geomorphology London Edward Arnold 1979.
6. G.W. Tyrrell; Principles of Petrology Bombay: B.I. Pub., 1980.
7. F.H.Lahee; Field Geology 6th edition Delhi : CBS Publishers & Distributers , 1987.
8. David M. Raup and Steven M; Principles of paleontology 2nd New Delhi : CBS Publishers, 2004