Course Curriculum

M. Sc. Programme in
Atmosphere and Ocean Sciences

School of Earth Ocean and Climate Sciences
Indian Institute of Technology Bhubaneswar
Argul, Khorda
Bhubaneswar -752050, Odisha
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Compliance Report:

Item	Committee Recommendation Credits	School's Proposal Credits
Theory	50-60 Core - 60-80% Elective: 20-40%	60 Core:80% Elective:20%
Labs.	12-18	13
Seminars	4	4
Thesis **Part-I** **Part – II**	10 16	10 16
Field work	4	4
Total	100 -108*	107*

***This includes 6 special credits towards field work/field training under earth science special category.**

Subject Name	Code	L-T-P	Credit	Contact Hour	Syllabus Page No.
SEMESTER – I					
Fundamental of Meteorology & Oceanography	**CL5L101**	**3-0-0**	**3**	**3**	**09**
Mathematical and Statistical Methods in Climate Science	**CL5L102**	**3-0-0**	**3**	**3**	**09-10**
Physics of Atmosphere & Ocean	**CL5L103**	**3-0-0**	**3**	**3**	**10**
Dynamics of Atmosphere & Ocean	**CL5L104**	**3-0-0**	**3**	**3**	**10-11**
Atmospheric Chemistry and Aerosol	**CL5L105**	**3-0-0**	**3**	**3**	**11**
Modelling of Dynamical Processes of Ocean and Atmosphere	**CL5L106**	**3-0-0**	**3**	**3**	**12**
Weather Analysis and Forecasting Laboratory	**CL5P101**	**1-0-3**	**3**	**4**	**12-13**
Application of Statistics and Mathematics in Climate Science Laboratory	**CL5P102**	**0-0-3**	**2**	**3**	**13**
		Total	**23**	**25**	
SEMESTER – II					
Air-Sea Interaction	**CL5L201**	**3-0-0**	**3**	**3**	**13-14**

Numerical Weather Prediction	**CL5L202**	**3-0-0**	**3**	**3**	**14**
Ocean State Forecasting	**CL5L203**	**3-0-0**	**3**	**3**	**14-15**
Observational techniques in Climate Science	**CL5L204**	**3-0-0**	**3**	**3**	**15-16**
Remote Sensing and GIS	**CL5L205**	**3-0-0**	**3**	**3**	**16**
Tropical Meteorology	**CL5L206**	**3-0-0**	**3**	**3**	**16-17**
Remote Sensing and GIS Laboratory	**CL5P201**	**0-0-3**	**2**	**3**	**17**
Numerical Simulation Laboratory – Atmospheric Processes	**CL5P202**	**0-0-3**	**2**	**3**	**17-18**
Numerical Simulation Laboratory – Oceanic Processes	**CL5P203**	**0-0-3**	**2**	**3**	**18**
Field work -I (4 ~ 6 Weeks)	**CL5T201**	**0-0-0**	**2**	**0**	**18**
		Total	**26**	**27**	
SEMESTER – III					
Micro Meteorology and Oceanography	**CL5L301**	**2-0-0**	**2**	**2**	**18-19**

Atmospheric Diffusion, Air and Water Pollution	**CL5L302**	**2-0-0**	**2**	**2**	**19**
Elective – I	**CL5L3XX**	**3-0-0**	**3**	**3**	**20-24**
Elective – II	**CL5L3XX**	**3-0-0**	**3**	**3**	**20-24**
Objective Analysis and Data Assimilation	**CL5L303**	**2-0-0**	**2**	**2**	**24**
Satellite Oceanography	**CL5L304**	**2-0-0**	**2**	**2**	**24-25**
Seminar I	**CL5S301**	**0-0-0**	**2**	**0**	**25**
Project Work -I	**CL5D302**	**0-0-0**	**10**	**0**	**25**
		Total	**26**	**14**	
SEMESTER – IV					
Science of Climate Change	**CL5L401**	**2-0-0**	**2**	**2**	**26**
Satellite Meteorology	**CL5L402**	**2-0-0**	**2**	**2**	**26-27**
Elective – III	**CL5L4XX**	**3-0-0**	**3**	**3**	**27-33**
Elective – IV	**CL5L4XX**	**3-0-0**	**3**	**3**	**27-33**

Numerical Product's Diagnostics Laboratory(Not Found)	**CL5P401**	**0-0-3**	**2**	**3**	**33**
Seminar II	**CL5S401**	**0-0-0**	**2**	**0**	**33**
Field Work – II /Industrial Training	**CL5T401**	**0-0-0**	**2**	**0**	**33**
Project Work -II	**CL5D401**	**0-0-0**	**16**	**0**	**33-34**
		Total	**32**	**13**	

ELECTIVE COURSES M. SC. (ATMOSPHERE AND OCEAN SCIENCES)

Subject Name	**New Code**	**L-T-P**	**Credit**	**Contact Hour**	**Syllabus Page No.**
Elective – I to II					
Ocean Modelling	**CL5L311**	**3-0-0**	**3**	**3**	**20**
Mesoscale Modelling	**CL5L312**	**3-0-0**	**3**	**3**	**20-21**
Tropical Cyclone and Storm Surge Modelling	**CL5L313**	**3-0-0**	**3**	**3**	**21**
Biological Oceanography	**CL5L314**	**3-0-0**	**3**	**3**	**21-22**
Air Pollution and Control	**CL5L315**	**3-0-0**	**3**	**3**	**22**
Mountain Meteorology	**CL5L316**	**3-0-0**	**3**	**3**	**22-23**

Computational Geosciences	**CL5L317**	**2-1-0**	**3**	**3**	**24**
Elective – III to IV					
Dynamics of Tropical Cyclones	**CL5L411**	**3-0-0**	**3**	**3**	**27**
Advanced Oceanography	**CL5L412**	**3-0-0**	**3**	**3**	**27-28**
Global Tectonics and Climate Change	**CL5L413**	**3-0-0**	**3**	**3**	**28-29**
Ocean Resource and Technology	**CL5L414**	**3-0-0**	**3**	**3**	**29**
Air Quality Modelling	**CL5L415**	**3-0-0**	**3**	**3**	**30**
Coastal Processes and Ecosystems	**CL5L416**	**3-0-0**	**3**	**3**	**30-31**
Ocean Circulations and Wave Modelling	**CL5L417**	**2-1-0**	**3**	**3**	**31**
High Performance Computing in Atmosphere and Ocean sciences	**CL5L418**	**2-1-0**	**3**	**3**	**32**
Basics of Fluid Dynamics	**CL5L419**	**3-0-0**	**3**	**3**	**32-33**

SEMESTER – I

Subject Code: CL5L101	Subject Name: Fundamental of Meteorology & Oceanography	L-T-P: 3-0-0	Credit: 3
Pre-requisite(s): Nil			
Weather and climate, composition of atmosphere, radiation in the atmosphere, Air temperature and pressure, atmospheric moisture, properties of sea water, definition and measurement of oceanic parameters, basic physical laws, classification of forces in oceanography and meteorology and, atmospheric and oceanic motions.			
Text/Reference Books: 1. Wallace and Hobbs. *Atmospheric Science, Second Edition: An Introductory Survey,*Elsevier 2. Garrison T. *Essential of Oceanography*, Cengage Learning 3. John A. Knauss. *Introduction to physical Oceanography*, Waveland Pr Inc. 4. Marshall. John, and R. Alan Plumb. *Atmosphere, Ocean, and Climate Dynamics: An Introductory*, Academic Press.			

Subject Code: CL5L102	Subject Name: Mathematical and Statistical Methods in Climate Science	L-T-P: 3-0-0	Credit: 3
Pre-requisite(s): Nil			
Rank and inverse of matrix, consistency of linear system of equations, eigenvalues and eigenfunctions, orthonormal systems. Taylor's theorem and infinite series, functions of several variables, maxima and minima, ordinary differential equations, series solution of Legendre and Bessel equations, Laplace transforms. Initial and boundary value problems, complex analysis, periodic, even and odd functions, Time series analysis: Fourier and spectral methods. Probability, conditional probability, mean, median and variance, analysis of variance distributions. **Text/Reference Books:**			

1. Hans von Storch and Francis W. Zwier, *Statistical analysis in climate research.* Cambridge University Press.
2. W. J. Emery, Richard E. Thomson. *Data Analysis Methods in Physical Oceanography.* Elsevier Science
3. Trauth, E. Sillmann, R. Gebbers, N. Marwan. *MATLAB® Recipes for Earth Sciences*, Springer

Subject Code: CL5L103	**Subject Name: Physics of Atmosphere and Ocean**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Thermodynamics of dry air, thermals; Thermodynamic of moist air: thermodynamic properties of water; Clausius - Clapeyron (C-C) equation, moist processes in the atmosphere, adiabatic; saturated and unsaturated accent, Thermodynamic diagrams, Moist convection, formation of cloud droplets, precipitation, thermodynamics of sea water, Processes at the sea surface, salinity, bulk temperature, measurement techniques of SST; heat flux and its global distribution, sea surface hydrology, space waves and tides, ocean surface waves, internal waves, Kelvin waves, Rossby waves, tidal currents and storm surges.

Text/Reference Books:

1. Holton J R: *An Introduction to Dynamical Meteorology,* Academic Press
2. John R. Howell, Robert Siegel, M. Pinar Menguc. *Thermal Radiation Heat Transfer.* CRC Press
3. Lynne D. Talley: *Descriptive physical oceanography: an introduction,* Academic Press
4. John Ralph Apel. *Principles of Ocean Physics*. Academic Press

Subject Code: CL5L104	**Subject Name: Dynamics of Atmosphere and Ocean**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Fundamentals of Geophysical Fluid Dynamics, Equations of motion in rotating frame; potential vorticity conservation, Simplified equations for ocean and atmosphere; Instabilities and Waves, Large-Scale Atmospheric Circulation Equatorial dynamics, heat-induced tropical circulations; Mid-latitude circulation; planetary waves and stratosphere; Ocean Dynamics: Ekman layers, Sverdrup transport, western boundary currents; Large-scale ocean circulation; Response of ocean to a moving storm or hurricane; oceanic mixed layer.

Text/Reference Books:

1. Gill A. *Dynamics of Ocean and Atmosphere*, Academic Press
2. Pond and Pickard. *Introductory Dynamical Oceanography*, Butterworth-Heinemann
3. John A. Knauss. *Introduction to physical oceanography*, Waveland Pr Inc
4. Joseph Pedlosky. *Waves in the Ocean and Atmosphere: Introduction to Wave Dynamics*, Springer

Subject Code: CL5L105	**Subject Name: Atmospheric Chemistry and Aerosol**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Major global cycles of the earth's atmosphere, atmospheric composition and residence times, oxidation-reduction reactions and chemical kinetics, solution chemistry, acid deposition and precipitation chemistry, gas phase atmospheric reactions, atmospheric photochemical reactions and smog formation, atmospheric aerosols, particulate matter and visibility degradation. Chemistry of the troposphere, upper atmosphere and pollution, ions in the atmosphere and airglow, atmospheric chemistry and climate change.

Text/Reference Books:

1. Barbara J. Finlayson-Pitts, James N. Pitts Jr. *Chemistry of the Upper and Lower Atmosphere: Theory, Experiments and Applications 1st Edition*, Academic Press
2. Wayne Richard P. *Chemistry of Atmosphere 3 Rev ed Edition*, Oxford University Press
3. Kirill Ya. Kondratyev,Lev S. Ivlev, Vladimir F. Krapivin, Costas A. Varotsos. *Atmospheric Aerosol Properties*, Springer

Subject Code: CL5L106	Subject Name: Modelling of Dynamic Processes of Oceans and Atmosphere	L-T-P: 3-0-0	Credit: 3

Pre-requisite(s): Nil

Finite difference approximations, Discrete analogues of differential equations in meteorology, relaxation methods, advection equations, Time differencing schemes, stability analysis, shallow-water models and filtering, Integral invariants, enstrophy and energy conserving schemes, Matsuno, leap-frog schemes, geostrophic adjustment, spectral methods, semiimplicit formulation, Non-linear instability, vertical coordinates, vertical discretization, Limited area models, Ocean mixing and ocean wave modeling.

Text/Reference Books:

1. Kantha and Carol Anne Clayson. *Numerical Models of Oceans and Oceanic Processes,* Academic Press
2. Benoit Cushman-Roisin and Jean-Marie Beckers. *Introduction to Geophysical Fluid*
3. *Dynamics, Volume 101, Second Edition: Physical and Numerical Aspects.* Academic Press
4. James C. McWilliams. *Fundamentals of Geophysical Fluid Dynamics,* Cambridge University Press
5. Mark Z Jacobson. *Fundamentals of Atmospheric Modeling,* Cambridge University Press

Subject Code: CL5P101	Subject Name: Weather Analysis and Forecasting Laboratory	L-T-P: 1-0-3	Credit: 4

Pre-requisite(s): Nil

Meteorological instruments, sensors, radiosonde, meteorological parameters, GTS, weather codes and decoding of weather observations, programming languages, Unix & shell programming, data formats, software tools for meteorological data, thermodynamic diagrams, weather charts, air masses and fronts, jet streams, mid-latitude and tropical disturbances; synoptic features during different seasons, meso-scale systems, monsoon

climatology, 850 hPa & 200 hP, ψ and χ fields, mass & wind fields, cyclone development, synoptic forecasting.

Subject Code: CL5P102	**Subject Name: Application of Statistics and Mathematics in Climate Science Laboratory**	L-T-P: 0-0-3	**Credit: 2**
Pre-requisite(s): Nil			
Boundary value problems, meteorological fields in terms of orthogonal functions, normal modes, Fourier-Legendre transforms, FFT; Asymptotic expansions, method of multiple scales applied to atmospheric motions, Calculus of variations and Rayleigh-Ritz method; Probability, covariance and correlation, multivariate distributions and analysis, principal component analysis of climate data, singular value decomposition (SVD), Uncertainty analysis, Data assimilation techniques, error statistics, statistical softwares for satellite data analysis.			

SEMESTER – II

Subject Code: CL5L201	**Subject Name: Air-Sea Interaction**	**L-T-P: 3-0-0**	**Credit: 3**
Pre-requisite(s): Nil			
Ocean-atmosphere system, transfer properties between atmosphere and ocean, oceanic absorption of solar energy, fluxes in the surface boundary layer over the sea, marine boundary layer, ENSO, variability of the ocean parameters in relation to Indian monsoon physical parameterizations of the air-sea interaction, coupled ocean-atmosphere modeling.			
Text/Reference Books: 1. G. T. Csanady and Mary Gibson. *Air-Sea Interaction: Laws and Mechanisms*, Cambridge University Press 2. Hobbs P V. *Basic Physical Chemistry for The Atmospheric Sciences*, Cambridge University Press			

3. J. R. Garratt. *The Atmospheric Boundary Layer,* Cambridge University Press
4. Boris A. Kagan. *Ocean Atmosphere Interaction and Climate Modeling*, Cambridge University Press

Subject Code: CL5L202	**Subject Name: Numerical Weather Prediction**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Introduction: Overview of numerical weather prediction. Governing equations: continuous equations, map projections, vertical coordinate system, wave oscillations in the atmosphere, filtering approximations. Numerical methods: finite-difference methods, time and space differencing, stability analysis; spectral method, spherical harmonics, boundary conditions. Numerical models: Global models, regional models, mesoscale models. Parameterization of sub-grid scale physical processes: planetary boundary layer, moist microphysics physics, cumulus convection, radiation, air-sea interaction processes, and land surface processes. Data assimilation: Objective analysis schemes, continuous data assimilation techniques - 3D & 4D Variational assimilation; initialization. Predictability and Ensemble forecasting: Fundamental concept about chaotic systems and atmospheric predictability.

Text/Reference Books:

1. Tim Vasquez *Weather Analysis and Forecasting Handbook*, Weather Graphics Technologies
2. Eugenia Kalnay. *Atmospheric modelling, data assimilation and predictability*, Cambridge University Press
3. Patrick Santurette, Christo Georgiev. *Weather Analysis and Forecasting: Applying Satellite Water Vapor Imagery and Potential Vorticity Analysis 1st Edition*, Academic Press

Subject Code: CL5L203	**Subject Name: Ocean State Forecasting**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

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 neighbourhood. 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.

Text/Reference Books:

1. Schott and McCreary. *The monsoon circulation of the Indian Ocean*, Progress in Oceanography, Science Direct
2. W. J. Emery, Richard E. Thomson. *Data Analysis Methods in Physical Oceanography,* Elsevier Science
3. Robert N. Miller. *Numerical Modeling of Ocean Circulation*, Cambridge University Press
4. Kantha L. H. & C. A. Clayson. *Numerical Models of Oceans and Oceanic Processes,* Academic Press

Subject Code: CL5L204	**Subject Name: Observational techniques in Climate Science**	**L-T-P: 2-0-0**	**Credit: 2**

Pre-requisite(s): Nil

General measurement system, principles, measurement of meteorological parameters, wind speed, temperature and humidity, pressure etc, in-situ and remote measurements, SODAR, LIDAR, RADAR techniques, aerosol measurement techniques, optical depth, size distribution, chemical composition, trace gas measurement techniques.

Text/Reference Books:

1. Alexander Kokhanovsky, Gerrit De Leeuw. *Satellite Aerosol Remote Sensing Over Land,*Springer
2. A P Cracknell, Dorderecht: *D Reidel. Remote Sensing Applications in Marine Science and Technology.* CRC Press
3. E Stefan. *Measurement Methods in Atmospheric Sciences In situ and remote,*Borntraeger Science Publishers

4. Ghassem Asrar. *Theory and Applications of Optical Remote Sensing,*Wiley-Interscience

Subject Code: CL5L205	**Subject Name: Remote Sensing and GIS:**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Electromagnetic radiation, frequency and wavelength; nature of electromagnetic radiation, polarization, atmospheric windows and absorption bands; interaction with surface features, spectral reflectance, identification of surface elements based on spectral reflectance, spectral reflectance of vegetation. Types of sensors: multi-spectral, hyper-spectral, thermal IR and synthetic aperture radars; sensor design and selection; Image processing, digital image processing, radiometric and geometric corrections, atmospheric corrections, pixel resampling methods. Remote sensing of vegetation: leaf area index, soil line and vegetation, plant water and atmospheric water absorption bands. Applications in studying soil properties, rock and mineral identification, geomorphology, volcanology, fluvial processes, coastal processes and desertification.

Text/Reference Books:

1. George Joseph. *Fundamentals of Remote Sensing*, Orient Blackswan
2. S. Kumar. *Basics of Remote Sensing and GIS,* Laxmi Publications
3. Paul Longley et al. *Geographic Information Systems and Science,* Wiley
4. Ghassem Asrar. *Theory and Applications of Optical Remote Sensing*, Wiley-Interscience

Subject Code: CL5L206	**Subject Name: Tropical Meteorology**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Solar Energy, Differential heating; Moisture distribution in the Atmosphere, Global wind, pressure and precipitation distribution, The tropics; major synoptic and surface features; structure of the tropics; contrast between the tropics and mid-latitudes; important

distinctions; role of the tropics in the general circulation, Hadley and Walker circulations, basic scaling, tropical waves. Monsoon and its variability: Monsoon, semi-permanent features, Asian and Indian monsoon, epochs of monsoon, seasonal variability of monsoon, intra-seasonal variability, Madden-Julian Oscillation, role of Hadley and walker circulation in modulation intra-seasonal variability of monsoon. Interannual variability of monsoon, El Nino-Southern Oscillation (ENSO), Quasi-Biennial Oscillation (QBO); Tropical Cyclones: theories relevant to forecasting the genesis, motion and intensity of tropical cyclones; Tornadoes; Thunderstorms, Squall lines.

Text/Reference Books:

1. G C Asnani. *Tropical Meteorology (Vol 1-3, three Volumes)*, Willey
2. T.N. Krishnamurti, Stefanova and Misra. *Tropical Meteorology: An Introduction*, Springer
3. Wang, Bin. *The Asian Monsoon*, Springer
4. Steven A. Ackerman, John A. Knox. *Meteorology: Understanding the Atmosphere*, Jones & Bartlett Learning

Subject Code: CL5P201	**Subject Name: Remote Sensing and GIS Laboratory**	**L-T-P: 0-0-3**	**Credit: 2**

Pre-requisite(s): Nil

Remote sensing satellites and various data products (paper product & Digital), False Color Composition & Natural Composition, Formulation of Interpretation Keys, on screen Visual image Interpretation. Satellite digital data Formats, Geo-referencing of Digital Image. Image enhancement techniques, Image ratio and image classification. Land, Ocean and Atmosphere Remote Sensing Data Formats, Processing, Interpretation & Analysis. GIS software, 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 (Pction of Geo-database, Integration of attribute data, Analysis using Map algebra, Map composition and finalization, Web-GIS.

Subject Code: CL5P202	**Subject Name: Numerical Simulation Laboratory – Atmospheric Processes**	**L-T-P: 0-0-3**	**Credit: 2**

Pre-requisite(s): Nil
Data Analysis in Atmospheric Science with FORTRAN, MATLAB and Visualization of Atmospheric datasets. Development of simple Atmospheric radiative transfer models. Implementation of simple climate models and atmospheric processes.

Subject Code: CL5P203	**Subject Name: Numerical Simulation Laboratory – Oceanic Processes**	**L-T-P: 0-0-3**	**Credit: 2**
Pre-requisite(s): Nil			
Programming in FORTRAN/C: Program layout, variables and data structures, functions, loops and conditional statements, input/output routines; examination and implementation of useful algorithms. Data Analysis in Ocean Science with MATLAB: Script and Functions, M-file, Plots and Visualization of ocean models datasets. Shallow Water equation and solutions. Wind driven circulation. Ocean model. Coastal Upwelling.			

Subject Code: CL5T201	**Field Work – I (4 ~ 6 weeks)**	**L-T-P: 0-0-0**	**Credit: 2**
Pre-requisite(s): Nil			

SEMESTER – III

Subject Code: CL5L301	**Subject Name: Micro-Meteorology and Oceanography**	**L-T-P: 2-0-0**	**Credit: 2**
Pre-requisite(s): Nil			
Effects and sources of Air Pollutants, Air Quality Standards, solar Radiation, Wind system, Stability conditions, Mixing Height and mixed layer depth, Turbulence in atmosphere and			

oceans, Heat Island Effect, Land Sea Breeze, Puffs and Plumes, Nuclear Power Plants, Thermal Power Plants, Land Use Planning. An introduction to viscous flow. Atmospheric Surface Boundary layer, Momentum and Heat exchanges with homogeneous Surfaces, building Wakes and other Topographical Effect and, drag & Heat Transfer Coefficients, Experimental Implication of Meteorological and oceanographic Instruments, Various Techniques of Sampling and Standarisation, , The Eddy Diffusion Models, Gaussian Models, Evaluation of Dispersion parameters, optimal Stack height by using Nomograms, Long term and Short term Dispersion models, dry and Wet deposition, precipitation Chemistry, The Monin- Obukhov Similarity Theory, Modern Automatic Air Sampling and Monitoring Techniques, Siting Criteria for Meteorological Instruments and tracer Techniques, Statistical analysis of Meteorological and oceanography Data.

Text/Reference Books:

1. Xuhui Lee, William Massman and Beverly Law. Handbook of Micrometeorology: *A Guide for Surface Flux Measurement and Analysis,* Springer
2. Kantha and Clayson. *Small Scale Processes in Geophysical Fluid Flows,* Academic Press
3. Manfred Wendisch and Ping Yang. *Theory of Atmospheric Radiative Transfer*,Wiley-VCH

Subject Code: CL5L302	**Subject Name: Atmospheric Diffusion and Air and water Pollution**	**L-T-P: 2-0-0**	**Credit: 3**

Subject Code: Nil

Various sources and types of pollutants in the atmospheric environment, Reynolds averaging, closure problem, atmospheric diffusion, types of boundary conditions for modelling dispersion. soln of diffusion equation for instantaneous and continuous sources; dispersion from 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.

Text/Reference Books:

1. Roland B. Stull. *An Introduction to Boundary Layer Meteorology,* Springer
2. S. Pal Arya. *Air Pollution Meteorology and Dispersion,* Oxford University Press.
3. Mark Z Jacobson. *Air Pollution and Global Warming: History, Science, and Solutions,* Cambridge University Press

Elective – I & II

Subject Code: CL5L311	Subject Name: Ocean Modelling	L-T-P: 3-0-0	Credit: 3
Pre-requisite(s): Nil			
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 neighbourhood. 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.			
Text/Reference Books: 1. D B Haidvogel, A Beckmann ***Numerical Ocean Circulation Modeling,*** World Scientific Publishing Company 2. Kantha L. H. & C. A. Clayson. *Numerical* ***Models of Oceans and Oceanic Processes***, Academic Press			

Subject Code: CL5L312	Subject Name: Mesoscale Modelling	L-T-P: 3-0-0	Credit: 3
Pre-requisite(s): Nil			
Governing Equations: Shallow water theory, Bottom friction, note on convection terms. Numerical Scheme: Numerical scheme for linear equation; Numerical scheme for convection term; Numerical scheme for bottom friction term Stability and Truncation errors: Rounding-off and truncation errors; Stability; Consistency and truncation error Initial Conditions: Initial conditions; Bottom deformation due to the fault motion Open and other Boundary Conditions: Open Boundary Conditions for Regular Waves and Forced Input; Open Boundary Conditions for Free Transmission. Boundary Conditions for Water Overflowing Structures; Boundary Conditions at Run-up Front: Wave front condition; Boundary Conditions When Water Overflows Structures.			

Text/Reference Books:

1. Kantha and Clayson. *Small Scale Processes in Geophysical Fluid Flows,* Academic Press
2. Eric P. Chassignet and J. Vernon. *Ocean Modeling and Parameterization,* Springer
3. Z. Kowalik & T. S. Murthy. *Numerical Modeling of Ocean Dynamics,* World Scientific Pub

Subject Code: CL5L313	**Subject Name: Tropical Cyclone and Storm Surge Modelling**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Modelling and understanding of influence of Large Scale environment, Meso-scale processes, Oceanic Influences, Influence of domain size, Influences of Topographical Interactions, Influences of Frontal Interaction, Warm Air Interaction, Influences of Aerosols, Anthropogenic Influences on tropical cyclone, Modeling of ocean circulation, waves & tides, upwelling and estuarine circulation, modeling storm surges.

Text/Reference Books:

1. Mohanty et al. *Monitoring and Prediction of Tropical Cyclones in the Indian Ocean and Climate Change,* Springer
2. Y Charabi. *Indian Ocean Tropical Cyclones and Climate Change,* Springer
3. J. P. Terry. *Tropical Cyclones,* Springer

Subject Code: CL5L314	**Subject Name: Biological Oceanography**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Oceanic life and ecosystems, biological productivity of ocean, biological exploitation of ocean, uses and problems of ocean, theories of population in marine ecological communities, mathematical models, ecological fluxes, scale analysis, effects of marine pollution on living resources. Physico-biological models, estuarine biological modeling, coastal ecosystem modeling.

Text/Reference Books:

1. James W. Nybakken. *Marine Biology: An Ecological Approach*, Benjamin Cummings.
2. Patricia A. Wheeler, Charles B. Miller. *Biological Oceanography*, Wiley-Blackwell
3. Timothy R. Parsons, Carol Lalli. *Biological Oceanography: An Introduction.* Butterworth-Heinemann

Subject Code: CL5L315	**Subject Name: Air pollution and Control**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Air pollution: definition, sources, classification. Dynamics of pollutant dispersion and disposal. Effects on environment including living and non-living matter, ambient air quality monitoring techniques. Air pollution indices, standards, norms, rules and regulations. Removal processes. An introduction to air pollution meteorology. Air laboratory-High Volume Sampling, handy Sampler, Bioaerosols sampler, Indoor Air Sampler, stack sampling

Text/Reference Books:

1. S. Pal Arya. *Air Pollution Meteorology and Dispersion*, Oxford University Press.
2. M. Lazaridis. *First Principles of Meteorology and Air Pollution*, Springer
3. Mark Z Jacobson. *Air Pollution and Global Warming: History, Science, and Solutions.* Cambridge University Press

Subject Code: CL5L316	**Subject Name: Mountain Meteorology**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

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 Guinea, 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.

Text/Reference Books:

1. David Whiteman. *Mountain Meteorology: Fundamentals and Applications*, Oxford University Press
2. Roger G. Barry. *Mountain Weather and Climate*, Cambridge University Press
3. F.K. Chow. *Mountain Weather Research and Forecasting*, Springer

Subject Code: CL5L317	**Subject Name: Computational Geoscience**	**L-T-P: 2-1-0**	**Credit: 3**

Pre-requisite(s): Nil

Introduction to probability: random experiments, events, sample space, definitions of probability. Conditional probability and independence of events, Bayes theorem. Random variables, discrete and continuous probability distributions, joint probability distributions, conditional probability distributions. Mathematical expectation, moment generating and characteristic functions.

Binomial, Poisson, Normal, Gamma, Exponential, Hypergeometric, Multinomial, Chi-square, t, and F distributions. Introduction to statistical inference, sampling distributions, point and interval estimation, hypothesis testing involving one and two univariate populations. Linear models ANOVA. Linear and multiple regression. Introduction to multivariate techniques PCA, factor analysis, linear discriminant analysis, classification.

Text/Reference Books:

1. W. H. Press, S. A. Teukolsky, W. T. Vetterling, & B. P. Flanner. *Numerical Recipes in C/Fortran: The Art of Scientific Computing*, Cambridge University Press
2. Trauth, E. Sillmann, R. Gebbers, N. Marwan. *MATLAB® Recipes for Earth Sciences,* Springer
3. D Wilks. *Volume 100: Statistical Methods in the Atmospheric Sciences, 3rd Edition,* Elsevier

Subject Code: CL5L303	**Subject Name: Objective Analysis & Data Assimilation**	**L-T-P: 2-0-0**	**Credit: 2**

Pre-requisite(s): Nil

The observing systems: present & future, subjective and objective analysis, function fitting, method of successive correction, Statistical Interpolation; Univariate and multivariate analysis, dynamic and normal-mode initialization, variational methods, variational and ensemble based assimilation, Kalman filtering, sensitivity analysis, estimation theory, 3D-/4DVAR shallow water model and its adjoint, radar data assimilation basics, oceanic data assimilation at mesoscale and assimilation of altimetry data.

Text/Reference Books:

1. Eugenia Kalnay. *Atmospheric modeling, data assimilation, and predictability*, Cambridge University Press
2. Arthur G., J.F. Kasper, R.A. Nash, C. F. Price., A. A. Sutherland. *Applied Optimal Estimation,* MIT Press
3. Pierre P. Brasseur and Jacques C.J. Nihoul. *Data Assimilation: Tools for Modelling the Ocean in a Global Change Perspective,* Springer

Subject Code: CL5L304	**Subject Name: Satellite Oceanography**	**L-T-P: 2-0-0**	**Credit: 2**

Pre-requisite(s): Nil

Introduction to satellite remote sensing of the ocean; Propagation and sensing of EM waves and their interaction and scattering with the ocean's surface; Atmospheric absorption and scattering of microwave; visible and infrared radiation; Celestial mechanics for understanding orbital dynamics and geometric distortions; Brief review of electromagnetic wave theory, antenna patterns and ocean surface processes; Detailed survey of major instruments for measuring oceanographic variables from space; Applications of visible, infrared, and microwave observations using objective, multi-spectral, and characteristic vector analysis; Emphasis on new methodologies, error assessments, sampling considerations and data interpretation.

Text/Reference Books:

1. G.A. Maul. *Introduction to Satellite Oceanography*, Springer
2. S Martin. *An Introduction to Ocean Remote Sensing*, Cambridge University Press
3. Ian S. Robinson. *Discovering The Ocean From Space*, Springer

Subject Code: CL5S301	**Subject Name: Seminar I**	**L-T-P: 0-0-0**	**Credit: 2**
Pre-requisite(s): Nil			
Students will be allotted different topics to give a write-up and presentation. They will be evaluated on both.			

Subject Code: CL5D302	**Subject Name: Project Work - I**	**L-T-P: 0-0-0**	**Credit: 10**
Pre-requisite(s): Nil			
Each student will be allotted a small research project during 3rd semester based on their interest. Part of the assigned project work needs to be complete in 3rd semester and the remaining work will be done in the 4th semester.			

SEMESTER – IV

Subject Code: CL5L401	Subject Name: Science of Climate Change	L-T-P: 2-0-0	Credit: 2
Pre-requisite(s): Nil			
Description of the climate system, natural greenhouse effect and the effect of trace gases and aerosols, feedbacks in the climate system, climate change in the past, ice ages, proxy records, abrupt climate change, Instrumental record of climate, climate variability on various time-scales, simple models of climate, General Circulation Models, natural and anthropogenic climate change: detection and attribution, impacts and mitigation of climate change.			
Text/Reference Books: 1. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller: *IPCC, 2007, Changes in Atmospheric Constituents and in Radiative Forcing. In: Climate Change 2007: Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* 2. J. David Neelin. *Climate Change and Climate Modeling,* Cambridge University Press 3. Kevin E. Trenberth. *Climate System Modeling,* Cambridge University Press 4. Boris A. Kagan. *Ocean Atmosphere Interaction and Climate Modeling, Cambridge University Press*			

Subject Code: CL5L402	Subject Name: Satellite Meteorology	L-T-P: 2-0-0	Credit: 2
Pre-requisite(s): Nil			
Satellite Meteorology, satellite observing system; retrieval of clouds, winds, temperature, humidity,trace gases and aerosols, rain; Image interpretation, ocean colours, SST, scatterometer studies, energy budget, Microwave soundings from satellites. Radar equation, Doppler & other polarization techniques, measurement of precipitation, severe storm detection, cyclonic storm detection and track prediction, hail detection and prediction, Lidar, acoustic radar & its principles.			

Text/Reference Books:

1. Kidder and Vonder Harr. *Satellite Meteorology: : An Introduction,*Academic Press
2. Ghassem Asrar. *Theory and Applications of Optical Remote Sensing,* Wiley-Interscience
3. John R Jensen. *Remote Sensing of the Environment: An Earth Resource Perspective,* Prentice Hall
4. R. R. Kelkar. *Satellite Meteorology*, BS Publications

Elective – III & IV

Subject Code: CL5L411	**Subject Name: Dynamics of Tropical Cyclones**	**L-T-P: 3-0-0**	**Credit: 3**
Pre-requisite(s): Nil			
Tropical cyclone classification, complexity of tropical cyclone motion from a wide variety of external and internal dynamical forcing and their interaction, large-scale environmental flow, the axially symmetric circulation of the tropical cyclone, planetary vorticity (or ambient potential vorticity) gradient, processes involved in the binary cyclone interaction, trochoidal motion, the lower boundary forcing, large-scale steering, tropical cyclone movement in association with complex interaction of large-scale steering, track deflection relative to the environmental flow.			
Text/Reference Books: 1. R. A. Anthes: *Tropical cyclones: Their evolution, structure and effects,*American Meteorological Society. 2. Elsberry. *A global view of tropical cyclones,* Office Of Naval Research 3. Stephen Guimond . *Tropical Cyclone Inner-Core Dynamics: A Latent Heat Retrieval and Its Effects on Intensity and Structure Change; And the Impacts of Effective Diffusion,* UMI Dissertation Publishing			

Subject Code: CL5L412	**Subject Name: Advanced Oceanography**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Western boundary intensification, barotropic currents and baroclinic transport over topography. Meso-scale eddies and variability. Indian Ocean dipole circulation, Linear waves, wave spectra, wave propagation. Wave energy eqn. Breaking waves, reflection and dissipation, theory of tides, Tidal currents. Tidal processes in embayments and estuaries, Wind and buoyancy driven currents, Near-shore circulation, alongshore and rip currents, littoral drift, sediment transport, coastal ocean response to wind forcing, storm surges, coastal upwelling and fronts, Kelvin, Yanai, Rossby, inertia-gravity waves.

Text/Reference Books:

1. Joseph Pedlosky. *Waves in the Ocean and Atmosphere: Introduction to Wave Dynamics*, Springer
2. D B Haidvogel, *A Beckmann. Numerical Ocean Circulation Modeling.* World Scientific Publishing Company
3. Gill A. *Dynamics of Ocean and Atmosphere*, Academic Press
4. Cavaleri L. et al. *Dynamics and Modelling of Ocean Waves New Ed Edition*, Cambridge University Press

Subject Code: CL5L413	**Subject Name: Global Tectonics and Climate Change**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Origin of the solar system, meteorites and Earth; Seismology, earthquakes and the earth's interior; Gravity variations on the earth's surface, Geopotential and gravity fields; Isostasy, isostatic equilibrium and compensation.

Global tectonics – concept of plates and their movement; Paleo-magnetism and past plate motions with special reference to the Indian plate. Heat flow and geothermics – calculation of equilibrium and evolving geotherms; Radiogenic heat; Plate cooling models; Driving forces for plate motions; The origin of ocean basins and global plate tectonics.

Tectonics and climate - Glaciers and Ice ages; Orogeny and carbon-dioxide budget. Brief look at other planets: Mercury, Mars and Venus, Planetary interiors and Magnetism; Lunar Magnetism and heat flow.

Continental lithosphere – cratons; sedimentary basins; continental margins and rift zones; Mantle petrology and chemical composition.

Text/Reference Books:

1. Haq, B.U., and Milliman, J.D. *The tectonic and geologic evolution of Southeast Asian seas and islands*, American Geophysical Union
2. Bott, M.H.P. *The interior of the earth: its structure, constitution and evolution* Elsevier
3. William F. Ruddiman. *Tectonic Uplift and Climate Change*, Springer

Subject Code: CL5L414	**Subject Name: Ocean Resource and Technology**	**L-T-P: 3-0-0**	**Credit: 3**

Pre-requisite(s): Nil

Ocean boundaries; fundamentals of marine geological principles; Geomorphology and structure of the Ocean floor, continental slope and shelf. Marine sediments: their formation; types; distribution and classification.

Distribution of marine minerals along the Indian Coasts; Marine geo-physical technology; prospecting for oil-bearing strata; natural gas and oil traps. Marine mineral resources: Placer deposits hydrocarbon deposits and polymetallic nodules; Exploration and exploitation of natural minerals off the coast. Energy from oceans - Tides, Waves, Currents, Salinity and thermal gradients with special reference to Indian coast - Energy converters for extraction of ocean energy - Design principles of wave power, tidal power and OTEC systems -Cost-benefit analysis autonomous underwater vehicle (AUV); ocean bottom features by swath bathymetry.

Text/Reference Books:

1. A.P. Cracknell. *Remote Sensing Applications in Marine Science and Technology*, Springer
2. Joao, Cruz. *Ocean Wave Energy: Current Status and Future Perspectives*, Springer
3. Michel K. Ochi, Michael K. Ochi. *Ocean Waves: The Stochastic Approach*, Cambridge University Press

Subject Code: CL5L415	Subject Name: Air Quality Modelling	L-T-P: 3-0-0	Credit: 3
Pre-requisite(s): Nil			
Introduction; air pollutants; Effects on Human and Ecosystem: Epidemiology, chronic and acute effects on human and ecosystem, industrialization. Regulations: Regulatory, political and economic controls, air pollution laws. Emission Factors: Toxic release inventories, sampling and measurements. Modeling theory: Diffusion based models, receptor and source apportionment models and atmospheric residence times; Gaussian Plume and Modification/Applications; Particle Dynamics: Settling and drag forces, Stokes law, particle size distributions; Control of particulates; Control of gaseous pollutants: Behavior and control of volatile organics, sulfur and nitrogen oxides; Control of mobile source emissions.			
Text/Reference Books: 1. Michael S Feldman. *Applications of Satellite Remote Sensing Data for Regional Air Quality Modeling*UMI Dissertation Publishing 2. Wayne Richard P. *Chemistry Of Atmosphere 3 Revised Edition*, Oxford University Press 3. Alexander Baklano. *Meteorological and Air Quality Models for Urban Areas*, Springer			

Subject Code: CL5L416	Subject Name: Coastal Processes and Ecosystems	L-T-P: 3-0-0	Credit: 3
Pre-requisite(s):			
Ocean Waves: Wave properties and characteristics; The generation of deep-sea water waves by wind events; extreme values of waves; The propagation of deep-sea water waves; Wave energy and groups of waves; Wave climatology around the coast of India; Shallow water waves; Evolution of wave characteristics in shoaling water. Surf Zone and Beaches: Breaking wave types and their relation to wave and beach environments; set-up in the surf zone; swash; rip current, undertow and long-shore drift; influence of breaking waves on sediment transport; stable beach profiles; re-shaping of beach structure in the surf zone; regional beach types. Shelf circulation: local and remote forcing; winds, tides, inertial motion; free and forced			

shelf waves, Kelvin waves; interaction between shelf and open ocean, jets/phenomena. Estuaries: types of estuary; estuarine classification; estuarine circulation.

Text/Reference Books:

1. Peter Nielsen. *Coastal and Estuarine Processes*, World Scientific Publishing Company
2. Daniel M. and Alongi. *Coastal Ecosystem Processes*, CRC Press
3. Laurie L. Richardson. *Remote Sensing Of Aquatic Coastal Ecosystem Processes: Science And Management Applications*, Springer
4. Tetsuo Yanagi. *Coastal Oceanography*, Springer

Subject Code: CL5L417	**Subject Name: Ocean Circulations and Wave Modelling**	**L-T-P: 2-1-0**	**Credit: 3**

Pre-requisite(s): Nil

Physical description of wave evolution – Fundamental geophysical fluid dynamics, wave growth by wind theories, wave spectrum, effects of small scale disturbances and gustiness on wave growth, wave induced stress, drag of air flow over sea surface; Wave-wave interaction – general formalism, Wave dissipation by surface processes; Bottom friction and percolation – dissipation over sandy bottoms, parameterization of bottom stresses; Numerical modeling of ocean waves – model classes and generation, wave sensitivity studies, operational application and analysis; Extreme events - storm surges, tsunami and cyclones; governing equations of ocean circulations – geotropic flows, principles of vorticity dynamics, vortex theories to oceans, upwelling, baroclinic and barotropic instability with applications; theory of fronts and jets – gulf stream, equatorial dynamics and ocean currents; governing

Text/Reference Books:

1. Joseph Pedlosky. *Waves in the Ocean and Atmosphere: Introduction to Wave Dynamics*, Springer
2. Kantha and Clayson. *Numerical Models of Oceans and Oceanic Processes*, Academic Press
3. D. B. Haidvogel, *A Beckmann. Numerical Ocean Circulation Modeling*, World Scientific Publishing Company

Subject Code: CL5L418	Subject Name: High Performance Computing in Atmosphere and Ocean Sciences	L-T-P: 2-1-0	Credit: 3

Pre-requisite(s): Nil

Basic ideas on multitasking and massively parallel processing, different 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.

Text/Reference Books:

1. Lars Petter Røed. *Atmospheres and Oceans on Computers-Fundamentals*
2. Laurence T. Yang and Minyi Guo. *High-Performance Computing: Paradigm and Infrastructure*
3. John Levesque and Gene Wagenbreth. *High Performance Computing: Programming and Applications,*Chapman and Hall/CRC

Subject Code: CL5L419	Subject Name: Basics of Fluid Dynamics	L-T-P: 3-0-0	Credit: 3

Pre-requisite(s): Nil

Introduction to Tensors & Tensors Equations, Concept of continuum and definition of a fluid, Body and surface forces, stress tensor, Scalar and vector fields, Eulerian and Lagrangian description of flow. Motion of fluid element - translation, rotation and vorticity; continuity equation, stream function and velocity potential. Potential Flows. Transport theorems, constitutive equations, derivation of Navier Stokes equations for compressible flow. Boundary layer: derivation, exact solutions, Blasius, Falkner Skan, series solution and numerical solutions. Approximate methods. Momentum integral method. Two dimensional and axisymmetric jets. Description of turbulent flow, velocity correlations, Reynold's stresses, Prandtl's Mixing Length Theory, Karman's velocity defect law, universal velocity distribution.

Text/Reference Books:

1. G.Batchelor. *An introduction to Fluid Dynamics,* Cambridge University Press
2. Prandtl L. *Essentials of Fluid Dynamics,* Hafner Publishing Co
3. P.K. Kundu. *Fluid Mechanics,* Academic Press
4. F.M.White. *Fluid Mechanics,* McGraw-Hill Science
5. Modi and Seth. *Fluid Mechanics,* Standard Book House

Subject Code: CL5P401	**Laboratory Name: Numerical Products Diagnostics Laboratory**	**L-T-P: 0-0-3**	**Credit: 2**
Pre-requisite(s): Nil			
Students will be allotted different topics to give a write-up and presentation. They will be evaluated on both.			

Subject Code: CL5S401	**Subject Name: Seminar II**	**L-T-P: 0-0-0**	**Credit: 2**
Pre-requisite(s): Nil			
Students will be allotted different topics to give a write-up and presentation. They will be evaluated on both.			

Subject Code: CL5T401	**Field work – II/ Industrial Training**	**L-T-P: 0-0-0**	**Credit: 2**
Pre-requisite(s): Nil			

Subject Code: CL5D401	**Subject Name: Project Work -II**	**L-T-P: 0-0-0**	**Credit: 16**

Pre-requisite(s): Nil
Each student will be allotted a small research project during 3rd semester based on their interest. Part of the assigned project work needs to be complete in 3rd semester and the remaining work will be done in the 4th semester.