# Course Curriculum
# M. Tech. Programme
# in
# Climate Science and Technology


## Indian Institute of Technology Bhubaneswar
School of Earth, Ocean and Climate Sciences
Odisha 752050


May 2025

| Abstract | | |
|---|---|---|
| **Semester** | **Credit** | **Contact Hour** |
| **Sem 1** | **19** | **21** |
| **Sem 2** | **19** | **15** |
| **Sem 3** | **14** | **-** |
| **Sem 4** | **14** | **-** |
| **Total** | **67** | **36** |

## Semester-1

| Sl No. | Code and Subject | Type | L-T-P | Credit | Contact Hour |
|---|---|---|---|---|---|
| **1** | CL6L151: Physics of the weather and climate systems | Dept. Core | 3-0-0 | 3 | 3 |
| **2** | CL6L152: Science of Climate Change | Dept. Core | 3-0-0 | 3 | 3 |
| **3** | OE 1 / DE 1 | Elective | 3-0-0 | 3 | 3 |
| **4** | OE 2 / DE 2 | Elective | 3-0-0 | 3 | 3 |
| **5** | OE 3 / DE 3 | Elective | 3-0-0 | 3 | 3 |
| **6** | CL6P151: Programming and Computational Lab | Lab | 0-0-3 | 2 | 3 |
| **7** | CL6P152: Weather Analysis and Forecasting Lab | Lab | 0-0-3 | **2** | **3** |
| | **Total** | | | **19** | **21** |

*DC: Department. Core

## Semester-2

| Sl No. | Code and Subject | Type | L-T-P | Credit | Contact Hour |
|---|---|---|---|---|---|
| **1** | CL6L251: Simulation of Atmosphere and Ocean Processes | Dept. Core | 3-0-0 | 3 | 3 |
| **2** | CL6L252: Dynamics of atmosphere and ocean | Dept. Core | 3-0-0 | 3 | 3 |
| **3** | CL6L253: Instrumentation and Observation Systems | Dept. Core | 3-0-0 | 3 | 3 |
| **4** | OE 4 / DE 4 | Lab | 3-0-0 | 3 | 3 |
| **5** | CL6P251: Modelling and Visualization Lab | Lab | 0-0-3 | 3 | 3 |
| **6** | CL6T251: Industrial Visit | | 0-0-0 | 2 | 0 |
| **7** | CL6D251: Thesis Part 1 | MTP | 0-0-0 | 2 | 0 |
| | **Total** | | | **19** | **15** |

*DC: Department. Core

| Semester-3 | | | | | |
|---|---|---|---|---|---|
| **Sl No.** | **Code and Subject** | **Type** | **L-T-P** | **Credit** | **Contact Hour** |
| 1 | CL6D351: Thesis Part 2 | MTP | 0-0-0 | 14 | 0 |
| **Total** | | | | **14** | |

| Semester-4 | | | | | |
|---|---|---|---|---|---|
| **Sl No.** | **Code and Subject** | **Type** | **L-T-P** | **Credit** | **Contact Hour** |
| **1** | CL6D451: Thesis Part 3 | MTP | 0-0-0 | 14 | 0 |
| **Total** | | | | **14** | |

# M. Tech. in Climate Science and Technology

## Subject Details

| Semester-1 | | | | | |
|---|---|---|---|---|---|
| **Sl No.** | **Code and Subject** | **Type** | **L-T-P** | **Credit** | **Contact Hour** |
| **1** | CL6L151: Physics of the weather and climate systems | DC | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |
| | **Syllabus:**<br><br>Atmospheric structure, composition and properties, atmospheric pressure, wind and circulation, thermodynamics of dry and moist air, first law of thermodynamics, clausius-clapeyron relationship, carnot's cycle, atmospheric stability, saturated and unsaturated ascent, potential temperature, geopotential, hypsometric relationship, radiation and energy balance, tropical and mid-latitude weather systems, cloud processes and precipitation, global warming and climate change, el-nino and southern oscillation.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br>• Understand how weather and climate systems works.<br>• Identify the basic processes drive weather and climate systems.<br>• Apply concepts to real time weather scenario's.<br><br>**Text/Reference Books:**<br>• Atmospheric Science: An Introductory Survey, J.M. Wallace and P. V Hobbs<br>• An Introduction to Atmospheric Thermodynamics, A.A.Tsonis<br>• Meteorology Today: An Introduction to Weather, Climate and the Environment, C. Donald Ahrens, Robert Hensen | | | | |
| **2** | CL6L152: Science of Climate Change | DC | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s): Nil** | | | | |
| | **Syllabus:** Description of the climate system, atmospheric radiation, 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 | | | | |

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|---|---|---|---|---|---|
| | 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, climate and geo-engineering.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br><br>• Understand the components and mechanisms of the climate system, including the natural greenhouse effect, trace gases, aerosols, and feedback loops.<br>• Analyze past climate change events, such as ice ages and abrupt climate changes, using proxy records and the instrumental climate record.<br>• Evaluate the causes and consequences of climate change, differentiating between natural and anthropogenic factors, and explore mitigation strategies.<br><br>**Text/Reference Books:**<br>• The Working Group I contribution to the Sixth Assessment Report, *Climate Change 2021: The Physical Science Basis*<br>• Climate Change and Climate Modelling, Ed. J. David Neelin, Cambridge University Press, ISBN 978-0-521-84157-3, 2015, 4th Edition | | | | |
| **3** | OE 1 / DE 1 | Elective | 3-0-0 | 3 | 3 |
| **4** | OE 2 / DE 2 | Elective | 3-0-0 | 3 | 3 |
| **5** | OE 3 / DE 3 | Elective | 3-0-0 | 3 | 3 |
| **6** | CL6P151: Programming and Computational Lab | Lab | 0-0-3 | 2 | 3 |
| | **Pre-requisite(s):** Nil | | | | |
| | **Syllabus:** An introduction to Linux, Python syntax, Python variables, Python data types, numpy operations, Xarray, Python blocks, Arrays, Climate data visualization.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br><br>• Identify the Python syntax, variables, and data types.<br>• Write Python code in blocks.<br>• Explain and code the numpy and Xarray operations.<br>• Handle netCDF (.nc) dataset in Python.<br>• Analyze and plot climate data. | | | | |

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|---|---|---|---|---|---|
| | **Text/Reference Books:**<br>1. Shen, S. S. P., & North, G. R. (2023). *Statistics and Data Visualization in Climate Science with R and Python*. Cambridge: Cambridge University Press. | | | | |
| **7** | CL6P152: Weather Analysis and Forecasting Lab | Lab | 0-0-3 | 2 | 3 |
| | **Pre-requisite(s):** Nil | | | | |
| | **Syllabus:** Global Telecommunication System (GTS), Atmospheric Measurements, Instruments, Thermodynamic Diagrams, Station Data, Weather chart plotting and interpretation, Satellite Data Analysis, Monsoon, Cyclone, Heatwave, Cold Wave, and Thunderstorm Analysis and forecasting.<br><br>**Learning outcomes:** At the end of the course, the students will be able to<br>• Understand, interpret weather charts.<br>• Familiarized with state-of-the-art forecasting systems and products<br>• Able to analyse real-time weather events with different products.<br><br>**Text/Reference Books:**<br>1. Tim Vasquez, *Weather Analysis and Forecasting Handbook,* Weather Graphics Technology Publications<br>2. Ramage, C.S. (1971) Monsoon Meteorology. Academic Press, New York, 296 p. | | | | |
| | **Total** | | | **19** | **21** |

| **Semester-2** | | | | | |
|---|---|---|---|---|---|
| **Sl No.** | **Subject** | **Type** | **L-T-P** | **Credit** | **Contact Hour** |
| **1** | CL6L251: Simulation of Atmosphere and Ocean Processes | Dept. Core | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s): NIL** | | | | |
| | **Syllabus:** Governing equations for Atmospheric and Oceanic Processes: continuous equations, grid structure, model errors, map projections, vertical coordinate system, filtering approximations, Numerical methods: finite-difference methods, time and space differencing, stability analysis; spectral method, boundary conditions. Numerical models: Hydrostatic, | | | | |

Non-hydrostatic models, mesoscale models, climate models. Principal of Coupling Air-Sea Interaction Processes, Parameterization of sub-grid scale physical processes: planetary boundary layer, moist microphysics, cumulus convection, radiation, air-sea interaction processes, and land surface processes. Data assimilation: Objective analysis schemes, initialization. Predictability and Ensemble forecasting,

**Learning outcomes:** At the end of the course, the students will be able to:

- Understand the components of models
- Able to familiarize with the working principle of different models
- Understand application specific models and its limitations

**Text/Reference Books:**

- Numerical Weather and Climate Prediction, Thomas tomkins warner,Cambridge University Press
- Parameterization Schemes: Keys to Understanding Numerical Weather Prediction Model, David J stenrud, Cambridge University Press
- Atmospheric Data Analysis, Roger Daley, Cambridge University Press

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|---|---|---|---|---|---|
| **2** | CL6L252: Dynamics of atmosphere and ocean | DC | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |

**Syllabus:**

Atmospheric Dynamics: Fundamentals of Geophysical Fluid Dynamics, Equations of motion in the rotating frame; potential vorticity conservation, balanced flows; barotropic and baroclinic instabilities and waves.

Ocean Dynamics: Introduction to Physical Oceanography, Conservation laws, Barotropic and baroclinic fields, Stability, Equations governing the oceanic flow, Ekman layers, Sverdrup transport, western boundary currents.

**Learning outcomes: At the end of the course, the students will be able to:**

- Explain the fundamental forces acting on geophysical fluids.
- Write the equations relevant to the geophysical phenomena.
- Identify the reasons for changes in the atmospheric and oceanic conditions.
- Quantify the motions and forces acting on the Earth-system components.

**Text/Reference Books:**

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|---|---|---|---|---|---|
| | • Gill, A. E. (1982). *Atmosphere-ocean dynamics* (Vol. 30). Academic press.<br>• Pond, S., & Pickard, G. L. (1983). *Introductory dynamical oceanography*. Gulf Professional Publishing.<br>• Cushman-Roisin, B., & Beckers, J. M. (2011). *Introduction to geophysical fluid dynamics: physical and numerical aspects*. Academic press.<br>• Vallis, G. K. (2017). *Atmospheric and oceanic fluid dynamics*. Cambridge University Press.<br>• Pedlosky, J. (2013). *Geophysical fluid dynamics*. Springer Science & Business Media. | | | | |
| 3 | CL6L253: Instrumentation and Observation Systems | DC | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |
| | **Syllabus:**<br>Instruments & Observation Systems: Principles, Techniques, Types, Advantages & Limitations, Instrument calibration & maintenance; Measurement Methodology & Interpretation: Standards, References, Uncertainties, Quality Control; Observational Data Processing & Analysis: Analytical Techniques & Approaches; Equipments and their characterization; Measurement of atmospheric/ocean/climate variables: Parameters, Phenomena, Sampling Strategy, Experiment Design; Applications & Challenges.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br><br>• Familiar with instruments & techniques used for atmosphere/ocean climate observations<br>• Select the appropriate instrument for the appropriate measurement<br>• Quantify measurement uncertainties and instrument errors, quality control data sets, and formulate observation strategies<br>• Design measurement strategy for proper measurement of climate variables<br><br>**Text/Reference Books:**<br>• Guide to Meteorological Instruments and Methods of Observation, 6th Ed., WMO-No 8.<br>• Compendium of Lecture notes on Meteorological Instruments, WMO-No 622. | | | | |

<table>
<tr><td></td><td colspan="5"><ul><li>A. S. Morris, Measurement & Instrumentation Principles, 3rd Ed., Butterworth-Heinemann Ltd.</li><li>E. O. Doebelin, Measurement Systems: Application and Design, 5th Ed., McGraw-Hill.</li></ul></td></tr>
<tr><td>4</td><td>OE3 / DE 3</td><td>Elective</td><td>3-0-0</td><td>3</td><td>3</td></tr>
<tr><td>5</td><td>CL6P251: Modelling and Visualization Lab</td><td>Lab</td><td>0-0-3</td><td>2</td><td>3</td></tr>
<tr><td></td><td colspan="5">Pre-requisite(s):</td></tr>
<tr><td></td><td colspan="5">Syllabus:<br>– Introduction to climate datasets (reanalysis, satellite, and in-situ observations), Basic statistical techniques: mean, variance, anomalies, trend analysis, Time series analysis and spectral methods;<br>– Definition and significance of climate indices (Niño, DMI, NAO, etc.), Formulation of the Niño and DMI indices, Lead-lag correlation analysis and its applications, Composite analysis techniques;<br>– Introduction to climate and ocean models: Model setup, boundary conditions, and parameterization, Running basic simulations and troubleshooting;<br>– Evaluating model performance using observational data, Skill scores: RMSE, correlation, bias analysis;<br>– Case studies of extreme weather/climate events<br><br>Learning outcomes: At the end of the course, the students will be able to:<ul><li>Apply fundamental numerical methods in atmospheric and oceanic sciences.</li><li>Analyze climate datasets using statistical and computational tools.</li><li>Interpret outputs from climate models to assess atmospheric and oceanic processes.</li><li>Evaluate uncertainties and limitations in numerical climate models.</li><li>Apply diagnostic techniques to identify key dynamical processes in the climate system.</li></ul>Text/Reference Books:<ul><li>Marshall, J., & Plumb, R. A. (2007) – Atmosphere, Ocean, and Climate Dynamics</li><li>Wilks, D. S. (2011) – Statistical Methods in the Atmospheric Sciences</li><li>Various research papers/ websites as required for the climate models and uncertainty quantification techniques.</li></ul></td></tr>
<tr><td>7</td><td>CL6T251: Industrial Visit</td><td>Training / Field</td><td>0-0-0</td><td>2</td><td>0</td></tr>
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|---|---|---|---|---|---|
| | **Pre-requisite(s): NIL** | | | | |
| | **Syllabus:** The students will visit the related research organizations/industries and will interact with scientists.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br><br>• Understand the utility of various instruments and techniques<br>• Obtain a first-hand exposure to the translation of theory into practical utilities<br>• Experience the application potentials of classroom concepts learnt to analyse various phenomena<br>• Broaden their outlook of organisational work culture<br><br>**Text/Reference Books: Nil** | | | | |
| **8** | CL6D251: Thesis Part 1 | MTP | 0-0-0 | 4 | 0 |
| | **Total** | | | **20** | **16** |

| Semester-3 | | | | | |
|---|---|---|---|---|---|
| **Sl No.** | **Subject** | **Type** | **L-T-P** | **Credit** | **Contact Hour** |
| 1 | CL6D351: Thesis Part 2 | MTP | 0-0-0 | 18 | 0 |
| **Total** | | | | **18** | |

| Semester-4 | | | | | |
|---|---|---|---|---|---|
| **Sl No.** | **Subject** | **Type** | **L-T-P** | **Credit** | **Contact Hour** |
| **1** | CL6D451: Thesis Part 3 | MTP | 0-0-0 | 18 | 0 |
| **Total** | | | | **18** | |

## List of Electives M.Tech Climate Science and Technology

| Sl No. | Code | Subject Name | L-T-P | Credit | Contact Hour |
|---|---|---|---|---|---|
| 1 | CL6L501 | **Urban Weather and Climate** | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s): Nil** | | | | |

**Syllabus:** Concept of Urban Surface, Biosphere, Hydrosphere and Atmosphere, Local Climate Zones, Urban Meteorology, Heat Islands, Air Pollution, Surface Energy Balance, Clouds and Precipitation Processes, Macro and Micro Controls of Urban Atmosphere, Mitigation and Adaptation, Urban Management, Climate Sensitive Design Practices.

**Learning outcomes:** At the end of the course, the students will be able to:

- Grasp the interactions between urban areas and the atmosphere, including heat islands, pollution islands, energy balance, and the urban water cycle.
- Develop skills in understanding and analyzing urban climate phenomena using observational datasets, physical models, and numerical simulations.
- Learn to apply urban microclimate sensitivity for urban planning and design principles to mitigate environmental impacts and enhance urban sustainability.

**Text/Reference Books:**


- Oke, T. R., Mills, G., Christen, A., Voogt, J. A. (2017). Urban Climates. United Kingdom: Cambridge University Press.
- Stewart, I. D., and G. Mills. *The Urban Heat Island: A Guidebook*. Amsterdam: Elsevier, 2021.
- Lee, X. (2023). Fundamentals of Boundary-Layer Meteorology. Germany: Springer International Publishing.

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|---|---|---|---|---|---|
| 2 | CL6L502 | **Planetary Boundary Layer** | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |

**Syllabus:**

Introduction to PBL: definition, structure and characteristics, factors influencing height, diurnal changes, etc. Turbulence: Introduction, Reynold's decomposition and averaging, turbulence intensity, Reynold's decomposition of conservation equations, Reynold's stresses, turbulent fluxes; Vertical momentum equation, Bousinesque approximation; Prognostic equations for turbulence variance and fluxes; Turbulent Kinetic Energy: conservation equations, stability, turbulence scales; turbulence closure problem; Turbulent fluxes parameterizations: K-theory, Mixing length theory; Similarity theories

**Learning outcomes:** At the end of the course, the students will be able to:

- Identify and distinguish boundary layer processes from free atmosphere
- Quantify and estimate boundary layer fluxes from turbulence theory
- Quantify boundary layer parameters from the data with different parameterizations

**Text/Reference Books:**

- Roland B. Stull . *An Introduction to Boundary Layer,* Springer
- E. B. Kraus. *Atmosphere-Ocean Interaction,* Oxford University Press.
- J. R. Garratt .*The Atmospheric Boundary Layer* , Cambridge University Press.
- R.M. Stewart:*The Atmospheric Boundary Layer",* WMO-523.

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|---|---|---|---|---|---|
| 3 | CL6L503 | **Ocean Circulation and Wave Modeling** | 3-0- 0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |

**Syllabus:** Scales of various oceanic processes, Ocean circulation fundamentals, Governing primitive equations of ocean modeling, Important approximations, parameterizations, and mixing schemes, Shallow water equations, Types of ocean models, Temporal and spatial scales of oceanic waves, Wave spectrums (JONSWAP), Wave induced stress, Wave dissipation, Wave-wave interaction, Fundamental equations of wave modeling, Initial and boundary conditions, Storm surge and its modeling, Tsunamis.

**Learning outcomes:**

- Identify the important forces and factors governing an oceanic process.

- Explain the temporal and spatial scales of an oceanic phenomenon.
- Solve the governing equations of an oceanic process.
- Quantify the effect of oceanic waves.

**Text/Reference Books**

- Haidvogel, D. B., & Beckmann, A. (1999). Numerical ocean circulation modeling. Imperial College Press.
- Kantha, L. H., & Clayson, C. A. (2000). Numerical models of oceans and oceanic processes. Elsevier.
- Pedlosky, J. (2003). Waves in the ocean and atmosphere: introduction to wave dynamics (Vol. 260). Berlin: Springer.
- Holthuijsen, L. H. (2010). Waves in oceanic and coastal waters. Cambridge University Press.
- Komen, G. J., Cavaleri, L., Donelan, M., Hasselmann, K., Hasselmann, S. P. A. E., & Janssen, P. A. E. M. (1996). Dynamics and modelling of ocean waves (p. 554).

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|---|---|---|---|---|---|
| 4 | CL6L504 | **Advanced Data Analysis in Climate Science** | 2-0-2 | 3 | 4 |

**Pre-requisite(s):** Basic concepts of calculus, linear algebra, PDE, probability and statistics. Working knowledge with any programming and visualization software.

**Syllabus:**

Analysis in the time domain versus the spectral domain. Time series and nonlinear dynamics; Harmonic Analysis – Fourier Transform, Discrete Fourier Transform, Filtering, Introduction to Wavelets; Stochastic processes, Stationarity and trend tests, Introduction to Principal Component Analysis (PCA); Enhancing the Signal-to-Noise (S/N) Ratio, Singular Spectrum Analysis (SSA), Monte Carlo SSA; Extreme Value Theory; Implications for understanding the climate system and prediction.

**Learning outcomes:** At the end of the course, the students will be able to:

- Use advanced statistical data analysis techniques in climate sciences.
- Conduct their own analyses and professionally interpret results in scientific literature.
- Exercise the application and interpretation with real data.

**Text/Reference Books:**

- Storch H von, Zwiers FW. *Statistical Analysis in Climate Research.* Cambridge University Press; 1999.

- DelSole T, Tippett M. References. In: *Statistical Methods for Climate Scientists*. Cambridge University Press; 2022:514-522.
- Zhang, Z. (2018). *Multivariate time series analysis in climate and environmental research* (p. 287). Cham: Springer International Publishing.
- Jolliffe, I. T. (2002). *Principal component analysis for special types of data* (pp. 338-372). Springer New York.
- Brigham, O. E., The Fast Fourier Transform, Prentice Hall, First Edition, 1974.
- Burrus, C. S., Gopinath, R. A., & Guo, H. (1998). Wavelets and wavelet transforms. R*ice University, Houston edition, 98*.
- Ghil, M., Allen, M. R., Dettinger, M. D., Ide, K., Kondrashov, D., Mann, M. E., ... & Yiou, P. (2002). Advanced spectral methods for climatic time series. *Reviews of Geophysics*, *40*(1), 3-1.
- Many other articles, websites and research reviews based on requirements.

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|---|---|---|---|---|---|
| 5 | CL6L505 | **Tropical Climate Dynamics and Variability** | 3-0-0 | 3 | 3 |

**Pre-requisite(s):** Dynamics of atmosphere and ocean; Physics of the weather and climate systems.

**Syllabus:**

Tropical climate in a zonally symmetric framework - theories, applications, and limitations; Role of diabatic heating in the atmosphere – CISK and WISHE, Radiative-convective equilibrium, Matsuno-Gill heating, Moisture mode theory, Organization of convection; Intraseasonal Variability – Structure and skeleton of MJO, Theories of MJO; Indian monsoon variability – Evolution of Indian monsoon, movement of ITCZ, Coupled ocean-atmosphere phenomena, roles of Tibetan Plateau and Indian Ocean; ENSO-monsoon relationship, Variability in monsoon - ISO; ENSO – Seasonal phase-locking, Bjerknes Feedback Mechanism of ENSO, ENSO theories; Climate change – Effects in tropics, Changes in atmospheric circulation, Atlantic Ocean, Indian Ocean.

**Learning outcomes:** At the end of the course, the students will be able to:

- Apply advanced-level theoretical concepts of tropical climate and variability.
- Identify the primary processes responsible for driving tropical climate variability on different space-time scales.
- This course is aimed to prepare the students for research in tropical climate variability.

**Text/Reference Books:**

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|---|---|---|---|---|---|
| | • Tropical Meteorology: An Introduction, T. N. Krishnamurti, Lydia Stefanova & Vasubandhu Misra, DOI 10.1007/978-1-4614-7409-8<br>• An Introduction to Large-Scale Tropical Meteorology, Vasubandhu Misra, https://doi.org/10.1007/978-3-031-12887-5<br>• Intraseasonal Variability in the Atmosphere-Ocean Climate System, William K.-M. Lau, Duane E. Waliser, https://link.springer.com/book/10.1007/978-3-642-13914-7<br>• The Asian Monsoon, Bin Wang, https://link.springer.com/book/10.1007/3-540-37722-0<br>• Many other articles, websites, and research reviews based on requirements. | | | | |
| 6 | CL6L506 | **Satellite Oceanography and Meteorology** | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s): NIL** | | | | |
| | **Syllabus:**<br>Satellite-based sensing of the ocean & atmosphere: introduction, Electromagnetic (EM) wave propagation and sensing, EM wave interaction with the ocean's surface, ocean surface processes, Atmospheric absorption and scattering of EM radiation; Satellite observations: visible, infrared and microwave observations, space based measuring instruments, latest methodologies, satellite data analysis, error assessments, sampling considerations and data interpretation; Geophysical Parameter Retrieval from satellite platforms: Basic principles, Retrieval algorithms (empirical, semi-analytical, etc.), Ocean and Atmospheric, examples, applications.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br><br>• Obtain specific details about ocean and atmospheric processes and parameters from satellite observations<br>• Analyse satellite data sets for understanding the dynamics of the ocean and atmosphere<br>• Retrieve atmospheric and oceanic variables from satellite observations<br><br>**Text/Reference Books:**<br>• G. A. Maul, Introduction to Satellite Oceanography, Springer<br>• R. R. Kelkar, Satellite Meteorology, BS Publications<br>• E. Stefan. Measurement Methods in Atmospheric Sciences - *in situ* and remote, Borntraeger Science Publishers<br>• A. P. Cracknell (Dorderecht: D Reidel). Remote Sensing Applications in Marine Science and Technology, CRC Press<br>• S. Q. Kidder and T. H. Vonder Haar, Satellite Meteorology: an Introduction, Academic Press | | | | |

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| | • I. S. Robinson, Satellite Oceanography – an introduction for Oceanographers and Remote Sensing scientists, Ellis Horwood Ltd.<br>• H. R. Gordon and A. Y. Morel, Remote assessment of ocean color for interpretation of satellite visible imagery: a review, Springer-Verlag | | | | |
| 7 | CL6L507 | **Sea Level Science** | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s):** Nil | | | | |
| | **Syllabus:** Background of Sea level, Ocean, Cryosphere and Sea Level Change, Introduction to basis statistics of sea level, Geological Sea level indicator, Vertical displacement of shorelines, Observation and measurement system of sea level, Shallow water gravity waves, Dispersion relation, Wave Spectrum, Tidal forces, Tidal analysis techniques and prediction, Tidal dynamics, Shallow water dynamics, Storm surges, Tsunamis, Spatio-temporal variability of sea level, short term and long term variability, Application of sea-level studies in multi-disciplinary science and technology.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br>• Explain ocean tide, storm surge, tsunami and climate modes.<br>• Identify and distinguish the spatio-temporal variability of sea level.<br>• Develop a tool for sea level observation and prediction.<br>• Provide crucial information to the coastal engineers.<br><br>**Text/Reference Books:**<br>• Pugh, D., & Woodworth, P. (2014). Sea-level science: understanding tides, surges, tsunamis and mean sea-level changes. Cambridge University Press.<br>• Boon, J. D. (2013). Secrets of the tide: tide and tidal current analysis and predictions, storm surges and sea level trends. Elsevier.<br>• Colin V. Murray-Wallace and Colin D. Woodroffe (2018). Quaternary Sea-Level Changes: A Global Perspective. Cambridge University Press<br>• Lennart Bengtsson and others (2014).<br>• Intergovernmental Oceanographic Commission. (2006). Manual on sea level measurement and interpretation. Volume IV-An update to 2006. | | | | |
| 8 | CL6L508 | Atmospheric Aerosols and Climate | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s): NIL** | | | | |

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|---|---|---|---|---|---|
| | **Syllabus:** General Characteristics of the Atmosphere, Atmospheric Aerosols, Sources and Sinks, Types, Size Distribution and Chemical composition, Physical, Optical and Radiative Properties, Aerosol Growth, Coagulation, and Deposition, Cloud Condensation Nuclei (CCN), Ice Nuclei (IN), New Particle Formation, Dynamics of Single Particles, Monitoring Techniques, Direct and Indirect Effect, Aerosol-Cloud-Climate Interaction, Aerosols, Air Quality and Health<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br>• Understand the fundamental properties of atmospheric aerosols, including their size, composition, and formation mechanisms.<br>• Understand the complex interactions between aerosols and climate systems, focusing on their effects on radiation balance, cloud formation, and precipitation patterns.<br>• Evaluate the role of aerosols in anthropogenic climate change and air quality and explore the potential for aerosol-based climate mitigation strategies at regional and global scales.<br><br>**Text/Reference Books:**<br>• Seinfeld, J. H., & Pandis, S. N. (2016). *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change.* 3rd Edition. Wiley-Interscience. ISBN: 978-1118947401<br>• Boucher, O. (2015). *Atmospheric Aerosols: Properties and Climate Impacts.* Springer. ISBN: 978-94-017-9648-4 | | | | |
| 9 | CL6L509 | Mesoscale Atmospheric Modeling | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s): NIL** | | | | |
| | **Syllabus:** Governing equations, Hydrostatic and Non-hydrostatic models, Mesoscale convective systems, Parameterization processes (clouds microphysics, surface, planetary boundary layer, radiative, land surface processes), Mesoscale instabilities, Synoptic and thermal induced circulation, Horizontal and vertical resolution and grid structure, Application of mesoscale model over tropical regions, Modeling of Monsoon processes, Tropical cyclone, Thunderstorm, Heavy rainfall and Cloud burst, WRF modelling and configuration.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br>• Provide knowledge to understand mesoscale models.<br>• Familiarize and understand mesoscale processes. | | | | |

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| | • Identify appropriate models for weather specific events.<br><br>**Text/Reference Books:**<br>• Mesoscale Meteorology and Forecasting, Peter Ray<br>• Mesoscale Meteorological Modeling, Roger Pilke<br>• Mesoscale convective processes in atmosphere, Robert J Trapp | | | | |
| 10 | CL6L510 | Ocean Resources and Technology | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |
| | **Syllabus:** Energy from oceans, Tides, Waves, Currents, Salinity, wind, and geothermal energy with special reference to the Indian coast, Energy converters for the extraction of ocean energy, Design principles of wave power, tidal power, and Ocean Thermal Energy Conversion (OTEC) systems. Principles of desalinization. Operational requirements and challenges of oceanic resource extractions. Resources (Living and Nonliving): Fisheries, Freshwater, chemicals and minerals. Oceanographic factors relevant to resource conservation and utilization. Sustainable utilization of coastal resources.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br>• Identify the potential resources from the oceans.<br>• Explain various methods for converting the resources from the ocean<br>• Quantify various forms of energy available from the oceans<br>• Work towards the sustainable extraction and utilization of oceanic resources<br><br>**Text/Reference Books:**<br>• Cruz, J. (2007). *Ocean wave energy: current status and future perspectives*. Springer Science & Business Media.<br>• Roonwal, G. S. (2017). *Indian Ocean resources and technology*. CRC Press.<br>• Cassedy, E. S., & Grossman, P. Z. (1998) *Introduction to energy: resources, technology, and society*. Cambridge University Press.<br>• Green, D. R., & Payne, J. L. (Eds.). (2017). *Marine and Coastal Resource Management: Principles and Practice*. Routledge. | | | | |
| 11 | CL6L511 | Data Assimilation | 3-0 -0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |

**Syllabus:** 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.

**Learning outcomes:** At the end of the course, the students will be able to:

- **Understand** the fundamentals of data assimilation and its importance in weather and climate models.
- **Analyze** different data assimilation techniques, including variational and sequential methods.
- **Implement** basic data assimilation algorithms using Python/MATLAB.
- **Evaluate** the impact of observational data on model predictions.
- **Apply** data assimilation concepts to real-world atmospheric and oceanic datasets.

**Textbooks:**

1. **Kalnay, E.** (2003) *Atmospheric Modeling, Data Assimilation, and Predictability*
2. **Carrassi, A., Bocquet, M., Bertino, L., & Evensen, G.** (2023) *Data Assimilation: Methods, Algorithms, and Applications*
3. **Lewis, J. M., Lakshmivarahan, S., & Dhanya, A.** (2006) *Dynamic Data Assimilation: A Least Squares Approach*

**Software and Tools:**

- **Programming:** Python (NumPy, SciPy, xarray, Matplotlib), MATLAB
- **Data Formats:** NetCDF, GRIB
- **Models/Datasets:** ERA5, GFS, ECMWF, HYCOM

**Online Resources:**

- ECMWF and NOAA data assimilation tutorials

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| **12** | CL6L512 | **Weather and Climate Extremes** | 3-0- 0 | 3 | 3 |
| | **Pre-requisite(s): NIL** | | | | |
| | **Syllabus:** Extreme events, Tropical cyclone, Thunderstorms and lightning, Heat Wave, Cold Wave, Cloud burst, Hailstorms, Fog, Dust storms, Monsoon heavy rainfall, Orographically driven convection, Western Disturbances, Air pollution, Drought, Flood conditions, ENSO cycle and impact over Indian region, Weather and Climate extremes over India, Observations and modeling of extreme events, Forecasting of extreme events. Tropical and midlatitude extreme events,<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br>• Familiarize with extreme weather and climate events.<br>• Understand the cause and prediction of extreme weather events.<br>• Equip students necessary knowledge and domain expertise.<br><br>**Text/Reference Books:**<br>• Essentials of Meteorology – Donald Ahrens<br>• Mesoscale Meteorological Modeling, R Pilke<br>• Mesoscale Meteorology and Forecasting, Peter Ray | | | | |
| **13** | CL6L513 | Artificial Intelligence and Machine Learning in Climate Sciences | 2-0-2 | 3 | 4 |
| | **Pre-requisite(s):** Basic knowledge of climate science, statistics, and programming | | | | |
| | **Syllabus:**<br>Regression models (Linear, Polynomial, Ridge, Lasso), Classification models (Decision Trees, Random Forest, SVM), Clustering techniques (K-Means, Hierarchical etc.), Dimensionality reduction (PCA/EOF), Introduction to Neural Networks (ANN, CNN, RNN), LSTMs and GRUs for time series forecasting. Application: Climate pattern recognition, downscaling techniques.<br>Introduction of AI as a tool for Climate Prediction and Forecasting. AI-based weather forecasting models.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br><br>• Apply supervised and unsupervised learning techniques to climate-related problems.<br>• Use deep learning models to predict and analyze climate patterns.<br>• Interpret the performance and limitations of AI-based climate models.<br>**Text/Reference Books:** | | | | |

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| | • Goodfellow et al., **Deep Learning** (MIT Press, 2016)<br>• Murphy, **Machine Learning: A Probabilistic Perspective** (MIT Press, 2012)<br>• Wilks, **Statistical Methods in the Atmospheric Sciences** (Elsevier, 2019)<br>• LeCun et al., **Deep Learning for Earth System Science** (Annual Review of Environment and Resources, 2021) |

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| **14** | CL6L514 | Polar Oceanography | 3-0-0 | 3 | 3 |
| | **Pre-requisite(s):** | | | | |
| | **Syllabus:**<br><br>Introduction to Polar Oceanography: Definition and importance of polar regions, Arctic vs. Antarctic: Geographic, climatic, and oceanic differences, History and development of polar oceanography. Physical Properties of Polar Oceans. Sea Ice Formation and Dynamics: Formation and types of sea ice, Seasonality and long-term variability. Polar Ocean Circulation: Major currents in the Arctic (Beaufort Gyre, Transpolar Drift), Antarctic Circumpolar Current and thermohaline circulation, Role of polar oceans in global conveyor belt circulation Ocean-Atmosphere Interactions: Air-sea exchange processes in polar regions, The influence of atmospheric circulation on polar ocean dynamics, Teleconnections: ENSO, Arctic Oscillation (AO), and Antarctic Oscillation (AAO) Polar Marine Ecosystems: Biological productivity in polar oceans, Food webs and key species (krill, phytoplankton, fish, and marine mammals), Impact of ice cover on marine ecosystems, Pollution and environmental policies for polar regions, Observing Polar Oceans: Remote sensing and satellite observations, Role of research stations and autonomous vehicles (e.g., Argo floats, gliders).<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br><br>• **Understand** the unique characteristics of polar oceans, including their physical, chemical, and biological properties, polar currents and mechanism<br>• **Analyze** the role of sea ice in oceanic and atmospheric interactions, the assessment of impacts of climate change. | | | | |

- **Interpret** observational and satellite-based data on polar oceanographic phenomena.

- **Apply** knowledge of polar oceanography to real-world challenges like global warming, marine ecosystems, and policy-making.

**Text/Reference Books:**

- **Polar Oceanography, Part I & II** – W. O. Smith Jr.
- **Sea Ice** – D. N. Thomas & G. S. Dieckmann
- **The Oceans and Climate** – G. Siedler, J. Church, & J. Gould

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| 15 | CL6L515 | Monsoon Dynamics | 3-0-0 | 3 | 3 |

**Pre-requisite(s):** Dynamics of atmosphere and ocean; Physics of the weather and climate systems.

**Syllabus:**
Importance of monsoons in climate and society; historical context of Indian monsoon research; Seasonal cycle, spatial distribution of rainfall, interannual variability; overview of observational networks; Physical processes - heat budgets, and the role of moisture transport in monsoon circulation; role of the Intertropical Convergence Zone (ITCZ), mid-tropospheric dynamics, and the influence of orography; Mechanisms of monsoon onset; active/break spells; seasonal transitions; Understanding active and break phases (intraseasonal variability); the influence of the MJO on monsoon variability; Teleconnections: ENSO, IOD, and Beyond; Impact of Aerosols and Land Use Changes; Monsoon Modeling and Forecasting capabilities; Impacts of global warming on the Indian monsoon; uncertainties in future projections.

**Learning outcomes:** At the end of the course, the students will be able to:

- Describe the fundamental physical processes governing the Indian monsoon.
- Analyze synoptic and large-scale patterns that influence monsoon onset, progression, and withdrawal.

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| | • Evaluate the role of intraseasonal variability, including active and break phases, and understand teleconnections such as ENSO and the Indian Ocean Dipole.<br>• Utilize statistical and numerical modeling methods to interpret monsoon behavior and predict seasonal variations.<br>• Critically review and synthesize current research literature on monsoon dynamics and identify emerging challenges in the field.<br>• Communicate complex scientific concepts effectively, both in writing and through oral presentations.<br><br>**Text/Reference Books:**<br>• The Asian Monsoon, Bin Wang, https://link.springer.com/book/10.1007/3-540-37722-0<br>• Tropical Meteorology: An Introduction, T. N. Krishnamurti, Lydia Stefanova & Vasubandhu Misra, DOI 10.1007/978-1-4614-7409-8<br>• An Introduction to Large-Scale Tropical Meteorology, Vasubandhu Misra, https://doi.org/10.1007/978-3-031-12887-5<br>• Intraseasonal Variability in the Atmosphere-Ocean Climate System, William K.-M. Lau, Duane E. Waliser, https://link.springer.com/book/10.1007/978-3-642-13914-7<br>• Indian Summer Monsoon Variability:El Niño-Teleconnections and Beyond, Jasti S. Chowdary, Anant Parekh, C. Gnanaseelan. ISBN: 9780128224021<br>• Many other articles, websites, and research reviews based on requirements. |

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| **16** | CL6L601 | Statistical Methods in Climate Science | 3-1-0 | 4 | 4 |
| | **Pre-requisite(s):** Preliminary courses on calculus and linear algebra. | | | | |
| | **Syllabus:**<br>Discrete and Continuous Random Variables, Joint and Conditional Probability Distributions, Maximum Likelihood Estimation (MLE); Confidence Intervals and Hypothesis Testing (t-tests, chi-square tests), Monte Carlo Methods and Resampling Techniques; Spectral Density Estimation and Power Spectra, Moving Average (MA) and Autoregressive (AR) Models; Regression and Correlation Methods in Climate Data. | | | | |

**Learning outcomes:** At the end of the course, the students will be able to:

- Develop skills in probability, statistics, and time series analysis applied to climate data.
- Apply spectral and EOF techniques for climate variability analysis.
- Perform statistical downscaling techniques to refine model outputs.
- Gain hands-on experience in predictive modeling for climate applications.

**Text/Reference Books:**

- Papoulis, A., and U. Pillai, Probability, Random variables and Stochastic Processes, McGraw Hill, Fourth edition, 2002.
- Gillard. J, A first course in statistical inference, Springer Undergraduate Mathematics Series, Springer, 2020.
- Wilks, D. *Statistical Methods in the Atmospheric Sciences*, Academic Press, Second Edition, 2006.
- Von Storch, H., and Zwiers, F. *Statistical Analysis in Climate Research*, Cambridge University Press, 1999.

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| **17** | CL6L602 | **Numerical Methods in Climate Studies** | 2-0 -2 | 3 | 3 |

**Pre-requisite(s):**

**Syllabus:** Finite difference approximation schemes, grid point method, Time difference schemes, Stability analysis of numerical schemes, The three-level scheme, suppression of the computational mode, Computational phase speed, dispersion due to the spatial and time discretisation and resolution, The one-dimensional shallow water equations with spatial and temporal discretisation, Rayleigh friction, Laplacian friction, the advection-diffusion equation

**Learning outcomes:** At the end of the course, the students will be able to:

- Explain what is a numerical model of the atmosphere and ocean.
- Identify various finite difference schemes used in atmospheric and ocean models.
- Calculate the truncation error related to finite difference schemes.
- Derive stability criterion of finite difference schemes and visualize it.
- Identify the computational dispersion due to spatial and temporal discretisation and resolution.
- Implement various finite difference schemes in a simple 1-D advection equation through the Fortran programming language and explain their behavioral characteristics

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| | **Text/Reference Books:**<br>1) Döös, K., Lundberg, P., & Aldama Campino, A. (2022). *Basic Numerical Methods in Meteorology and Oceanography.* Stockholm: Stockholm University Press. DOI: https://doi.org/10.16993/bbs<br>2) Chandrasekar A. (2022). *Numerical Methods for Atmospheric and Oceanic Sciences*. Cambridge University Press<br>Kantha, L. H., & Clayson, C. A. (2000). *Numerical models of oceans and oceanic processes.* Elsevier | | | | |
| **18** | CL6L603 | **Geoinformatics and Remote Sensing** | 2-0-2 | 3 | 4 |
| | **Pre-requisite(s): Basic Physics & Mathematics** | | | | |
| | **Syllabus:**<br>Basics of Geoinformatics: Geographic Information System (GIS) Fundamentals, Functions, Data input, data structure and data formats, GPS basics; Geoinformatics Utility: Spatial Data Analysis, Data Visualization, Data Models, Applications, GIS enabled services.<br><br>Remote Sensing (RS): Terminologies, Electromagnetic Radiation, Sensors, Digital Mapping; RS Data Processing & Interpretation: Methods & Tools, Classification & Enhancement Techniques; Latest RS Sensors; RS Applications in Climate Sciences.<br><br>**Learning outcomes:** At the end of the course, the students will be able to:<br>• Utilise Geoinformatics & Remote Sensing Techniques for analysis and interpretation in thematic studies and climate change phenomena<br>• Leverage georeferenced data (*in situ* & satellite based) for critical applications<br>• Familiarise themselves with RS & GIS applications for adaptive innovations<br><br>**Text/Reference Books:**<br>• G. S. Srivastava, Introduction to Geoinformatics (2014), $1^{st}$ Ed., McGraw Hill Education, pp. 278.<br>• S. Gopi, Global Positioning System: Principles and Applications (2005), Tata Mac-Graw Hill, pp. 337.<br>• P. Longley et al., Geographic Information Science and Systems (2015), $4^{th}$ Ed., Wiley, pp. 496. | | | | |

- R. G. Reeves, Manual of Remote Sensing (1991), vol 1., American Society of Photogrammetry and Remote Sensing, Falls Church, Virginia, USA.
- G. Joseph and C. Jeganathan, Fundamentals of Remote Sensing (2018), 3rd Ed., The Orient Blackswan, pp. 624.
- T. M. Lillesand and R. W. Kiefer, Remote Sensing and Image Interpretation (2007), 4th Ed., John Wiley and Sons, New York
- J. R. Jensen, Introductory digital image processing: a remote sensing perspective (2017), 4th Ed., Pearson Education, pp. 544.

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| 19 | CL6L604 | **Parameterization of Physical Processes** | 3-0-0 | 3 | 3 |

**Pre-requisite(s): NIL**

**Syllabus:** Parameterization of subgrid scale processes, Cumulus parameterization and different types, Convective Adjustment, Moisture and Mass flux based schemes, Deep and Shallow convection, Closure problem, Boundary layer parameterization, Local and non-local schemes, Clouds microphysical processes and parameterization, Radiation parameterization (shortwave, longwave), Land Surface parameterization.

**Learning outcomes:** At the end of the course, the students will be able to:

- Able to elaborate the concept of parameterization.
- Enable students to familiarize how the parameterization works in models.
- Understand the limitations as well as the advantages of parameterization.

**Text/Reference Books:**

- Parameterization Schemes: Keys to Understanding Numerical Weather Prediction Model, David J stenrud, Cambridge University Press
- Numerical Weather and Climate Prediction, Thomas Tompkins Warner, Cambridge University Press
- Micrometeorology by S.P. Arya, Academic Press