Course Curriculum
Joint M. Sc. – Ph. D. Programme in
Atmosphere and Ocean Sciences

Indian Institute of Technology Bhubaneswar

School of Earth, Ocean and Climate Sciences

Odisha 752050

May 2025

Abstract		
Semester	Credit	Contact Hour
Sem 1	19	22
Sem 2	23	25
Sem 3	20	12
Sem 4	18	-
Total	80	58

Semester-1					
Sl No.	Code and Subject	Type	L-T-P	Credit	Contact Hour
1	CL5L151: Introduction to Atmospheric Science	DC	3-0-0	3	3
2	CL5L152: Introduction to Oceanography	DC	3-0-0	3	3
3	CL5L153: Mathematics and Statistics for Climate Science	DC	3- 1 -0	4	4
4	CL5L154: Remote Sensing and GIS for Climate Science	DC	2-0-2	3	4
5	CL5L155: Fluid Dynamics	DC	2-0-2	3	4
6	CL5P151: Climate Data Analysis Lab	Lab	1-0-3	3	4
Total				19	22

Semester-2					
Sl No.	Code and Subject	Type	L-T-P	Credit	Contact Hour
1	CL5L251: Dynamical Meteorology and Oceanography	DC	3-0- 0	3	3
2	CL5L252: Tropical Meteorology	DC	3-0-0	3	3
3	CL5L253: Atmospheric and Ocean Observations	DC	3-0-0	3	3
4	CL5L254: Basics of Climate Variability and Change	DC	3- 1-0	4	4
5	CL5L255: Numerical Modelling of Atmosphere and Ocean	DC	3-1-0	4	4
6	CL5P251: Field Work and Observations Lab	Lab	1-0-3	3	4
7	CL5P252: Numerical Modelling and Diagnostics Lab	Lab	1-0-3	3	4
Total				23	25

*DC: Dept. Core

Semester-3					
Sl No.	**Code and Subject**	**Type**	**L-T-P**	**Credit**	**Contact Hour**
1	CL5S351: Technical Writing and Communications in Climate Science	Dept. Core	0-0-0	2	0
2	OE 1 / DE 1	Elective	3-0-0	3	3
3	OE 2 / DE 2	Elective	3-0-0	3	3
4	OE 3 / DE 3	Elective	3-0-0	3	3
5	OE 4 / DE 4	Elective	3-0-0	3	3
6	CL5D351: Project	Project/Thesis	0-0-0	6	0
Total				**20**	**12**

Semester-4					
Sl No.	**Code and Subject**	**Type**	**L-T-P**	**Credit**	**Contact Hour**
1	CL5D451: Project	Project/Thesis	0-0-0	18	-
Total				**18**	-

Joint M.Sc. – Ph. D. Programme in Atmosphere and Ocean Sciences

Subject Details

Semester-1					
Sl No.	**Subject Code and Name**	**Type**	**L-T-P**	**Credit**	**Contact Hour**
1	CL5L151: Introduction to Atmospheric Science	DC	3-0-0	3	3
	Pre-requisite(s):				
	Syllabus: Atmospheric composition and properties, general circulation of atmosphere, thermodynamic of dry and moist air, clausius-clapeyron relationship, moist processes in the atmosphere, adiabatic, saturated and unsaturated accent, moist convection, clouds and precipitation, atmospheric stability, hydrostatic balance, geopotential, hypsometric equation, radiation and energy balance, greenhouse effect, monsoon, cyclones and severe tropical and mid-latitude weather systems **Learning outcomes:** At the end of the course, the students will be able to: • Learn about key topics in atmospheric science, like weather systems, atmospheric physics, composition, and climate. • Able to understand and explain basic concepts • Describe different processes and their consequences • Apply concepts to real time weather systems. **Text/Reference Books:** • Atmospheric Science: An Introductory Survey, J.M. Wallace and P. V Hobbs • An Introduction to Atmospheric Thermodynamics, A.A.Tsonis • Meteorology Today: An Introduction to Weather, Climate and the Environment, C. Donald Ahrens, Robert Hensen				
2	CL5L152: Introduction to Oceanography	DC	3-0-0	3	3
	Pre-requisite(s):				
	Syllabus:				

Oceans and Ocean basins, Properties of Seawater and Spatio-Temporal-Vertical Variability, Ocean Layers, T-S Diagram, Ocean Instruments, Ocean Current System, Eddies, Waves and Tides, wave propagation. coastal upwelling and fronts, Geostrophic Flow, Wind-driven Current, Ocean Heat Budget, Indian Ocean dipole, ENSO, Ocean and Climate: Ocean and Blue economy.

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

- Explain the characteristics of the ocean properties
- Identify upwelling-downwelling zones from winds and currents
- Relate the oceanic processes with the climate

Text/Reference Books:

- Pickard, G. L., & Emery, W. J. (1961). Descriptive physical oceanography: an introduction. Oxford: Butterworth.
- Talley, L. D. (2011). Descriptive physical oceanography: an introduction. Academic press.
- Garrison, T., & Ellis, R. (2001). Essentials of oceanography (p. 480). Brooks/Cole.

3	CL5L153: Mathematics and Statistics for Climate Science	DC	3- 1 -0	4	4

Pre-requisite(s): Preliminary courses on calculus and linear algebra.

Syllabus:

Probability and Statistics –
Discrete and Continuous Random Variables, Derived Distributions, Distributions of Sample Statistics, Confidence Intervals, Hypothesis Testing, Goodness-of-Fit Tests.

Time Series Analysis –
Fourier Transform, Fast Fourier Transform, Inverse Fourier Transform.

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

- Students learn when and how to apply different approaches in probability and statistics, and time-frequency analysis, to atmosphere-ocean datasets (both observed and model simulations).
- At the end of the course, they also should be able to grasp more advanced techniques available for observational analysis.

	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. • Ross, S., Introduction to Probability and Statistics for Engineers and Scientists, Elsevier, Fourth edition, 2009 (or Third edition, 2005). • Wilks, D., Statistical Methods in the Atmospheric Sciences, Academic Press, Second Edition, 2006. • Brigham, O. E., The Fast Fourier Transform, Prentice Hall, First Edition, 1974.				
4	CL5L154: Remote Sensing and GIS for Climate Science	DC	2-0-2	3	4
	Pre-requisite(s): Basic Physics and Mathematics				
	Syllabus: Fundamentals of Remote Sensing (RS): Terminologies; Electromagnetic Radiation, Optical/Thermal/Microwave RS; RS Sensors: Types, Resolutions; Aerial Photography & Photogrammetry; RS Data Processing & Interpretation: Visual Interpretation in RS, Spectral Signatures, Digital Image: Concepts, Image data formats, Image processing; Multispectral Image: Classification, Enhancement Techniques, On-screen Interpretation; RS Applications in Terrestrial, Marine Atmospheric & Climate Sciences. Geographic Information System (GIS): Fundamentals, Types, Elements, Data Structures, Spatial Analysis, Basic GIS Modeling & Applications **Learning outcomes:** At the end of the course, the students will be able to: • Understand the principles and applications of Remote Sensing Technology • Utilize Remote Sensing resources for observation of terrestrial, ocean and atmospheric parameters • Evaluate the significance of long-period, large-area and high resolution measurements in Climate Sciences • Enhance their knowledge on Remote Sensing and its Applications for solving real life problems **Text/Reference Books:** • G. Joseph and C. Jeganathan, Fundamentals of Remote Sensing (2018), 3rd Ed., The Orient Blackswan, pp. 624.				

	• F. S. Sabins & J. M. Ellis, Remote Sensing: Principles, Interpretation, and Applications (2020), 4th Ed., Waveland Pr Inc., pp. 524. • J. R. Jensen, Introductory digital image processing: a remote sensing perspective (2017), 4th Ed., Pearson Education, pp. 544.. • P. Longley et al., Geographic Information Science and Systems (2015), 4th Ed., Wiley, pp. 496.				
5	CL5L155: Fluid Dynamics	DC	2-0-2	3	4
	Pre-requisite(s):				
	Syllabus: Properties of fluids; Viscosity: Newtonian and non-Newtonian fluids, frictional forces; Pressure and its measurements: manometry, barometry, buoyancy, pressure gradient forces; Bernoulli's principle and applications; Linear and angular deformations and vorticity; Stream function and velocity potential; Dimensional analysis: Buckingham Pi theorem, scale analysis, similitude; Basics of turbulence: Reynolds decomposition and turbulence stresses. **Learning outcomes:** At the end of the course, the students will be able to: • Identify and classify fluid flows based on flow and fluid characteristics • Measure pressure and quantify pressure gradient and frictional forces • Apply Bernoulli's equation for different flow scenarios • Represent quantitative and qualitative flow visualization using concepts of • stream functions and other • Identify and design dimensionless parameters for different flows and use in • flow simulations • Quantify basic turbulence flow properties **Text/Reference Books:** • White, Frank M. Fluid Mechanics. Tata McGraw-Hill. • Kundu, P.K., Cohen, I.M. and Dowling, D.R., Fluid Mechanics, Academic Press, Elsevier				
6	CL5P151: Climate Data Analysis Lab	Lab	1-0-3	3	4
	Pre-requisite(s):				
	Syllabus: Overview of climate science and the role of data analysis. Types of climate data: observational, reanalysis, and model data.				

Sources of climate data and formats, Downloading and reading climate data using Python/equivalent language.

Data Cleaning and Preprocessing.

Exploratory Data Analysis (EDA) – mean, median, standard deviation, time series analysis.

Statistical Analysis of Climate Data – Correlation and regression analysis, confidence intervals, hypothesis testing, Fourier Analysis, and Filtering.

Climate Data Visualization - Advanced plotting techniques (e.g., contour plots).

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

- Bridging the basics of climate science concepts and data analysis techniques.
- Gain proficiency in using software tools such as Python, R, and relevant libraries for data analysis.
- Learn techniques for data acquisition, cleaning, processing, and visualization.
- Develop skills in statistical analysis and interpretation of climate data.
- Apply learned techniques to real-world climate datasets and problems.
- Effectively communicate results through reports and presentations.

Text/Reference Books:

- Wilks, D. S. (2011). *Statistical Methods in the Atmospheric Sciences*. Academic Press.
- VanderPlas, J. (2016). *Python Data Science Handbook*. O'Reilly Media.
- IPCC Assessment Reports and relevant scientific literature.

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<tr><th colspan="6">Semester-2</th></tr>
<tr><th>Sl No.</th><th>Subject</th><th>Type</th><th>L-T-P</th><th>Credit</th><th>Contact Hour</th></tr>
<tr><td>1</td><td>CL5L251: Dynamical Meteorology and Oceanography</td><td>DC</td><td>3-0-0</td><td>3</td><td>3</td></tr>
<tr><td></td><td colspan="5">Pre-requisite(s):</td></tr>
<tr><td></td><td colspan="5">Syllabus: Governing equations in rotating flows: Continuity and momentum equations, Coriolis forces, concepts of circulation, vorticity, and divergence in fluid flows: Kelvin's theorem, potential vorticity; Equilibrium flows: Geostrophic equilibrium, hydrostatic equilibrium, thermal wind balance, inertial flow, cyclostrophic flow, gradient winds; Barotropic waves and instability; Mass and salinity conservation in oceans; Ekman flow

Learning outcomes: At the end of the course, the students will be able to:
• Identify the basic meteorological and ocean processes that determine the observed weather and ocean currents
• Approximate the flow fields of the atmosphere and ocean from given force distributions
• Identify some of the basic atmospheric and ocean flows and the forces responsible for them
• Quantify the distribution of scalars like water vapour, energy, salt etc in the atmosphere and ocean flows

Text/Reference Books:
• J. R. Holton Holton, J. R., 2004: An Introduction to Dynamic Meteorology, 4th ed., Elsevier Academic Press.
• Gill A. Dynamics of Ocean and Atmosphere, Academic Press
• J. Pedloskey, Geophysical Fluid Dynamics</td></tr>
<tr><td>2</td><td>CL5L252: Tropical Meteorology</td><td>DC</td><td>3-0-0</td><td>3</td><td>3</td></tr>
<tr><td></td><td colspan="5">Pre-requisite(s):</td></tr>
<tr><td></td><td colspan="5">Syllabus: Introduction to tropics: definition, distinguishing characteristics of tropics, distribution of temperature, pressure, and moisture; Hadley cell and ITCZ; monsoon: definition, monsoon systems of the world; Indian monsoon: characteristics, intraseasonal and inter-annual variability, factors affecting monsoon, modelling and changing monsoon, Convectively coupled equatorial waves and MJO, observations and modelling; Tropical inter-annual</td></tr>
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	variations: Walker circulation, ENSO, IOD, Quasi-biennial oscillations; tropical cyclones **Learning outcomes:** At the end of the course, the students will be able to: • Distinguish tropical atmospheric phenomena and dynamics from extra-tropics • Handle equations governing tropical atmosphere • Identify different factors affecting tropical weather and climate like • monsoons and cyclones • Qualitatively estimate the remote effects of large-scale tropical processes on weather **Text/Reference Books:** • G C Asnani. Tropical Meteorology (Vol 1-3, three Volumes),Willey • T.N. Krishnamurti, Stefanova and Misra. Tropical Meteorology: An Introduction, Springer • Wang, Bin. The Asian Monsoon, Springer					
3	CL5L253: Atmospheric and Ocean Observations	DC	3-0-0	3	3	
	Pre-requisite(s): Fundamental Physics & Mathematics					
	Syllabus: General Observation Systems & Principles; Measurements & Standards; Types and Sources of Error; Error Estimations & Propagation; Observational Data Processing, Quality Check & Analysis; Observational Tools (*in situ* & remote sensing); Equipment & Measurements: Atmospheric Parameters (wind speed & direction, temperature, pressure, humidity, etc.), Ocean Parameters: (temperature, salinity, currents, etc.); Observational Networks **Learning outcomes:** At the end of the course, the students will be able to: • Understand the principles & techniques used in atmospheric & ocean observations • Compute errors & uncertainties associated with measurements and measuring instruments • Apply data quality checks to ascertain the reliability of measured observations **Text/Reference Books:**					

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- Guide to Meteorological Instruments and Methods of Observation. 6th Ed., WMO-No 8.
- Compendium of Lecture notes on Meteorological Instruments. WMO-No 622.
- F. Dobson, L. Hasses and R. Davis, Air-Sea Interaction - Instruments and Methods, Premium Press.
- I. S. Robinson, Measuring the Ocean from Space, Springer.
- R. Venkatesan, Amit Tandon, Eric D'Asaro and M. A. Atmanand, Observing the Oceans in Real Time, Springer Oceanography Series, Springer Cham

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<tr><td>4</td><td>CL5L254: Basics of Climate Variability and Change</td><td>DC</td><td>3- 1-0</td><td>4</td><td>4</td></tr>
<tr><td></td><td colspan="5">Pre-requisite(s):</td></tr>
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Syllabus:
Description of the climate system; feedback in the climate system. Role of diabatic heating in the atmosphere. Climate variability on various time scales; introduction to different modes of climate variability. The relative roles of the atmosphere, ocean, land surface, and cryosphere in driving climate variability and change at different time and space scales. Natural and anthropogenic climate change- detection and attribution, impacts and mitigation of climate change. Effects of warming in the tropics, Changes in atmospheric circulation, Atlantic Ocean, and Indian Ocean. Effects of warming in the Indian summer monsoon. Basic introduction to global efforts in understanding and predicting climate change through WCRP (CLIVAR), IPCC, IGBP, etc.

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

- Learn basic level concepts of tropical climate and variability and their applications.
- Explain to a lay-person what controls the climate system and what role each of the components, the atmosphere, the ocean, and the cryosphere plays. The student will also be able to evaluate the importance of uncertainties in climate prediction.
- Critically read science articles on climate change and understand seminars on climate dynamics and climate change.

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	Text/Reference Books: • An Introduction to Large-Scale Tropical Meteorology, Vasubandhu Misra, https://doi.org/10.1007/978-3-031-12887-5 • Kevin E Trenberth: Climate System Modeling, Cambridge University Press. • Climate Change 2021: The Physical Science Basis • Many other articles, websites, and research reviews based on requirements.				
5	CL5L255: Numerical Modelling of Atmosphere and Ocean	DC	3-1-0	4	4
	Pre-requisite(s): NIL				
	Syllabus: Overview of numerical weather prediction. Governing equations: continuous equations, map projections, vertical coordinate system, filtering approximations, model errors, grid structure, Numerical methods: finite-difference methods, time and space differencing, stability analysis; Numerical models: Global models, regional models, mesoscale models. Parameterization: planetary boundary layer, moist microphysics physics, cumulus convection, radiation, air-sea interaction processes, and land surface processes. Data assimilation: Objective analysis, data assimilation techniques, 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				
6	CL5P251: Field Work and Observations Lab	Lab	1-0-3	3	4
	Pre-requisite(s): Atmospheric and Ocean Observations Course				

	Syllabus: Atmospheric & Ocean Measurements and Instruments: Specifications, Limitations, Utility; Station Data, Forecasting techniques, Weather chart plotting and interpretation, Analysis of Atmospheric & Ocean eather events, Field observations and campaigns **Learning outcomes:** At the end of the course, the students will be able to • Understand, analyse and interpret observational data & charts. • Familiarize and utilise state-of-art instruments, forecasting systems and products • Able to apply their classroom concepts to analyse atmospheric & oceanic phenomena • Obtain real-time experience of making measurements using various equipment in the field **Text/Reference Books:** • T. Vasquez, *Weather Analysis and Forecasting Handbook,* Weather Graphics Technology Publications • E. Stefan, Measurement Methods in Atmospheric Sciences: In situ and remote, Borntraeger Science Publishers • *Compendium of Lecture notes on Meteorological Instruments*. WMO-No 622. • F. Dobson, L. Hasses and R. Davis, Air-Sea Interaction, Instruments and Methods, Premium Press. • A P Cracknell (Dorderecht: D Reidel), Remote Sensing Applications in Marine Science and Technology, CRC Press				
7	CL5P252: Numerical Modelling and Diagnostics Lab	Lab	1-0-3	3	4
	Pre-requisite(s): Basic knowledge of calculus, physics, and programming (Python/MATLAB recommended)				
	Syllabus: Statistical representation of the climate data, Formulation of the Niño and DMI index, Lead-lag correlation, composite analysis. Configuration of atmosphere and ocean models. Model assessment techniques. Model experiments of atmospheric and oceanic applications. **Learning outcomes:** At the end of the course, the students will be able to: • **Understand** fundamental numerical methods applied in atmospheric and oceanic sciences.				

- **Develop** simple models to solve basic atmospheric and oceanic equations.
- **Analyze** observational and model data using numerical tools.
- **Interpret** outputs from global and regional climate models.
- **Evaluate** uncertainties and limitations of numerical models.
- **Apply** diagnostic methods to identify key dynamical processes.

Text/Reference Books:

Textbooks:

1. Durran, D. R. (2010) *Numerical Methods for Fluid Dynamics: With Applications to Geophysics*
2. Marshall, J., & Plumb, R. A. (2007) *Atmosphere, Ocean, and Climate Dynamics*
3. Wilks, D. S. (2011) *Statistical Methods in the Atmospheric Sciences*

Software and Tools:

- Programming: Python (NumPy, SciPy, xarray, Matplotlib, Cartopy), MATLAB
- Data Formats: NetCDF, GRIB
- Models/Datasets: CMIP6, ERA5, GFS, HYCOM

Online Resources:

- NOAA, ECMWF, and NASA data portals
- GitHub repositories on geophysical fluid dynamics

Total	**21**	**24**

*DC: Dept. Core

Semester-3					
Sl No.	**Subject**	**Type**	**L-T-P**	**Credit**	**Contact Hour**
6	CL5S351: Technical Writing and Communications in Climate Science	Core	0-0-0	2	0
	Pre-requisite(s): Nil				

Syllabus:

Importance of communication in climate science; Structure of Scientific Papers and Reports; Research Proposals and Funding Applications; Oral and Poster Presentations - Structuring scientific presentations, Slide design principles (avoiding clutter, effective visuals), Poster presentation best practices; Communicating Climate Science to the Public; Publication Process and Ethics in Scientific Writing.

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

- **Apply** the principles of scientific and technical writing.
- **Write clear, concise, and structured** research papers, reports, and proposals.
- **Effectively communicate** climate science concepts to scientific and non-scientific audiences.
- **Improve oral communication skills** through presentations, posters, and public outreach.
- **Critically evaluate** scientific literature and peer-reviewed publications.
- **Adhere to publication ethics** and the peer-review process.

Text/Reference Books:

1. *Alley, M. (2018). The Craft of Scientific Writing (4th ed.). Springer.*
2. *Schimel, J. (2012). Writing Science: How to Write Papers That Get Cited and Proposals That Get Funded. Oxford University Press.*
3. *Day, R. A., & Gastel, B. (2011). How to Write and Publish a Scientific Paper (7th ed.). Cambridge University Press.*
4. *Montgomery, S. L. (2003). The Chicago Guide to Communicating Science. University of Chicago Press.*

	5. *Tufte, E. R. (2001). The Visual Display of Quantitative Information. Graphics Press.* 6. *Various research papers.*				
2	OE 1 / DE 1	Elective	3-0-0	3	3
3	OE 2 / DE 2	Elective	3-0-0	3	3
4	OE 3 / DE 3	Elective	3-0-0	3	3
5	OE 4 / DE 4	Elective	3-0-0	3	3
6	CL5D351: Project	Project/Thesis	0-0-0	6	0
Total				**20**	**12**

*OE/DE: Open Elective/Department Elective

Semester-4					
Sl No.	**Subject**	**Type**	**L-T-P**	**Credit**	**Contact Hour**
1	CL5D451: Project	Project/Thesis	0-0-0	18	
Total				**18**	-

List of Electives M.Sc AO

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.

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.

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).				
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.

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:

- Tropical Meteorology: An Introduction, T. N. Krishnamurti, Lydia Stefanova & Vasubandhu Misra, DOI 10.1007/978-1-4614-7409-8

- An Introduction to Large-Scale Tropical Meteorology, Vasubandhu Misra, https://doi.org/10.1007/978-3-031-12887-5
- 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
- The Asian Monsoon, Bin Wang, https://link.springer.com/book/10.1007/3-540-37722-0
- 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:

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.

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

- Obtain specific details about ocean and atmospheric processes and parameters from satellite observations
- Analyse satellite data sets for understanding the dynamics of the ocean and atmosphere
- Retrieve atmospheric and oceanic variables from satellite observations

Text/Reference Books:

- G. A. Maul, Introduction to Satellite Oceanography, Springer
- R. R. Kelkar, Satellite Meteorology, BS Publications
- E. Stefan. Measurement Methods in Atmospheric Sciences - *in situ* and remote, Borntraeger Science Publishers
- A. P. Cracknell (Dorderecht: D Reidel). Remote Sensing Applications in Marine Science and Technology, CRC Press
- S. Q. Kidder and T. H. Vonder Haar, Satellite Meteorology: an Introduction, Academic Press
- I. S. Robinson, Satellite Oceanography – an introduction for Oceanographers and Remote Sensing scientists, Ellis Horwood Ltd.

	• 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. **Learning outcomes:** At the end of the course, the students will be able to: • Explain ocean tide, storm surge, tsunami, and climate modes. • Identify and distinguish the spatio-temporal variability of sea level. • Develop a tool for sea level observation and prediction. • Provide crucial information to the coastal engineers. **Text/Reference Books:** • Pugh, D., & Woodworth, P. (2014). Sea-level science: understanding tides, surges, tsunamis and mean sea-level changes. Cambridge University Press. • Boon, J. D. (2013). Secrets of the tide: tide and tidal current analysis and predictions, storm surges and sea level trends. Elsevier. • Colin V. Murray-Wallace and Colin D. Woodroffe (2018). Quaternary Sea-Level Changes: A Global Perspective. Cambridge University Press • 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				

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

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

- Understand the fundamental properties of atmospheric aerosols, including their size, composition, and formation mechanisms.
- Understand the complex interactions between aerosols and climate systems, focusing on their effects on radiation balance, cloud formation, and precipitation patterns.
- 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.

Text/Reference Books:

- Seinfeld, J. H., & Pandis, S. N. (2016). *Atmospheric Chemistry and Physics: From Air Pollution to Climate Change.* 3rd Edition. Wiley-Interscience. ISBN: 978-1118947401
- 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.

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

- Provide knowledge to understand mesoscale models.
- Familiarize and understand mesoscale processes.

- Identify appropriate models for weather specific events.

Text/Reference Books:

- Mesoscale Meteorology and Forecasting, Peter Ray
- Mesoscale Meteorological Modeling, Roger Pilke
- 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.

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

- Identify the potential resources from the oceans.
- Explain various methods for converting the resources from the ocean
- Quantify various forms of energy available from the oceans
- Work towards the sustainable extraction and utilization of oceanic resources

Text/Reference Books:

- Cruz, J. (2007). *Ocean wave energy: current status and future perspectives*. Springer Science & Business Media.
- Roonwal, G. S. (2017). *Indian Ocean resources and technology*. CRC Press.
- Cassedy, E. S., & Grossman, P. Z. (1998) *Introduction to energy: resources, technology, and society*. Cambridge University Press.
- 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				
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, **Learning outcomes:** At the end of the course, the students will be able to: • Familiarize with extreme weather and climate events. • Understand the cause and prediction of extreme weather events. • Equip students necessary knowledge and domain expertise. **Text/Reference Books:** • Essentials of Meteorology – Donald Ahrens • Mesoscale Meteorological Modeling, R Pilke • 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: 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; Introduction of AI as a tool for Climate Prediction and Forecasting. AI-based weather forecasting models. **Learning outcomes:** At the end of the course, the students will be able to: • Apply supervised and unsupervised learning techniques to climate-related problems. • Use deep learning models to predict and analyze climate patterns. • Interpret the performance and limitations of AI-based climate models. **Text/Reference Books:** • Goodfellow et al., **Deep Learning** (MIT Press, 2016) • Murphy, **Machine Learning: A Probabilistic Perspective** (MIT Press, 2012) • Wilks, **Statistical Methods in the Atmospheric Sciences** (Elsevier, 2019) • LeCun et al., **Deep Learning for Earth System Science** (Annual Review of Environment and Resources, 2021)

14	CL6L514	Polar Oceanography	3-0-0	3	3
	Pre-requisite(s):				
	Syllabus: 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). **Learning outcomes:** At the end of the course, the students will be able to: • **Understand** the unique characteristics of polar oceans, including their physical, chemical, and biological properties, polar currents and mechanism • **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

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.
- Evaluate the role of intraseasonal variability, including active and break phases, and understand teleconnections such as ENSO and the Indian Ocean Dipole.
- Utilize statistical and numerical modeling methods to interpret monsoon behavior and predict seasonal variations.
- Critically review and synthesize current research literature on monsoon dynamics and identify emerging challenges in the field.
- Communicate complex scientific concepts effectively, both in writing and through oral presentations.

Text/Reference Books:

- The Asian Monsoon, Bin Wang, https://link.springer.com/book/10.1007/3-540-37722-0
- Tropical Meteorology: An Introduction, T. N. Krishnamurti, Lydia Stefanova & Vasubandhu Misra, DOI 10.1007/978-1-4614-7409-8
- An Introduction to Large-Scale Tropical Meteorology, Vasubandhu Misra, https://doi.org/10.1007/978-3-031-12887-5
- 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

	• Indian Summer Monsoon Variability:El Niño-Teleconnections and Beyond, Jasti S. Chowdary, Anant Parekh, C. Gnanaseelan. ISBN: 9780128224021 • Many other articles, websites, and research reviews based on requirements.

16	CL6L551	Advanced Dynamical Meteorology	3-0-0	3	3
	Pre-requisite(s): Dynamic Meteorology				
	Syllabus: Quasi-geostrophic analysis, circulation and vorticity theorems, Ertel-Rossby invariants, Ertel's PV conservation theorem, Thomson's and Bjerkness baroclinic circulation theorem, quasi-geostrophic turbulence; barotropic and baroclinic instabilities, symmetric instabilities; quasi-geostrophic motion in equatorial area, heat-induced tropical circulations; Rossby waves, tropical cyclone dynamics **Learning outcomes:** At the end of the course, the students will be able to: • Quantify the flows in non-geostrophic equilibrium • Identify planetary waves and estimate the wave properties • Identify and quantify the instabilities and resultant weather • Formulate the equations governing tropical cyclones **Text/Reference Books:** • J R Holton and Geroge J Hakim: *An introduction to Dynamical Meteorology,* International Geophysics Series. • George J.Haltiner and Frank L.Martin: *Dynamical and physical Meteorology,* International Geophysics Series • George J Haltiner and Roger T Williams: *Numerical Prediction and Dynamical Meteorology,* John Wiley & Sons • B.Haurwitz, *Dynamic Meteorology,* Mcgraw-Hill Book Co				

17	CL6L552	Advanced Dynamical Oceanography	3-0-0	3	3
	Pre-requisite(s):				

	Syllabus: Governing equations for ocean dynamics, wind and buoyancy-driven circulation, Geostrophic flow, and vorticity dynamics, Quasi-geostrophic flow, Gravity waves, Internal gravity waves, Effect of rotations - Rossby Adjustment problems. Effect of rotation and stratifications - Kelvin, Sverdrup, Poincaré waves, Effect of boundaries, Instability- baroclinic: Eddies and Fronts, Vortex Rossby Waves. **Learning outcomes:** At the end of the course, the students will be able to: • Formulate geophysical fluid dynamical flow. • Identify the mechanism of the **Text/Reference Books:** • Gill, A. E. (1982). Atmosphere-ocean dynamics (Vol. 30). Academic press. • Pedlosky, J. (2003). Waves in the Ocean and Atmosphere: Introduction to Wave Dynamics. Springer. • Gangopadhyay, A. (2022). Introduction to ocean circulation and modeling. CRC Press.

18	CL6L553	Marine Hazards and Prediction	3-0-0	3	3
	Pre-requisite(s):				
	Syllabus: Introduction to Marine Hazards- Definition and classification of marine hazards, Human and environmental impacts, and Role of ocean and atmospheric processes. Tsunamis – Generation and Prediction, Tsunami warning systems and modeling. Marine Heatwaves and Impacts. Tropical Cyclones and Storm Surges- Formation and intensification of cyclones. Storm surge dynamics and impact on coastal regions. Coastal Flooding and Sea-Level Rise, Ocean Waves, and Rogue Waves. Harmful Algal Blooms (HABs) and Red Tides, Causes and types of harmful algal blooms, and Detection methods (satellite, in-situ, remote sensing). Oil Spills and Marine Pollution- Transport and dispersion of pollutants, Modeling oil spill trajectories, Ocean Acidification and Its Hazards, Marine Hazard Prediction and Modeling- Observational data sources (satellites, buoys, radars), Numerical modeling of marine hazards. **Learning outcomes:** At the end of the course, the students will be able to:				

	• **Understand** the physical mechanisms behind various marine hazards. • **Analyze** observational and model datasets related to marine hazards. • **Apply** numerical and statistical methods to predict marine hazards. • **Evaluate** the impact of climate change on the frequency and intensity of marine hazards. Textbooks: 1. Pugh, D., & Woodworth, P. (2014) *Sea-Level Science: Understanding Tides, Surges, Tsunamis, and Mean Sea-Level Changes* 2. Glickman, T. (2000) *Glossary of Meteorology* (American Meteorological Society) 3. Gonnert, G., Dube, S. K., Murty, T., & Siefert, W. (2007) *Storm Surges and Tsunamis: Hazards, Risks, and Mitigation* Online Resources: • NOAA and ECMWF marine hazard forecasts • UNESCO-IOC Tsunami Warning System

19	CL6L554	Air-Sea Interactions	3-0-0	3	3
	Pre-requisite(s): Nil				
	Syllabus: Atmosphere and Ocean boundary layer, Surface radiative and turbulent heat fluxes and their variability, Statistics of turbulence, Logarithmic wind profiles, Bulk transfer equations, Monin-Obukhov similarity theory, Earth's energy budget and imbalance, atmosphere and Ocean energy transport, basics of wind driven oceanic circulation, Hydrological cycle, Basics of El Niño Southern Oscillation and its effects on Marine life, Ocean water-mass transformation due to heat and freshwater fluxes **Learning outcomes:** At the end of the course, the students will be able to: • Explain the boundary layer structure of the atmosphere and ocean. • Identify the regions of high and low surface radiative and turbulent heat fluxes and explain the reasons associated with it.				

	• Calculate the wind speed at a particular level above the surface given the wind profile. • Explain the difference between Logarithmic wind profiles and Monin-Obukhov similarity theory. • Calculate energy imbalance from the time series of ocean heat content change. • Derive the global mean surface temperature using the surface emission. • Compute the direction of ocean water transport given the wind stress. • Define the components of the hydrological cycle • Explain the coupled ocean-atmosphere mechanism that leads to El Niño Southern Oscillation and its impact on marine life. • Identify and quantify the water-mass transformation due to air-sea heat and freshwater fluxes. **Text/Reference Books:** 1. Stull, R. B. (2012). *An introduction to boundary layer meteorology* (Vol. 13). Springer Science & Business Media. 2. Hartmann, D. L. (2015). *Global physical climatology* (Vol. 103). Newnes. 3. Csanady, G. T. (2001). *Air-sea interaction: laws and mechanisms.* Cambridge University Press. 4. Trenberth, K. E. (2022). *The changing flow of energy through the climate system.* Cambridge University Press. 5. Marsh, R., & Van Sebille, E. (2021). *Ocean currents: physical drivers in a changing world.* Elsevier.