Five-Year Integrated PG in
Climate Science & Data Analytics

Curriculum

KERALA UNIVERSITY OF FISHERIES AND OCEAN STUDIES (KUFOS), KOCHI

2026

YEAR 1 – FOUNDATIONS

Semester 1

Introductory Physics (Major 1)

Data Handling & Scientific Computing (Minor 1)

Laboratory I: Programming And Observational Analysis (Minor 2)

Introduction To Climate Studies (MDC)

Semester 2

Mathematical Methods (Major 1)

Probability & Statistics (Minor 1)(DSE)

Laboratory II: Statistical Computing and Climate Data Analysis (Minor 2)

General Climatology (MDC)

YEAR 2 – CLIMATE & MACHINE LEARNING

Semester 3

Weather and Climate Disasters (Major 1)

Physical Oceanography I (Major 2)

Climate Risk Vulnerability and Management (Major 3/DSE)

Indigenous Knowledge for Disaster Risk Reduction (MDC)

MATLAB (Minor 1)

Satellite Remote Sensing and Applications (VAC)

Semester 4

Machine Learning I (Minor 1)

Physical Oceanography II (Major 1)

Earth System Science (Major 2)

Deep Learning for Climate Applications (Major 3)

Remote Sensing and Geo-informatics (SEC)

YEAR 3 – CLIMATE MODELS & DATA SCIENCE

Semester 5

Climate Dynamics (Major 1)

Radiation And Aerosol- Cloud Interactions (Major 2)

Machine Learning II (Minor 1)

Computational Methods for Climate Data and Modelling (Major 3)

Laboratory III: Climate Diagnostics and ML Implementation (Major 4)

Artificial Intelligence & Machine Learning in Weather & Climate (SEC)

Semester 6

Climate Change: Science & Impacts (Major 1)

Extreme Events and Risk Analytics (Major 2)

Climate Data Lab (Major 3)

Laboratory IV: Climate Risk and ML Application (Minor 1)

Satellite Meteorology and Ocean Colour (SEC)

YEAR 4 – ADVANCED & RESEARCH

Semester 7

Climate & Weather Modelling (Major 1)

Extreme Weather and Coastal Hazards (Major 2)

Data Engineering for Climate Analytics (Minor 1)

Atmospheric Chemistry & Climate Interactions (Major 3)

Laboratory V: Modelling And Deep Learning Applications (Minor 2)

Big Data Systems and Cloud Computing for Climate (Minor 3)

Semester 8

Climate Services and Decision Support Systems (Major)

Climate Predictability and Seasonal Forecasting (Major)

MOOC

Honours Mini Project / Field Study

Semester 9

Research Methodology & Scientific Writing

Semester 10

Major Project / Dissertation

Five-Year Integrated PG Programme – Climate Science and Data Analytics

Course Structure (Major with Minor)

Course Components	Number of Courses												Total
	Semester 1	Semester 2	Semester 3	Semester 4		Semester 5	Semester 6	Total	Semester 7	Semester 8	Semester 9	Semester 10	
Major (DSC/DSE) (4 Credit /Course)	1	1	3	3	Internship	4	3	**15**	3	2	3 (Mini Project)		**23**
Minor (DSC) (4 Credit /Course)	2	2	1	1		1	1	**8**	3		2		**11**
MDC (3 Credit /Course)	1	1	1 (IKS)					**3**					**3**
AEC (3 Credit /Course)	Eng Hindi/Mal	Eng Hindi/Mal						**4**					**4**
SEC (3 Credit /Course)				1		1	1	**3**					**3**
VAC (3 Credit /Course			1	1			1	**3**					**3**
Project/ Dissertation										12/8		20+2	**3**
Total Courses	**6**	**6**	**6**	**6**		**6**	**6**	**36**	**6**	**2+1**	**5**	**1**	**50**
Total Credits	**21**	**21**	**22**	**22**	**2***	**23**	**22**	**133**	**24**	**20**	**20**	**22**	**219**
Total Hours/Week	**25**	**25**	**25**	**25**		**25**	**25**	**Exit Option**	**25**	**25**	**25**	**25**	

Five-Year Integrated PG Climate and Data Analytics

YEAR 1 – SEMESTER 1

Total Credits: 21

Total Hours/Week:25

CDAT 101 Introductory Physics

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental principles of mechanics, gravitation, motion, forces, and rotational dynamics governing natural and engineered systems.

CO2: Apply the concepts of units, dimensions, measurement techniques, error analysis, and dimensional methods in solving physical science problems.

CO3: Describe the principles of optics, wave phenomena, and electromagnetic radiation, and interpret their applications in natural and technological systems.

CO4: Analyze the basic concepts of electricity, energy generation, power transmission, and renewable energy technologies relevant to sustainable development.

CO5: Interpret the physical properties of matter, fluids, heat, sound, and electromagnetic waves, and relate these concepts to atmospheric, environmental, and climate science applications.

Module 1 Units and Dimensions

Development of physics and the birth of new scientific concepts with reference to scientific contributions of Galileo – perspectives on the universe, Newton- deterministic universe.

Fundamental and derived quantities. Units and dimensions, dimensional analysis, order of magnitude, significant figures, errors.

Module 2 Motion

Velocity, acceleration, momentum, Idea of inertia, force - laws of motion. Newton's law of gravitation, acceleration due to gravity, mass and weight, apparent weight, weightlessness. Rotational motion, Moment of inertia, torque, centripetal and centrifugal acceleration examples- banking of curves, centrifugal pump, roller coasters.

Module 3 Light

Reflection, refraction, diffraction, interference, scattering (elementary ideas only) – examples from daily life – apparent depth, blue colour of sky, twinkling of stars. Total internal reflection, mirage, sparkling of diamond, primary and secondary rainbow – optical fibres. Concave and convex mirrors, lenses – focal length, power of a lens, refractive index, prism, dispersion. Human eye, defects of the eye – myopia, hypermetropia, presbyopia and astigmatism and their correction by lens.

Module 4 Electricity

Voltage and current, ohms law. Electric energy, electric power, calculation of energy - requirement of electric appliances – transformer, generator, hydroelectric power generation – wind power – solar power – nuclear power.

Module 5 Matter and Energy

Different phases of matter, fluids - surface tension, viscosity- capillary rise, Bernoulli's theorem and applications -Heat energy, temperature, different temperature scales – degree Celsius, Fahrenheit and Kelvin. Waves – transverse and longitudinal waves, sound waves, Doppler Effect. Electromagnetic waves.

Reference

1. Fundamentals of Physics with Applications by Arthur Beiser

2. Conceptual Physics by Paul G Hewitt

CDAT 102: Data Handling & Scientific Computing (Minor Course)

Credits: 4

Course Outcomes (COs)

CDAT 102 – Data Handling & Scientific Computing

Upon successful completion of this course, students will be able to:

CO1: Demonstrate proficiency in Python programming fundamentals, including variables, data types, operators, control structures, and modular programming techniques.

CO2: Develop and implement computational solutions using functions, loops, conditional statements, exception handling, and structured programming practices.

CO3: Apply numerical computing techniques using NumPy for efficient manipulation, analysis, and processing of multidimensional scientific datasets.

CO4: Perform data handling, cleaning, transformation, and management using Pandas for environmental, atmospheric, and climate-related datasets.

CO5: Create scientific visualizations and process gridded climate datasets using Python-based tools, enabling effective analysis and interpretation of climate and environmental data

Unit I: Programming Fundamentals

Python syntax and structure; variables and data types; arithmetic and logical operations; input/output functions; script execution; debugging basics.

Unit II: Control Flow and Modular Design

Conditional statements; nested loops; iterative problem solving; function definition and scope; modular programming; exception handling; documentation and code commenting standards.

Unit III: Numerical Computing with Python

NumPy arrays; array indexing and slicing; vectorized operations; broadcasting; mathematical functions; random number generation; handling multidimensional arrays.

Unit IV: Data Handling and Manipulation

Pandas data structures; importing CSV and text files; data cleaning; handling missing values; filtering and grouping; merging datasets; datetime operations for climate data.

Unit V: Scientific Visualization and Dataset Processing

Matplotlib plotting (line, scatter, bar, contour); subplot creation; labeling and legends; exporting figures; introduction to NetCDF format; reading gridded datasets; basic climate time series analysis workflow.

CDAT103 – Laboratory I: Programming & Observational Analysis (Minor 2)

Credits: 4

Course Outcomes (COs)

Upon successful completion of this laboratory course, students will be able to:

CO1: Demonstrate competency in the use of basic meteorological instruments and standard methods for collecting and recording surface atmospheric observations.

CO2: Apply statistical techniques to compute and interpret descriptive measures such as mean, variance, standard deviation, and anomalies from meteorological datasets.

CO3: Develop programming skills for processing, analyzing, and visualizing weather and climate data through time-series plots and graphical representations.

CO4: Process and interpret climate datasets in NetCDF format using appropriate computational tools and scientific data analysis techniques.

CO5: Integrate observational data analysis, programming, and climate data visualization methods to solve practical problems and communicate scientific findings effectively

Surface meteorological data collection methods; instrument familiarization; data logging; computation of mean, variance, and anomalies; time series plotting; introduction to NetCDF processing; climate dataset visualization; mini computational assignment integrating programming and data interpretation.

Multi-disciplinary Courses

CDAT 104: Introduction to Climate (Credits 3)

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental characteristics of the Sun–Earth–atmosphere system, including atmospheric composition, structure, and basic atmospheric optical phenomena.

CO2: Describe the distribution and role of atmospheric gases, temperature, pressure, winds, clouds, and greenhouse processes in the Earth's climate system.

CO3: Interpret the fundamental mechanisms governing weather and climate, including atmospheric circulation, Coriolis force, global wind systems, and jet streams.

CO4: Identify and explain the formation, characteristics, and impacts of major weather systems such as air masses, monsoons, tropical cyclones, thunderstorms, and precipitation processes.

CO5: Analyze the factors controlling climate, distinguish between climate variability and climate change, and evaluate the influence of ocean–atmosphere interactions on regional and global climate patterns.

UNIT 1

Sun, Earth and the Atmosphere - Sun-Earth relationship- solstices and equinoxes- motion of earth- structure and composition of the atmosphere- dry air, water vapour and aerosols- atmospheric optics: mirages, rainbows, haloes: atmospheric refraction, coronas, scattering.

UNIT 2

Major and trace gases; vertical temperature profile; troposphere, stratosphere, mesosphere, thermosphere characteristics; ozone layer; pressure variation with altitude; Greenhouse effect; Winds; pressure gradient force; Clouds-formation, types and classification

UNIT 3

Weather and Climate; Coriolis force; global circulation cells (Hadley, Ferrel, Polar); subtropical highs and ITCZ; jet streams overview.

UNIT 4

Air mass classification; Tropical cyclones; Monsoon (basic concept); thunderstorms (basic structure); precipitation types; synoptic scale vs mesoscale processes.

UNIT 5

Causes of climate change; Factors controlling climate (latitude, altitude, continentality, ocean currents); climate variability vs climate change; role of ocean currents in regional climates.

Semester 2

CDAT201 – Mathematical Methods (Major)

Credits: 4

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Apply the principles of differential and integral calculus to analyze rates of change, accumulation processes, and physical phenomena relevant to climate and environmental sciences.

CO2: Utilize matrix algebra, determinants, eigenvalues, and eigenvectors to solve linear systems and interpret mathematical relationships in scientific applications.

CO3: Demonstrate proficiency in vector algebra and coordinate systems for representing and analyzing physical quantities in atmospheric, oceanic, and environmental systems.

CO4: Develop and solve simple mathematical models involving growth, decay, and differential equations to describe natural and environmental processes.

CO5: Interpret mathematical solutions and quantitative results to understand and explain climate, environmental, and Earth system dynamics.

Unit I: Differential Calculus

Limits and continuity; derivatives of algebraic and trigonometric functions; higher-order derivatives; partial derivatives (introductory); applications to rates of change in physical systems.

Unit II: Integral Calculus

Definite and indefinite integrals; substitution methods; integration by parts (basic); applications in accumulation problems; area under curves; physical interpretations in energy and mass balance.

Unit III: Linear Algebra

Matrices and matrix operations; determinants; inverse matrices; solving linear systems using matrix methods; eigenvalues and eigenvectors (introductory concept); applications in environmental modeling.

Unit IV: Vector Algebra and Coordinate Systems

Scalar and vector quantities; vector addition and multiplication; dot and cross products; Cartesian coordinate system; introduction to cylindrical and spherical coordinates (conceptual); gradient operator (basic introduction).

Unit V: Mathematical Modeling Applications

Exponential growth and decay models; simple differential equation models; steady-state solutions; energy balance modeling (zero-dimensional model); interpretation of mathematical solutions in environmental context.

CDAT202 – Probability & Statistics (Minor 1)

Credits: 4

Course Outcomes (COs)

CDAT202 – Probability & Statistics

Upon successful completion of this course, students will be able to:

CO1: Apply descriptive statistical techniques and graphical methods to summarize, visualize, and interpret scientific and environmental datasets.

CO2: Demonstrate an understanding of probability theory and use probabilistic concepts to analyze uncertainty and random processes in natural systems.

CO3: Analyze discrete and continuous probability distributions and apply statistical measures such as expectation, variance, and probability functions to real-world problems.

CO4: Utilize sampling methods, estimation techniques, confidence intervals, and hypothesis testing concepts for statistical inference and decision-making.

CO5: Evaluate measurement errors, quantify uncertainties, and assess the reliability and significance of observational and environmental data using statistical methods.

Unit I: Descriptive Statistics and Data Representation

Measures of central tendency; measures of dispersion; skewness and kurtosis; graphical representation of data (histograms, boxplots, scatter plots); frequency distributions; exploratory data analysis techniques.

Unit II: Fundamentals of Probability Theory

Sample space and events; probability axioms; conditional probability; Bayes' theorem; independent and dependent events; combinatorics basics; applications to environmental phenomena.

Unit III: Random Variables and Probability Distributions

Discrete and continuous random variables; probability mass and density functions; expectation and variance; binomial distribution; Poisson distribution; normal distribution; central limit theorem (conceptual introduction).

Unit IV: Sampling and Statistical Estimation

Population vs sample; sampling techniques; sampling distributions; point estimation; confidence intervals; bias and variance; introduction to hypothesis testing concepts.

Unit V: Error Analysis and Uncertainty Quantification

Measurement error types; propagation of uncertainty; standard error; statistical significance; interpretation of uncertainty in environmental datasets; reliability of observational data.

CDAT203 – Laboratory II: Statistical Computing and Climate Data Analysis (Minor 2)

Credits: 4

Course Outcomes (COs)

Upon successful completion of this laboratory course, students will be able to:

CO1: Apply Python-based statistical computing tools to organize, process, and analyze environmental and climate datasets using NumPy and Pandas libraries.

CO2: Perform probability simulations and implement statistical distributions to investigate uncertainty, variability, and stochastic processes in environmental systems.

CO3: Conduct statistical inference and hypothesis testing using computational methods and interpret the significance of results in scientific and environmental applications.

CO4: Process and analyze observational, reanalysis, and NetCDF-based climate datasets to derive climatological statistics, anomalies, and temporal variability patterns.

CO5: Integrate statistical analysis, data visualization, and climate data interpretation techniques to investigate environmental phenomena and communicate findings through computational projects and scientific reports.

Unit I: Introduction to Statistical Computing with Python

Introduction to Python-based statistical computing; use of NumPy for numerical operations; use of Pandas for structured data handling; importing datasets from CSV and text formats; basic data cleaning procedures; handling missing and inconsistent values; computation of descriptive statistics including mean, median, variance, standard deviation, skewness, and kurtosis; visualization of statistical distributions using histograms and box plots.

Unit II: Probability Simulations and Distribution Analysis

Generation of random numbers using computational tools; simulation of probability experiments; implementation and visualization of probability distributions including normal, binomial, Poisson, and exponential distributions; sampling from distributions; Monte Carlo simulation for uncertainty estimation; graphical comparison of theoretical and simulated distributions.

Unit III: Statistical Inference and Hypothesis Testing

Implementation of hypothesis testing techniques using Python; t-tests for sample mean comparison; chi-square tests for categorical data; calculation of confidence intervals; interpretation of p-values; testing statistical significance in environmental datasets; analysis of variability and uncertainty in observational data.

Unit IV: Environmental and Climate Data Processing

Importing and processing environmental datasets from observational and reanalysis sources; introduction to NetCDF data structure; extraction of variables from gridded datasets; temporal aggregation of data; calculation of climatological means and anomalies; visualization of time series of temperature, rainfall, and sea surface temperature.

Unit V: Exploratory Data Analysis and Mini Project

Correlation analysis between environmental variables; scatter plots and regression visualization; analysis of rainfall frequency distributions; examination of seasonal variability in climate datasets; identification of trends and anomalies; preparation of graphical outputs and statistical summaries; mini computational project involving statistical analysis and interpretation of an atmospheric or oceanographic dataset.

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Multi-disciplinary Courses

CDAT 204 – GENERAL CLIMATOLOGY

Credits: 3

Course Outcomes (COs)

CDAT 204 – General Climatology

Upon successful completion of this course, students will be able to:

CO1: Explain the classification, characteristics, and evolution of air masses and frontal systems, and assess their influence on regional weather conditions.

CO2: Describe the formation, structure, and lifecycle of mid-latitude cyclones and analyze the atmospheric processes governing extratropical weather systems.

CO3: Interpret the development and organization of tropical weather systems, including tropical cyclones, monsoon depressions, and other convective disturbances.

CO4: Analyze the dynamics of monsoon circulation, seasonal atmospheric variability, and the influence of large-scale climate drivers on monsoon behavior.

CO5: Evaluate the role of jet streams and upper-level atmospheric circulation in the development, movement, and intensity of large-scale weather systems and climate patterns.

Unit I: Air Masses and Frontogenesis

Air mass classification (continental, maritime, tropical, polar); source regions and modification processes; thermodynamic and moisture characteristics of air masses; frontal boundaries including cold fronts, warm fronts, occluded fronts, and stationary fronts; mechanisms of frontogenesis and frontolysis; vertical structure of frontal zones; weather associated with frontal passages.

Unit II: Mid-Latitude Cyclones

Polar front theory; lifecycle of extratropical cyclones; cyclogenesis processes; baroclinic instability (conceptual basis); frontal wave development; warm conveyor belt and cold conveyor belt structures; interaction between cyclones and jet streams; cloud bands and precipitation patterns associated with extratropical cyclones.

Unit III: Tropical Weather Systems

Formation and development of tropical cyclones; environmental conditions for cyclogenesis including sea surface temperature, atmospheric instability, and vertical wind shear; cyclone structure including eye, eyewall, and rainbands; cyclone intensity scales; tropical disturbances such as easterly waves and monsoon depressions; convective organization in tropical systems.

Unit IV: Monsoon Systems and Seasonal Circulation

Land–sea thermal contrast; seasonal migration of the Intertropical Convergence Zone (ITCZ); monsoon circulation systems; onset and withdrawal of monsoon; active and break cycles; role of low-level jet streams; monsoon depressions and synoptic disturbances; influence of ENSO and other climate drivers on monsoon variability.

Unit V: Jet Streams and Upper-Level Atmospheric Circulation

Formation and characteristics of jet streams; subtropical jet and polar front jet; thermal wind relationship (conceptual); jet streak dynamics; upper-level divergence and convergence; role of jet streams in cyclone development; interaction between jet streams and large-scale weather systems.

Semester 3

CDAT 301 Weather and Climate Disasters (Major 1)

Course Outcomes (COs)

CDAT 301 – Weather and Climate Disasters

Upon successful completion of this course, students will be able to:

CO1: Explain the formation, characteristics, impacts, and forecasting of major weather-related disasters including tropical cyclones, floods, droughts, thunderstorms, heat waves, cold waves, and air pollution hazards.

CO2: Analyze the spatial distribution, vulnerability, risk factors, and management strategies associated with floods, droughts, landslides, and avalanches in India.

CO3: Evaluate the scientific basis of climate change, including natural and anthropogenic drivers, greenhouse gas impacts, sea-level rise, cryospheric changes, ozone depletion, and future climate projections.

CO4: Interpret the principles and applications of disaster forecasting, monitoring, early warning systems, and the role of satellites, radars, and numerical prediction systems in disaster risk reduction.

CO5: Assess disaster risk using the concepts of hazard, exposure, vulnerability, resilience, adaptation, and disaster risk reduction, and evaluate national strategies for climate resilience and disaster management.

UNIT 1 :
Weather related disasters Tropical cyclones: storm surges, strong winds, heavy rain - Cyclone hazard zonation of Indian Coast line- Cyclone warning system in India-Southwest monsoon: inter annual and decadal variability - droughts and floods- Monsoon onset date variability - Long break monsoon spells -early / late withdrawal of monsoon- Thunderstorms and lightning duststorms - associated Squall, Hail stones and Tornadoes - Short period heavy rain spells - cloud burst - Flash Floods – Non cyclone Strong Winds - Heat and Cold waves -Sunburns, heat burst- Fog - air pollution hazards

UNIT 2:
Flood, drought and landslides Flood Risk Zones in India - Flood forecasting and warning system in India, Drought Prone areas of India- drought management: Forecasting of droughts - Drought management short and long term measures - landslides and avalanches-vulnerability and risk in India-risk mitigation-issues and challenges-monitoring, warning and preparedness.

UNIT 3: Climate and Climate change

Natural and anthropogenic climate change - increase of green house gases and their global impact on climate- melting of glaciers and polar ice - sea level rise and its impact - ozone depletion – IPCC AR6 report and future projections of climate.

UNIT 4: Forecast and warning of disasters Cyclone warning system in India - Satellites and Radar network for cyclone warning-forecast of cyclone track and intensity - storm surge prediction - short and medium range forecast of monsoon rainfall- seasonal (long range) forecast of monsoon rainfall - prediction of climate change.

Unit 5: Disaster, hazard and vulnerability Disaster, hazard, exposure and vulnerability, disaster risk reduction and management. risk transfer, adaptation, resilience .Climate extremes and impacts-human impacts' and strategies for disaster reduction - national disaster management plans

CDAT302 – Physical Oceanography I (Major 2)

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Course Outcomes (COs)

CDAT 302 – Physical Oceanography I

Upon successful completion of this course, students will be able to:

CO1: Explain the major physiographic features of the world's oceans, including ocean basins, continental margins, mid-ocean ridges, trenches, and seafloor topography, and their role in shaping ocean circulation.

CO2: Describe the physical properties of seawater, including temperature, salinity, density, stratification, and their influence on ocean structure and dynamics.

CO3: Analyze the formation, characteristics, and distribution of major water masses and evaluate the processes governing ocean stratification, mixing, and deep-water formation.

CO4: Interpret the fundamental mechanisms of ocean circulation, including wind-driven currents, gyres, western boundary currents, thermohaline circulation, and their role in global climate regulation.

CO5: Demonstrate knowledge of modern ocean observational techniques and instruments used for measuring, monitoring, and analyzing oceanographic parameters from in-situ and satellite-based platforms.

Unit I: Ocean Basins and Seafloor Topography

Major ocean basins; continental margins; mid-ocean ridges; trenches; bathymetric features; seafloor spreading (conceptual overview); ocean volume and depth distribution; global ocean geometry.

Unit II: Physical Properties of Seawater

Salinity and temperature distribution; density structure; equation of state of seawater (conceptual); thermocline; halocline; pycnocline; vertical stratification; heat capacity of seawater.

Unit III: Water Masses and Ocean Stratification

Formation of water masses; T–S diagrams; identification of major global water masses; vertical mixing processes; deep water formation; role of polar regions in global circulation.

Unit IV: Ocean Circulation Basics

Wind-driven circulation (introductory); surface currents; gyres; western boundary currents; thermohaline circulation (conceptual overview); global conveyor belt; role of ocean in heat redistribution.

Unit V: Ocean Observational Techniques

In-situ measurement systems; CTD instruments; Argo floats; drifting buoys; ship-based measurements; satellite altimetry (introductory); SST retrieval methods; ocean data archives.

CDAT303: CLIMATE RISK VULNERABILITY AND MANAGEMENT (Major 3)

Credits 4

Course Outcomes (COs)

CDAT 303 – Climate Risk, Vulnerability and Management

Upon successful completion of this course, students will be able to:

CO1: Explain the scientific basis of climate variability and climate change, including paleoclimate evidence, global warming, ecosystem responses, and impacts on human and natural systems.

CO2: Analyze the influence of climate change on the Asian summer monsoon, tropical cyclone activity, extreme weather events, and regional climate variability over India and the Indian Ocean region.

CO3: Assess climate-related risks, vulnerabilities, and impacts on ecosystems, agriculture, food security, public health, and socio-economic systems using appropriate climate risk frameworks.

CO4: Evaluate climate change mitigation and adaptation strategies, including greenhouse gas reduction measures, renewable energy adoption, carbon sequestration, sustainable agriculture, and ecosystem-based approaches.

CO5: Examine national and international climate policies, conventions, and management frameworks, and apply principles of climate resilience, adaptation planning, and sustainable development to address climate risks.

UNIT 1

Introduction - Climate change and climate variability- Global warming – Paleo climate - Methods to study Paleo climate – Ice ages - Bond cycle - Abrupt climate changes-- Effects of climate change in biosphere and ecosystem-stressors in ecosystem-ecological threshold changes in the timing of seasonal life cycle-range shifts-food web disruption pathogens, parasites and diseases- health impacts-extreme risks-agriculture and food supply impacts.

UNIT 2

Climate change in Asian Summer monsoon: Climate change in monsoon over India (Kerala) and the role of global SST anomalies – Extreme weather events – impact of Climate Change on the genesis of tropical cyclones over North Indian Ocean – Rapid intensification of tropical cyclones- Recent warming of the equatorial Indian Ocean and its impacts – Aerosol caused cooling of the Tibetan anticyclone and its impact – climate change in monsoon depression frequency

UNIT 3

Adaptation and mitigation in Climate Change: Stabilisation of green house gas emissions –role of forests – climate conventions and treaties – changes needed in energy and transport sectors –use of renewable energy sources– Climate change mitigation and adaptation measures.- Sustainable agriculture practices – Blue carbon – Carbon sequestration – Geoengineering-Methods for reducing the carbon footprints.

UNIT 4

Climate mitigation and adaptation – green technologies-reduction in emissions-increasing green cover-renewable energy- Climate change policies - Indian Climate change policies and planning.

CDAT304 – Indigenous Knowledge in Disaster Risk Reduction

Credits 4

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Explain the foundations of ancient Indian meteorological knowledge, including traditional observations of weather, climate, seasonal cycles, and environmental processes.

CO2: Interpret meteorological concepts described in classical Indian texts such as Brihat Samhita and evaluate their relevance in the context of modern atmospheric science.

CO3: Analyze the role of indigenous environmental governance, water resource management, and disaster preparedness practices documented in historical Indian literature.

CO4: Assess traditional knowledge systems related to monsoon forecasting, agricultural planning, and community-based climate adaptation strategies across different regions of India.

CO5: Evaluate indigenous disaster risk reduction practices and explore opportunities for integrating traditional ecological knowledge with modern climate services, disaster management, and resilience planning.

Credits: 2

Unit I: Foundations of Indian Meteorological Knowledge

Historical evolution of meteorological thought in India; astronomical observations and seasonal cycles; traditional calendars and climate tracking;

Unit II: Classical Texts

Meteorological references in ancient texts; astronomical–meteorological linkages; environmental indicators used for seasonal forecasting; interpretation of traditional forecasting approaches in modern scientific context.

Unit III: Environmental Governance

References to agriculture and seasonal rainfall; state management of drought and famine; irrigation planning; water resource management in ancient India; environmental risk governance in historical context.

Unit IV: Indigenous Knowledge of Monsoon and Agriculture

Traditional indicators of monsoon onset; wind patterns and oceanic observations in coastal communities; crop-calendar alignment with rainfall; oral traditions and community forecasting; regional monsoon indicators.

Unit V: Indigenous Disaster Risk Reduction Practices

Traditional flood management techniques; coastal settlement planning; cyclone shelters in traditional architecture; drought resilience strategies; water harvesting systems; community-based early warning practices; integration of indigenous knowledge with modern climate services.

CDAT305-MATLAB (Minor 1)

Credits 4

Course Outcomes (COs)

Deep Learning for Climate Applications

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental principles of deep neural network architectures, activation functions, optimization algorithms, and regularization techniques used in deep learning.

CO2: Develop and implement convolutional neural network (CNN) models for spatial pattern recognition, feature extraction, and analysis of atmospheric and climate datasets.

CO3: Apply recurrent neural networks (RNNs) and long short-term memory (LSTM) networks to model temporal dependencies and perform climate and weather time-series forecasting.

CO4: Evaluate and optimize deep learning models using advanced training techniques, hyperparameter tuning, model interpretability methods, and performance assessment metrics.

CO5: Design and apply deep learning solutions for climate and weather applications, including extreme event prediction, precipitation forecasting, climate model bias correction, and climate simulation emulation.

UNIT I

Introduction to MATLAB- Matrices and Arrays, Array Creation, Matrix and Array Operations. Built-in-functions- Scalar functions, Vector functions, Matrix functions. Line plots, 2D and 3D plots. M-files: Scripts and functions. - Basic Matlab data structures, file i/o, string handling, code efficiency and analysis, Matlab debugger.
UNIT 2

Conditional Statements. Colon Operator. Characters and text, Structures, Linear Algebra, Operations on Nonlinear functions, Multivariate data, data analysis. Vector products and transpose: Multiplying Matrices, Identity matrices, System of Linear Equations, Permutations of Triangular matrices, Square matrices, Rectangular matrices. Nonsingular coefficient matrix.Iterative method for solving linear system of equations Inverses and determinants. Eigen values, eigen decomposition, Multiple Eigen values, Schur decomposition, Operations on non-linear functions.

UNIT 3
Introduction to Numerical Methods - Linear algebra, numerical integration and differentiation, solving systems of ODE's and interpolation of data.Data Visualization and Statistics - Basic statistical tools in Matlab and more advanced data visualization tools (2D and 3D data visualization). Graphics- Basic plotting functions, Creating Mesh and surface plots, Plotting Image Data, basic plotting functions. Creation mesh and surface plots.

UNIT 4
Practical applications on climate variability- Generic scripts -Means, STD-Anomalies

Correlations-Hofmoeller (ACW)-Time series (SSTA..):detrending filtering Interpolation regular &irregular grids- EOFs REOFs CEOFs -Spectral analysis -Wavelets -Probability, Density Functions.Simple Climate Models- Energy balance box- model, ice-albedo feedback with multiple steady states.

Value Added Course

CDAT305 Satellite Remote Sensing and Applications

Credits: 4

Course Outcomes (COs)

CDAT305 – Satellite Remote Sensing and Applications

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental principles of remote sensing, electromagnetic radiation, radiative interactions, and sensor characteristics relevant to Earth observation systems.

CO2: Describe the operation and applications of satellite platforms, sensor systems, and observational technologies used for atmospheric, oceanic, and environmental monitoring.

CO3: Apply satellite remote sensing techniques to retrieve and interpret atmospheric parameters such as clouds, precipitation, temperature, humidity, aerosols, and wind fields.

CO4: Analyze oceanographic variables including sea surface temperature, ocean color, sea level variability, surface winds, and ocean circulation using satellite observations.

CO5: Process, interpret, and evaluate remote sensing datasets by integrating satellite and in-situ observations for climate monitoring, environmental assessment, and decision-making applications.

Unit I: Electromagnetic Radiation and Remote Sensing Principles

Electromagnetic spectrum; radiation laws; atmospheric absorption and scattering; radiative transfer concepts (introductory); passive and active remote sensing; sensor characteristics and resolution.

Unit II: Satellite Platforms and Sensor Systems

Polar-orbiting and geostationary satellites; radiometers and spectrometers; microwave and infrared sensors; temporal and spatial resolution; satellite calibration and validation.

Unit III: Atmospheric Remote Sensing Applications

Cloud property retrieval; rainfall estimation algorithms; atmospheric temperature and humidity sounding; aerosol optical depth; satellite-based wind estimation; vertical profiling techniques.

Unit IV: Ocean Remote Sensing Applications

Sea surface temperature retrieval; ocean color and chlorophyll estimation; altimetry and sea level anomalies; scatterometer wind measurements; detection of ocean currents and eddies.

Unit V: Remote Sensing Data Processing and Interpretation

Data preprocessing steps; georeferencing; image enhancement; retrieval uncertainty; merging satellite and in-situ data; limitations and error sources; applications in climate monitoring.

Semester 4

CDAT401-Machine Learning I (Minor)

Credits: 4

Course Outcomes (COs)

Machine Learning I

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental concepts of machine learning, including supervised and unsupervised learning, model training and testing, overfitting, underfitting, and performance evaluation techniques.

CO2: Apply regression-based machine learning algorithms and regularization methods to develop predictive models for environmental and climate-related variables.

CO3: Implement and evaluate classification algorithms for identifying patterns, categories, and extreme events in atmospheric and climate datasets.

CO4: Perform data preprocessing, feature engineering, dimensionality reduction, and dataset preparation techniques to improve machine learning model performance.

CO5: Develop and assess machine learning solutions for climate science applications, including extreme rainfall prediction, temperature anomaly classification, ENSO detection, and climate downscaling.

Unit I: Foundations of Machine Learning

Supervised vs unsupervised learning; training and testing datasets; overfitting and underfitting; bias–variance tradeoff; cross-validation; performance metrics.

Unit II: Regression Algorithms

Linear regression (review in ML context); polynomial regression; ridge and lasso regression; regularization; model selection; application to temperature and rainfall prediction.

Unit III: Classification Algorithms

Logistic regression; k-nearest neighbors; decision trees; support vector machines; confusion matrix; ROC curves; classification metrics.

Unit IV: Feature Engineering and Data Preprocessing

Normalization and standardization; handling missing data; categorical encoding; dimensionality reduction; principal component analysis (computational implementation); dataset splitting strategies.

Unit V: ML Applications in Climate Science

Predicting extreme rainfall events; temperature anomaly classification; ENSO phase detection; downscaling applications; performance comparison with traditional statistical models.

CDAT402-Physical Oceanography II (Major 1)

Credits: 4

Course Outcomes (COs)

Physical Oceanography II

Upon successful completion of this course, students will be able to:

CO1: Explain the physical mechanisms governing wind-driven ocean circulation, including Ekman transport, Sverdrup balance, gyre formation, coastal upwelling, and western boundary current dynamics.

CO2: Analyze the processes controlling thermohaline circulation, deep-water formation, ocean stratification, and global overturning circulation and their significance for climate regulation.

CO3: Describe the generation, propagation, and transformation of ocean waves and evaluate their role in coastal processes, marine hazards, and energy transfer.

CO4: Interpret the dynamics of tides, coastal circulation, and estuarine processes, and assess their interactions with coastal morphology and marine environments.

CO5: Evaluate ocean–atmosphere coupling processes, including heat exchange, sea surface temperature variability, mixed-layer dynamics, and oceanic influences on weather, climate variability, and climate change.

Unit I: Advanced Ocean Dynamics

Ekman transport and Ekman spiral, surface stress and momentum transfer, pressure gradient force, Coriolis force, geostrophic currents, Sverdrup transport, potential vorticity (conceptual), western boundary intensification.

Unit II: Ocean Mesoscale and Submesoscale Processes

Ocean fronts, mesoscale eddies, warm-core and cold-core rings, ocean jets and meanders, mesoscale variability, submesoscale processes, internal waves, vertical transport of heat, salt and nutrients.

Unit III: Ocean Waves

Wave properties, wavelength, frequency and phase speed, deep-water waves, shallow-water waves, wave dispersion, wave energy propagation, wave refraction, wave shoaling, wave breaking, storm surge dynamics and coastal impacts.

Unit IV: Tides and Coastal–Estuarine Dynamics

Astronomical forcing of tides, tidal constituents, tidal prediction, spring and neap tides, coastal circulation, estuarine circulation, estuarine mixing processes, sediment transport, coastal erosion and accretion, interaction between tides and coastal morphology.

Unit V: Ocean–Climate Interactions and Prediction

El Niño–Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Madden–Julian Oscillation (MJO), ocean heat content variability, marine heatwaves, ocean–atmosphere feedback mechanisms, seasonal climate prediction, ocean forecasting systems, operational oceanography applications.

CDAT403-Earth System Science (Major 2)

Credits: 4

Course Outcomes (COs)

Earth System Science

Upon successful completion of this course, students will be able to:

CO1: Explain the structure and functioning of the Earth system by describing the interactions among the atmosphere, hydrosphere, lithosphere, biosphere, and cryosphere, and their roles in maintaining planetary equilibrium.

CO2: Analyze the Earth's energy budget and radiative processes, including solar radiation, greenhouse effects, radiative transfer mechanisms, and global energy balance.

CO3: Evaluate the major biogeochemical cycles, including carbon, nitrogen, and hydrological cycles, and assess their significance in regulating climate and environmental processes.

CO4: Interpret the interactions among Earth system components, including atmosphere–ocean coupling, land–atmosphere exchanges, cryosphere feedbacks, and human influences on climate variability and change.

CO5: Demonstrate knowledge of modern Earth system observation networks, remote sensing platforms, climate datasets, and data management techniques used for monitoring and understanding Earth system processes.

Unit I: Earth as an Integrated System

Earth system components: atmosphere, hydrosphere, lithosphere, biosphere, cryosphere; Earth as a complex adaptive system; system boundaries and subsystems; feedback mechanisms (positive and negative feedbacks); equilibrium and disequilibrium states; forcing and response; nonlinearity and tipping points; spatial and temporal scales in Earth processes; anthropogenic perturbations to natural systems.

Unit II: Earth's Energy Budget and Radiative Processes

Solar constant and solar geometry; distribution of insolation; shortwave and longwave radiation; absorption, scattering, and reflection; planetary albedo; blackbody radiation concept; Stefan–Boltzmann law (conceptual use); greenhouse gases and radiative trapping; vertical energy transfer; global mean energy balance models; surface–atmosphere radiative exchange.

Unit III: Biogeochemical Cycles

Carbon reservoirs and fluxes; photosynthesis and respiration; ocean carbon uptake; anthropogenic CO_2 emissions; nitrogen fixation and denitrification; hydrological cycle components (evaporation, condensation, precipitation, runoff); coupling between water and energy cycles; feedbacks between biosphere and climate; role of soils and vegetation in climate regulation.

Unit IV: Earth System Interactions

Atmosphere–ocean coupling mechanisms; land–atmosphere energy and moisture exchanges; cryosphere–albedo feedback; ocean heat transport; teleconnections and large-scale variability (ENSO conceptual introduction); role of topography in climate; human–climate interactions and land-use change impacts.

Unit V: Earth System Observation and Data Framework

Surface meteorological networks; ocean buoys and Argo floats; radiosondes; remote sensing platforms; satellite orbits and coverage; reanalysis datasets; climate data archives; data quality control; homogenization of climate records; observational uncertainties; introduction to climate data portals.

CDAT404-Deep Learning for Climate Applications

Credits: 4

Course Outcomes (COs)

CDAT404 – Deep Learning for Climate Applications

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental concepts of deep neural networks, including network architectures, activation functions, optimization algorithms, regularization techniques, and challenges associated with deep learning model training.

CO2: Develop and implement Convolutional Neural Network (CNN) models for spatial pattern recognition, feature extraction, and analysis of climate and weather datasets.

CO3: Apply Recurrent Neural Networks (RNNs) and Long Short-Term Memory (LSTM) networks to model temporal dependencies and perform forecasting of climate variables and seasonal climate variability.

CO4: Evaluate and optimize deep learning models using advanced training techniques, hyperparameter tuning, transfer learning approaches, and model interpretability methods to improve predictive performance.

CO5: Design and assess deep learning applications for climate and weather prediction, including extreme event forecasting, climate model bias correction, surrogate modeling, and comparison with traditional dynamical forecasting approaches.

Unit I: Deep Neural Network Architecture

Multi-layer perceptron; activation functions (ReLU, sigmoid, tanh); gradient descent optimization; loss functions; dropout and regularization; vanishing and exploding gradients.

Unit II: Convolutional Neural Networks (CNN)

Image representation of climate fields; convolution operations; pooling layers; feature extraction; CNN architecture for spatial pattern recognition; cyclone detection applications.

Unit III: Recurrent Neural Networks (RNN) and LSTM

Sequential data modeling; memory cells; long short-term memory networks; time-series forecasting; sequence-to-sequence models; seasonal outlook prediction.

Unit IV: Advanced Training Techniques

Batch normalization; hyperparameter optimization; learning rate scheduling; transfer learning; model interpretability tools (SHAP, feature importance); avoiding overfitting.

Unit V: Applications in Climate and Weather

Extreme event prediction; precipitation nowcasting (conceptual); bias correction using neural networks; surrogate modeling for climate simulations; comparison with dynamical forecasting.

CDAT405 – R Programming for Climate Data Analysis (VAC)

Credits: 4

Course Outcomes (COs)

CO1: Demonstrate proficiency in R programming for scientific computing, data manipulation, and statistical analysis.

CO2: Apply statistical techniques to process, analyze, and interpret atmospheric, oceanographic, and climate datasets using R.

CO3: Develop effective scientific visualizations and publication-quality graphics for climate and environmental data.

CO4: Analyze climate datasets, including NetCDF and geospatial data, to investigate climate variability, trends, and environmental processes.

CO5: Apply reproducible analytical workflows and advanced R packages for statistical modeling, machine learning, and climate data analytics.

UNIT I: Introduction to R Programming

Introduction to R and RStudio; installation and working environment; R syntax and programming fundamentals; variables and data types; vectors, matrices, arrays, lists, and data frames; operators and expressions; conditional statements and loops; user-defined functions; packages and libraries; importing and exporting datasets; workspace management; scripting and documentation.

UNIT II: Data Manipulation and Statistical Computing

Data structures in R; data cleaning and preprocessing; handling missing values; sorting, filtering, grouping, and merging datasets; descriptive statistics; probability distributions; correlation and covariance analysis; hypothesis testing; linear regression; statistical modeling; data transformation using dplyr**,** tidyr**,** and data.table packages.

UNIT III: Data Visualization

Scientific visualization using base R and ggplot2; line plots; scatter plots; histograms; boxplots; bar charts; heat maps; contour plots; correlation matrices; customization of plots; themes and faceting; visualization of climate and environmental datasets; preparation of publication-quality scientific figures.

UNIT IV: Climate Data Analysis Using R

Reading and processing NetCDF, CSV, and raster datasets; analysis of observational, satellite, and reanalysis datasets; temporal aggregation; climatology computation; anomaly analysis; trend detection; time-series analysis; climate index computation (ENSO, SOI, IOD); spatial interpolation; introduction to geospatial analysis using terra**,** sf, and raster packages.

UNIT V: Advanced Applications in Climate Science

Reproducible research using R Markdown; automated report generation; machine learning using caret and randomForest packages; statistical modeling of climate variables; extreme event analysis; dashboard development using Shiny **(**introductory); integration of R with GIS and remote sensing datasets; applications of R in atmospheric science, oceanography, climate modeling, and environmental research.

Skill Enhancement Courses (Credits 3)

CDAT406 – Remote Sensing and Geoinformatics for Climate Applications

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Explain the principles of remote sensing and geoinformatics, including electromagnetic radiation, sensor systems, and geospatial data structures used in Earth observation.

CO2: Acquire, preprocess, and interpret satellite-derived datasets using appropriate correction techniques, coordinate systems, and geospatial standards.

CO3: Apply GIS-based analytical techniques to manage, visualize, and analyze spatial datasets for environmental and climate-related applications.

CO4: Utilize remote sensing and geospatial technologies to investigate atmospheric, terrestrial, oceanic, and disaster-related processes relevant to climate science.

CO5: Develop geospatial decision-support products for climate risk assessment, adaptation planning, and environmental management through the integration of remote sensing and GIS tools.

Credits: 4

Unit I: Fundamentals of Remote Sensing and Geoinformatics

Introduction to remote sensing and geoinformatics; principles and components of remote sensing systems; electromagnetic radiation and its interaction with the atmosphere and Earth's surface; electromagnetic spectrum; spectral signatures of natural features; passive and active remote sensing systems; spatial, spectral, radiometric, and temporal resolution; remote sensing platforms including ground-based, airborne, and satellite systems; introduction to Geographic Information Systems (GIS); components and functions of GIS; applications of remote sensing and GIS in climate and environmental studies.

Unit II: Satellite Systems and Environmental Data Acquisition

Polar-orbiting and geostationary satellite systems; Earth observation missions and their applications; meteorological satellites and sensors; optical, thermal infrared, microwave, and radar sensors; principles of LiDAR and Synthetic Aperture Radar (SAR); satellite data products and formats; acquisition and preprocessing of satellite datasets; image corrections including geometric and radiometric correction; georeferencing and projection systems; metadata standards and data quality assessment; introduction to open-access Earth observation datasets and climate data portals.

Unit III: Geospatial Data Analysis and GIS Techniques

Types of spatial data: vector and raster data models; coordinate systems and map projections; spatial database concepts; geospatial data creation and editing; spatial query and attribute analysis; overlay analysis; buffering and proximity analysis; digital elevation models (DEMs) and terrain analysis; interpolation techniques; geostatistical methods; land use and land cover mapping; change detection techniques; integration of remote sensing products within GIS environments for climate and environmental applications.

Unit IV: Remote Sensing Applications in Climate and Environmental Studies

Retrieval of atmospheric parameters including cloud properties, aerosol optical depth, temperature, humidity, and rainfall; satellite-based estimation of sea surface temperature and ocean colour; vegetation indices such as NDVI and EVI; drought monitoring using remote sensing techniques; flood inundation mapping; forest and ecosystem monitoring; glacier and snow cover assessment; urban heat island studies; coastal zone monitoring; disaster assessment and damage mapping; applications of geospatial technologies in climate variability and climate change studies.

Unit V: Geoinformatics for Climate Risk Assessment and Decision Support

Climate hazard mapping and vulnerability assessment; integration of geospatial datasets for disaster risk analysis; multi-criteria decision analysis in GIS; spatial modeling of climate impacts; climate change adaptation planning using geospatial tools; web GIS and cloud-based geospatial platforms; introduction to Google Earth Engine and geospatial big data analytics; development of climate information products and decision-support systems; ethical considerations and limitations in geospatial applications; emerging trends in remote sensing and geoinformatics for sustainable development.

YEAR 3 – SEMESTER 5

Total Credits: 20

CSS501 – Climate Dynamics (Major 1)

Credits: 4

Course Outcomes (COs)

CSS501 – Climate Dynamics

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental principles of geophysical fluid dynamics and apply conservation laws to describe atmospheric and oceanic motions across different spatial and temporal scales.

CO2: Analyze the effects of Earth's rotation, pressure gradients, and fluid dynamical balances on large-scale atmospheric and oceanic circulation systems.

CO3: Interpret vorticity, circulation, wave dynamics, and thermodynamic processes governing weather, climate variability, and planetary-scale atmospheric motions.

CO4: Apply geostrophic and quasi-geostrophic theories to investigate atmospheric flow patterns, stability conditions, and large-scale dynamical processes in the climate system.

CO5: Evaluate the role of frictional processes, ocean circulation, upwelling systems, and coupled atmosphere–ocean interactions in regulating regional and global climate dynamics.

UNIT I: Fundamentals of Geophysical Fluid Dynamics

Introduction to Climate Dynamics and Geophysical Fluid Dynamics, distinguishing characteristics of geophysical flows, spatial and temporal scales of atmospheric and oceanic motions, importance of Earth's rotation in geophysical systems, differences between atmospheric and oceanic circulation, data acquisition methods in atmospheric and ocean sciences, scale analysis and dimensional analysis, finite difference approximations and numerical representations, higher-order numerical methods and truncation errors, aliasing and sampling issues in geophysical data, kinematics of fluid motion, Reynolds number and flow regimes.

UNIT II: Conservation Laws and Rotating Fluid Dynamics

Conservation of mass, momentum and energy, Euler and Navier–Stokes equations, local and material derivatives, fundamental forces acting on atmospheric and oceanic motions, hydrodynamic equations in rotating coordinate systems, geostrophic and hydrostatic approximations, atmospheric stability and stratification, vertical coordinate systems including Cartesian, isobaric and sigma coordinates, balanced flows such as geostrophic, inertial, cyclostrophic and gradient wind balance, trajectories and streamlines, thermal wind balance, barotropic and baroclinic atmospheres.

UNIT III: Vorticity, Waves and Atmospheric Thermodynamics

Circulation and vorticity concepts, Kelvin's circulation theorem, vorticity equations in natural coordinates, Stokes' theorem and Helmholtz's theorem, Bjerknes circulation theorem and its physical interpretation, Taylor–Proudman theorem, Rossby waves and their atmospheric significance, Kelvin waves and equatorial wave dynamics, equations of motion governing large-scale atmospheric circulation, planetary wave propagation and climate variability.

UNIT IV: Geostrophic and Quasi-Geostrophic Dynamics

Homogeneous geostrophic flow, generalization to non-geostrophic flow, geostrophic equations and approximations, inertial motion and inertial oscillations, thermal wind currents in frictionless atmospheres, quasi-geostrophic dynamics and simplifying assumptions, governing equations of quasi-geostrophic flow, continuity equation in atmospheric dynamics, thermodynamics of dry and moist atmospheres, potential temperature and atmospheric stability, dry adiabatic and pseudo-adiabatic lapse rates, Coriolis force and its dynamical effects, Bernoulli's theorem and atmospheric applications.

UNIT V: Ocean Circulation and Frictional Processes

Frictional effects in atmospheric and oceanic currents, Ekman's theory of wind-driven circulation, Ekman spiral and Ekman transport, drag coefficient and boundary layer processes, coastal upwelling and downwelling mechanisms, bottom friction and shallow-water effects, Sverdrup balance and Sverdrup transport, equatorial undercurrent and equatorial circulation, Stommel's theory of ocean circulation, Munk's theory and lateral friction, western boundary current intensification, role of ocean circulation in climate regulation.

CSS502 – Radiation and Aerosol–Cloud Interactions

Credits: 4

Course Outcomes (COs)

CSS502 – Radiation and Aerosol–Cloud Interactions

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental principles of radiative transfer, including absorption, emission, scattering processes, and the role of radiation in the Earth's energy balance.

CO2: Describe the physical and chemical properties, sources, transport mechanisms, and atmospheric distribution of natural and anthropogenic aerosols.

CO3: Analyze aerosol–radiation interactions and evaluate their influence on radiative forcing, atmospheric heating rates, and regional and global climate systems.

CO4: Assess the effects of aerosols on cloud microphysics, cloud radiative properties, precipitation processes, and aerosol–cloud interaction mechanisms.

CO5: Evaluate the role of aerosols in climate variability and climate change using observational datasets, climate model simulations, and current scientific understanding of aerosol–climate feedbacks and uncertainties.

UNIT I: Fundamentals of Radiative Transfer

Nature of electromagnetic radiation, solar and terrestrial radiation, shortwave and longwave radiation processes, blackbody radiation and Planck's law, Stefan–Boltzmann law and Wien's displacement law, absorption, emission and scattering processes, optical depth and transmissivity, emissivity and absorptivity, atmospheric windows, radiative flux divergence, radiative heating and cooling rates, concept of radiative equilibrium and energy balance of the Earth–atmosphere system.

UNIT II: Aerosol Properties and Sources

Introduction to atmospheric aerosols, classification of aerosols, natural and anthropogenic aerosol sources, primary and secondary aerosols, aerosol formation mechanisms, size distribution and aerosol modes, physical and chemical properties of aerosols, black carbon, organic carbon, sulfate aerosols, mineral dust and sea salt aerosols, aerosol lifetime, transport and removal processes, spatial and temporal variability of aerosols.

UNIT III: Aerosol–Radiation Interaction

Principles of aerosol-radiation interaction, direct radiative forcing of aerosols, aerosol optical properties, aerosol optical depth, single scattering albedo, asymmetry parameter, absorption and scattering coefficients, aerosol-induced atmospheric heating and cooling, surface dimming and brightening effects, top-of-atmosphere radiative forcing, regional and global radiative impacts of aerosols, estimation of aerosol heating rates and radiative efficiency.

UNIT IV: Aerosol–Cloud Interaction

Cloud condensation nuclei and ice nuclei, aerosol effects on cloud microphysical properties, first indirect effect (Twomey effect), second indirect effect (Albrecht effect), cloud droplet number concentration and effective radius, cloud albedo modification, semi-direct effect, aerosol influence on cloud lifetime and cloud fraction, impact on precipitation formation processes, aerosol effects on convective and stratiform clouds, observational and modelling approaches for aerosol–cloud interactions.

UNIT V: Climate Impacts of Aerosols

Role of aerosols in climate variability and climate change, regional and global climate impacts of aerosols, aerosol influence on monsoon systems and hydrological cycle, interactions between aerosols and large-scale circulation systems, aerosol feedback mechanisms, representation of aerosols in climate models, uncertainties in aerosol forcing estimates, satellite and ground-based observations of aerosols, observational constraints on climate impacts, future challenges in aerosol–climate research.

CDAT 503 – Machine Learning II

Credits: 4

Course Outcomes (COs)

CDAT503 – Machine Learning II

Upon successful completion of this course, students will be able to:

CO1: Explain the principles of ensemble learning, tree-based algorithms, neural networks, and deep learning architectures, and evaluate their strengths and limitations for environmental data analysis.

CO2: Develop and implement advanced machine learning models, including random forests, gradient boosting methods, artificial neural networks, CNNs, and LSTMs, for climate and weather applications.

CO3: Apply appropriate model training, validation, optimization, and regularization techniques to improve predictive performance and prevent overfitting in machine learning systems.

CO4: Evaluate machine learning and deep learning models using statistical and forecast verification metrics, and assess their robustness, reliability, and interpretability.

CO5: Design and analyze machine learning solutions for atmospheric and environmental problems, including extreme event prediction, cyclone forecasting, climate outlook generation, environmental monitoring, and climate risk assessment.

UNIT I: Ensemble and Tree-Based Methods

Introduction to ensemble learning techniques, decision trees and their limitations, bagging and bootstrap aggregation methods, random forest algorithms and applications, feature selection and feature importance measures, boosting concepts and methodologies, gradient boosting machines, XGBoost and advanced boosting techniques, hyperparameter tuning strategies, model optimization, overfitting and underfitting in ensemble models, methods for controlling model complexity and improving generalization performance.

UNIT II: Neural Networks Fundamentals

Introduction to artificial neural networks, biological inspiration and computational models, perceptron architecture and learning process, activation functions including sigmoid, tanh and ReLU, feedforward neural networks, network architecture design, loss and cost functions, gradient descent optimization, backpropagation algorithm and weight updates, training and validation of neural networks, regularization techniques including dropout and weight decay, challenges in neural network training.

UNIT III: Deep Learning Architectures

Introduction to deep learning and hierarchical feature learning, convolutional neural networks (CNNs) for spatial data analysis, convolution, pooling and feature extraction operations, image classification and pattern recognition, recurrent neural networks (RNNs) for sequential and temporal data, long short-term memory (LSTM) networks and gated architectures, deep learning applications in climate and environmental datasets, climate image classification, weather pattern recognition, time-series forecasting and prediction of atmospheric variables.

UNIT IV: Model Evaluation and Validation

Principles of model evaluation and performance assessment, training, validation and testing datasets, train–test split strategies, cross-validation methods, k-fold and stratified cross-validation, confusion matrix and classification accuracy, precision, recall and F1-score, receiver operating characteristic (ROC) curves and area under the curve (AUC), skill scores and forecast verification metrics, robustness testing, sensitivity analysis, model comparison and selection techniques.

UNIT V: Machine Learning Applications in Climate and Environmental Systems

Applications of machine learning and deep learning in atmospheric and environmental sciences, extreme rainfall forecasting and prediction, cyclone track and intensity prediction, temperature anomaly detection and forecasting, seasonal climate outlook modeling, drought and flood prediction, environmental monitoring and assessment, comparison of machine learning approaches with dynamical climate models, model interpretability and explainable artificial intelligence (XAI), uncertainty assessment in machine learning predictions, future prospects of artificial intelligence in climate science and environmental management.

CSS504 – Computational Methods for Climate Data and Modelling

Credits: 4

Course Outcomes (COs)

CSS504 – Computational Methods for Climate Data and Modeling

Upon successful completion of this course, students will be able to:

CO1: Explain the structure, hierarchy, and fundamental components of climate models, including Earth System Models, General Circulation Models, and their underlying numerical frameworks.

CO2: Process, analyze, and interpret climate model outputs using standard climate data formats, statistical techniques, and visualization methods.

CO3: Apply numerical methods to evaluate model stability, sensitivity, uncertainty, and ensemble behavior in climate simulations and projections.

CO4: Assess climate model performance through diagnostics, bias evaluation, comparison with observational datasets, and interpretation of climate variability and extreme events.

CO5: Develop reproducible computational workflows for climate modeling studies using automation, version control, data management, and best practices in scientific computing and research documentation.

UNIT I: Structure of Climate Models

Introduction to climate modeling, evolution and hierarchy of climate models, zero-dimensional and one-dimensional climate models, energy balance models, intermediate complexity models, Earth system models, General Circulation Models (GCMs), atmospheric, oceanic and coupled climate models, model grid structures and spatial resolution, discretization of governing equations, boundary conditions and initial conditions, parameterization concepts in climate models, strengths and limitations of different modeling approaches.

UNIT II: Working with Climate Model Output

Introduction to climate model datasets, NetCDF file structure and metadata, multidimensional gridded datasets, climate data formats and standards, extraction and processing of climate variables, temporal averaging and climatological means, spatial averaging and regional analysis, anomaly computation and trend analysis, regridding techniques and interpolation methods, handling large climate datasets, visualization and interpretation of model outputs.

UNIT III: Numerical Stability and Model Sensitivity

Numerical methods used in climate models, time stepping schemes and integration methods, numerical stability criteria, truncation and discretization errors, Courant–Friedrichs–Lewy (CFL) condition, parameter sensitivity analysis, model tuning and calibration, ensemble simulations and ensemble forecasting, uncertainty quantification and error propagation, sources of uncertainty in climate projections, interpretation of ensemble results.

UNIT IV: Diagnostics of Climate Simulations

Evaluation of climate model performance, analysis of mean climate state, assessment of climate variability and trends, bias detection and bias correction methods, comparison of model outputs with observational and reanalysis datasets, model skill assessment and performance metrics, diagnostics of temperature, precipitation and circulation fields, analysis of extreme climate events, visualization of spatial and temporal climate patterns, interpretation of climate simulation results.

UNIT V: Computational Workflow Design and Version Control

Design and organization of climate modeling workflows, script automation and batch processing, data management strategies, reproducible research principles, workflow documentation and reporting standards, introduction to version control systems, repository management and collaborative development, tracking model experiments and code modifications, best practices for scientific computing, quality assurance in climate modeling studies, ethical considerations in computational climate research.

CSS505 – Laboratory III: Climate Diagnostics and ML Implementation

Credits: 4

Course Outcomes (COs)

CSS505 – Laboratory V: Climate Diagnostics and ML Implementation

Upon successful completion of this laboratory course, students will be able to:

CO1: Process, analyze, and visualize reanalysis and observational climate datasets to investigate atmospheric circulation patterns, climate variability, and long-term trends.

CO2: Compute and interpret major climate indices and teleconnection patterns, including ENSO, IOD, and PDO, and assess their influence on regional climate variability.

CO3: Analyze aerosol and atmospheric datasets using observational and satellite-derived products to evaluate aerosol variability and aerosol–climate interactions.

CO4: Implement machine learning techniques for climate data analysis, including data preprocessing, feature selection, predictive modeling, classification, and model evaluation.

CO5: Integrate climate diagnostics, climate model evaluation, and machine learning methods to conduct scientific investigations, interpret results, and communicate findings through technical reports and project presentations.

UNIT I: Climate Dataset Exploration and Reanalysis Analysis

Introduction to global climate datasets, climate data sources and formats, accessing and processing reanalysis datasets such as ERA5, NCEP and MERRA, extraction of atmospheric variables including temperature, pressure, wind speed, humidity and geopotential height, quality control and preprocessing of reanalysis data, visualization of spatial fields using maps, contour plots and vector fields, computation of climatological means and seasonal averages, anomaly calculation and trend analysis, interpretation of large-scale atmospheric circulation patterns from reanalysis datasets.

UNIT II: Climate Indices and Variability Analysis

Introduction to climate variability and climate indices, computation of ENSO indices using sea surface temperature datasets, calculation of Niño region anomalies, Southern Oscillation Index (SOI) analysis, identification of interannual and decadal variability patterns, analysis of the Indian Ocean Dipole (IOD) and Pacific Decadal Oscillation (PDO), correlation and regression analysis of climate variables, teleconnection patterns and their climatic significance, relationships between ENSO and regional climate variables such as rainfall, temperature and circulation anomalies.

UNIT III: Aerosol and Atmospheric Dataset Analysis

Introduction to aerosol observational datasets, analysis of aerosol optical depth (AOD) from satellite and ground-based observations, spatial and temporal variability of aerosols, visualization of aerosol distribution using maps and time series, examination of aerosol transport pathways and source regions, analysis of aerosol-radiation interactions, relationships between aerosols, clouds and climate variables, interpretation of aerosol trends and variability, application of observational datasets for understanding aerosol–climate interactions and regional climate impacts.

UNIT IV: Machine Learning Applications in Climate Data

Introduction to machine learning techniques for climate data analysis, preparation and preprocessing of climate datasets, feature selection and dimensionality reduction methods, implementation of regression algorithms for climate prediction, classification techniques for identifying climate patterns and extreme events, development of training, validation and testing datasets, model evaluation using statistical and machine learning performance metrics, cross-validation techniques, interpretation of machine learning outputs, applications in weather forecasting, climate variability analysis and environmental prediction.

UNIT V: Climate Model Diagnostics and Integrated Project

Processing and analysis of climate model outputs, extraction and visualization of climate variables from model simulations, spatial anomaly mapping of temperature, precipitation and circulation fields, comparison of model outputs with observational and reanalysis datasets, evaluation of model performance and biases, interpretation of climate variability and trends in simulations, assessment of extreme events using climate model outputs, integrated mini-project involving climate data analysis, climate dynamics interpretation and machine learning applications, preparation of technical reports and presentation of scientific results.

CSS505 – Artificial Intelligence and Machine Learning in Weather and Climate

Credits: 4

Course Outcomes (COs)

CO1: Explain the fundamental concepts of artificial intelligence, machine learning, and deep learning, and evaluate their applications in weather forecasting, climate modeling, and Earth system science.

CO2: Apply machine learning algorithms and artificial intelligence techniques to process, analyze, and model atmospheric, oceanographic, and climate datasets.

CO3: Develop predictive models for weather, climate variability, and extreme events using supervised, unsupervised, and deep learning approaches.

CO4: Evaluate the performance, interpretability, uncertainty, and ethical aspects of AI-based weather and climate prediction models using appropriate validation techniques.

CO5: Design AI-driven solutions for weather forecasting, climate prediction, climate services, disaster risk reduction, and environmental decision-support systems using modern computational frameworks. (Destination Earth)

UNIT I: Fundamentals of Artificial Intelligence and Machine Learning

Introduction to artificial intelligence, machine learning, and deep learning; history and evolution of AI in Earth system science; supervised, unsupervised, semi-supervised, and reinforcement learning; AI workflow for weather and climate applications; data preparation and feature engineering; training, validation, and testing datasets; overfitting and underfitting; bias–variance tradeoff; model evaluation metrics; ethics and responsible AI in environmental applications. (Destination Earth)

UNIT II: Machine Learning Techniques for Weather and Climate

Regression and classification algorithms; decision trees; random forests; support vector machines; k-nearest neighbors; clustering techniques; dimensionality reduction; feature selection; ensemble learning methods; preprocessing of meteorological and climate datasets; handling missing data; model optimization and cross-validation; applications in atmospheric and climate prediction. (MDPI)

UNIT III: Deep Learning for Atmospheric and Climate Applications

Artificial neural networks; multilayer perceptrons; convolutional neural networks (CNNs); recurrent neural networks (RNNs); long short-term memory (LSTM) networks; transformers and foundation models; graph neural networks (introductory); training deep learning models; hyperparameter optimization; explainable AI; uncertainty estimation; applications to satellite imagery, weather forecasting, climate downscaling, and Earth system modeling. (arXiv)

UNIT IV: AI Applications in Weather and Climate Prediction

Weather forecasting using AI; nowcasting techniques; seasonal forecasting; climate variability prediction; prediction of extreme weather events including tropical cyclones, floods, droughts, and heatwaves; climate model bias correction; statistical downscaling; data assimilation using machine learning; hybrid physics-informed AI models; operational AI forecasting systems; forecast verification and performance assessment. (Destination Earth)

UNIT V: Emerging Trends and Future Directions

AI foundation models for weather and climate; digital twins of the Earth; generative AI applications; climate services and decision-support systems; AI for disaster risk reduction; renewable energy forecasting; environmental monitoring; big data and cloud-based AI workflows; challenges in operational implementation; uncertainty, interpretability, governance, and future research directions in AI-driven weather and climate science. (arXiv)

YEAR 3 – SEMESTER 6

Total Credits: 20

CDAT601 – Climate Change: Science and Impacts (major)

Credits: 4

Course Outcomes (COs)

CDAT601 – Climate Change: Science and Impacts

Upon successful completion of this course, students will be able to:

CO1: Explain the scientific evidence, observational records, and detection–attribution methodologies used to understand past and present climate change.

CO2: Analyze the role of radiative forcing, climate sensitivity, feedback mechanisms, and anthropogenic influences in driving climate variability and long-term climate change.

CO3: Evaluate observed and projected regional climate change patterns, including changes in temperature, precipitation, monsoon systems, extreme events, ocean conditions, and cryospheric processes.

CO4: Assess the impacts of climate change on natural ecosystems, water resources, agriculture, biodiversity, human health, and socio-economic systems using vulnerability and risk assessment frameworks.

CO5: Examine climate change mitigation and adaptation strategies, international climate policies, future climate scenarios, and sustainable pathways for enhancing climate resilience and reducing climate risks.

UNIT I: Evidence and Detection of Climate Change

Introduction to climate change and climate variability, instrumental records of global and regional temperature change, historical climate observations, ocean heat content trends and ocean warming, glacier retreat and ice-sheet mass balance changes, observations of sea-level rise and contributing factors, paleoclimate evidence of climate change, detection and attribution methodologies, distinction between climate change detection and attribution, internal climate variability and external climate forcing, observational datasets and uncertainties in climate change assessment.

UNIT II: Radiative Forcing and Climate Sensitivity

Concept of Earth's energy balance, greenhouse gas radiative forcing, carbon dioxide, methane and other greenhouse gases, aerosol forcing and aerosol–climate interactions, land-use and land-cover change forcing, radiative forcing metrics and measurements, equilibrium climate sensitivity, transient climate response, climate feedback mechanisms including water vapor, cloud and ice-albedo feedbacks, estimation of climate feedback parameters, uncertainty ranges in climate projections and future climate scenarios.

UNIT III: Regional Climate Change Patterns

Spatial variability of climate change, polar amplification and Arctic climate change, observed and projected changes in monsoon systems, regional precipitation shifts and hydrological changes, drought occurrence and persistence, heatwave frequency, intensity and duration, extreme rainfall events and their intensification, ocean warming and marine heatwaves, regional sea-level rise, impacts on tropical and mid-latitude circulation systems, regional climate model projections and uncertainty assessment.

UNIT IV: Impacts on Natural and Human Systems

Impacts of climate change on water resources and hydrological systems, agricultural productivity and food security, coastal vulnerability and sea-level rise impacts, cryosphere decline and glacier loss, ecosystem responses and biodiversity impacts, urban heat island intensification under climate change, climate-sensitive diseases and public health implications, socio-economic impacts of climate extremes, disaster risk amplification, compound and cascading climate risks, vulnerability and risk assessment frameworks.

UNIT V: Mitigation and Adaptation Frameworks

Climate change mitigation concepts and strategies, carbon emission reduction pathways, renewable energy transition and decarbonization, carbon capture and storage technologies, negative emission technologies and carbon dioxide removal approaches, adaptation planning and implementation, climate resilience and sustainable development strategies, ecosystem-based adaptation, international climate agreements and policy frameworks, IPCC assessment framework, Shared Socioeconomic Pathways (SSPs), scenario-based climate projections, challenges and opportunities for climate action.

CDAT 602 – Extreme Events and Risk Analytics(major 2)

Credits: 4

Course Outcomes (COs)

CDAT602 – Extreme Events and Risk Analytics

Upon successful completion of this course, students will be able to:

CO1: Apply statistical methods and extreme value theory to characterize, quantify, and analyze the frequency, magnitude, and recurrence of extreme weather and climate events.

CO2: Explain the physical mechanisms governing extreme weather systems, including tropical cyclones, extreme rainfall, floods, droughts, heatwaves, and cold waves, and assess their impacts.

CO3: Evaluate disaster risk using hazard, exposure, vulnerability, and resilience frameworks, and apply risk assessment methodologies for climate-related hazards.

CO4: Develop and assess data-driven approaches for extreme event prediction using statistical, machine learning, and forecasting techniques, and evaluate their operational applications in early warning systems.

CO5: Analyze the influence of climate change on the occurrence, intensity, and frequency of extreme events, and assess adaptation, mitigation, and resilience strategies for managing future climate risks.

UNIT I: Statistical Characterization of Extremes

Introduction to extreme weather and climate events, definition and classification of extremes, statistical characteristics of rare events, threshold exceedance analysis, return period and return level concepts, probability distributions for extremes, generalized extreme value (GEV) distribution, generalized Pareto distribution, peak-over-threshold (POT) method, estimation of recurrence intervals, stationary and non-stationary extreme value analysis, trends and variability in extreme events, applications of extreme value statistics in climate studies.

UNIT II: Extreme Weather Systems

Characteristics of extreme weather systems, tropical cyclone formation and intensity metrics, cyclone track and intensity forecasting, rapid intensification processes, mechanisms of extreme rainfall events, mesoscale convective systems and heavy precipitation, flash floods and urban flooding, drought characteristics and classification, Standardized Precipitation Index (SPI) and Standardized Precipitation Evapotranspiration Index (SPEI), heatwave definition and metrics, cold wave dynamics and impacts, monitoring and assessment of weather extremes.

UNIT III: Risk Assessment Framework

Introduction to disaster risk concepts, hazard, exposure and vulnerability assessment, disaster risk equation and risk components, probabilistic and deterministic risk assessment approaches, hazard mapping and risk zonation, loss exceedance probability curves, impact-based forecasting principles, socioeconomic dimensions of risk, multi-hazard risk assessment, compound and cascading hazards, resilience and adaptive capacity, disaster risk reduction strategies and climate risk management frameworks.

UNIT IV: Data-Driven Extreme Event Prediction

Introduction to predictive analytics for extreme events, data preparation and quality control for extreme event analysis, feature selection and dimensionality reduction techniques, machine learning approaches for severe weather prediction, classification of extreme weather events, threshold-based warning systems, development of early warning indicators, ensemble forecasting methods, probabilistic forecasting of extremes, forecast verification techniques, evaluation of forecast skill using statistical and machine learning metrics, operational applications in early warning systems.

UNIT V: Climate Change and Extremes

Observed changes in weather and climate extremes, attribution of extreme events to climate change, event attribution methodologies, shifting climatic baselines and changing risk profiles, intensity–frequency–duration relationships, future projections of extreme weather and climate events, changes in tropical cyclones, droughts, floods and heatwaves under climate change, uncertainty quantification in climate projections and risk models, adaptation and mitigation implications, climate resilience planning for future extremes.

CDAT603 – Climate Data Laboratory (major)

Course Outcomes (COs)

Upon successful completion of this laboratory course, students will be able to:

CO1: Acquire, organize, preprocess, and manage observational, satellite, reanalysis, and climate model datasets using appropriate climate data standards and quality control procedures.

CO2: Apply computational techniques to process, analyze, and visualize multidimensional climate datasets and communicate results using scientifically appropriate graphical representations.

CO3: Compute and interpret major climate indices, assess climate variability, and investigate teleconnection patterns using statistical methods and climate diagnostics.

CO4: Analyze climate extremes and implement predictive analytics techniques to assess climate risks and evaluate the performance of climate prediction models.

CO5: Conduct an independent climate data analysis project by integrating climate science concepts, statistical methods, and computational tools, and effectively communicate scientific findings through technical reports and presentations.

Credits: 4

Unit I: Climate Data Acquisition and Management

Introduction to climate data sources and repositories; acquisition of observational datasets from national and international agencies; accessing reanalysis datasets such as ERA5, NCEP, and MERRA; downloading satellite-derived climate products; introduction to climate model datasets; NetCDF and HDF data formats; metadata interpretation and documentation; data quality control procedures; handling missing values and outlier detection; organization and management of climate datasets; climate data archiving practices.

Unit II: Climate Data Processing and Visualization

Reading and processing multidimensional climate datasets using Python libraries; temporal aggregation techniques (daily, monthly, seasonal, and annual means); spatial subsetting and regional extraction; anomaly calculation and climatology development; generation of time-series plots; spatial visualization using contour maps and filled contour plots; creation of Hovmöller diagrams; visualization of wind vectors and streamlines; preparation of publication-quality figures for climate datasets.

Unit III: Climate Variability and Teleconnection Analysis

Computation of climate indices including Niño 3.4, Southern Oscillation Index (SOI), Indian Ocean Dipole (IOD) index, and Arctic Oscillation Index; correlation and regression analysis of climate variables; lag correlation studies; empirical orthogonal function (EOF) analysis (introductory); trend detection techniques; significance testing of climate relationships; identification of teleconnection patterns and their impacts on regional climate variability.

Unit IV: Climate Extremes and Predictive Analytics

Calculation of climate extreme indices; analysis of rainfall extremes and heatwave events; estimation of return periods and return levels; implementation of extreme value analysis techniques; preparation of datasets for predictive modeling; application of regression and classification techniques to climate datasets; evaluation of model performance using statistical metrics; interpretation of predictive outputs for climate risk assessment.

Unit V: Integrated Climate Data Project

Selection of a climate-related problem for investigation; formulation of objectives and analytical workflow; acquisition and preprocessing of relevant datasets; application of statistical, visualization, and machine learning techniques; interpretation of climate variability and extreme event patterns; preparation of technical reports and scientific posters; oral presentation of project findings; peer review and discussion of project outcomes.

CDAT 604– Laboratory IV: Climate Risk and ML Applications

Credits: 4

Course Outcomes (COs)

CDAT605 – Laboratory VI: Climate Risk and ML Applications

Upon successful completion of this laboratory course, students will be able to:

CO1: Analyze long-term climate variability and trends using observational and reanalysis datasets, and apply statistical techniques to identify significant climate changes and anomalies.

CO2: Perform quantitative assessment of extreme weather and climate events using extreme value analysis, return period estimation, hazard characterization, and risk evaluation methods.

CO3: Develop and implement machine learning models for climate and weather prediction, including data preprocessing, feature selection, model training, validation, and performance evaluation.

CO4: Apply deep learning techniques to climate time-series datasets for predictive modeling, forecasting, and comparison with conventional statistical approaches.

CO5: Integrate climate projections, machine learning methods, and risk assessment frameworks to evaluate future climate impacts, quantify uncertainties, and communicate findings through technical reports and project presentations.

UNIT I: Climate Trend and Variability Analysis

Detection and analysis of long-term climate trends, quality control and preprocessing of climate datasets, temporal and spatial trend estimation techniques, statistical significance testing of climate trends, variability analysis using observational and reanalysis datasets, seasonal and interannual variability assessment, trend visualization and interpretation, identification of climate anomalies and changing climate patterns.

UNIT II: Extreme Event Analysis

Statistical characterization of extreme weather and climate events, estimation of return periods and return levels, generalized extreme value (GEV) analysis, peak-over-threshold methods, extreme rainfall frequency analysis, heatwave index calculation and interpretation, drought and flood event assessment, temporal changes in extremes, climate-related hazard assessment and risk characterization.

UNIT III: Machine Learning Applications in Climate Data

Implementation of ensemble machine learning algorithms, random forests and boosting methods, feature selection and preprocessing techniques, development of predictive models for climate variables, training and validation of machine learning models, model performance assessment, application of machine learning techniques to weather and climate prediction, interpretation of machine learning outputs for environmental decision-making.

UNIT IV: Deep Learning and Predictive Modeling

Design and implementation of neural network models, feedforward neural networks and deep learning architectures, neural network training using climate time-series datasets, optimization and regularization techniques, forecasting of climate variables using deep learning approaches, cross-validation and robustness testing, evaluation of predictive skill, comparison of deep learning and conventional statistical methods in climate prediction.

UNIT V: Climate Projection Analysis and Integrated Risk Modeling

Bias correction techniques for climate model projections, analysis and interpretation of future climate scenarios, uncertainty assessment in climate projections, climate impact and vulnerability analysis, integrated climate risk modeling approaches, hazard, exposure and vulnerability assessment, development of climate risk indicators, interdisciplinary mini-project involving climate data analysis, machine learning applications and risk assessment, preparation of technical reports and presentation of project findings.

CDAT606 – Satellite Meteorology and Ocean Colour

Credits: 4

Course Outcomes (COs)

CO1: Explain the principles of satellite meteorology, remote sensing, and ocean colour observations, including sensor characteristics and radiative processes used in atmospheric and oceanographic studies.

CO2: Analyze satellite-derived atmospheric products for monitoring clouds, rainfall, aerosols, water vapour, temperature, severe weather systems, and climate variability.

CO3: Interpret ocean colour products to assess phytoplankton distribution, chlorophyll concentration, suspended sediments, primary productivity, and coastal water quality.

CO4: Apply satellite datasets and geospatial techniques for monitoring weather systems, marine environments, coastal hazards, and climate-related processes.

CO5: Evaluate the applications and limitations of satellite meteorology and ocean colour remote sensing in weather forecasting, climate research, marine resource management, and environmental decision-making. (India Meteorological Department)

UNIT I: Fundamentals of Satellite Meteorology and Remote Sensing

Introduction to satellite meteorology; principles of remote sensing; electromagnetic radiation and atmospheric interactions; radiative transfer concepts; passive and active remote sensing; satellite orbits; polar-orbiting and geostationary satellites; meteorological satellite systems; sensor characteristics; spatial, spectral, temporal, and radiometric resolutions; satellite image interpretation; data formats and preprocessing. (India Meteorological Department)

UNIT II: Satellite Meteorological Observations

Satellite observation of clouds; cloud classification; cloud top temperature and height; water vapour imagery; atmospheric temperature and humidity sounding; rainfall estimation; sea surface temperature retrieval; atmospheric motion vectors; aerosol optical depth; dust and smoke detection; tropical cyclone monitoring; severe weather nowcasting; satellite applications in weather forecasting and climate monitoring. (India Meteorological Department)

UNIT III: Fundamentals of Ocean Colour Remote Sensing

Introduction to ocean colour; optical properties of seawater; inherent and apparent optical properties; ocean optics; ocean colour radiometry; atmospheric correction; ocean colour sensors; Ocean Colour Monitor (OCM), MODIS, VIIRS, Sentinel-3 OLCI; retrieval of chlorophyll-a concentration; coloured dissolved organic matter (CDOM); suspended particulate matter; diffuse attenuation coefficient; bio-optical algorithms. (Wikipedia)

UNIT IV: Ocean Colour Applications

Primary productivity estimation; phytoplankton biomass and bloom detection; harmful algal bloom monitoring; coastal water quality assessment; sediment transport and river plumes; marine ecosystem monitoring; fisheries applications; ocean fronts and eddies; carbon cycle studies; climate variability and ocean colour; marine pollution monitoring; coastal zone management using ocean colour products. (Wikipedia)

UNIT V: Satellite Applications in Weather, Oceanography and Climate

Integration of satellite observations with numerical weather prediction; satellite data assimilation; climate data records; monitoring monsoon systems; drought and flood assessment; cyclone track and intensity estimation; sea surface temperature and ocean circulation studies; marine heatwaves; coastal hazard monitoring; applications in disaster management; emerging satellite missions; artificial intelligence in satellite meteorology; future developments in Earth observation systems. (India Meteorological Department)

Mandatory Internship (6–8 Weeks After Semester 6)

Upon successful completion of the internship, students will be able to:

CO1: Apply theoretical knowledge of climate science, data analytics, meteorology, oceanography, and environmental systems to real-world professional and research environments.

CO2: Demonstrate competency in the collection, processing, analysis, and interpretation of atmospheric, oceanographic, climate, or environmental datasets using appropriate scientific and computational tools.

CO3: Develop problem-solving, technical, communication, teamwork, and professional skills through active participation in operational, industrial, or research-based projects.

CO4: Prepare and present technical reports, scientific analyses, and seminar presentations that effectively communicate internship objectives, methodologies, results, and recommendations.

CO5: Evaluate practical challenges, emerging technologies, and research opportunities in climate science, weather forecasting, environmental monitoring, disaster management, and climate-related industries.

Exit Qualification After Year 3

Bachelor of Science (B.Sc.) in Climate and Data Science

At this stage, students possess:

- Strong climate system understanding
- Applied statistical and ML competence
- Extreme event analytics capability
- Research exposure

YEAR 4 – SEMESTER 7

Total Credits: 20

CDAT701 – Climate and Weather Modeling

Credits: 4

Course Outcomes (COs)

CDAT 701 – Climate and Weather Modeling

Upon successful completion of this course, students will be able to:

CO1: Explain the hierarchy, structure, and components of atmospheric and climate models, including General Circulation Models, Regional Climate Models, Earth System Models, and coupled modeling systems.

CO2: Analyze the governing equations, physical parameterization schemes, and numerical approaches used to represent atmospheric and climate processes in weather and climate models.

CO3: Evaluate the role of model initialization, boundary conditions, data assimilation, and ensemble techniques in improving weather forecasts and climate predictions.

CO4: Assess model performance through bias analysis, verification techniques, comparison with observational datasets, and interpretation of multi-model ensemble simulations.

CO5: Apply weather and climate modeling frameworks to forecasting, climate projection, downscaling, extreme event simulation, risk assessment, and decision-support applications in climate-sensitive sectors.

UNIT I: Hierarchy of Atmospheric and Climate Models

Introduction to atmospheric and climate modeling, evolution of numerical weather and climate models, zero-dimensional energy balance models, one-dimensional radiative–convective models, general circulation models (GCMs), regional climate models (RCMs), Earth system models (ESMs), coupled atmosphere–ocean models, model resolution and grid structures, horizontal and vertical discretization, spectral and finite difference modeling approaches, model components and coupling frameworks, strengths and limitations of different model hierarchies.

UNIT II: Governing Equations and Parameterization

Fundamental equations governing atmospheric motion, primitive equations in conceptual form, hydrostatic and non-hydrostatic approximations, conservation of mass, momentum and energy, representation of unresolved sub-grid scale processes, convection parameterization schemes, cloud microphysics parameterizations, planetary boundary layer schemes, radiation transfer schemes, land surface models and surface flux parameterizations, challenges and uncertainties associated with parameterization techniques.

UNIT III: Model Initialization and Boundary Conditions

Importance of initial and boundary conditions in atmospheric modeling, sensitivity to initial conditions, boundary forcing datasets and external drivers, sea surface temperature (SST) boundary conditions, atmospheric and land surface initialization procedures, model spin-up and equilibrium processes, ensemble initialization techniques, data assimilation concepts, nudging and relaxation methods, reanalysis-driven simulations, initialization strategies for weather forecasting and climate prediction systems.

UNIT IV: Model Evaluation and Bias Assessment

Principles of model evaluation and verification, assessment of mean climate state, temperature and precipitation bias analysis, seasonal cycle simulation and validation, representation of interannual climate variability, comparison with observational and reanalysis datasets, Taylor diagrams and statistical evaluation techniques, model skill metrics and performance indicators, systematic model errors and sources of uncertainty, multi-model ensemble approaches, overview of the Coupled Model Intercomparison Project (CMIP), interpretation of ensemble model outputs.

UNIT V: Applications of Climate and Weather Models

Applications of atmospheric and climate models in weather forecasting and climate prediction, seasonal forecasting systems, climate projection scenarios and future climate assessment, regional climate downscaling techniques, simulation of extreme weather and climate events, high-resolution weather and climate modeling, climate services and decision support systems, model-based risk assessment and hazard prediction, applications in agriculture, water resources and disaster management, emerging trends in climate and weather modeling.

CSS702 – Extreme Weather and Coastal Hazards

Credits: 4

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Explain the physical processes responsible for the formation, evolution, and impacts of extreme weather systems, including tropical cyclones, severe convective storms, heatwaves, and heavy rainfall events.

CO2: Analyze coastal processes and hazards such as storm surges, coastal erosion, sea-level rise, marine heatwaves, and coastal inundation, and assess their implications for human and natural systems.

CO3: Evaluate the role of modern observational systems, forecasting techniques, and early warning mechanisms in monitoring and predicting extreme weather and coastal hazards.

CO4: Apply risk assessment methodologies and disaster management principles to develop strategies for reducing vulnerability and enhancing resilience in coastal regions.

CO5: Assess the impacts of climate change on extreme weather and coastal hazards and propose adaptation and sustainable management strategies to support climate-resilient coastal development.

UNIT I: Extreme Weather Systems

Introduction to extreme weather and climate events; classification of meteorological hazards; tropical cyclones and their life cycle; cyclone structure and intensity classification; rapid intensification processes; thunderstorms and mesoscale convective systems; lightning and hailstorm formation; tornadoes and waterspouts; heatwaves and cold waves; fog and visibility hazards; heavy rainfall mechanisms; cloudbursts and flash floods; meteorological factors controlling extreme events; trends in extreme weather under climate change.

UNIT II: Coastal Hazards and Processes

Introduction to coastal environments and hazards; coastal geomorphology and shoreline processes; waves, tides, and coastal currents; coastal erosion and accretion; storm surge generation and propagation; wave setup and coastal inundation; sea-level rise and its drivers; saltwater intrusion in coastal aquifers; coastal flooding mechanisms; marine heatwaves and ecological impacts; vulnerability of coastal ecosystems; socioeconomic implications of coastal hazards.

UNIT III: Monitoring and Forecasting of Extreme Events

Observational systems for hazard monitoring; meteorological satellites and remote sensing applications; Doppler Weather Radar principles and applications; ocean observing systems and buoy networks; cyclone track and intensity forecasting techniques; storm surge prediction models; early warning systems for extreme weather and coastal hazards; ensemble forecasting approaches; impact-based forecasting; uncertainty in hazard prediction; forecast verification and performance assessment.

UNIT IV: Coastal Risk Assessment and Disaster Management

Hazard, exposure, vulnerability, and risk concepts; coastal risk assessment frameworks; hazard zonation and susceptibility mapping; disaster risk reduction strategies; preparedness and evacuation planning; community-based disaster management; coastal resilience and adaptation measures; ecosystem-based approaches including mangrove restoration and nature-based solutions; national and international frameworks for disaster risk reduction; Sendai Framework for Disaster Risk Reduction; coastal disaster governance in India.

UNIT V: Climate Change and Future Coastal Risks

Observed and projected changes in extreme weather events; climate change influence on tropical cyclones, storm surges, and coastal flooding; regional sea-level rise projections; changing return periods of coastal hazards; integrated assessment of compound hazards; climate scenarios and future coastal vulnerability; adaptation pathways for coastal communities; sustainable coastal zone management; climate-informed decision support systems; emerging technologies and research frontiers in coastal hazard science.

CDAT 703 – Deep Learning for Climate Applications

Credits: 4

Course Outcomes (COs)

CSS703 – Deep Learning for Climate Applications

Upon successful completion of this course, students will be able to:

CO1: Explain the theoretical foundations of deep learning, including neural network architectures, optimization algorithms, activation functions, regularization methods, and training strategies used in climate and weather applications.

CO2: Develop and implement convolutional neural network (CNN) models for spatial pattern recognition, feature extraction, and classification of atmospheric and climate datasets.

CO3: Apply recurrent neural networks (RNNs) and long short-term memory (LSTM) networks to model temporal dependencies and perform forecasting of climate variability, weather parameters, and extreme events.

CO4: Evaluate, optimize, and interpret deep learning models using advanced training techniques, hyperparameter tuning, transfer learning, explainable artificial intelligence (XAI), and uncertainty assessment methods.

CO5: Design and assess deep learning solutions for climate and weather applications, including extreme event prediction, precipitation forecasting, climate downscaling, climate model bias correction, and environmental decision-support systems.

UNIT I: Deep Neural Network Architecture

Introduction to deep learning and neural network architectures, multi-layer perceptron (MLP) models, network structure and hidden layers, activation functions including sigmoid, tanh and ReLU, forward propagation and backpropagation algorithms, gradient descent optimization techniques, stochastic and mini-batch gradient descent, loss and cost functions for regression and classification problems, regularization methods including dropout and weight decay, vanishing and exploding gradient problems, strategies for stable and efficient deep neural network training.

UNIT II: Convolutional Neural Networks (CNN)

Introduction to convolutional neural networks and spatial data analysis, representation of climate and weather fields as images, convolution operations and filter design, feature maps and feature extraction, pooling layers and dimensionality reduction, CNN architecture and network design, training and optimization of CNN models, spatial pattern recognition in atmospheric datasets, classification and detection of weather systems, cyclone detection and tracking applications, climate pattern analysis using convolutional neural networks.

UNIT III: Recurrent Neural Networks (RNN) and LSTM

Introduction to sequential data modeling, recurrent neural network architecture and functioning, temporal dependency and sequence learning, memory mechanisms in neural networks, long short-term memory (LSTM) networks and gating structures, sequence-to-sequence learning models, processing climate and weather time-series data, forecasting atmospheric variables using RNNs and LSTMs, seasonal climate outlook prediction, prediction of climate variability and extreme events using temporal deep learning frameworks.

UNIT IV: Advanced Training Techniques

Advanced optimization techniques for deep learning, batch normalization and training stabilization, hyperparameter tuning and optimization strategies, learning rate scheduling methods, early stopping and model regularization, transfer learning concepts and applications, model interpretability and explainable artificial intelligence, feature importance analysis, SHAP and related interpretability techniques, uncertainty estimation in deep learning models, methods for preventing overfitting and improving model generalization performance.

UNIT V: Applications in Climate and Weather

Applications of deep learning in atmospheric and climate sciences, extreme weather and climate event prediction, precipitation nowcasting and short-term forecasting concepts, bias correction of climate model outputs using neural networks, surrogate modeling and emulation of climate simulations, weather pattern recognition and classification, climate downscaling applications, forecasting of temperature, rainfall and circulation anomalies, comparison of deep learning approaches with dynamical forecasting systems, challenges, limitations and future opportunities of artificial intelligence in weather and climate prediction.

CDAT704 – Atmospheric Chemistry and Climate Interactions

Credits: 4

Course Outcomes (COs)

CDAT704 – Atmospheric Chemistry and Climate Interactions

Upon successful completion of this course, students will be able to:

CO1: Explain the composition, chemical processes, and transformation pathways of atmospheric trace gases, greenhouse gases, ozone, and reactive chemical species, and their roles in atmospheric chemistry and climate regulation.

CO2: Analyze the formation, evolution, transport, and removal of atmospheric aerosols and evaluate their impacts on air quality, atmospheric composition, and climate systems.

CO3: Assess the interactions and feedback mechanisms between atmospheric chemistry and climate, including aerosol–radiation interactions, aerosol–cloud processes, ozone–climate coupling, and chemistry–transport dynamics.

CO4: Evaluate the linkages between air pollution and climate change, including environmental, health, and socio-economic impacts, and examine mitigation strategies and policy responses for sustainable air quality management.

CO5: Apply knowledge of chemical transport models and coupled chemistry–climate models to interpret atmospheric chemical processes, evaluate model performance, assess uncertainties, and investigate climate–chemistry interactions using observational and modeling approaches.

UNIT I: Atmospheric Chemical Composition

Introduction to atmospheric chemistry, composition and structure of the atmosphere, major atmospheric trace gases, greenhouse gases and their climatic significance, ozone chemistry and ozone balance, tropospheric and stratospheric ozone processes, methane chemistry and atmospheric lifetime, nitrogen oxides and their role in atmospheric reactions, volatile organic compounds (VOCs) and their sources, atmospheric oxidation processes involving hydroxyl radicals, chemical cycles of major atmospheric constituents, lifetime and fate of greenhouse gases in the atmosphere.

UNIT II: Aerosol Chemistry and Transformation

Introduction to atmospheric aerosols and their classification, primary and secondary aerosol formation processes, sources and characteristics of sulfate, nitrate and organic aerosols, sulfate formation pathways in the atmosphere, black carbon properties and aging processes, mineral dust emissions and long-range transport, heterogeneous and multiphase chemical reactions, aerosol growth and transformation mechanisms, wet and dry deposition processes, aerosol removal pathways, impacts of aerosol chemistry on air quality and climate.

UNIT III: Chemistry–Climate Feedback Mechanisms

Interactions between atmospheric chemistry and climate systems, ozone–climate feedback mechanisms, radiative effects of atmospheric trace gases, aerosol radiative forcing and climate impacts, direct and indirect aerosol effects, cloud–aerosol interactions and cloud microphysical responses, chemistry–transport models and their applications, feedbacks between atmospheric composition and circulation, stratosphere–troposphere exchange processes, chemical influences on climate variability and long-term climate change, uncertainties in chemistry–climate interactions.

UNIT IV: Air Pollution and Climate Linkages

Sources and characteristics of air pollution, urban and industrial air pollution, regional haze formation and impacts, transboundary transport of atmospheric pollutants, interactions between air quality and climate change, health impacts of atmospheric pollution, climate and health co-benefits of emission reductions, mitigation strategies for air pollution control, environmental policies and regulations, atmospheric chemistry responses to emission reductions, sustainable approaches for improving air quality and climate outcomes.

UNIT V: Representation in Climate Models

Introduction to chemical transport models (CTMs), coupled chemistry–climate models (CCMs), representation of atmospheric chemistry in climate simulations, emission inventories and emission scenarios, chemical parameterization schemes in atmospheric models, aerosol and trace gas representation in Earth system models, uncertainty in chemical parameterizations, sensitivity studies and model evaluation, observational datasets for validation, satellite and ground-based observations, verification and validation of chemistry–climate model simulations, future developments in atmospheric chemistry modeling.

CDAT 705 – Laboratory V: Modeling and Deep Learning Applications

Credits: 4

Course Outcomes (COs)

CDAT705 – Laboratory VII: Modeling and Deep Learning Applications

Upon successful completion of this laboratory course, students will be able to:

CO1: Configure, execute, and analyze simplified atmospheric and climate model experiments to investigate climate processes, model sensitivity, and system responses to different forcing conditions.

CO2: Process and interpret climate model datasets, perform forecast verification, evaluate ensemble predictions, and assess uncertainties in climate simulations and projections.

CO3: Develop and implement deep learning models, including CNNs and LSTMs, for spatial and temporal climate data analysis, pattern recognition, and climate forecasting applications.

CO4: Apply data assimilation techniques, evaluate model biases, and integrate observational and reanalysis datasets to improve the accuracy and reliability of climate and weather simulations.

CO5: Design and execute integrated modeling and artificial intelligence projects by combining numerical modeling, machine learning, and climate data analysis techniques to address real-world climate and environmental challenges.

UNIT I: Climate and Weather Model Experiments

Introduction to numerical modeling frameworks, execution of simplified atmospheric and climate model experiments, model configuration and setup procedures, analysis of model outputs, sensitivity experiments and parameter variations, investigation of atmospheric circulation and climate processes through numerical simulations, interpretation of model behavior under different forcing conditions, assessment of model performance and limitations.

UNIT II: Climate Model Data Analysis and Forecast Verification

Introduction to climate model datasets, acquisition and processing of CMIP datasets, extraction and visualization of climate variables, temporal and spatial analysis of model outputs, comparison of historical and future climate simulations, ensemble forecasting concepts, ensemble forecast verification techniques, probabilistic forecast assessment, forecast skill metrics, interpretation of uncertainty and model spread in ensemble predictions.

UNIT III: Deep Learning Applications for Climate Data

Preparation and preprocessing of climate datasets for deep learning applications, implementation of convolutional neural networks (CNNs) for spatial climate fields, feature extraction and climate pattern recognition, recurrent neural networks (RNNs) and long short-term memory (LSTM) networks for temporal climate data, climate time-series forecasting, model training and optimization, performance evaluation of deep learning models, and comparison with traditional statistical approaches.

UNIT IV: Data Assimilation and Model Bias Evaluation

Introduction to data assimilation concepts and methodologies, demonstration of simplified data assimilation frameworks, integration of observational data into model simulations, analysis of forecast improvements through assimilation, identification and quantification of model biases, bias correction techniques, comparison of model simulations with observational and reanalysis datasets, evaluation of systematic errors and uncertainty in climate and weather models.

UNIT V: Integrated Modeling and Artificial Intelligence Project

Design and implementation of an integrated mini-project combining numerical modeling and artificial intelligence techniques, climate data analysis and feature engineering, application of machine learning and deep learning algorithms for prediction and classification tasks, model validation and performance assessment, interpretation of scientific results, preparation of technical reports and project documentation, oral presentation of project findings and demonstration of research outcomes.

CSS706 – Big Data Systems and Cloud Computing for Climate (Minor 3)

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Explain the characteristics, challenges, and management requirements of large-scale climate datasets and apply FAIR principles for effective climate data stewardship.

CO2: Apply distributed computing and parallel processing techniques to efficiently store, process, and analyze high-dimensional climate and environmental datasets.

CO3: Utilize cloud computing technologies, virtualization, and containerized environments to support scalable climate data analysis and modeling workflows.

CO4: Design automated and reproducible data pipelines integrating climate datasets with computational and machine learning frameworks for scientific applications.

CO5: Develop visualization products and decision-support systems that effectively communicate climate information, uncertainties, and risks to diverse stakeholders for evidence-based decision-making.

Credits: 4

UNIT I: Characteristics of Climate Big Data

Introduction to climate big data and its significance; characteristics of climate datasets including volume, velocity, variety, veracity, and value; high-resolution spatial and temporal datasets; observational datasets from meteorological stations, satellites, and ocean observing systems; reanalysis products and climate model outputs; multidimensional geospatial datasets; challenges in climate data storage, retrieval, and management; metadata standards and documentation practices; data interoperability and sharing; FAIR data principles (Findable, Accessible, Interoperable, and Reusable); quality assurance and stewardship of climate data archives.

UNIT II: Distributed Computing and Parallel Processing

Introduction to high-performance computing and distributed computing systems; concepts of parallel processing and scalability; distributed file systems and storage architectures; parallel programming paradigms; MapReduce framework and applications; processing of large NetCDF and HDF datasets; chunking and partitioning strategies for climate data; parallel computation using Dask and similar frameworks; optimization of computational workflows; applications of distributed computing in climate modeling, reanalysis processing, and environmental analytics.

UNIT III: Cloud Computing Platforms for Climate Applications

Fundamentals of cloud computing and service models (IaaS, PaaS, and SaaS); virtualization technologies and virtual machines; cloud-based storage systems; introduction to containerization and Docker; orchestration concepts; scalable computing environments for climate applications; workflow automation in cloud environments; utilization of cloud platforms for climate data analysis; resource allocation and cost optimization; security, privacy, and governance of environmental datasets; applications of cloud computing in climate research and operational services.

UNIT IV: Data Pipelines and Reproducible Workflows

Principles of automated climate data management; automated data acquisition and ingestion systems; Extract–Transform–Load (ETL) concepts; preprocessing and transformation pipelines for climate datasets; reproducible computational workflows; workflow scheduling and monitoring; integration of climate datasets with machine learning pipelines; version control and documentation standards; quality control procedures in automated workflows; management of large-scale climate data processing systems; best practices in scientific computing and collaborative research environments.

UNIT V: Visualization and Decision Support Systems

Principles of scientific visualization and visual analytics; interactive visualization tools for climate data exploration; web-based climate dashboards and geospatial information systems; visualization of multidimensional datasets and uncertainty; development of decision-support products for climate services; communication of climate risks to stakeholders; geospatial storytelling and science communication techniques; dashboard design principles for policymakers and practitioners; applications in disaster risk reduction, adaptation planning, and climate-informed decision-making; emerging trends in climate informatics and digital climate services.

YEAR 4 – SEMESTER 8

Total Credits: 20

CDAT801 – Climate Predictability and Seasonal Forecasting

Credits: 4

Course Outcomes (COs)

CDAT801 – Climate Predictability and Seasonal Forecasting

Upon successful completion of this course, students will be able to:

CO1: Explain the fundamental concepts of weather and climate predictability, including deterministic and probabilistic forecasting, chaos theory, atmospheric and oceanic memory, and limits of prediction.

CO2: Analyze the principles, methodologies, and performance of seasonal and subseasonal forecasting systems, including dynamical models, ensemble forecasting techniques, and hindcast-based prediction approaches.

CO3: Apply statistical, machine learning, and hybrid forecasting methods to develop and evaluate seasonal climate predictions and climate outlook products.

CO4: Assess forecast quality using deterministic and probabilistic verification metrics, forecast calibration techniques, and uncertainty evaluation methods to improve prediction reliability.

CO5: Evaluate the application of seasonal forecasting systems in monsoon prediction, ENSO forecasting, drought early warning, climate services, and decision-support frameworks for climate-sensitive sectors.

UNIT I: Concepts of Predictability

Introduction to predictability in weather and climate systems, deterministic and probabilistic predictability concepts, sources of predictability in the climate system, internal climate variability and external forcing, boundary-forced predictability, atmospheric and oceanic memory, nonlinear dynamics and chaos theory, Lyapunov growth and error amplification, predictability limits in atmospheric systems, weather versus climate predictability, timescales of climate variability and prediction, challenges in long-range forecasting.

UNIT II: Seasonal and Subseasonal Forecast Systems

Introduction to seasonal and subseasonal forecasting, dynamical seasonal prediction systems, coupled atmosphere–ocean forecast models, subseasonal-to-seasonal (S2S) prediction frameworks, ensemble forecasting techniques, ensemble generation methods and perturbation strategies, hindcasting and retrospective forecasting, forecast initialization procedures, lead time and forecast horizon considerations, forecast skill assessment, operational seasonal forecasting systems and applications.

UNIT III: Statistical and Hybrid Forecasting Approaches

Principles of statistical climate forecasting, empirical prediction methods, regression-based seasonal outlook models, teleconnection-based forecasting approaches, machine learning applications in seasonal climate prediction, artificial intelligence techniques for climate forecasting, hybrid dynamical–statistical prediction frameworks, multi-model and multi-method forecasting systems, forecast combination and ensemble averaging techniques, advantages and limitations of statistical and hybrid approaches, emerging trends in climate prediction.

UNIT IV: Forecast Verification and Skill Assessment

Introduction to forecast verification and validation, deterministic and probabilistic forecast evaluation methods, Brier score and Brier skill score, ranked probability score and ranked probability skill score, anomaly correlation coefficient, mean square error and skill metrics, reliability diagrams and forecast calibration, discrimination and sharpness measures, probabilistic forecast evaluation techniques, uncertainty assessment and communication, calibration and post-processing methods for improving forecast skill.

UNIT V: Applications in Monsoon and ENSO Forecasting

Operational monsoon forecasting systems and methodologies, seasonal prediction of Indian summer monsoon rainfall, ENSO monitoring and seasonal outlook generation, teleconnections between ENSO and monsoon variability, drought prediction and early warning systems, agricultural and water resource advisories based on seasonal forecasts, climate services for disaster risk reduction, forecast-based decision support systems, integration of seasonal forecasts into early warning frameworks, challenges and future directions in operational climate forecasting.

CDAT802 – Climate Services and Decision Support Systems

Credits: 4

Course Outcomes (COs)

CDAT802 – Climate Services and Decision Support Systems

Upon successful completion of this course, students will be able to:

CO1: Explain the framework, components, and operational mechanisms of climate services, including climate information generation, stakeholder engagement, and national and global climate service systems.

CO2: Analyze the design and implementation of multi-hazard early warning systems, impact-based forecasting approaches, and risk communication strategies for disaster risk reduction and climate resilience.

CO3: Apply climate information and forecasting products to support decision-making in agriculture, water resources, disaster management, coastal planning, energy systems, and climate risk management.

CO4: Evaluate the role of climate services in policy development, governance frameworks, adaptation planning, and climate-informed decision-making at local, national, and international levels.

CO5: Assess uncertainties in climate predictions and projections, communicate climate risks effectively, and apply ethical principles, transparency, and accountability in climate services and decision-support systems.

UNIT I: Framework of Climate Services

Introduction to climate services and their importance, definition, scope and objectives of climate services, components of climate service systems, generation and delivery of climate information, user engagement and stakeholder participation, co-production of climate knowledge, climate information needs assessment, operational climate information systems, climate data and forecasting services, national climate service frameworks, global frameworks for climate services (GFCS), challenges and opportunities in climate service implementation.

UNIT II: Early Warning Systems

Concepts and principles of early warning systems, multi-hazard early warning framework, risk monitoring and hazard detection, forecasting and warning generation, forecast-based financing and anticipatory action, impact-based forecasting approaches, warning communication strategies, communication protocols and dissemination channels, community-based early warning systems, last-mile connectivity challenges, emergency response coordination, evaluation and effectiveness of early warning systems for disaster risk reduction.

UNIT III: Sectoral Applications

Applications of climate services across socio-economic sectors, climate services for agriculture and food security, agro-meteorological advisories and crop forecasting, climate information for water resource management, drought and flood management applications, coastal planning and coastal risk assessment, climate services for disaster risk reduction and resilience building, energy demand and renewable energy forecasting, insurance and climate risk management, sector-specific decision support systems and climate adaptation strategies.

UNIT IV: Policy Interface and Governance

Role of climate information in policy and decision-making, climate policy instruments and governance frameworks, adaptation planning and implementation strategies, integration of climate services into national climate action plans, climate risk communication and stakeholder engagement, institutional mechanisms for climate service delivery, decision-making frameworks under climate risk, governance challenges in climate adaptation, international agreements and policy initiatives, strengthening climate-informed governance systems.

UNIT V: Uncertainty Communication and Ethical Considerations

Nature and sources of uncertainty in climate predictions and projections, communicating probabilistic forecasts and climate risks, interpretation of forecast confidence and reliability, decision-making under uncertainty, risk perception and behavioral responses, ethical considerations in climate information services, ethical use of artificial intelligence and machine learning in climate applications, transparency and accountability in predictive systems, responsible communication of climate information, trust-building and stakeholder confidence in climate services.

CDAT803 – Honours Mini Project / Field Study

Credits: 4

CO1: Identify and formulate a scientifically relevant research problem or applied project in climate science, environmental systems, or climate data analytics through independent investigation and critical review of literature.

CO2: Acquire, process, and manage observational, reanalysis, model, or field-based datasets using appropriate scientific, statistical, and computational methodologies.

CO3: Apply climate modeling, data analytics, machine learning, or field-based research techniques to investigate scientific questions and generate evidence-based solutions.

CO4: Analyze, interpret, and critically evaluate research findings while assessing uncertainties, limitations, and practical implications of the study.

CO5: Prepare and defend a dissertation-style project report and effectively communicate scientific results through oral presentations, technical documentation, and scholarly discussion.

Independent research or applied project under faculty supervision; problem formulation; dataset acquisition; modeling or ML implementation; interpretation of results; preparation of dissertation-style report; seminar presentation and defense; integration of climate science and data analytics tools.

🎓 Exit Qualification After Year 4

Bachelor of Science (Honours) in Climate and Data Science

YEAR 5 – RESEARCH PROJECT

Semester 9

Credits: 20

CDAT901 – Research Methodology & Scientific Writing

Upon successful completion of this course, students will be able to:

CO1: Formulate scientifically relevant research problems, hypotheses, and objectives through critical evaluation of literature and identification of knowledge gaps in atmospheric, oceanographic, climate, and environmental sciences.

CO2: Design and implement appropriate research methodologies, data collection strategies, experimental frameworks, and data management plans while ensuring scientific rigor and reproducibility.

CO3: Communicate scientific findings effectively through the preparation of research papers, technical reports, conference presentations, posters, and other scholarly documents using accepted scientific standards.

CO4: Apply principles of research ethics, publication integrity, responsible data management, and ethical use of emerging technologies, including artificial intelligence, in scientific investigations.

CO5: Develop comprehensive research proposals, project plans, and funding applications, and demonstrate professional skills in scientific presentation, peer review, and research project management.

UNIT I: Research Design and Problem Formulation

Introduction to scientific research and research methodology, types of research approaches, identification of research problems and knowledge gaps, formulation of research questions and hypotheses, development of research objectives and scope, literature survey techniques and database searching, critical evaluation of scientific literature, conceptual and theoretical frameworks, interdisciplinary research approaches, problem formulation in atmospheric, oceanographic and climate sciences, development of innovative and impactful research themes.

UNIT II: Data Collection and Experimental Design

Principles of scientific data collection, primary and secondary data sources, observational and experimental datasets, field measurements and monitoring techniques, sampling methods and sampling design, observational studies versus modeling studies, experimental design principles, data quality assurance and quality control procedures, reproducibility and replicability in scientific research, data management planning, metadata standards, storage, archiving and sharing of scientific datasets.

UNIT III: Scientific Communication

Importance of scientific communication, structure and components of scientific papers, preparation of titles, abstracts and keywords, writing introductions and literature review sections, methodology and results presentation, discussion and conclusion writing, preparation and presentation of figures, tables and graphical abstracts, scientific visualization techniques, citation and referencing styles, reference management software, preparation of technical reports, conference papers and poster presentations, effective scientific communication strategies.

UNIT IV: Research Ethics and Integrity

Principles of research ethics and responsible conduct of research, plagiarism and plagiarism detection tools, data fabrication, falsification and misrepresentation, authorship criteria and publication ethics, peer review ethics, conflict of interest and disclosure requirements, responsible data management and sharing practices, intellectual property rights and copyright issues, ethical considerations in climate and environmental research, ethical use of artificial intelligence and machine learning in scientific investigations, research integrity and professional accountability.

UNIT V: Proposal Development and Presentation

Fundamentals of research proposal development, identification of funding opportunities and grant mechanisms, structure and components of research proposals, formulation of research methodology and work plans, budgeting principles and resource allocation, project timeline design and milestone planning, risk assessment and contingency planning, oral and visual presentation skills, scientific presentation techniques, peer review process and proposal evaluation criteria, responding to reviewer comments and revisions, preparation of project reports and final research documentation.

CDAT 902 Dissertation / Research Project (Part I – Progress Phase)

Course Outcomes (COs)

Upon successful completion of this course, students will be able to:

CO1: Identify and formulate a novel research problem in climate science, atmospheric science, oceanography, climate modeling, or climate data analytics through critical evaluation of existing knowledge and research gaps.

CO2: Conduct a comprehensive literature review, develop a conceptual research framework, formulate research objectives and hypotheses, and establish a scientifically rigorous research plan.

CO3: Acquire, preprocess, and manage observational, satellite, reanalysis, and model datasets, and design appropriate statistical, computational, machine learning, or modeling methodologies for research investigations.

CO4: Perform exploratory data analysis, develop preliminary experiments or simulations, evaluate initial findings, and refine research strategies based on diagnostic assessment of results.

CO5: Prepare and present a professional research progress report, effectively communicate research methodology and preliminary outcomes, and demonstrate readiness for advanced independent research in the dissertation phase.

Literature Review and Research Framework

Review of scientific literature; identification of research gaps; development of conceptual framework; preparation of an annotated bibliography; formulation of hypotheses.

Data Collection and Methodology Design

Acquisition of observational, satellite, reanalysis, or model datasets; data preprocessing; selection of statistical or machine learning methods; design of modeling or computational workflow

Preliminary Analysis and Experimental Setup
Exploratory data analysis; preparation of model inputs; preliminary simulations or ML experiments; diagnostic evaluation of early results.

Interim Progress Report and Seminar
Preparation of a detailed progress report; presentation of research proposal, methodology, and preliminary results before the Departmental committee.

Semester 10

Credits: 22

Course Outcomes (COs)

CDAT1001 – Dissertation / Research Project (Part II – Completion Phase)

Upon successful completion of this course, students will be able to:

CO1: Conduct independent and advanced research by applying climate science, modeling, statistical, machine learning, or data analytics techniques to address complex scientific problems.

CO2: Analyze and interpret research results using appropriate statistical, computational, and scientific methods, and critically evaluate findings in the context of existing literature and observational evidence.

CO3: Develop high-quality scientific visualizations, technical analyses, and data products that effectively communicate patterns, relationships, and insights from climate and environmental datasets.

CO4: Prepare a comprehensive dissertation following accepted scientific and academic standards, demonstrating proficiency in research methodology, scientific writing, data interpretation, and scholarly communication.

CO5: Defend research findings through professional presentations and viva voce examinations, demonstrating critical thinking, subject expertise, and the ability to communicate scientific results to academic and professional audiences.

Unit I: Advanced Research Implementation
Execution of full modeling experiments or data-driven analysis; processing of large climate datasets; refinement of machine learning or statistical models.

Unit II: Result Analysis and Interpretation
Statistical evaluation of results; identification of patterns in climate variability or extreme events; comparison with observational datasets and previous studies.

Unit III: Scientific Visualization and Documentation
Preparation of spatial maps, time-series plots, and diagnostic figures; synthesis of research findings; integration of results into scientific narrative.

Unit IV: Dissertation Writing
Preparation of thesis chapters, including introduction, literature review, methodology, results, discussion, and conclusions; formatting according to university guidelines.

Unit V: Thesis Submission and Viva Voce
Submission of final dissertation; seminar presentation of results; evaluation by internal and external examiners; viva voce examination.