Indian Institute of Space Science and Technology

Department of Space,

Thiruvananthapuram

Curriculum and Syllabus for

DUAL DEGREE EARTH SYSTEM SCIENCE

Department of Earth and Space Sciences

Curriculum and Syllabus for M.Tech. in Earth System Science (Dual Degree Programme)- Operative from 2024

Program Educational Objectives (PEO)

Equip graduates with a strong foundation in the core areas of Earth System Science, including atmospheric science, oceanography, and geology, enabling them to analyze and interpret the complex interactions within the Earth system

Encourage a spirit of scientific inquiry and innovation by engaging students in cutting-edge research and problem-solving relevant to Earth system processes, environmental change, and sustainable development.

Prepare students for successful careers in academia, research institutions, government agencies, and industry by imparting practical skills, computational techniques, and data analysis methods commonly used in Earth system studies.

Instill a deep understanding of the societal relevance of Earth system science and promote ethical practices, environmental stewardship, teamwork, and effective communication to address global and regional challenges.

Program Outcomes (PO)

Program Outcomes	Statements
PO1	Demonstrate in-depth understanding of atmospheric, oceanic, and geological processes and their interconnections, with the ability to apply this knowledge to analyze Earth system dynamics.
PO2	Design and conduct experiments, analyze observational and model-based data, and apply appropriate tools and techniques to investigate scientific questions in Earth system science.
PO3	Identify, formulate, and solve complex problems related to climate change, natural hazards, and environmental sustainability using interdisciplinary approaches and modern scientific tools.
PO4	Communicate scientific concepts, methodologies, and research outcomes effectively through oral, written, and digital means; work efficiently in multidisciplinary teams and with diverse stakeholders.
PO5	Recognize the ethical, environmental, and societal implications of Earth system science research and applications and commit to responsible and sustainable scientific practices.

COURSE STRUCTURE

Semester VII

Code	Course Title	L	T	P	C
ESE 411	Dynamics of Atmosphere	3	0	0	3
ESE 412	Physical and Dynamical Oceanography	3	0	0	3
ESE 413	Earth Resources and Tectonic Systems	3	0	0	3
ESE 414	Radiation Processes in Atmosphere	3	0	0	3
ESE 415	Atmospheric Thermodynamics and Cloud Physics	3	0	0	3
ESE 431	Data Analysis in Atmospheric Science Lab	0	0	1	1
ESE 432	Geology Lab	0	0	1	1
	Total	15	0	2	17

Semester VIII

Code	Course Title	L	T	P	C
ESE 4XX	Elective I	3	0	0	3
ESE 4XX	Elective II	3	0	0	3
ESE 4XX	Elective III	3	0	0	3
ESE 4XX	Elective IV	0	0	0	3
ESE 4XX	Elective V	3	0	0	3
ESE 441	Numerical Modelling and Advanced Data Analysis Lab	0	0	1	1
ESE 442	Observational Techniques Lab	0	0	1	1
ESE 443	Planetary Geosciences Lab	0	0	1	1
ESE 451	Seminar	0	0	0	2
ESE 452	Comprehensive Viva-Voce	0	0	0	2
	Total	15	0	0	22

Semester IX

Code	Course Title	L	T	P	C
ESE 454	Project (Midterm + Phase I)	0	0	0	14
	Total	0	0	0	14

Semester X

Code	Course Title	L	T	P	C
ESE 455	Project (Midterm + Phase II + Thesis)	0	0	0	18
	Total	0	0	0	18

Summary

Semester	**Credits**
VII	17
VIII	22
IX	14
X	18
Total	**71**

DEPARTMENT ELECTIVE COURSES

Code	Course Title	L	T	P	C
ESE 461	Planetary Atmospheres	3	0	0	3
ESE 462	Numerical Weather Prediction	3	0	0	3
ESE 463	Planetary Geosciences	3	0	0	3
ESE 464	Aerosol-Cloud-Climate Interaction	3	0	0	3
ESE 465	Air-Sea Interaction	3	0	0	3
ESE 466	Satellite Meteorology and Oceanography	3	0	0	3
ESE 467	Boundary Layer Meteorology	3	0	0	3
ESE 468	Polar Science	3	0	0	3
ESE 469	Ionosphere and Space Physics	3	0	0	3
ESE 470	General Circulation and Monsoon	3	0	0	3
ESE 471	Land – Atmosphere Interaction Dynamics	3	0	0	3
ESE 472	Atmospheric and Oceanic Instrumentation and Measurement Techniques	3	0	0	3

- **Any other relevant approved elective from different branch can be taken after taking approval from PG coordinator**
- **In addition, any one relevant NPTEL/Swayam course can be taken as an elective**

Semester - VII

ESE 411 **Dynamics of Atmosphere** **(3 0 0) Credits**

Syllabus

Concept of fluid, Continum model, Lagrange and Eulerian description of fluid flow, continuity, momentum and energy equations, boundary layer theory, turbulent flow, Inertial and Non Inertial frames; Fundamental Forces - Pressure Gradient Forces, Gravitational Force, Friction or Viscous Force, Apparent forces -Centrifugal Force, Coriolis force, Rossby number, Effective Gravity; Hydrostatic balance, Momentum Equations-Cartesian Coordinate System, Spherical – Polar coordinate system. Scale analysis of momentum equations. Balanced motion - Geotropic Wind, Gradient Wind, Inertial flow, Cyclostropic flow, Thermal wind, Continuity equation – Horizontal divergence, Vertical motion. Isobaric coordinate System -Transformation of momentum & continuity equations. Circulation & Vorticity – Kelvins circulation theorem, Bjerknes circulation theorem. Application to Land & Sea breeze.

Vorticity equation. Potential vorticity - Application to Lee of the mountain trough, divergence equation, linear and non-linear balance equations, scale analysis of vorticity and divergence equations for planetary and synoptic scale motions; Atmospheric waves –sound wave, gravity wave, Rossby wave, Quasi-geostrophic analysis- quasi-geostrophic omega equation, the general circulation- available potential energy,-barotropic instability, baroclinic instability, tropical dynamics

Course Outcomes (COs):

Course Outcomes	**Statements**
CO1	Apply the fundamental equations of fluid dynamics (continuity, momentum, and energy equations) in Cartesian and spherical coordinate systems to analyze atmospheric motions under different force balances and reference frames.
CO2	Examine balanced atmospheric flows (geostrophic, gradient, cyclostrophic, inertial, and thermal wind) and perform scale analysis of momentum, vorticity, and divergence equations for planetary and synoptic-scale motions.
CO3	Analyze atmospheric circulation and vorticity concepts including Kelvin’s and Bjerknes’ circulation theorems, potential vorticity, and their applications to mesoscale and synoptic phenomena such as land–sea breeze and lee trough formation.
CO4	Interpret atmospheric wave dynamics and large-scale circulation processes through quasi-geostrophic theory, omega equation analysis, instability mechanisms (barotropic and baroclinic), and tropical dynamics

ESE 412 **Physical and Dynamical Oceanography** **(3 0 0) Credits**

Syllabus

Unit I:

Physical properties of Sea water, density of sea water, density parameters, specific volume anomaly, Temperature, Salinity, Cholorinity and their determination, distribution of temperature, salinity and density in space and time, The oceanic Mixed Layer and Thermocline, Sea level variation, acoustical and optical properties of sea water, Formation and classification of water masses, T-S diagram and Water masses of the world ocean.

Unit II:

Equations of Motion: Dominant Forces for Ocean Dynamics, Coordinate Systems, Types of Flow in the Ocean, Conservation of Mass and Salt, The Total Derivative, Momentum Equation, Conservation of Mass: Continuity Equation, Solutions to the Equations of Motion. Stability in the Ocean, Mixing in the Ocean.

Course Outcomes (COs):

Course Outcomes	**Statements**
CO1	Explain and quantify the physical properties of seawater (temperature, salinity, density, specific volume anomaly, chlorinity) and interpret their spatial and temporal variability in the global ocean.
CO2	Analyze vertical ocean structure including the mixed layer and thermocline, sea-level variations, and the formation and classification of water masses using T–S diagrams.
CO3	Apply the fundamental equations governing ocean dynamics (mass, salt, and momentum conservation) in appropriate coordinate systems to describe different types of oceanic flows.
CO4	Evaluate ocean stability and mixing processes using solutions of the equations of motion and assess the dominant forces controlling large-scale ocean circulation.

ESE 413 **Earth Resources and Tectonic Systems** **(3 0 0) Credits**

Syllabus

Internal Structure of Earth:

Introduction to Earth and formation theories. Seismicity and earth's interior. Compositional and Rheological divisions of Earth; crust, mantle and core; discontinuities. Mineralogy and Earth Resources. Minerals, ores, petroleum, coal and natural gas- their origin, structure and composition, accumulation/migration, source/reservoir rocks, distribution in space and time. General physical, chemical and optical properties of common rock forming minerals.

Igneous, Metamorphic and Sedimentary Petrology:

Tectonic Systems:

Concept of continental drift, sea-floor spreading and plate tectonics; tectonics. Nature of plate boundaries: convergent, divergent and transform type. Precambrian and Phanerozoic plate tectonics. Evolution of the Himalayas, Indian Ocean and Andaman's.

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Explain the origin, internal structure, and compositional as well as rheological divisions of the Earth using seismic evidence, and describe major discontinuities within the crust, mantle, and core.
CO2	Identify and classify common rock-forming minerals and rocks (igneous, sedimentary, and metamorphic) based on their physical, chemical, and optical properties, and interpret their formation processes.
CO3	Analyze the origin, accumulation, migration, and spatial distribution of major Earth resources (minerals, ores, petroleum, coal, and natural gas) in relation to source and reservoir rock characteristics.
CO4	Evaluate plate tectonic processes including continental drift, sea-floor spreading, and different plate boundary interactions, and interpret their role in the evolution of the Himalayas, Indian Ocean, and Andaman region.

ESE 414 **Radiation Processes in Atmosphere** **(3 0 0) Credits**

Syllabus

The spectrum of electromagnetic radiation; Solid angle, Fundamental of radiometric quantities, Concepts of scattering, absorption and polarization of radiation, Quantitative description of radiation; Blackbody Radiation: The Plank Function, Wiens displacement Law, The Stefan-Boltzmann Law; Kirchoff's Law, Radiative equilibrium.

Absorption line profiles: Line formation and line shape, Absorption and emission by gas molecules, Physics of scattering and absorption by particles, Rayleigh Scattering, Raman Scattering, Lorentz-Mie theory of light scattering, Geometric Optics.

Radiative transfer in planetary atmosphere, Equation of radiative transfer, Radiative transfer in a plane parallel atmosphere, Beer-Bouguer Law, Reflection and absorption by a layer of the atmosphere, Absorption and emission of infrared radiation in cloud-free atmosphere, Vertical profiles of radiative heating rate; Earth's radiation budget, the Role of radiation in climate.

Application of radiative transfer to remote sensing of atmospheric properties: Retrieval of meteorological variables, gases, particulate information and surface properties.

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Explain the fundamental principles of electromagnetic radiation, radiometric quantities, blackbody radiation laws, and radiative equilibrium, and apply them to atmospheric energy balance problems.
CO2	Analyze radiative processes in the atmosphere including molecular absorption and emission, line broadening mechanisms, and scattering by gases and particles (Rayleigh, Raman, and Mie theory).
CO3	Apply the equation of radiative transfer in plane-parallel atmospheres to quantify atmospheric absorption, emission, reflection, and vertical radiative heating rates, and interpret Earth's radiation budget in the context of climate.
CO4	Evaluate and apply radiative transfer principles to remote sensing retrieval of atmospheric and surface parameters, including meteorological variables, trace gases, aerosols, and cloud properties.

ESE 415 **Atmospheric Thermodynamics and Cloud Physics** **(3 0 0) Credits**

Syllabus

Basic concepts, composition of the atmosphere, equation of state, hydrostatic equilibrium, first law of thermodynamics, application of first law, entropy, second law, heat capacity, dry adiabatic processes, transfer processes, moist thermodynamic processes in atmosphere, static stability, cloud characteristics and processes, Global energy and entropy balances, thermodynamic feedback in the climate system, thermodynamic diagrams.

Cloud Physics: Types of clouds, Cloud microphysical processes, growth of cloud droplets, condensation, collision and coalescence, Bergeron-Findeisen theory, rain formation, cold and warm clouds, artificial rainmaking. Effects of Aerosols on Clouds: Cloud Condensation Nuclei, Cloud Droplet Spectra, and Precipitation (Heterogeneous Nucleation of water vapour condensation, Cloud Condensation Nuclei, Development of Cloud Droplet Spectra, Effects of Clouds on Aerosols: Nucleation of Aerosol in and near Clouds.

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Explain the thermodynamic principles governing the atmosphere, including equation of state, hydrostatic equilibrium, first and second laws of thermodynamics, entropy, and dry and moist adiabatic processes.
CO2	Analyze atmospheric stability, transfer processes, cloud formation mechanisms, and global energy and entropy balances using thermodynamic diagrams and feedback concepts in the climate system.
CO3	Evaluate cloud microphysical processes including droplet growth by condensation, collision–coalescence, Bergeron–Findeisen mechanism, and precipitation formation in warm and cold clouds.
CO4	Assess the role of aerosols in cloud formation and precipitation processes, including heterogeneous nucleation, cloud condensation nuclei (CCN), cloud droplet spectra development, and aerosol–cloud interactions.

Semester – VIII

ESE 461 **Planetary Atmospheres** **(3 0 0) Credits**

Syllabus

Introduction to Planets and Planetary Systems- Orbital motion – Gravitational field that shape the Earth – Internal structure of planet and its satellite, Equation of state, Density profiles, Mass-Radius relationship, The origin and evolution solar system, planetary atmospheres, Elemental abundance, outgassing processes, capture processes, Erosion and escape processes, surface processes – condensation, Adsorption, dissolution, chemical weathering, Atmospheric feedbacks – Observed atmospheric changes in Earth and other planets.

Spectroscopy and composition of planetary atmospheres, Processes causing compositional variations, Vertical temperature structure of Venus, Mars Titan, Jupiter, Uranus and Neptune. Water on Mars, Venus and Jupiter, Thermal tides, Lapse rate, Radiative transfer in planetary atmospheres, Clouds in Planetary atmospheres, Structure of clouds in Venus and Mars, Cloud Microphysics, Dust Dynamics and Storms, The general circulation regimes, Dynamics of Earth, Venus, Mars and other Jovian planets hydrodynamic instabilities, modelling of planetary atmosphere, Climate of Venus, Mars, Mechanism of climate change in Planetary atmospheres, Atmospheres of Exoplanets.

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Explain the origin and evolution of planetary systems, gravitational controls on planetary structure, mass–radius relationships, and the physical processes governing the formation and evolution of planetary atmospheres.
CO2	Analyze atmospheric composition and vertical thermal structure of terrestrial and giant planets using spectroscopy, radiative transfer principles, and processes such as outgassing, escape, erosion, and chemical weathering.
CO3	Evaluate dynamical processes in planetary atmospheres including general circulation regimes, thermal tides, hydrodynamic instabilities, dust storms, and cloud microphysics, with comparative analysis of Earth, Venus, Mars, and Jovian planets.
CO4	Assess mechanisms of climate evolution and variability in planetary atmospheres, including feedback processes, modeling approaches, and emerging understanding of exoplanet atmospheres.

ESE 462 **Numerical Weather Prediction** **(3 0 0) Credits**

Syllabus

Introduction: Numerical Weather Prediction as an Initial Value Problem, Filtering Problem, Finite Difference techniques for various partial differential equations (parabolic, hyperbolic and elliptic), Time integration schemes, Explicit, Implicit, and semi-implicit Schemes.

Consistency and stability [CFL condition], Von Newmann stability analysis for various finite difference schemes, Staggered grid, Nonlinear instability, Arakawa Jacobians, Semi lagrangian methods, Spectral Technique, Galerkin methods, Introduction to Hierarchy of numerical models: Barotropic models, Equivalent barotropic model, Two level baroclinic model, Shallow water model, Primitive equation models, Brief overview of sub-grid scale processes (convection, boundary layer, radiation, land surface), Objective analysis, Initialization schemes, Data assimilation, Variational schemes, Kalman Filter schemes , High resolution regional modelling- Nested grids, Boundary conditions , Ensemble forecasting

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Formulate numerical weather prediction as an initial value and filtering problem, and apply finite-difference techniques and time-integration schemes (explicit, implicit, semi-implicit) to solve parabolic, hyperbolic, and elliptic partial differential equations.
CO2	Analyze numerical accuracy and stability of discretization schemes using consistency criteria, CFL condition, and Von Neumann stability analysis, and evaluate advanced numerical techniques such as staggered grids, Arakawa Jacobians, semi-Lagrangian, and spectral methods.
CO3	Compare and implement different hierarchical atmospheric models (barotropic, baroclinic, shallow water, primitive equation models) and assess the role of sub-grid scale parameterizations in numerical simulations.
CO4	Evaluate data assimilation and forecasting methodologies including objective analysis, initialization schemes, variational methods, Kalman filter approaches, nested regional modeling, and ensemble forecasting systems.

ESE 463 **Planetary Geosciences** **(3 0 0) Credits**

Syllabus

Remote Sensing techniques applicable to planetary geology; applications derived from interaction of electromagnetic radiation (X-ray, gamma-ray, visible, near-IR, mid-IR, radar) with geologic materials. Remote sensing applications formineralogy, petrology and geochemical analyses for terrestrial and extraterrestrial environments.

SolarSystem: major concepts, planets, satellites, asteroids, meteorites and comets; formation and internal differentiation of the planets; general features of Terrestrial and Jovian planets.

Planetary atmospheres; exo- and endogenic processes associated with origin and internal evolution of planets – planetary volcanism, craters, impact cratering processes, elemental composition; mineralogy and petrology; thermal, seismic and magnetic properties, and chronological techniques.

Earth as a reference material; geology and geophysics of terrestrial planets: mars, venus and mercury; comparative planetology of Jupiter, Uranus and Saturn and their satellites; physical properties, composition, mineralogy and petrology of the air less rocky bodies: the Moon and its Terrestrial Analogues, Io, Phobos and Deimos, minor bodies such as asteroids, comets, meteor, meteoroid and meteorites.

Past, present and future planetary exploration missions.

Analyses and Interpretation of data gathered through various missions: identification of surface and morphological features, mineralogy and petrology.

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Apply remote sensing principles across multiple spectral domains (X-ray, gamma-ray, visible, infrared, and radar) to interpret mineralogical, petrological, and geochemical characteristics of terrestrial and extraterrestrial surfaces.
CO2	Explain the formation, internal differentiation, and structural evolution of planets, satellites, asteroids, comets, and meteorites within the framework of Solar System evolution.
CO3	Analyze exogenic and endogenic planetary processes—including volcanism, impact cratering, tectonism, and atmospheric evolution—using Earth as a reference for comparative planetology.
CO4	Interpret observational data from past and ongoing planetary exploration missions to identify surface morphology, mineral composition, petrology, and geophysical characteristics of planetary bodies.

ESE 464 **Aerosol-Cloud-Climate Interaction** **(3 0 0) Credits**

Syllabus

Tropospheric Aerosols: Aerosols, Historical understanding of tropospheric aerosols, Contemporary understanding of tropospheric aerosols; Particle Sources and Strengths - widespread surface sources (Biogenic sources, Volcanoes, Ocean and fresh water, Crustal and Cryospheric Aerosols, Biomass burning); Spatial Sources - Gas to particle conversion (Sulfur & Nitrogern - Containing compounds, Organic and Carbonaceous Particles), Cloud as a Source of Aerosols, External Sources; Particle Size Distribution and Chemical Compositions (Polar aerosols, Background aerosols, Maritime aerosols, Remote continental aerosols, Desert dust storm aerosols, Rural aerosols, Urban aerosols); Transport, Geographical Distribution, Residence Time and influence of Clouds, Aerosol Optical Depth; Cloud Optical depth and Effective Particle Radius.

Aerosol-Cloud Interaction: Effects of Aerosols on Clouds: Cloud Condensation Nuclei, Cloud Droplet Spectra, and Precipitation (Heterogeneous Nucleation of water vapour condensation, Cloud Condensation Nuclei, Development of Cloud Droplet Spectra, Effect of Aerosol on Development of Precipitation, Stability of CCN population); Aerosol Effects on Cloud Radiative Properties (Effect of Aerosol on Cloud Optical Thickness and Albedo, Effects of Fossil Fuel and Biomass Burning, Ship tracks in Clouds, DMS-Cloud-Climate Hypothesis, Aerosol Effects on Ice in Clouds-Ice Nuclei). Effects of Clouds on Aerosols: Scavenging of Aerosol by Clouds (In-cloud Nucleation Scavenging, Below-Cloud Removal of Aerosol by Precipitation); Chemical Reaction in Clouds and their effects on Aerosol; Acidification of Cloud water and Precipitation; Nucleation of Aerosol in and near Clouds.

Course Outcomes (COs):

Course Outcomes	**Statements**
CO1	Explain the sources, formation mechanisms, size distribution, and chemical composition of tropospheric aerosols, and analyze their spatial distribution, transport processes, and residence times in different atmospheric environments.
CO2	Evaluate gas-to-particle conversion processes, cloud-mediated aerosol formation, and the role of natural and anthropogenic emissions in determining aerosol optical depth and radiative properties.
CO3	Analyze aerosol–cloud interactions including CCN activation, cloud droplet spectrum development, precipitation modification, aerosol indirect effects, and impacts on cloud optical thickness and albedo.
CO4	Assess the bidirectional interactions between aerosols and clouds, including scavenging processes, in-cloud chemical reactions, acidification of cloud water, ice nucleation, and implications for climate forcing.

ESE 465 **Air-Sea Interaction** **(3 0 0) Credits**

Syllabus

Introduction to the Coupled System, Overview of the atmosphere–ocean system, Differences in thermodynamic and dynamic properties of air and seawater, Importance of air–sea interaction in weather and climate. Air–Sea Fluxes, Surface energy balance: shortwave, longwave, sensible and latent heat fluxes, Bulk aerodynamic formulas; transfer coefficients; stability corrections, Momentum flux: wind stress, drag coefficients, surface roughness, Gas exchange processes and solubility. Ocean Surface Layer and Mixed Layer Processes: Structure of the ocean mixed layer; diurnal variability. Surface buoyancy fluxes: heating, cooling, evaporation, precipitation. Entrainment, mixing, and vertical heat redistribution. Mixed-layer deepening and restratification. Upper-Ocean Response to Winds, Ekman balance, Ekman layer, Ekman transport and Ekman pumping, Coastal upwelling and downwelling, Inertial oscillations and near-inertial waves, Wind-driven circulation and regional responses. Surface Waves and Air–Sea Momentum Transfer, Generation of ocean surface waves by wind, Wave spectrum, wave age, and wave–current interaction, Wave-induced stress and its role in momentum exchange, Breaking waves, spray, and their influence on fluxes. Coupled Boundary Layers, Atmospheric boundary layer over the ocean, Marine boundary layer clouds and cloud–aerosol interactions, Oceanic boundary layer turbulence and stratification, Coupling mechanisms between atmospheric and oceanic boundary layers. Air–Sea Interaction in Weather Systems: Monsoon circulations and cross-equatorial flows, Tropical cyclones: energy input, ocean cooling, and feedbacks, ENSO, MJO, and large-scale tropical variability, Midlatitude storms, fronts, and air–sea coupling.

Air–Sea Interaction in Climate: Role of oceans in heat uptake, storage, and transport, Climate feedbacks involving SST, surface fluxes, clouds, and circulation, Ocean–atmosphere coupling in climate modes: ENSO, IOD, PDO, AMO, Air–sea processes in climate change: marine heatwaves, sea-surface warming, stratification changes.

Course Outcomes (COs):

Course Outcomes	Statements
CO1	A coherent grasp of surface fluxes and exchange processes governing momentum, heat, moisture, and gases at the air–sea interface.
CO2	A scientific basis for the behaviour of the ocean mixed layer, including responses to wind forcing, buoyancy fluxes, entrainment, and mixing.
CO3	A dynamical perspective on coupled atmosphere–ocean phenomena, covering monsoons, ENSO, tropical cyclones, and other major modes of variability influenced by air–sea interactions.
CO4	An integrated view of observational and modelling approaches used to investigate air–sea processes, including satellite data, in situ measurements, and coupled numerical models.

ESE 467 **Boundary Layer Meteorology** **(3 0 0) Credits**

Syllabus

Introduction: definitions and background, variables, wind and flow, turbulent transports; Taylor's hypothesis and observing techniques, boundary layer depth and structure Mathematical and conceptual tools: Turbulence and its spectrum; spectral gap; mean and turbulent parts; basic statistical methods; rules of averaging; turbulent kinetic energy; kinematic flux, eddy flux; stresses. Governing equations for turbulent flow: methodology, basic equations, simplifications and approximations, equations for mean variables in a turbulent flow. Mixed layer theory: mixing and entropy; governing equations, model behavior, surface fluxes and entrainment. Cloud-topped boundary layers: moisture variables; radiative processes, observed structure; governing equations, entrainment. Trade wind boundary layer: mean structure and fluxes; moist convective processes; sub-cloud layer interactions; strato-cumulus to trade cumulus transitions. Deep convection and Marine boundary layer: controls on deep convection; MABL modification by downdrafts; boundary layer recovery; boundary layer modeling and parameterizations.

Course Outcomes	Statements
CO1	Understanding of boundary layer processes, turbulent transports, and key variables including wind, fluxes, and boundary layer depth.
CO2	Application of statistical and conceptual tools for analyzing turbulence, including energy spectra, averaging methods, and turbulent fluxes.
CO3	Formulation and interpretation of governing equations for turbulent flow, mixed layer dynamics, and surface–atmosphere interactions.
CO4	Analysis of different boundary layer regimes including cloud-topped, trade wind, and marine boundary layers, with emphasis on convective processes and model parameterizations.

ESE 472 Atmospheric and Oceanic Instrumentation and Measurement Techniques (3 0 0) Credits

Syllabus

Instruments and Measurement Systems: Instrument Response, Measurement Quality, Signal to Noise ratio, Measurement Artifacts, Sources of Uncertainties, Calibration procedures. Basic statistics, concept of error and uncertainty analysis, Error analysis, probability distribution functions, regression analysis, least square fit, Measurement of meteorological variables: wind, pressure, temperature, humidity, dew point temperature and rain fall, Snow and Rain Sampling Techniques. Radar Principles: Radar equation, Various types of Radar, Estimation of rainfall from weather radar measurements Lidars: Basic lidar principles, Various types of Lidar, Lidar probing of aerosols and clouds, Principles of Microwave Radiometers for atmospheric probing of temperature and water vapour. Principles of Visible, IR and Microwave Remote Sensing techniques, satellite orbits and their characteristics Basic concepts of satellite remote sensing: Instantaneous field of view, pixel resolution, swath, panoramic corrections, ground track, revisit period, orbital precession, Basics of satellite data structure and formats, Levels of data processing, Basic principles for retrieval of geophysical parameters from satellite observations in different spectral bands: estimation of surface reflectance, brightness temperature, detection of clouds, estimation of aerosol optical depth, estimation of cloud top temperature, Principle of GPS technique for measurement of water vapour.
Aerosols: Measurement of aerosol optical properties: aerosol optical depth, scattering coefficient, absorption coefficient, angular scattering measurements, Measurement of aerosol physical and chemical properties: aerosol sampling, Sampling Inlet types and Sampling Efficiency, Sampling and Measurement using Inertial
Radiation: Measurement of solar radiation, radiance and irradiance, spectral radiance, measurement of shortwave and longwave fluxes, Oceanic Research Vessels, Expendable Bathythermograph (XBT), Optical and Infrared Imaging and altimeter system, Interferometry Techniques, CTD sonde, Acoustic Doppler Current Profiler (ADCP), Moored and Drifting Buoys and Satellite Instrumentation

Course Outcomes (COs):

Course Outcomes	Statements
CO1	Introduce the principles, functioning, and limitations of atmospheric and oceanic measurement systems, including instruments used for observing meteorological variables, aerosols, trace gases, clouds, and radiation
CO2	Develop foundational understanding of statistical methods, error analysis, and uncertainty quantification essential for interpreting and validating observational data
CO3	Interpret and evaluate observational, reanalysis, and model datasets to identify large-scale circulation features and climate trends
CO4	Natural and anthropogenic forcings alter general circulation, contributing to climate variability, extremes, and long-term climate change