DEPARTMENT OF ATMOSPHERIC SCIENCE
SCHOOL OF EARTH SCIENCES

M.Sc. Atmospheric Science

(Course Structure and Syllabus)

Central University of Rajasthan

JUNE 2020

DEPARTMENT OF ATMOSPHERIC SCIENCE
SCHOOL OF EARTH SCIENCES

M.Sc. Atmospheric Science

(2-Years M.Sc. Programme)

Atmospheric Science is an umbrella term for the study of the Earth's atmosphere, its processes, the effects other systems have on the atmosphere, and the effects of the atmosphere on these other systems. This programme includes meteorology, atmospheric physics, chemistry and dynamics, aeronomy and climatology. The design of the Master programme in Atmospheric Science is aimed at imbibing the students with fundamental scientific methodology in mathematics, physics and chemistry to enable them to appreciate, understand and investigate the complex behavior of Earth's atmosphere and climate system using the aforementioned tools. The applications of Atmospheric Science to the study of agriculture, aviation, water resources, disaster mitigation (due to extreme weather, severe storms, cyclone, etc.), air quality and climate prediction harbor immense possibilities which are highly relevant at present and in future, since several facets of the human life are intrinsically impacted by our atmosphere. The curriculum of Masters Programme in Atmospheric Science launched in the University in 2016 adheres to the application of meteorology to the common people needs. The department has identified the thrust areas of research which include:

1. Numerical Modeling of Atmospheric and Oceanic Processes
2. Climate Dynamics and Variability
3. Indian Monsoon Studies
4. Mesoscale Modelling and Data Assimilation
5. Computational Methods in Atmospheric Science
6. Remote Sensing of the Atmosphere
7. Severe Convective Storms and Extreme Weather System
8. Desert Meteorology
9. Atmospheric Chemistry and Air Quality
10. Climate Change Impacts

Programme Objectives

1. To impart the basic and advanced knowledge of various processes and phenomena in the field of Atmosphere Science and Meteorology.
2. To provide skills in theory, numerical modelling of Atmospheric processes and their applications in weather forecasting and development of early warning systems for extreme weather events.
3. To train the students with quantitative and scientific reasoning skills for operational organizations, academia, research & development organizations.
4. To produce trained manpower in providing solutions to various challenges and issues related to atmospheric sciences and other interdisciplinary areas.

Programme Outcomes

1. **Knowledge:** Develop deeper insights in multiple aspects of Atmospheric Science for better scientific understanding and interpretation of various atmospheric phenomena.
2. **Modern tool usage:** Apply mathematical and computational tools and techniques to study atmospheric processes
3. **Conduct investigation of complex problems:** Demonstrate quantitative skills for interpreting atmospheric observations to numerical modeling and forecasting of weather systems.
4. **Enhance Instrumentation skill:** Explain the principles behind meteorological instrumentation and create graphical depictions of meteorological information.
5. **Analytical skill:** Demonstrate critical and analytical skills to interpret and predict weather systems using different products (model results, maps, satellite imagery, etc.).
6. **Communication:** Demonstrate skills for communicating their technical knowledge and scientific results.
7. **Research and Jobs:** Building foundation for higher studies and research as well as capability to get science jobs.
8. **Problem Analysis and Project:** Confidence for independent pursuit of projects, research, start-ups and entrepreneurship.
9. **Society and Sustainability:** Understand the impact of optimal solutions in societal and environmental contexts, and demonstrate the knowledge for sustainable development.

COURSE STRUCTURE

First Semester

S. No.	Course Type	Course Code	Name of the Course	Credit
1	Core	ATS401	Fundamentals of Earth System Sciences	4
2	Core	ATS402	Physics of the Atmosphere	4
3	Core	ATS403	Dynamics of the Atmosphere	4
4	Core	ATS404	Mathematical and Statistical Methods for Earth Sciences	4
5	Core (Practical)	ATS405	Instrumentation and Data Analysis for Atmospheric Observations	2
6	Core (Practical)	ATS406	Programming Techniques for Atmospheric Sciences	2
7	D-Elective - I			4
8	Fitness			0.5
9	Societal			0.5
			Total Credits	**25**

Second Semester

S. No.	Course Type	Course Code	Name of the Course	Credit
1	Core	ATS411	Modelling of Atmospheric Processes	4
2	Core	ATS412	Tropical Meteorology and Climatology	4
3	Core	ATS413	Physics and Dynamics of the Oceans	4
4	Core (Practical)	ATS414	Weather Analysis and Visualization Laboratory	2
5	Core (Practical)	ATS415	Remote Sensing and GIS Laboratory for Atmospheric Science	2
6	D-Elective-II			4
7	D-elective- III			4
8	Fitness			0.5
9	Societal			0.5
			Total Credits	**25**

Third Semester

S. No.	Course Type	Course Code	Name of the Course	Credit
1	Core	ATS501	Mesoscale Modelling and Extreme Weather Events	4
2	Core	ATS502	Numerical Weather Prediction- Parameterization Schemes and Data Assimilation	4
3	Core (Practical)	ATS503	Numerical Simulation and Weather Prediction Laboratory	2
4	Core	ATS510	Internship	2
5	D-Elective-IV			4
6	D-Elective- V			4
7	Elective-I			4
8	Fitness			0.5
9	Societal			0.5
			Total Credits	**25**

Fourth Semester

S. No.	Course Type	Course Code	Name of the Course	Credit
1	Core	ATS511	Dissertation	12
2	D-Elective -VI			4
3	Elective-II			4
4	Fitness			0.5
5	Societal			0.5
			Total Credits	**21**

Note:
Elective Course: *Student has option to take course from other departments of the University or from available online courses.*
In all the semesters, there is a scope to run MOOCs (Massive Open Online Courses) as per the availability of relevant course and with approval from concerned authority.

Types of Courses and Credit Distribution

Core Courses	= 36 Credits (9 courses of 4 credits each)
D-Elective (Discipline Specific Elective)	= 24 Credits (6 courses of 4 credits each)
Elective (Ex-Discipline)	= 08 Credits (2 courses of 4 credits each)
Laboratory Courses	= 10 Credits (5 courses of 2 credits each)
Dissertation	= 12 Credits (Last semester)
Internship	= 02 Credits (Third semester)
Fitness	= 02 credits (all four semesters)
Societal	= 02 Credits (all four semesters)

Total Credits: 25 (Semester-I) +25 (Semester-II) +25 (Semester-III) +21 (Semester-IV) = **96 Credits**

Discipline Specific Electives

S. No.	Semester	Course Code	Name of the Course	Credits
1	I	ATS407	Simulation of Atmospheric Processes	4
2	I	ATS408	Upper and Middle Atmosphere	4
3	II	ATS416	Advances in Instrumentations related to Atmospheric studies	4
4	II	ATS417	Computational Fluid Dynamics	4
5	II	ATS418	Climate Change and Disaster Management	4
6	II	ATS419	Satellite Meteorology	4
7	III	ATS504	Atmospheric Chemistry, Air Pollution & Climate	4
8	III	ATS505	Cloud Physics and Dynamics	4
9	III	ATS506	HPC applications in Atmospheric Sciences	4
10	III	ATS507	Boundary Layer Meteorology	4
11	III	ATS508	Desert Meteorology and Climate	4
12	IV	ATS512	Climate Change and Crop Modelling	4
13	IV	ATS513	Hydrometeorology	4
14	IV	ATS514	Radar Meteorology	4
15	IV	ATS515	Aviation Meteorology	4

SEMESTER-WISE SYLLABUS
Semester I

ATS401	Fundamentals of Earth System Sciences	4 credits (60 hrs)

Course Description: This course is aimed at providing a basic understanding of Atmospheric Science as a component of the Earth System Science. The interactions and interdependencies of different components of the Earth System and their impact on human life as well as climate will be elucidated with examples. Simple numerical calculations will be done to have a quantitative perception of several physical concepts introduced in this course.

Course Prerequisite: Basic knowledge of intermediate level science (Physics, Chemistry, Mathematics).

Course Objectives:
1. To develop knowledge regarding the inter-relationships of Earth System Science components and their impacts on Earth's atmosphere and climate.
2. To provide understanding the atmospheric composition, structure and the forces that drive three-dimensional atmospheric motions.
3. To impart the knowledge of the typical vertical variation of atmospheric variables used to quantify the atmospheric state, including temperature, pressure, humidity, winds etc.
4. To introduce students to the basic concepts and principles of clouds and their formation mechanisms, together with the precipitation types, and their interactions with aerosols and radiation.

Course Content:
Components of the Earth System, hydrologic and biogeochemical cycles, soil composition, Carbon flux and photosynthesis, vegetation dynamics, landscape heterogeneity, Land-use/land-cover changes, Theories about the origin of life and the nature of fossil record. Geological Time Scale, Basic concepts of seismology and internal structure of the Earth
Structure of the atmosphere and its composition, Thermodynamic state: distribution of temperature, density, pressure, water vapour, salinity, etc., Equations of state, Planetary Atmospheres
Basics of Fundamental forces in the atmosphere and ocean, Formation of Cloud droplets and Precipitation, Radiation basics and budget, Aerosol-Cloud interaction and Ozone depletion, Characteristics of Ocean Basins, Properties of Sea water, Mixed layer, Heat Budgets of the Ocean, Ekman Spiral and Dynamics, Upwelling and down welling processes, Currents, Atmosphere-Ocean interaction: some examples of air-sea interaction.

Course Outcomes:

1. The student will acquire an understanding of the basic tenets governing the structure, constitution, physics and dynamics of the Earth's atmosphere.
2. Understanding the functioning and inter-relationships of Earth System Science components and their impacts on climate.
3. The student should be able to acquire knowledge of atmospheric and oceanic circulations, atmosphere-ocean interaction, aerosol cloud interaction, hydrologic and biogeochemical cycles.
4. The student should be able to know important aspects of vegetation as well as ocean dynamics including the El Nino/Southern Oscillation and Indian Ocean Dipole.

Assessment Method: Two internal written exams of 20 marks and one final Semester written exam of 60 marks will be done for grading student's performance.

Recommended Readings:
1. Neil C: The Atmosphere and Ocean: A Physical Introduction (Advancing Weather and Climate Science), Wiley.

2. Maarten HP Ambaum: Thermal Physics of the Atmosphere (Advancing Weather and Climate Science), Wiley.
3. Gary E. Thomas, Knut S: Radiative Transfer in the Atmosphere and Ocean, Cambridge Atmospheric and Space Science Series.
4. Bonan G: Ecological Climatology: Concepts and Applications, 2nd Edition, Cambridge.
5. Shuttleworh WJ: Terrestrial Hydrometeorology, 1st Edition, John Wiley & Sons.

ATS402	Physics of the Atmosphere	4 credits (60 hrs)

Course Description: This course introduces the physical processes associated with atmospheric composition, basic radiation and energy concepts, the equation of state, the zeroth, first, and second law of thermodynamics, the thermodynamics of dry and moist atmospheres, thermodynamic diagrams, statics, and atmospheric stability.

Course Prerequisite: Basic Knowledge of Bachelor level Physics.

Course Objectives:

1. To introduce students to the basic concepts and principles of atmospheric physics.
2. To understand the thermodynamics of dry and moist air, radiative transfer in the atmosphere, saturated and unsaturated accent, thermodynamic diagrams, turbulent fluxes.
3. To impart the knowledge of saturated and unsaturated accent, moist convection, surface turbulent fluxes, vertical turbulent diffusion.

Course Content:

Thermodynamics of dry, thermals, Thermodynamic of moist air, thermodynamic properties of water; Clausius - Clapeyron (C-C) equation, moist processes in the atmosphere, adiabatic, Simple and complex radiative transfer in the atmosphere, shortwave and longwave radiation computation, radiative heating in the atmosphere, saturated and unsaturated accent, Thermodynamic diagrams, Moist convection, Aerodynamic formulae for surface turbulent fluxes, vertical turbulent diffusion, Cloud physics; Nucleation and Growth of Cloud Droplets, Warm Rain Formation, Collision–coalescence, Ice Crystal Nucleation and Growth, Homogeneous nucleation of ice by freezing and deposition, Heterogeneous nucleation of ice on flat and curved surfaces, Atmospheric Electricity; Principles of atmospheric electricity, Charge generation and separation mechanisms, Cloud electrification mechanism.

Course Outcomes: Students will obtain a fundamental understanding of the atmospheric thermal structure, radiative transfer for solar and terrestrial wavelengths, global energy balance, and cloud physics at the graduate level**.**

1. Students can demonstrate knowledge of the physical processes in the atmosphere
2. Students can apply the knowledge of thermodynamic diagrams, calculate thermodynamic parameters
3. Students can demonstrate knowledge of the moist convection, atmospheric instability, formation of clouds.

Assessment Method: Two internal written exams of 20 marks and one final Semester written exam of 60 marks will be done for grading student’s performance.

Recommended Readings:

1. Holton JR: An Introduction to Dynamical Meteorology, Academic Press
2. Howell JR, Siegel R, Menguc M. Pinar: Thermal Radiation Heat Transfer, CRC Press
3. Lynne D. Talley: Descriptive Physical Oceanography: An Introduction, Academic Press
4. Apel J R: Principles of Ocean Physics. Academic Press.

5. Hess SL: Introduction to Theoretical Meteorology, Holt, Rinehart, and Winston, New York.

ATS403	Dynamics of the Atmosphere	4 credit (60 hrs)

Course Description: Dynamic meteorology is the branch of fluid dynamics concerned with the meteorologically significant motions of the atmosphere. It forms the primary scientific basis for weather and climate prediction, and thus plays a primary role in the atmospheric sciences.

Course Prerequisite: Basic Knowledge of Bachelor level Physics, Mathematics.

Course Objectives:

1. To introduce students to the basic concepts and principles of atmospheric dynamics.
2. To impart knowledge of the laws governing the atmosphere, scale analysis, different coordinate systems.
3. To understand different types of atmospheric motions, barotropic and baroclinic Atmospheres, Circulation and vorticity; atmospheric waves and general circulation of the atmosphere.

Course Content:

Basic Fluid Dynamics, Local and Material Time Derivatives, Conservation Principles, Euler and Navier Stokes Equations, Fundamental forces; basic laws of conservation; hydrodynamic equations in rotating frame of reference; Scale Analysis; geostrophic and hydrostatic approximations; Atmospheric stability; Vertical coordinate system: Cartesian, Isobaric, Sigma, The balanced flow: Inertial, cyclostrophic flow, Gradient wind approximation; Trajectory and streamline; thermal wind balance; vertical motion; barotropic and baroclinic atmospheres; Circulation and vorticity; The circulation theorem, vorticity, vorticity in natural coordinates, the vorticity equation, scale analysis of the vorticity equation, potential vorticity, barotropic potential vorticity, Ertel- potential vorticity in isentropic coordinates, equations of motion in isentropic coordinates, the potential vorticity equation, potential vorticity conservation, integral coordinates on isotropic vorticity. Boussinesq approximation; Reynolds averaging; Synoptic Scale motion: Quasi-geostrophic analysis; Perturbation theory: Inertial, Acoustic, gravity, Poincare, Rossby and Kelvin waves. Atmospheric general circulation.

Course Outcomes:

1. Students can demonstrate the ability to apply the equations of motion to the quantitative description of a variety of atmospheric motions including the general circulation.
2. Students can demonstrate knowledge of the balanced and unbalanced flows that form the basis for the depiction of atmospheric motions
3. Students can demonstrate knowledge of the rotational aspects of large-scale atmospheric motions as described by vorticity and circulation
4. Students can demonstrate the ability to understand wave motions and stability concepts to atmospheric problems

Assessment Method: Two internal written exams of 20 marks and one final Semester written exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Holton JR: An Introduction to Dynamic Meteorology, Fourth Edn., Elsevier Press, 2004.
2. Martin JE: Mid-latitude Atmospheric Dynamics
3. Lynch H, Cassano JJ: Atmospheric Dynamics, Wiley, 2006.

ATS 404	Mathematical and Statistical Methods for Earth Sciences	4 credits (60 hrs)

Course Description: This course includes different mathematical methods used in the numerical weather prediction techniques for evaluating weather forecasts as well as the different computer methods for the development of accurate and robust weather forecast systems. This course will provide the exposure amongst students to use computers to develop and apply numerical algorithms for the solution of atmospheric related phenomena.

Course Prerequisite: Basic Knowledge of Bachelor level Mathematics.

Course Objectives:

1. To understand the different mathematical methods used in the numerical weather prediction techniques for evaluating weather forecasts.
2. To study the different computer methods for the development of accurate and robust weather forecast
3. systems.
4. Provide the exposure amongst students to use computers to develop and apply numerical algorithms for the solution of atmospheric related phenomena.

Course Content:

Rank and inverse of a matrix, consistency of linear system of equations, eigenvalues and eigen functions, orthonormal systems. Taylor's theorem and infinite series, functions of several variables, maxima and minima, ordinary differential equations, series solution of Legendre and Bessel equations, Laplace transforms. Initial and boundary value problems, complex analysis, periodic, even and odd functions, Time series analysis: Fourier analysis and spectral methods. Descriptive Statistics, analysis of variance distributions, Probability, conditional probability, Notion of probability, Probability laws, Discrete and continuous distributions, Normal distribution, Poisson's distribution, Random variables, Moments, Expectance operator, Gaussian statistics, Significance tests: Student's T, Fischer's Z, and F-test, Correlation (Pearson's rho, Kendall's tau), Goodness-of-fit tests (KS, Chi squared), Bayesian statistics, Markov Chain Monte Carlo methods, Kalman filter and Ensemble Kalman Filter.

Course Outcomes:

1. Students can use and demonstrate the ability to conduct different statistical verification methods of weather
   forecasts.
2. Students will learn and apply numerical technique and various statistical skills score to evaluate the model forecast and analysis.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Storch H von and. Zwier FW: Statistical analysis in climate research, Cambridge University Press.
2. Emery WJ, Thomson RE: Data Analysis Methods in Physical Oceanography, Elsevier Science.
3. Sillmann TE, Gebbers R, Marwan N: MATLAB® Recipes for Earth Sciences, Springer

ATS405 Instrumentation and Data analysis for Atmospheric Observations 2 Credits (60 Hrs.)

Course Description: This course provides an opportunity to the students to get a first-hand experience of the instrumentation used in Atmospheric Sciences. They get to handle sophisticated instruments and understand their working principles, maintenance and calibration procedures. They also get an insight into laboratory protocols, precautions to be taken while handling equipment and assembling instruments and designing their own experimental setups and measurement campaigns.

Course Prerequisite: Basic knowledge of meteorology, theoretical knowledge of basic Instrumentations used in Atmospheric Studies

Course Objective:

1. To inculcate an experimental mind-set and curiosity.
2. To train them in instrumentation and data analysis of Atmospheric observations.
3. To enable them appreciate the value of good quality data and experimental protocols.
4. To prepare them for vast opportunities lying in the field of experimental Atmospheric Science.

Course Content:

Laboratory protocols, Safety precautions, Familiarizing with meteorological instruments used in Atmospheric studies, operation, maintenance, calibration, data retrieval and archival. Handling gas cylinders, pressure regulators, tubing and fittings. Connector types and uses.
Automatic weather station, temperature, humidity, radiation and wind measurements, lightning detector. Measurements of aerosols and trace gases: microtops, aerosol sample collection, ion chromatography, O_3, CO, NO_x and SO_2 measurements, CH_4 measurements with Flame Ionisation Detector.
Micrometeorological studies and equipment, Tower observations.
Atmospheric soundings
Planning a Field campaign, setting up a Meteorological Field observatory.
Field trip.
(*the above topics will be covered depending on availability of facilities or through visits*)

Analysis of Meteorological Data using MATLAB: Introduction to MATLAB: Starting MATLAB Layout of graphical user interface (GUI), interactive commands operators and variables MATLAB help. Programming: syntax arrays, numeric, cell, structure Strings, built in functions (i.e. find, mean, max, min, sum, etc). File I/O (text, binary, netCDF, HDF), basic program organization, debugging. Graphics: Line, scatter, bar, surface, contour plots, etc Figure properties (i.e. Axis labels, tick marks). Colormaps saving your plots Images in MATLAB, Statistical analysis of time series data, Spectral analysis.

Course Outcomes:

This course will help the students in:

1. Development of basic laboratory etiquette and understanding laboratory protocols.
2. Familiarity of working with common instrumentation used in Atmospheric Studies.
3. Experience of operating and calibrating instruments and generating quality data.
4. Ability to partake and integrate easily in experimental setups w.r.t. both field and laboratory based experiments.
5. Analysisng atmospheric data

Assessment Method: Students will be evaluated by way of three written examinations: 2 internal assessments each carrying 20 marks, and a final semester exam of 60 marks. Also they have to prepare their practical record according to experiments designed. Practical record and viva will be a part for the final end of semester examination.

Recommended Readings:

1. WMO: Guide to Instruments and Methods of Observation, WMO No 8, 2018.
2. Heard D: Analytical Techniques for Atmospheric Measurement, 1st edition, 2006.
3. Paratap R: Getting Started with MATLAB: A Quick Introduction for Scientists & Engineers, 2010.
4. https://www.wmo.int/pages/prog/www/IMOP/CIMO-Guide.html

ATS406 Programming Techniques for Atmospheric Sciences 2 Credits (60 Hrs.)

Course Description: In this course, students will study and solve various numerical and statistical problems, by developing algorithms in FORTRAN, Python, and executing them on computer using datasets provided (or to be downloaded as instructed).

Course Prerequisite: Basic knowledge of any programming language
Course Objective:

1. To impart the basic and advanced knowledge of programming language.
2. To develop knowledge of computational tools and techniques to study atmospheric processes
3. To provide skill of computation for analyzing meteorological field.

Course Content:

FORTRAN fundamentals: integer constant, floating point constant, variables, arithmetic operator, relational operator, FORTRAN arithmetic and expression, input/output and format statements, declaration and initialization, branching and looping, Arithmetic IF, Logical IF, DO Loops, Dimension Statement, arrays, multidimensional arrays, functions, sub-programs and subroutines.
Python-Introduction, Data types: Numbers, Strings, Unicode Strings, Loops; Python Packages: Importing From a Package, Python Input Output-Fancier Output Formatting, Old string formatting, Reading and Writing Files,

Applications of FORTRAN and Python

1. Computation of meteorological variable using Fortran and python
2. Plotting meteorological variable and handling different data format using Fortran and python
3. Statistical analysis of meteorological data using FORTRAN and python

Course Outcomes:

1. Can be able to compute meteorological variables
2. Read and modify code
3. Learn a new programming language on their own.

Assessment Method: Two internal written exams of 20 marks and one final Semester written exam of 60 marks will be done for grading student’s performance. Each student have to keep a record of his/her computation work.

Recommended Readings:

1. Chapman SJ: Fortran 90/95 for Science and Engineering McGraw Hill Education, 2nd edition, 2013.
2. Press WH, Teukolsky SA, Vetterling WT and Flannery BP: Numerical Recipes in FORTRAN, Cambridge University Press, 2000.
3. Langtangen HP: A Primer on Scientific Programming with Python (First Edition), Springer, 2009.

4. Griffiths D: Head first programming: a learner's guide to programming using the python language.
5. Zelle JM: Python Programming: An Introduction to Computer Science,
6. Mckinney W: Python for Data Analysis: Data Wrangling with Pandas, NumPy, and Ipython.
7. Pratap Rudra: Getting Started with MATLAB: A quick introduction for Scientists and Engineers, Oxford University Press.

Semester – I Discipline Specific Electives

ATS407	Simulation of Atmospheric Processes	4 credits (60 Hrs.)

Course Description: This course is designed for the overview of different types of weather and climate models. The types of skill scores used for the verification of the weather/climate models are well explained in this module. Also this course will provide the current state of the art of visualization used in meteorology, focusing on visualization techniques and tools used for meteorological data analysis. In addition UNIX commands and shell programming are described in this course.

Course Prerequisite: Basic knowledge of meteorology and computer programming.

Course Objectives:

1. To understand the dynamics and thermodynamics governing the ocean and atmosphere on spatial and temporal scales appropriate for climate systems.
2. To impact the knowledge of how precision, accuracy, and analysis techniques are used to provide a description of the state of the atmosphere in Global, Regional, mesoscale and coupled models.
3. To introduce the different types of skill scores, predictability and ensemble forecasting used in Global, Regional, mesoscale and coupled models Outcomes :

Course Content:

Governing equations for Atmospheric and Oceanic Processes: continuous equations, map projections, vertical coordinate system, Global, regional, mesoscale, and coupled models, Principles and problems of climate modeling, climatic processes in a Global Climate model, Climate forcings, Uncertainties in weather and climate model, Weather Forecast verification methods across Time and Space Scales, Nesting strategies across different models, Impact of domain and model resolution, model spin-up Types of forecast and verification, standard diagnostics and skill scores, climate drift, climate geo-engineering, Bias correction techniques, Introduction to downscaling, Dynamical and Statistical downscaling, Components of time series, Analysis of Time Series, Analyzing trends and detrend in climate data, Introduction to parallel computing, different types of parallel computing used in simulation of atmospheric and oceanic phenomena.

Unix/Linux Operating System, Introduction to UNIX/LINUX, basic commands, file management; directories, file permission, copy, move, delete files, making and deleting directories, pipes and filters, archiving files, process in Unix, Vi editor, Shell Scripting, What is shell, different types of shell, using shell variables, special variables, using arrays, basic operators, decision making, shell loops, loop control, shell substitutions, IO redirections, shell functions,

Course Outcomes:

1. Students will analyze and demonstrate the visualization of the different types of atmospheric data sets with the UNIX and shell programming. .
2. Students can familiarize with the post-processing and visualization software (GrADs, Ferret and NCAR Graphics)

3. The students would be able to familiarize with the multiple data formats and implementations of weather model such as WRF.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Kantha and Clayson CA: Numerical Models of Oceans and Oceanic Processes, Academic Press.
2. McWilliams James C: Fundamentals of Geophysical Fluid Dynamics, Cambridge University Press.
3. Jacobson MZ: Fundamentals of Atmospheric Modeling, Cambridge University Press.

ATS408	**Upper and Middle Atmosphere**	**4 credits (60 hrs)**

Course Description: This course includes physical processes that occur in upper and middle atmosphere and also describe that interaction of upper and middle atmosphere with troposphere through vertical transport of heat, energy and momentum. This course also include detail guide for aviation sector regarding meteorology aspect as well as describe aviation Hazards.

Course Prerequisite: Basic Knowledge of Dynamic Meteorology

Course Objectives:

1. To develop knowledge about upper and middle atmosphere dynamics
2. To provide a understanding about the role of upper and middle atmosphere
3. To develop knowledge about meteorological condition that is important for aviation purpose

Course Content:

Upper and Middle Atmosphere

Composition and structure of stratosphere, mesosphere and thermosphere, Changes in chemical composition - homosphere, heterosphere, ozonosphere. Standard upper atmosphere. The ionosphere - composition morphology and general properties.
General climatology of the middle atmosphere, wind and temperature distribution. Zonally averaged circulation energetics of the middle atmosphere. Vertically Propagating Waves: Extratropical Rossby waves and Charney-Drazin criterion, Equitorial Waves and Gravity waves; Sudden Stratospheric Warming, Rossby wave Breaking, Large Scale Mixing and Transport, Brewer–Dobson Circulation, Residual (Diabatic) Circulations, Tropical Tropopause layer, tropopause dynamics, Quasi–Biennial Oscillation (QBO), Stratosphere-troposphere coupling.

Course Outcomes:

After attending this lesson, the user should be able to
1. Understand an overview of middle and upper atmosphere dynamics
2. Understand the interaction of middle and Upper atmosphere with troposphere.
3. Explain vertical transport of mass and momentum

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Andrews D, Holton J, Leovy C: Middle Atmosphere Dynamics, Academic Press, 1987.
2. Vallis GK : Atmospheric and Oceanic Fluid Dynamics, Cambridge University Press, 2006.
3. Brasseur GP and Solomon S: Springer Aeronomy of the Middle Atmosphere – Chemistry and Physics of the Stratosphere and Mesosphere, 2005.
4. Labitzke KG and van Loon H: The Stratosphere – Phenomena, History, Relevance, Springer, 1999.
5. Festschrift P: The Stratosphere: Dynamics, Transport, and Chemistry, Eds. Polvani, Sobel, Waugh AGU Monograph 190, 2010.

Semester II

ATS411	Modeling of Atmospheric Processes	4 credits (60 hrs)

Course Description: This course will introduce students to the Hierarchy of atmospheric models and impart knowledge on numerical discretization, integration & numerical instabilities. It will also educate students on different types of physical parameterization techniques, global and regional models used in weather forecasting.

Course Prerequisite: Basic understanding of physical and dynamical processes in atmosphere.

Course Objectives:

1. To introduce students to the Hierarchy of atmospheric models.
2. To impart knowledge on numerical discretization, integration & numerical instabilities.
3. To educate students on different types of physical parameterization techniques, global and regional models used in weather forecasting

Course Content:

Introduction to weather and climate models, Numerical Modeling vs. Other Modeling Approaches, Examples of atmospheric simulations, Atmospheric Instability: Thermodynamic and Dynamic instabilities, Inertial instability, Symmetric instability, Computational Instability, Barotropic and Baroclinic instabilities, Model Hierarchy (Simple, Intermediate, Complex), Filtered models; Barotropic model, Equivalent Barotropic model, Quasi-Geostrophic model, Two level Baroclinic model, Vorticity and Omega equations, Numerical discretization (finite difference, finite volume, spectral) and integration, CFL criterion, unconditionally stable numerical scheme, model components, dynamical core, physical parameterization, coupling of components, global and regional models used in weather forecasting and atmospheric simulations.

Course Outcomes:

1. Explain different types of models used for studying atmospheric processes
2. Discretize the differential equations used in atmospheric models.
3. Describe different physical parameterization methods used in atmospheric models

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Holton JR: An Introduction to Dynamical Meteorology, Academic Press
2. Hess SL: Introduction to Theoretical Meteorology, Holt, Rinehart, and Winston, New York.
3. Wallace JM and Hobbs PV: Atmospheric Science -An Introductory Survey, Academic Press.
4. Stull RB: Meteorology for Scientists and Engineers, Brooks/Cole, 2000.
5. Buyers HR: General Meteorology, McGraw Hill Book Company, 1977.
6. Randall D: An introduction to Atmospheric Modeling, Colorado State University, 2004

ATS 412	Tropical Meteorology and Climatology	4 credits (60 hrs)

Course Description: This course will provide to understand the different types of weather and climate phenomena. Also the different types of tools have been used to analyze these phenomena. Complete understanding these phenomena will help to understand the weather and climate modeling prediction in details.

Course Prerequisite: Basic Knowledge of Bachelor level Physics, Mathematics.

Course Objectives:

1. To expose and familiarize students with key atmospheric variables and structures, the types of weather data available, the manner by which these data are collected, and some of the ways that these data are displayed, analyzed, and used.
2. To introduce the concept of wide range of atmospheric phenomena and their roles in affecting weather and climate on local, regional, continental, and global scales

Course Content:

Differential heating, Factors affecting temperature distribution, Global wind, pressure and precipitation distribution, Atmospheric Pressure Belts and Wind Systems Trade wind inversion, Hadley and Walker circulation, ITCZ, monsoon trough, Monsoon monsoon including active and break cycles; monsoon variability on interannual and decadal time scales depressions, Somali Jet and jet streams, South West and North East Monsoons, intraseasonal variability of summer, Indian summer monsoon indices, synoptic features associated with onset, withdrawal, break, active and weak monsoons, formation and movement of western disturbances, Tropical Cyclones: theories relevant to forecasting the genesis, motion and intensity of tropical cyclones, Air masses and fronts, structure of cold and warm fronts; Weather systems associated with fronts, extra-tropical cyclones, anticyclones and blockings, tropical oceanic drivers such as the El Nino-Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD), Synoptic weather forecasting charts, Weather observations, and transmission, Prediction of Weather elements, hazardous weather elements.

Course Outcomes:

1. Students can demonstrate the ability to analyze and interpret conventional maps of surface and upper-air data, reanalysis and IMD gridded data as well as soundings on a thermodynamic diagram.
2. Students can demonstrate knowledge of the mechanisms for the formation and evolution of onset and withdrawal of Monsoon, Monsoon trough, monsoon depressions, El Nino/La Nina, Western Disturbances, Indian Ocean Dipole, Cyclones etc.

Assessment Method: Two internal written exams of 20 marks and one final Semester written exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Defant F and Morth HT: Compendium of Meteorology, vol. I, Synoptic Meteorology, WMO publication, 1978.
2. Riehl H: Climate and Weather in the Tropics, Academic Press, 1979.
3. Saucier, WJ: Principles of Meteorological Analysis, Dover Publications, 1989.
4. McGregor, GR, Nieuwolt S: Tropical Climatology, John Wiley and Sons, 1998.
5. Petterssen S: Weather Analysis and Forecasting Vol.I& II, McGraw-Hill, 1995.
6. Trauth M et al.: MATLAB Recipes for Earth Sciences, 3rd Edition, Springer, 2010.
7. Wilks DS: Statistical Methods in the Atmospheric Sciences, Academic Press Inc, 3rd Revised edition.

ATS413	Physics and Dynamics of the Oceans	4 Credits (60 Hrs.)

Course Description: Oceanography is the scientific study of oceans and seas. It deals with the distribution of oceanic water masses, morphology of the oceans along with its physical processes, dynamics of water masses and the role of oceans on controlling the global climate.

Course Prerequisite: Basic Knowledge of Physics and Dynamics of fluid

Course Objectives:

1. To develop knowledge about oceanic processes.
2. To develop knowledge about air-sea interaction and its impact on atmospheric processes
3. To develop knowledge about the role of ocean as climate drivers.

Course Content:

Historical oceanographic explorations, Physical properties of Sea water: Temperature, Salinity, and Density of oceanic masses, Conservation of Mass and Salt, Geographical distribution of Temperature and Salinity, The oceanic Mixed Layer and Thermocline, Density, Potential Temperature, and Neutral Density, Measurement of Temperature, Conductivity, Pressure, Instruments used in oceanographic studies, Measurement of Temperature and salinity With Depth, The Oceanic Heat Budget,
Equations of Motion: Dominant Forces for Ocean Dynamics, Coordinate Systems, Types of Flow in the Ocean, Air-sea interface and response of the Upper Ocean to Winds, Geostrophic Currents and Wind Driven Ocean Circulation, Equatorial Processes and their effects, Ocean Waves and Tides
Deep circulation in the ocean: Importance of the deep circulation, role of the oceans in climate and abrupt climate change, Stommel-Arons' theory of the deep circulation, Numerical Models, Coastal Processes and Ocean induced hazards

Course Outcomes:

After attending this lesson, the user should be able to

1. understand an overview of physics of oceans in terms of its features, distribution of water masses and their properties, dynamics processes of the oceans, air-sea interactions, importance of currents, waves, tides and other features.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Pickard GL and Emery WJ: Descriptive Physical Oceanography.
2. Sverdrup HU, Johnnson MW, Flemming RH: Oceans: Their Physics, Chemistry, and General Biology, Prentice-Hall, inc; Fifteenth Impression edition.
3. Reddy MPM: Descriptive Physical Oceanography.
4. Pond S and Pickard GL: Introductory Dynamic Oceanography.

ATS414	Weather Analysis and Visualization Laboratory	2 Credits (60 Hrs.)

Course Description: This course demonstrates familiarity with key atmospheric variables and structures, the types of weather data available, the manner by which these data are collected, and some of the ways that these data are displayed, analyzed and used with the different types of visualization Software (GrADs, NCL, CDO etc),

Course Prerequisite: Basic knowledge of computer and Meteorology

Course Objective:

1. To familiarize with the use of different types of atmospheric variables with different data formats.
2. Train students with the different types of visualization Software (GrADs, NCL, CDO etc),
3. To analyze the atmospheric variables for synoptic features during different seasons and different weather/climate phenomena.

Course Content:

Familiarization with Post-Processing and Visualization Software (GrADs / NCL / CDO),
Familiarization and visualization of atmospheric datasets (IMD Gridded and reanalysis data),
Thermodynamic diagrams, Isotachs and contour analysis, weather charts, jet streams, mid-latitude and tropical disturbances, synoptic features during different seasons, Mean sea level pressure, sea surface temperature and wind plots for cyclone development, Indian monsoon climatology of rainfall, wind pattern at 850 hPa & 200 hPa, Analyze the cases of strong and break monsoons using pressure, rainfall and wind fields and derive the basic features differentiating the weak and strong monsoons. Finding out the El-Nino and La-Nina years and Indian Ocean Dipole (IOD) index from the different reanalysis datasets. Familiarization with multiple Data Formats.

Course Outcomes:

1. Students can demonstrate the ability to analyze and interpret conventional maps of surface and upper-air data as well as soundings.
2. Students will learn weather and climate data processing and visualization techniques.
3. They will learn analysis, manipulation and interpretation of the data of the different weather/climate phenomena.
4. Explain the use of different data sets for the calculation of different indices of synoptic-scale and tropical weather systems as well as of the general circulation of the atmosphere.

Assessment Method: Two internal assessments each carrying 20 marks, and a final semester exam of 60 marks. Also they have to prepare their practical record according to experiments designed. Practical record and viva will be a part for the final end of semester examination.

Recommended Readings:

1. User's Guides: for GrADS, NCL and CDO
2. Visualization and analysis software documentations from websites
3. Wallace JM and Hobbs PV: Atmospheric Science -An Introductory Survey, Academic Press.
4. Das PK: Indian Monsoon,
5. Holton JR: An introduction to dynamic meteorology.

ATS415 Remote Sensing and GIS for Atmospheric Science 2 Credits (60 Hrs.)

Course Description: The course will provide hand-on-training to students to use remote sensing in the field of atmospheric science and meteorology. It will further focus on various applications of satellite- derived parameters in meteorology and weather forecasting. Application of GIS tool will provide additional features to present the various results and outcomes.

Course Prerequisite: Basic knowledge of Meteorology/ Remote sensing

Course Objective:

1. To provide fundamental understanding about current and future satellite missions and numerical weather forecasting
2. To utilize satellite based observations to monitor the environment and various meteorological processes/phenomena
3. To impart training on geo-informatics as a technology for integrating meteorology/climatology research and applications for geo-scientific community

Course Content:
Satellite datasets and familiarization with open data; Satellite data processing techniques, analysis and interpretations; radiometric and geometric corrections
Parameter Retrieval - Atmospheric, Land and Ocean (atmospheric temperature, Humidity, Aerosols, CO, Ozone, Clouds, Precipitation, Sea Surface temperature)
Application of Satellite - derived parameters in Meteorology (Tropical cyclones, Air masses, fronts, Jet streams, Atmospheric Pollutants); Global Environment, Rainfall variability, Air-Sea interaction, Extremes of Temperature and Precipitation.
Application of Doppler Weather Radar - derived parameters in Meteorology (Thunderstorms and Tropical cyclones
Applications of GIS - raster vector analysis; creation of shape file; layering; Coordinate Systems and Map Projection; Working with multidimensional data.

Course Outcomes:
On completion of the course, the student should:

1. know how to use remote sensing data for studies of processes in the atmosphere and climatological studies
2. know to acquire satellite images and interpretation for meteorological applications and weather forecasting
3. perform parameter retrieval processes to study meteorological and atmospheric processes
4. explain the basics of geographic information systems (GIS)

Assessment Method: Students will be evaluated by way of three written examinations: 2 internal assessments each carrying 20 marks, and a final semester exam of 60 marks.

Recommended Readings:

1. Cobb AB: Weather Observation Satellites, Rosen Publishing Group, 2003.
2. Kelkar RR: Satellite Meteorology, B S Publications, Hyderabad, 2007.
3. Kidder SQ and Vonder TH: Satellite Meteorology-An Introduction, Haar Academic Press, New York, 1995.
4. Rao PK and Ray PS: Weather Satellites: Systems, Data and Environmental Applications, American Meteorological Society, Boston, 1986.
5. Bader MJ, Forbes GS, Grant JR, Lilley RBE and Waters AJ: Images in Weather Forecasting, Cambridge University Press, 1995.
6. Barette EC and Curtis LF: Introduction to Environmental Remote Sensing, Chapman and Hill Publication, 1999.
7. Conway EM: Atmospheric Science at NASA: A History, Michener & Rutledge Bookseller, Baldwin City, KS, USA, 2008.
8. Menzel P: WMO Notes on Satellite Meteorology, NOAA/CIMSS, 1991.
9. https://gis.ucar.edu/projects/course-introduction-gis

Semester – II Discipline Specific Electives

ATS416	**Advances in Instrumentations related to Atmospheric Studies**	**4 Credits (60 Hrs.)**

Course Description: This course is aimed to make students realize the role of quality measurements to generate new understanding and validate existing concepts. This course will not only familiarize students with different meteorological instruments used for taking atmospheric observations, it will also stress on measurement techniques, calibration procedures and standardizations.

Course Prerequisite: Basic Knowledge of Physics, Electronics and fundamentals of Atmospheric Science.

Course Objectives:

1. To introduce students to different meteorological instruments used for taking atmospheric observations.
2. To impart knowledge on measurement techniques and calibration procedures.
3. To educate students on applications of SODAR, LIDAR, RADAR, measurement of aerosol optical depth, size distribution and chemical composition.

Course Content:

General measurement system, principles, measurement of meteorological parameters: wind speed and direction, temperature, humidity, pressure, radiation, aerosol measurement techniques: optical depth, size distribution, chemical composition, Microtops, Aethelometer, Nephelometer, Aerosol mass spectrometer, trace gas measurement: spectroscopic techniques, UV fluorescence for SO_2, Chemiluminescence for NOx, O_3 measurements, infrared technique for measurement of CO, Hydrocarbon measurements: Gas chromatographic and mass spectrometric techniques, in-situ and remote measurements, SODAR, LIDAR, RADAR, DOAS, measurements of cloud height, lightning detection, atmospheric sounders.

Course Outcomes:

1. Explain different meteorological instruments used for observing the atmosphere.
2. Understand the applications of SODAR, LIDAR, and RADAR for atmospheric measurements.
3. Describe the methods of measuring atmospheric aerosols and chemical composition.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. WMO: Guide to Meteorological Instruments and Methods of Observation, Sixth edition. Vol 8.
2. WMO: Compendium of Lecture notes on Meteorological Instruments, Vol 622.
3. Dobson F, Hasses L, and Davis R: Air-Sea Interaction. Instruments and Methods, Premium Press.
4. Bringi, VN and Chandrasekar V: Polarimetric Doppler weather radar: principles and applications, Cambridge University Press.

ATS417	**Computational Fluid Dynamics**	**4 Credits (60 Hrs.)**

Course Description: The primary objective of the course is to teach fundamentals of computational method for solving non-linear partial differential equations (PDE). The emphasis of the course is to teach CFD techniques for solving incompressible and compressible N-S equation in primitive variables.

Course Prerequisite: Numerical Methods, Fluid Mechanics, Computer Programming languages

Course Objectives:

1. To introduce and develop the main approaches and techniques which constitute the basis of numerical fluid mechanics for engineers and applied scientists.
2. To familiarize students with the numerical implementation of these techniques and numerical schemes, so as to provide them with the means to write their own codes and software, and so acquire the knowledge necessary for the skillful utilization of computational fluid dynamics (CFD) packages or other more complex software.
3. To cover a range of modern approaches for numerical and computational fluid dynamics, without entering all these topics in detail, but aiming to provide students with a general knowledge and understanding of the subject, including recommendations for further studies.

Course Content:

Basic equations of Fluid Dynamics: General form of a conservation law; Equation of mass conservation; Conservation law of momentum; Conservation equation of energy. The dynamic levels of approximation. Mathematical nature of PDEs and flow equations. Basic Discretization techniques: Finite Difference Method (FDM); The Finite Volume Method (FVM) and conservative discretization. Analysis and Application of Numerical Schemes: Consistency; Stability; Convergence; Fourier or von Neumann stability analysis; Modified equation; Application of FDM to wave, Heat, Laplace and Burgers equations. Integration methods for systems of ODEs: Linear multi-step methods; Predictor-corrector schemes; ADI methods; The Runge-Kutta schemes. Numerical solution of the compressible Euler equations: Mathematical formulation of the system of Euler equations; Space-centred schemes; Upwind schemes for the Euler equations – flux vector and flux difference splitting; Shock-tube problem. Numerical solution of the incompressible Navier-Stokes equations: Stream function-vorticity formulation; Primitive variable formulation; Pressure correction techniques like SIMPLE, SIMPLER and SIMPLEC; Lid-driven cavity flow. Numerical heat transfer: Brief discussion of numerical methods for conduction and convection.

Course Outcomes:

1. The students will grasp numerical modelling and its role in the field of fluid flow and heat transfer.
2. The students will learn various discretization methods, solution procedures and turbulence modeling to solve flow and heat transfer problems.
3. It will provide the students with a significant level of experience in the use of modern CFD software for the analysis of complex fluid-flow systems.
4. It will improve the student's understanding of the basic principles of fluid mechanics.
5. It will improve the student's research and communication skills using a self-directed, detailed study of a complex fluid-flow problem and to communicate the results in written form.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Pletcher R, Tannehill J and Anderson D: Computational Fluid Mechanics and Heat Transfer 3e, CRC Press, 2012.
2. Versteeg HK and Malalasekera W: An introduction to computational fluid dynamics: The finite volume method 3e, Pearson Education, 2007.
3. Hirsch C: Numerical Computation of Internal and External Flows, Vol.1 (1988) and Vol.2 (1990), John Wiley & Sons.

4. Fergiger JH, Peric M: Computational Methods for Fluid Dynamics 3e, Springer, 2002.
5. Chung TJ: Computational Fluid Dynamics 2e, Cambridge University Press, 2010.
6. Fletcher CAJ: Computational Techniques for Fluid Dynamics, Vol. 1 and 2, Springer, 1991.
7. Patankar SV: Numerical Heat Transfer and Fluid Flow, Hemisphere, 1980.
8. Anderson JD Jr.: Computational Fluid Dynamics, McGraw-Hill International Edition, 1995.

ATS418	Climate Change and Disaster Management	4 Credits (60 Hrs.)

Course Description: Climate change is now well known to increase in disasters numbers and intensities by aggravating hazards and the factors determining vulnerability of environment and society. This course focuses on the concepts, methods, framework and tools for better disaster management.

Course Prerequisite: Basic knowledge of meteorology and data handling

Course Objectives:

1. To provide knowledge base to link climate change and disasters, risk, vulnerability, their impacts
2. To comprehend on various measures of disaster management, preparedness and response
3. To enumerate on guidelines and tools for climate change adaptation and disaster risk reduction

Course Contents:

Climate change, Causes of Climate Change, climate variability and implications on disaster risk; Understanding the Phenomena of Disasters; Types of Disaster; Climatic extreme events and disasters; predictions and projections. Impacts of Natural Disasters-Socio Economic Impacts, Physical and Environmental Impacts; Impacts of Disasters in India; Frameworks, guidelines and organizations for Disaster Risk Reduction-global and India; Resilient Development; Hazard Assessment; Vulnerability Assessment; Impact Assessment; Risk Assessment; Tools and Methods in Disaster Risk Management; Early warning and communication; Strategies for Disaster Risk Reduction; Climate Change Mitigation; Climate change adaptation

Course Outcomes:

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

1. To develop a strong understanding of climate change impacts and disasters with focus on impacts, preparedness and future plans
2. To appreciate and comprehend on approaches and measures of disaster management, preparedness and response, and related policies, law and methods
3. To learn various methods, tools and guidelines for better integration of CCA-DRR for better disaster management.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance

Recommended Readings:

1. Shaw R and Krishnamurthy RR: Disaster Management: Global Challenges and Local Solutions, Universities Press (India) Pvt. Ltd., 2009.
2. Prizzia Ross: Climate Change and Disaster Management, Sentia Publishing, USA, 2015.
3. Gupta AK, Nair SS, Chatterji S and B-Lux Florian: Disaster Management and Risk Reduction, Narosa Publishing New Delhi, 2013.
4. Gupta AK, Nair SS and Sharma VK: Disaster Risk and Impact Management, Astral Publishing, New Delhi, 2018.
5. Gupta AK, Nair SS: Environmental Extremes - Disaster Risk Management: Addressing Climate Change. NIDM New Delhi, India. 2012.

ATS419	Satellite Meteorology	4 credits (60 hrs.)

Course Description: This course will provide idea, methodology and basic tools ability to describe in class a variety of atmospheric phenomena depicted on satellites imagery and help to understand the various approaches of the different retrieval algorithms for the weather parameters. This course will also provide the knowledge of techniques for sensing the atmosphere remotely using radio frequency, optical, and acoustic methods.

Course Prerequisite: Basic Knowledge of Remote Sensing and atmospheric radiation processes.

Course Objectives

1. To develop knowledge about interpreting satellite image
2. To develop knowledge about meteorological products provide by different satellite
3. To develop knowledge about satellite retrieval of different atmospheric and oceanic parameters.

Course Content:
Basics of satellite remote sensing: satellite orbits, sensor characteristics, view angle, passive and active remote sensing, meteorological satellites, polar orbiting & geo stationary satellites, current and future meteorological satellites of the world. atmospheric radiative transfer application in retrievals of geophysical parameters, aerosol remote sensing using ground-based (passive radiometer and LIDAR) and satellite platforms, retrieval algorithm, vertical distribution, cloud remote sensing, cloud detection using multi-spectral technique, issues in cloud-masking, CO_2 slice technique; Satellite image interpretation and enhancement techniques; trace gas retrievals, ocean colour remote sensing, SST retrieval, wind scatterometry, altimetry, microwave remote sensing: soil moisture retrieval, passive (brightness temperature) and active (radar) microwave remote sensing for precipitation, sounding, remote sensing of cryosphere, satellite meteorology for extreme weather events: Satellite observations used in models (i.e., Radiance, SSMI, ATOVS, CMV, SATEM, SATOB, MODIS, GPS-RO, etc.), synoptic scale weather systems, mesoscale weather systems, tropical cyclones, estimation of central pressure by using Dvorak's technique

Course Outcomes:
1. Students will be able to demonstrate skills for the analysis and interpretation of satellites imagery of the Atmosphere from the different sources.
2. Students can extract and analyses for the different extreme weather events (thunderstorms, cyclones, etc.) of the different satellite products available in India Meteorological Department and Indian Space Research Organizations (MOSDAC).

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks are being done for grading student's performance.

Recommended Readings:

1. Kiddr SQ and vonderHaar TH: Satellite Meteorology: An Introduction, Academic Press, 1995.
2. Coakley J and Yang P: Atmospheric Radiation, Wiley-tech, 2014.
3. Purkis S and Klemas V: Remote sensing and Global Environmental Change, Wiley-Blackwell, 2011.
4. Liang S, Li X and Wang J: Advanced Remote Sensing, Academic Press, 2012.
5. Remer L and Tanre D: Aerosol Remote Sensing, Springer, 2013
6. Martin S: An Introduction to Ocean Remote Sensing, Cambridge University Press, 2nd edition, 2014
7. Kelkar RR: Satellite Meteorology, 2nd Edition, BS publication.
8. Kelkar RR: Weather Satellites, Indian Meteorological Society, BSP publication.
9. Liou KN: An introduction to Atmospheric Radiation, 2nd Edition, International Geophysics series, Vol 34.

Semester III

ATS501	Mesoscale Modelling and Extreme Weather Events	4 Credits (60 Hrs.)

Course Description:

This course presents techniques and methods that used together, constitute the working components of a modern, operational mesoscale weather forecasting model. Also, this course provide knowledge of important cloud and precipitation forming mesoscale atmospheric systems, as well as the involved dynamical processes. In addition, the course will address the formation and causes of different extreme climate and weather events.

Course Prerequisite: Knowledge of Physics and Dynamics of the Atmosphere.

Course Objectives:

1. To understand and demonstrate knowledge of the structure and formation of atmospheric conditions conducive for their development and movement of the mesoscale phenomena.
2. To provide the exposure of tropical waves and their relationship to organized convection in the tropics and to tropical cyclogenesis.
3. To understand the concept, overview of the structure, formation and propagation of extreme and severe weather events.

Course Content:

Introduction to mesoscale phenomena, Mesoscale processes and modeling, scaling, observations and analysis, wave fundamentals, Lee waves and windstorms, orographically forced flows, orographic precipitation, differential heating, gravity currents and convective initiation, isolated convective storms, MCS -squall lines, internal structure of cyclones, rain bands - observations and theory, Hydrostatic approximation and nonhydrostatic dynamics, different types of atmosphere, Thunder storms – CAPE and CINE, Favourable conditions for severe thunderstorms, influence of vertical wind shear, stability indices, Life cycle and structure of thunderstorm, Dust storm(Andhi), Kalabaisaki, Hail storm. , Overview of WRF, Parameterizations in mesoscale models, Mesoscale instabilities, Overview of hazards: Tropical cyclones, Storm surges, Effects of Volcanic ashes on atmosphere, Cloud bursts, Tornadoes, Fog , Drought, Heavy rainfall and Flood forecastings, Land Slides triggered by heavy rainfall, Heat and Cold Waves, Man-made, natural and industrial disasters and warning systems,

Course Outcomes:

1. Students can learn demonstrate knowledge of a variety of mesoscale and small-scale atmospheric phenomena, including tropical storms, severe thunderstorms, and tornadoes and its modeling.

2. Students will demonstrate the implementation the mesoscale models such as Weather research Forecast (WRF) for 1-2 cases of the extreme weather event such as heavy rainfall events, severe thunderstorms, heat and cold wave etc.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks are being done for grading student's performance.

Recommended Readings:

1. Vasquez T: Weather Analysis and Forecasting Handbook, Weather Graphics Technology.
2. Burt CC: Extreme Weather: A Guide and Record Book, W W Notron and Company.
3. Pielke RA: Mesoscale Meteorological Modelling, Academic Press.
4. Atkinson BW: Mesoscale Atmospheric Circulation, Academic Press.
5. Ray PS: Mesoscale Meteorology and Forecasts, American Meteorological Society.

6. Kalnay E: Atmospheric modeling, data assimilation and predictability, University of Maryland, Cambridge University Press.
7. Daley R: Atmospheric Data Analysis, Cambridge University Press.

ATS502	Numerical Weather Prediction- Parameterization Schemes and Data Assimilation	4 Credits (60 Hrs.)

Course Description: The fundamentals of Numerical Weather Prediction (NWP) and Data assimilation, exposure on data acquisition and quality control techniques used for NWP, the concept of atmospheric predictability and ensemble forecasting.

Course Prerequisite: Basic understanding of physical and dynamical processes in atmosphere, modelling of atmospheric processes.

Course Objectives:

1. To learn the fundamentals of Numerical Weather Prediction (NWP) and Data assimilation
2. To provide exposure on data acquisition and quality control techniques used for NWP.
3. To understand the concept of atmospheric predictability and ensemble forecasting

Course Content:

Data Acquisition and Quality Control. Objective Analysis methods; Cressman technique, Optimum Interpolation scheme, etc, Data Assimilation; 3D and 4D Variational assimilation techniques, Ensemble based data assimilation, Numerical Prediction Models, Primitive Equation Models, short, medium and long range deterministic weather prediction, Parameterisation of Physical processes; Shortwave and Longwave parameterizations, Cumulus/ Convection parameterization, Cloud microphysics parameterization, PBL parameterization, Land-surface processes parameterization, Gravity wave drag parameterization, Lightning parameterization Limited Area Models (WRF, MPAS), Atmospheric Predictability, Butterfly effects, Probability and Ensemble Forecasting methods; perturbation of initial conditions, Multimodel ensemble.

Course Outcomes:

Students will learn the basics of Numerical Weather Prediction (NWP) and Data assimilation techniques.
1. Students will learn the methods of acquisition and exchange of global meteorological observations for Weather research and forecasting.
2. Students will get an exposure on short, medium and long range deterministic weather prediction, atmospheric predictability and ensemble forecasting.
3. Students will be able to compute Divergence, vorticity, stream function and simulate simple meteorological events.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Holton JR: An Introduction to Dynamical Meteorology, Academic Press.
2. Haltiner GJ and Williams RT: Numerical Prediction and Dynamic Meteorology, J. Wiley Pvt. Ltd.
3. Hess SL: Introduction to Theoretical Meteorology, Holt, Rinehart, and Winston, New York.
4. Wallace JM and Hobbs PV: Atmospheric Science -An Introductory Survey, Academic Press.
5. Thompson PD: Numerical Weather Prediction.
6. Randall D: An introduction to Atmospheric Modeling, Colorado State University, 2004.
7. WMO-GARP: Numerical Methods used in Atmospheric Models, Series No.17 .
8. Kalna E: Atmospheric modeling, data assimilation, and predictability, Cambridge University Press.

ATS503 Numerical Simulation and Weather Prediction Laboratory 2 Credits (60 Hrs.)

Course Description: In this course students will learn the applications of Atmospheric Modeling, Physics and Dynamics in the simulations of Atmospheric processes and Numerical Weather Prediction.

Course Prerequisite: Knowledge of computer programming, Linux/ Unix, numerical methods, and Atmospheric Modeling.

Course Objective:

1. To inculcate numerical simulation and visualization mind-set and curiosity.
2. To train them in implementation of numerical techniques in Atmospheric Sciences.
3. To enable them appreciate the value of good quality data and numerical experimental protocols.
4. To prepare them for vast opportunities lying in the field of numerical weather prediction, simulation and visualization.

Course Content:

Implementation of simple weather & climate models and atmospheric processes, Data Acquisition and Quality Control. Numerical Methods, Computation of Divergence, Vorticity, stream function, simulation of idealized cases (flow over topography, baroclinic wave, gravity wave, squall line, sea breeze, large eddy simulation, etc.) using the WRF model.

Course Outcomes:

This course will help the students in:

1. Development of basic skills for numerical simulation and visualization of atmospheric processes.
2. Familiarity of working with community weather & climate models and visualization software used in Atmospheric sciences.
3. Experience of conducting numerical experiments for sensitivity studies.
4. Ability to partake in field observations and their utilizations in numerical weather prediction models.

Assessment Method: Students will be evaluated by way of three examinations related to computational experiments for modeling and visualization of atmospheric processes: 2 internal assessments each carrying 20 marks, and a final semester exam of 60 marks.

Recommended Readings:

1. Wallace JM and Hobbs PV: Atmospheric Science -An Introductory Survey, Academic Press.
2. WMO: Numerical Methods used in Atmospheric Models, WMO-GARP Series No.17.
3. Vasquez T: Weather Analysis and Forecasting Handbook, Weather Graphics Technology.
4. Chung TJ: Computational Fluid Dynamics, Cambridge University Press, 2010.
5. Das Sumitabh: UNIX Concepts and Applications, McGraw-Hill Companies.
6. Rajaraman V: Computer Programming in FORTRAN-90 and 95, Phi Learning Pvt. Ltd., 2013.

Semester – III Departmental Electives

ATS 504	Atmospheric Chemistry, Air Pollution & Climate	4 Credits (60 Hrs.)

Course Description: This course is aimed at providing a basic understanding of atmospheric chemistry so that students will be able to relate the role of atmospheric chemistry on air quality and climate. They will learn about the chemical composition of the atmosphere and how it is changing with anthropogenic pressure as well as the subsequent impact on ecosystems, human health and climate. They will learn about gas phase chemical and photochemical reactions in the atmosphere. They will also learn about the genesis of aerosols from gaseous precursors and the interaction of gases and particles with solar radiation.

Course Prerequisite: Basic knowledge of chemistry (Intermediate level: knowledge of chemical kinetics, concepts of molecular orbitals), Basic knowledge if mathematics (differential equations, integration).

Course Objectives:

1. To develop an understanding of the gas phase chemical and photochemical reactions operating in the atmosphere and the chemical evolution of atmospheric aerosols
2. To develop an understanding the interlinkages of anthropogenic emissions, air pollution and climate
3. To develop an understanding about self-cleaning mechanisms in the atmosphere to initiate new ideas pertaining to mitigation of air pollution

Course Content:

Evolution of the earth's atmosphere. Atmospheric chemical constituents, Oxygen and carbon budgets. Half-life and residence time, spatial and temporal scales of variability. Evolution of chemical composition of the atmosphere, Altitude profile of atmospheric gases and aerosols, units for chemical abundance. Chemical and photochemical processes, Tropospheric chemical cycles**.**

Spatial, temporal and altitude variations of atmospheric ozone, ozone measurement techniques. Photochemical theory of ozone. Evolution of the ozone layer, sources and sinks of tropospheric and stratospheric ozone, Umkehr effect, anthropogenic perturbations to stratospheric ozone, Antarctic ozone hole. Meteorological processes affecting tropospheric and stratospheric ozone.

Atmospheric aerosols: Concentration and size, sources, and transformation, residence times of aerosols, geographical distribution and atmospheric effects. Stratospheric aerosols. Aerosol Dynamics: Nucleation, Condensation and Coagulation; Radiation Properties.

Atmospheric oxidation, radicals in the atmosphere, atmospheric hydrocarbon chemistry, evolution of methane, gas to particle conversion, transformation of air pollutants. Greenhouse gases and global warming potential.

Natural and anthropogenic air pollution, Sources of anthropogenic pollution, primary and secondary pollutants. Atmospheric effects- smog, acid rain, visibility. Ambient air quality standards, Air quality indices, Stability of atmosphere and its influence on pollutant dispersion, Effects of source configuration, Pollution transport models. Gaussian plume dispersion.

Atmospheric chemistry modelling: photochemical box models, regional and global models, chemistry transport models, chemistry climate models.

Course Outcomes:

1. Understanding the gas phase chemical and photochemical reactions operating in the atmosphere and the chemical evolution of atmospheric aerosols
2. Learning about the origin and fate of primary and secondary pollutants, self-cleaning mechanisms and ability to think of new ways to mitigate air pollution.
3. Understanding the interlinkages of anthropogenic emissions, air pollution and climate
4. This course will enable the students to compete for numerous research positions and jobs in this field.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Hobbs PV: Introduction to Atmospheric Chemistry, Cambridge University Press.
2. Seinfeld JH, Pandis SN: Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, Wiley-Interscience.
3. Finlayson-Pitts BJ, Pitts JN: Chemistry of the Upper and Lower Atmosphere Theory, Experiments, and Applications, Academic Press.
4. Wayne RP: Chemistry of Atmospheres, Oxford University Press.
5. Arya S Pal: Air Pollution Meteorology and Dispersion, Oxford University Press.
6. Hinds WC: Aerosol Technology: Principles, Behavior & Measurements of Airborne particles, Wiley.

ATS505	Cloud Physics and Dynamics	4 Credits (60 Hrs.)

Course Description:

This course provides a foundation and an overview of the physics and dynamics of clouds as typically found in the atmosphere. It will start with a short introduction to clouds and precipitation and a review of basic thermodynamics. The primary emphasis is placed on microphysical properties of clouds because this ultimately determines the evolution of clouds. The goal of this course is to

Course Pre-requisite: Atmospheric Physics and Thermodynamics

Course Objectives:

1. Develop an understanding of clouds and precipitation from the macroscale to the microscale.
2. Study of microphysical properties of clouds including the formation, growth, and thermodynamic interactions of cloud and precipitation particles.
3. Applications of the cloud physics framework for modern research and cloud microphysics parameterization in numerical models and cloud electrification.

Course Content:

Cloud Physics

Nucleation and Growth of Cloud Droplets – Homogeneous and Heterogeneous Nucleation on Soluble Surfaces, Kohler Curves, Condensation, Fick's law of diffusion, Energy balance at drop surface, Complete diffusional growth equation, Evaporation of drops, Impacts on DSDs, Supersaturation, Warm Rain Formation, Collision – coalescence, Ice Crystal Nucleation and Growth, Homogeneous nucleation of ice by freezing and deposition, Heterogeneous nucleation of ice on flat and curved surfaces, Ice Particle Growth: Growth mechanisms, Deposition, Capacitance, Habit theory, Fall speeds, Aggregation, Riming, Ice multiplication, Graupel and Hail Formation: Hail growth models, Melting, Atmospheric Electricity: Principles of atmospheric electricity, Charge generation mechanisms, Cloud electrification mechanism

Cloud Dynamics

Introduction: Classification of clouds, Cloud time scales, vertical velocities and liquid water contents, Thermodynamic Variables: Various forms of potential temperature, Dry and moist static energy etc., Cumulus Clouds: Boundary layer cumuli – an ensemble view, Plumes and Dust Devils, Theories of entrainment, detrainment, and downdraft initiation in cumuli, The role of precipitation, Cloud merger and larger scale convergence, Cumulonimbus Clouds and Severe Convective Storms: Descriptive storm models and storm types, Updrafts and turbulence in cumulonimbi, Updraft magnitudes and profiles, Turbulence, Downdrafts: origin and intensity, Low-level outflows and gust fronts, MCSs: Definition of mesoscale convective systems, Conceptual models of MCSs, Climatology of MCSs.

Course Outcomes:

Upon completion of the course, the students will be able to:

1. Communicate theoretical and applied topics of cloud and precipitation physics.
2. Compare and contrast microphysical processes operating in a given cloud/environment
3. Analyze datasets and identify distinct/implicative characteristics that confirm theoretical understanding of cloud microphysics or identify areas for improvement

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Rogers RR and Yau Y: A Short Course in Cloud Physics, Pergamon Press, 3rd Edition, 1989.
2. Pruppacher and Klett: Microphysics of Clouds and Precipitation, Kluwer Academic Publishers, 1997.
3. Houze RA: Cloud Dynamics, Academic Press.
4. Cotton WR and Anthes RA: Storm and Cloud Dynamics, Academic Press.
5. Cotton WR, Bryan GH, and van den Heever SC, 2011: Storm and Cloud Dynamics, 2nd Edition. Academic Press.
6. Emanuel KA: Atmospheric Convection, Academic Press
7. Ludlam FH: Clouds and Storms.
8. Lohmann, Luond and Mahrt: An Introduction to Clouds from the Microscale to Climate, Cambridge University Press, 2016.
9. Lamb and Verlinde: Physics and Chemistry of Clouds, Cambridge University Press, 2011.

ATS506	HPC applications in Atmospheric Sciences	4 Credits (60 Hrs.)

Course Description: Introductory course on High Performance Computing Systems, providing a solid foundation in parallel computer architectures, cluster operating systems, and resource management. This course will discuss fundamentals of what an HPC consists of, and how we can take advantage of such systems to solve large scale problems in weather and climate using different types of weather and climate models.

Course Prerequisite: Basic Knowledge of atmospheric science, computer application and UNIX/Linux operating system.

Course Objectives:

1. To provide the overview of different types of parallel computing used for weather/climate studies.
2. To teach the basics of high-performance computing.
3. To understand how weather and climate models are applied to solving problems in atmospheric sciences with high performance computing
4. To provide a phenomenological approach to understand the parallelization of weather/climate models in high performance computing architecture.

Course Contents:

Introduction to multitasking and massively parallel processing, Basic parallel computing, Von Neumann Computer Architecture, Flynn's Classical Taxonomy, Shared Memory, Distributed Memory, Hybrid Distributed-Shared Memory, General Parallel Terminology, different architectures, application of HPC in global and regional models, parallelism in weather and climate models, domain decomposition method, 1D, 2D and 3D parallelization of GCMs, Message Passing Interface, PVM, SHMEM, message passing libraries, high performance compilers, load balancing, interprocessor communication, network communication, graphical user interface, data formats, local and wide area networking,

Course Outcomes:

The students should be able to understand an overview of parallel computing, their architecture and different types of Parallelization. Also the students will able to run the GCMs and RCMs on parallel system.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Reading:

1. Røed Lars P: Atmospheres and Oceans on Computers-Fundamentals.
2. Yang LT and Guo M: High-Performance Computing: Paradigm and Infrastructure.
3. Levesque J and Wagenbreth G: High Performance Computing: Programming and Applications, Chapman and Hall CRC.
4. High Performance Computing in Science and Engineering, Transactions of the High-Performance Computing Center, Stuttgart (HLRS) 2017, Editors: Nagel, Wolfgang E., Kröner, Dietmar H., Resch, Michael M.

ATS507	Boundary Layer Meteorology	4 Credits (60 Hrs.)

Course Description:

This course explains how the earth and the atmosphere interact and how this interaction affects the atmospheric boundary layer. This course will discuss in detail about the different layer of the boundary layer of atmosphere and ocean. Also, how the boundary layer is changing in the different area in the different season is discussed in this course. The turbulence structure and the flux of energy in the atmospheric boundary layer by using theoretical and experimental results is discussed.

Course Prerequisite:

Basic Knowledge of Bachelor level Physics, mathematics and dynamics meteorology

Course Objectives:

1. This course provides a framework for understanding the basic physical processes that govern mass and heat transfer in the atmospheric boundary layer and the vegetated land surface.
2. Understand and describe fundamental turbulent processes in the atmospheric boundary layer over a diurnal

cycle
3. Understand the evolution of the boundary layer on a daily basis
4. Understand the concept of turbulence and its concepts

Course Contents:

Introduction to the boundary layer, definition and qualitative description of temporal evolution and vertical structure; Atmospheric turbulence, Boussinesq approximation, Reynold's averaging, interpreting variance/ covariance as turbulent kinetic energy and fluxes, Prognostic equations for mean variables in a turbulent flow, simplifications; Prognostic equations for turbulent fluxes and variances; TKE equation, static and dynamic instability, Reynold's number, Richardson number, obukhov length, stability parameter relationships, closure problem in turbulent flow, first-order local closure; surface boundary conditions, surface momentum, energy and moisture budgets, fluxes at surface and entrainment zone, drag and Bowen ratio methods; surface layer Similarity Theory, Buckingham Pi method, applications to wind profiles; Stable and convective mixed layer phenomena including nocturnal jets, thermals, dust devils; boundary layer clouds, fair-weather cumulus, fog; geographically generated local circulations like slope and valley winds, sea/lake breeze, geographically modified flow, fetch, internal boundary layer.

Course Outcomes:

On completion of the course the student should have a basic understanding of the salient features boundary layers in atmosphere and ocean. Also they should have knowledge on sources and mechanisms driving turbulence in ocean and atmosphere, and at the boundary between them. To know how boundary layer is changing throughout the day in different areas.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Stull RB: An introduction to boundary layer meteorology, Kluwer Academic Publishers.
2. Arya S Pal: Introduction to Micrometeorology, Academic Press.
3. Stull RB: Meteorology for scientists and Engineers, Brooks/Cole Thomson Learning.
4. Foken T and Napo CJ: Micrometeorology, Springer.
5. Kaimal JC and Finnigan JJ: Atmospheric Boundary Layer Flows, Oxford University Press, New York/Oxford, 1994.

ATS508	**Desert Meteorology and Climate**	**4 credits**

Course Description: This course is designed to cover science of desert meteorology. It covers various topics related to science and processes, vulnerability and mapping aspects to desert meteorology and climate.

Course Prerequisite: Basic Knowledge of meteorology

Objectives:
1. To provide knowledge of a wide range of atmospheric phenomena and their roles in affecting weather and climate in deserts
2. To understand the dynamic effects of deserts on meteorological processes.
3. To give exposure of various methods to detect the change in climate of deserts

Course Content:

Introduction; World deserts and their climate; Atmospheric dynamics of deserts; Dynamic feedback mechanisms in deserts; Atmospheric and surface energy budgets of deserts; Physics of the desert landscape; Numerical modeling of desert atmospheres; Desert boundary layers; Intro-desert microclimates and variability; Monsoon pattern in deserts; Desert severe weather; Drought indices, Changes in climate and aridity in desert; Different methods/tools of assessment; Desertification-Indicators, mapping and vulnerability assessment; Examples of atmospheric model applications in desert; Review of selected case studies.

Course Outcomes:
1. Students will learn about the various processes involved in desert meteorology
2. To give exposure to various analysis tools and techniques to aid in understanding meteorology and climate over desert region.

Assessment Method: Two internal written exams of 20 marks and one final Semester written exam of 60 marks will be done for grading student's performance.

Recommended Readings:
1. Thomas T Warner, Desert Meteorology, Cambridge University Press
2. Keshavamurty & Sankar Rao: The Physics of Monsoon.
3. J. F. P. Galvin, An Introduction to the Meteorology and Climate of the Tropics, Wiley-Blackwell
4. Prakash, I. 2001. *Ecology of Desert Environments*. Scientific Publishers, Jodhpur.
5. W.J. Saucier, Principles of Meteorological Analysis, Dover Publications 2012

ATS510	Internship	2 Credits (30 Hrs.)

Course Description:

In this course, the students are expected to work in some research topic offered by an organization (Academic or research Institute) for one to one-and-half month. In this process, the students are expected to get hands on training through research. An internship experience provides the student with an opportunity to explore career interests while applying knowledge and skills learned in the classroom in a work setting. The experience also helps students gain a clearer sense of what they still need to learn and provides an opportunity to build professional networks.

Course Objectives:

1. To get exposure and hands on practice of various tools, techniques, instruments available in other reputed institutes
2. To provide opportunity to interact with experts, resource person outside classroom
3. To have a wider exposure of the field and developing their understanding about different aspects of Atmospheric Science.
4. For communicating a practical understanding of Atmospheric Science.

Course Outcomes:

1. Students will learn the different instruments and methodology used for the prediction of weather and climate.
2. Students will learn new things and may able to interlink classroom learning with real time application
3. Students will learn to write report of their exposure and learning

Assessment Method: Each student will submit his/her internship report. Evaluation will be based on report submission and presentation in the department based on their visit to respective laboratories/institutions/industry.

Semester IV

ATS511	Dissertation	12 Credits

Course Description:

Each student will work for M. Sc. Project under the supervision of formally assigned supervisor in the department for 4 to 5 months. Student shall complete the process of academic interaction to obtain teachers consent to supervise his/her project work by the end of third semester. In this project, a research problem will be framed through literature review to develop student's skill in conducting research. In this course, students are advised to do the problem related to real application to common people with the help of state of the art weather and climate models. Students have to write and submit their research work in the form of dissertation based on their assigned work at the end of semester.

Course Objectives:

1. To develop research skill through real application of weather and climate processes.
2. To develop scientific demonstration and writing skill
3. To develop skill of scientific communication for a practical understanding of Atmospheric Science.

Course Outcomes:

1. Able to identify real existing problem and exposure to problem based learning
2. Students might publish his/her thesis work in national/internationally reputed journals.

Assessment Method: The work on research project will start in4thsemester under the supervision of assigned faculty member and will be completed by end of 4th semester with submission of dissertation. Dissertation will be evaluated by committee of expert members based on their progress presentation, final presentation, report and viva-voice. Finally, the grade will be awarded based on his/her performance in viva, dissertation writing and approached to the problem.

Semester – IV Discipline Specific Electives

ATS512	Climate Change and Crop Modelling	4 Credits (60 Hrs.)

Course Description: This course will provide better understanding of various process of climate change and agriculture. Course will enhance capacity of students to work on crop model in climate change scenarios by understanding the crop growth and yield tools.

Course Prerequisite: Basic knowledge of meteorology and data handling

Course Objectives:

1. To introduce students with foundations related to climate change and agriculture.
2. To enhance skills to measure and prediction of climate variables and impact on crop yield
3. To provide understanding of how to use crop models for better crop production and food security.

Course Content:

Description of the climate system, Feedbacks in the climate system, Emissions Projections, Introduction to link climate change and its impact on agriculture and food security; Agrometeorology; Elements and factors of weather and climate; Agrometeorological Observatory; Meteorological factors in photosynthesis; Role of CO2 concentration and turbulence in photosynthesis. Concept of Growing Degree Days, Soil-Plant-Atmosphere Continuum; Soil water dynamics and crop responses; Evapotranspiration; Radiation balance; Moisture Availability Index (MAI) and classification; Climate effect on crop water requirement and water productivity, Overview of cropping systems models; Experiments and data requirements in application of crop models; parameterization and validation of simulation models; Analysis of crop model results, Analysing risks and uncertainties; Bias-correction and downscaling in climate model projection; Model application in adaptation and mitigation studies

Course Outcomes:

1. Describe general agrometeorological processes across the fields of atmospheric science and agriculture.
2. Assess the key physical mechanisms and processes related to atmosphere-land interactions by using crop models.
3. Able to run crop model using various datasets and further use it for possible adaptation and mitigation measure to improve crop productivity.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Griffiths JF (ed.): Handbook of Agricultural Meteorology.
2. Mavi HS: Introduction to Agrometeorology.
3. Rao P, G.S.L.H.V: Agricultural Meteorology. Kerala Agricultural University, Press, Thrissur, 2005.
4. Mavi HS: Introduction to Agrometeorology, Oxford and IBH Publishing Co., New Delhi, 1996.
5. Cao, Weixing, White, Jeffrey W, Wang, Enli (Eds.): Crop Modeling and Decision Support, ISBN: 978-3-642-01132-0, Springer-Verlag Berlin Heidelberg, 2009.
6. Wallach, Makowski, Jones & Brun (Eds.): Working with Dynamic Crop Models-Tools and Examples for Agriculture and Environment, ISBN : 9780123970084, Academic Press.

ATS513	Hydrometeorology	4 Credits (60 Hrs.)

Course Description: This course is developed to provide better understanding of processes and phenomena related to hydrometeorology and its concerned with hydrologic problems. It will also provide overview of linkage between hydrometeorology and human society considering the climate change scenarios.

Course Objectives:
1. To introduce students with foundations related to precipitation, meteorology and hydrology
2. To enhance skills to measure and prediction of precipitation and stream flow
3. To provide understanding of how multiscale hydrometeorological processes affect humans and environment.

Course Prerequisite: Knowledge of meteorology and data handling

Course Content:

Hydrologic cycle; Relationship between hydrology, meteorology, and climatology; Movement of water in all three phases; Importance of study of hydrometeorology; Characteristics of precipitation;; Extreme precipitation processes; Drought; Floods; Precipitation and Evapotranspiration measurements (In-situ and remote sensing techniques); Stream and ground water flows; Geomorphological modelling and floodplain estimation; Snow hydrology; Instruments to measure stream flow and water levels; Human and Environment dimensions of hydrometeorology; Weather and hydrologic hazards; Resilience of communities to hydrometeorological hazards; Climate change impacts on hydrometeorology; Adaptation and Mitigation measures.

Course Outcomes:

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

1. Describe general hydrometeorological processes across the fields of atmospheric science and hydrology.
2. Assess the key physical mechanisms and processes related to atmosphere-land interactions related to hydrology, forecasting and water resource management.
3. Assess how physical processes in hydrometeorology may change in a climate change scenarios and possible adaptation measure to combat the impact on society.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance

Recommended Readings:

1. Ward AD and Elliot WJ: Environmental Hydrology, CRC-Lewis Press, 1995.
2. Bruise JR and Clark RH: Introduction to Hydrometeorology.
3. Viessman WJ and Lewis GL: Introduction to Hydrology (5th ed.), Prentice Hall.
4. Bowles DS and O'Connel PE: Recent advances in the modeling of hydrologic systems: Series C: Mathematical and Physical Sciences.
5. Lakshmi V, Albertson J and Sheake J (Ed.): Land surface hydrology, meteorology and climate; Observations and Modelling, Water Science and Application, Vol. 3, American Geophysical Union.
6. Rakhecha PR and Singh VP: Applied Hydrometeorology, Capital Publishing Company-Springer, New Delhi, India, 2009.

ATS514	Radar Meteorology	4 Credits (60 Hrs.)

Course Description: Radar Meteorology is the subject which describes the applications of Radar in observing the atmosphere and different weather phenomena.

Course Prerequisite: Basic Knowledge of Physics, Basic Electronics, Atmospheric Physics

Course Objectives:

1. Students can learn the ability to describe in class a variety of atmospheric phenomena depicted on radar imagery.
2. Students can learn the ability to quantify the reflectivity and radial velocity field as measured by radar given a description of a weather phenomenon.
3. Students can learn the ability to relate radar reflectivity to rainfall rate, and discuss factors that contribute to the uncertainty in the rainfall rate estimation.
4. Students can learn the ability to discuss basic principles of multi-parameter radar measurements.

Course Contents:

Introduction to Weather radars, Basic principles of radar meteorology. Electromagnetic waves. Principles of dielectrics. Ray wave propagation. Scattering by spherical hydrometeors. Scattering by nonspherical and melting hydrometeors. Different frequency bands used in the weather radars and their applications. Principles of pulsed radar, Polarimetric radars, Attenuation of EM Waves v/s wavelength, Scattering of EM waves (Rayleigh & Mie), Bending of radar beam with refraction (Sub & Super refraction), Effect of curvature of the Earth on the range of radar, Definitions of Beam width, Pulse width, PRF, Antenna gain, back scattering cross, Radar equation for a point target and for extended target. Concept of dB (dBZ, dBm & dBW), Principle of Doppler Weather radar, Block diagram of Doppler Weather radar and explanation of its major components. Introduction to magnetron, Klystron, waveguides and Ferrite Circulator, Introduction to DWR Base products (Z, V and W), Doppler Dilemma and its interpretation – Range and velocity ambiguities, Operation procedure of DWR – volume scans, scheduler mode of operation and product generation – on line and offline, Uniform Scan strategy used in IMD Doppler radars, Radar calibration, validation, Radar data dissemination and data archival, Introduction to advanced radars like Solid state and Phased array radars, Product algorithms, Derived DWR products – their interpretation and use in Nowcasting, Reflectivity (PPI, CAPPI, PCAPPI, MAX, VCUT,EBASE & ETOP), Radial Velocity (PPI, CAPPI, PCAPPI, MAX, VCUT, VVP_2), Spectrum Width (PPI, CAPPI, PCAPPI, MAX, VCUT, Layer Turbulence), Hydrological Products (SRI, PAC, VIL), Warning products (Severe Weather Index, HHW) Analysis of severe weather events (thunderstorms, hailstorms, line squall, heavy rainfall prediction, aviation safety and tropical cyclones) recorded by DWR and development of the nowcasting technique for their prediction.

Course Outcomes:

1. Students can demonstrate skills for the analysis and interpretation of radar imagery of the atmosphere.
2. Students can demonstrate familiarity with the electromagnetic principles underlying the sampling of the atmosphere using radars.

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance

Recommended Readings:

1. Raghavan S: Radar Meteorology, Springer, 2003.
2. Bringi VN and Chandrasekar V: Polarimetric Doppler Weather Radar: Principles and Applications, Cambridge University Press, 2001.

3. Frederic F: Radar Meteorology, Cambridge University Press, 2015.
4. David A: Radar in Meteorology, Springer, 2015.
5. Peter M: Weather Radar; Principles and Advance Applications, Springer, 2013.
6. Battan LJ: Radar Observation of the Atmosphere, University of Chicago Press, 1977.
7. Doviak and Zrnic: Doppler Radar and Weather Observations, Academic Press, 1993.
8. Rauber and Nesbitt: Radar Meteorology, Wiley Blackwell, 2018.

ATS515	**Aviation Meteorology**	**4 Credits (60 Hrs.)**

Course Description: Aviation meteorology deals with the impacts of meteorology on aviation sector.

Course Prerequisite: Basic Knowledge of Dynamic Meteorology

Course Objectives:

1. To develop knowledge about meteorological conditions that is important for aviation purpose
2. To impart knowledge on the role of meteorology in aviation

Course Content:

An overview of Aviation Organizations and their functioning, Effect of Weather on aviation, weather hazards associated with takeoff cruising and landing, inflight – icing probability, visibility, fog, clouds, rain, detection of low level wind shear, turbulence, thunderstorms, Microburst, Gust front. Understanding the Jet stream, Nowcasting and very short range forecasting, Preparation of meteorological documentation for a flight, Observation and reporting of weather for Aviation services (SIGMET, METAR/SPECI, TAF/Area forecast). Interpretation of meteorological Radar data for aviation applications, Interpretation of weather satellite data for use aviation applications, Preparation of a Significant weather chart from numerical model forecast outputs received on internet.

Course Outcomes:
After attending this lesson, the user should be able to
1. Understand the impacts of meteorology on Aviation sector
2. Understand the techniques used in aviation sector to deal with severe weather
3. Prepare for a career in the meteorological services in air force and commercial aviation

Assessment Method: Two internal written exams of 20 marks and one final Semester exam of 60 marks will be done for grading student's performance.

Recommended Readings:

1. Vallis GK : Atmospheric and Oceanic Fluid Dynamics, Cambridge University Press, 2006.
2. Pandharinath and Navale: Aviation Meteorology, BS Publications, 2012.
3. Agarwal and Om Prakash: Aviation Meteorology for Pilots, Blue Rose Publishers, 2018.

****