Central University of Rajasthan

DEPARTMENT OF ATMOSPHERIC SCIENCE
SCHOOL OF EARTH SCIENCES

Ph.D. Atmospheric Science

(Course Syllabus)

JUNE 2020

Preamble

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 harbour 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.

After succesfully running our Masters programme in Atmospheric science, there was a need to initiate the research programmes in the department as many potential students from the university and from other institutes looked for higher studies pertaining to Ph.D. degree. So we launched this PhD programme from July 2019). Further, the University has recruited qualified research oriented faculty having a thrust for research in the Atmospheric science. 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

Research will be encouraged on the thrust areas following an interdisciplinary approach. The pre-Ph.D. Course work is designed to update the students with required techniques and methods for scientific investigation. The main objectives of the pre-Ph.D. course are:

1. To update in research methodology pertaining to general aspects, analytical skills and subject specific techniques.
2. To create scientific aptitude and thinking in the area of interest.
3. To have an advance knowledge of the subject and identify the environmental problems of regional, national and global relevance.
4. To analyse and present the findings of research in an effective manner
5. To collaborate and develop linkages with other research groups working in their specialized areas
6. To prepare students for designing, conducting independent research in the area of their interest within the interdisciplinary domain of Atmospheric Sciences.

Programme Structure and Courses offered for PhD student:

No	Sub. Code	Title of the course	Type of Course	Credits
1	PATS001	Research Methodology	CORE	4
2	PATS002	Modelling and Simulation of Atmospheric Processes	CORE	4
3	PATS101	Tropical Meteorology	ELECTIVE *(Any Two)*	4
4	PATS102	General Circulation and Climate Modelling		4
5	PATS103	Air-Sea Interaction		4
6	PATS104	Atmospheric Chemistry: Measurements and Modelling		4
7	PATS105	Hydrology and Climate Change		4
8	PATS106	Modelling of Clouds and Precipitation		4

Total Credit Requirement: 16

Core Course (8 credits): PATS 001 (4 credits), PATS 002 (4 credits)

Elective Course (4 credits): PATS101 to PATS106 (***any two courses from list of elective courses as per his/her requirement***)

PATS001- Research Methodology 4 Credits (60 Hrs.)

Ph.D. Course Work
(Compulsory and Common for all Schools and Departments)

Course Objective:

The objective of the paper is to train doctoral students in research methodology .It will facilitate the students in understanding the tools and techniques of conducting their thesis. The course aims to augment the aptitude of research among the Ph.D. aspirants

Course Content: This course is divided ito 4 units as detailed below:

Unit – 1: Research Basics (Common for all Departments)

S. No.	Topic	No. of Lecture (in Hrs)
1	Research Basics: definition, purpose and types (qualitative, quantitative, cross-sectional, longitudinal, pure, applied, action, evaluation, historical, survey, exploratory and case study); Significance of research in applied sciences/ arts/ social sciences; Process of Research; Objectives and Dimensions of Research	3
2	Research problem, Research questions, Research design	2
3	Tools of Research: Library, Field, Laboratory; Methods of research: Qualitative and Quantitative	2
4	Systematic review of literature in applied sciences/arts/social sciences	2
5	Features of good research study Preparation of Research proposal/ synopsis	2
6	Research Ethics (Issues relating to referencing and documentation, copyrights, plagiarism etc.), Impact Factor, H-Index, Citation Index, references/ bibliography	2
7	Structuring the Ph.D. Thesis: chapter format, pagination, identification, using quotations, footnotes, abbreviations, presentation of tables and figures, referencing, documentation, use and format of appendices, indexing	2
	Total Lectures (Hrs)	**15**

Unit – 2 (A): Statistical Techniques (For Science Stream)
Duration: 15 Lectures/ Hr.

S. No.	Topic	No. of Lecture (in Hrs)
1	Data: Types (primary and secondary data), collection methods; presentation (Graphical and diagrammatical); relevance, limitations and cautions.	1
2	Data Processing: checking, editing, coding, transcriptions, classification and tabulation. Data analysis: meaning and methods; quantitative and qualitative analysis	2
3	Bivariate Data Analysis using Correlation and Regression analysis	2
4	Analysis of time series, Interpolation and Extrapolation	1
5	Statistical fallacies: Bias, Faulty generalization, inappropriate comparison, misuse of various tools like mean, median, mode, dispersion, correlation etc., technical errors.	1

6	Theoretical distribution: Normal, Poisson, Binomial with application in various area/ disciplines	2
7	Sampling: types, steps; sampling errors Sampling of attributes (including chi square test), Sampling of small and large sample variables (including Anova)	2
8	Hypothesis Testing: fundamentals of hypothesis testing in applied sciences/arts/social sciences	1
9	Statistical decision theory	1
10	Parametric vs. non-parametric tests	2
	Total Lectures (Hrs)	**15**

Unit 3: Data Analysis in Atmospheric Science

S. No.	Topic	No. of Lecture (in Hrs)
1	Introduction to different data sets used in the weather and climate modeling, conversion of different data formats	3
2	Time series analysis: Trend estimation, autocorrelation function, autoregressive models	3
3	Spatial statistics: Interpolation techniques, autocorrelation, Variogram estimation	3
4	Introduction of statistical packages (R/GrAds/Metlab): Calculation of various statistical parameters, tests, temporal and spatial data analysis, preparation of charts	3
5	Interpretation of charts/plotted meteorological variables	3
	Total Lectures (Hrs)	**15**

Unit 4: Application in Atmospheric Science

S. No.	Topic	No. of Lecture (in Hrs)
1	Trend analysis of different meteorological parameters	4
2	Introduction to Grads, plotting of different variables	4
3	Spatial and temporal analysis of meteorological parameters using GrAds/R/Metlab,	4
4	Familiarization of different weather and climate models	3
	Total Lectures (Hrs)	**15**

Recommended Readings:

1. Devore JL: Probability and Statistics for Engineering and the Sciences: CENAGAGE, Learning. Print in India.
2. Rice, JA: Mathematical Statistics and Data Analysis: CENAGAGE Learning Pvt. Ltd., 2007.
3. Spiegel MR and Stephens JL: Statistics, Tata McGraw Hill, 2010.
4. Das NG: Statistical Methods, Tata McGraw Hill, 2011.
5. Rosner BA: Fundamentals of Biostatistics, 7th Ed., Cenagage Learning Pvt. Ltd., 2011.
6. Neuman LW: Social Research Methods: Quantitative and Qualitative approaches, Allyn & Bacon, 560 pp6, 1997.
7. Srivastava VK (ed): Methodology and Fieldwork, Oxford University Press, New Delhi, 2004.
8. Catherine D: Practical Research Methods, New Delhi, UBS Publishers'Distributors, 2002.
9. Kothari CR: Research Methodology- Methods and Techniques, New Delhi, Wiley Eastern Limited, 1985.
10. Kumar Ranjit: Research Methodology-A Step-by-Step Guide for Beginners, 2nd Ed., Pearson Education, 2005.

PATS002- Modeling & Simulation of Atmospheric Processes 4 Credits (60 Hrs.)

Course Description: This course will introduce students to Weather and Climate models, 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, Knowledge of Mathematics and Numerical Analysis.

Course Objective:

1. To introduce students to the basic concepts and principles of atmospheric physics and modeling.
2. To teach the different mathematical methods used in the numerical weather prediction techniques for evaluating weather forecasts.
3. Provide the exposure amongst students to use computers to develop and apply numerical algorithms for the solution of atmospheric related phenomena.

Course Content:

Basics of Earth System Science (Earth system components, Physical phenomena in the Earth system, Globally averaged energy budget, Energy transports by atmosphere and ocean, concepts of radiative forcing, feedbacks and climate change), Physical Processes in the Earth System, Introduction to weather and climate models, Numerical Modeling vs. Other Modeling Approaches, Examples of atmospheric and oceanic simulations, Model Hierarchy (Simple, Intermediate, Complex); Governing equations in Cartesian, Isobaric and sigma coordinate systems; Numerical discretization (finite difference, finite volume, spectral) and integration, stability, CFL criterion, unconditionally stable numerical scheme; model components, dynamical core, physical parameterization, tracers, coupling of components; global and regional models used in weather forecasting and climate 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: 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. Holton JR: An Introduction to Dynamical Meteorology, Academic Press.
2. Howell JR, Siegel R, Menguc M.P:. Thermal Radiation Heat Transfer, CRC Press.
3. Talley LD: Descriptive physical oceanography: an introduction, Academic Press.
4. Apel JR: Principles of Ocean Physics, Academic Press.
5. Hess SL: Introduction to Theoretical Meteorology, Holt, Rinehart, and Winston, New York.
6. Martin JE: Mid-latitude Atmospheric Dynamics.
7. Wallace JM and Hobbs PV: Atmospheric Science -An Introductory Survey, Academic Press.
8. Stull RB: Meteorology for Scientists and Engineers, 2000.
9. Buyers HR: General Meteorology, McGraw Hill Book Company, 1977.
10. Randall D: An introduction to Atmospheric Modeling, Colorado State University, 2004.

PATS101- Tropical Meteorology 4 Credits (60 Hrs.)

Course Description: This course is to introduce students for better understanding of the meteorological processes in the tropics. Also this course aims to motivate the students to do future research focused on in the tropics. Students will gain knowledge basically on atmospheric circulation in the tropics, Tropical weather features such as tropical cyclones, monsoons, ENSO etc.

Course Prerequisite: Basic knowledge of Physics, Mathematics and Meteorology.

Course Objectives:

1. To introduce students to the overview of energy balance and the global climate system.
2. To give exposures on major cycles dominating intraseasonal and interannual tropical variability
3. To provide knowledge of the mechanisms for the formation and evolution of tropical storms

Course Content:

Solar Energy, Differential heating; Moisture distribution in the Atmosphere, Global wind, pressure and precipitation distribution, The tropics; major synoptic and surface features; structure of the tropics; contrast between the tropics and mid-latitudes; important distinctions; role of the tropics in the general circulation, Hadley and Walker circulations, basic scaling, tropical waves. Monsoon and its variability: Monsoon, semi-permanent features, Asian and Indian monsoon, epochs of monsoon, seasonal variability of monsoon, intra-seasonal variability, Madden-Julian Oscillation, role of Hadley and walker circulation in modulation intra-seasonal variability of monsoon. Interannual variability of monsoon, El Nino-Southern Oscillation (ENSO), Quasi-Biennial Oscillation (QBO); Tropical Cyclones: theories relevant to forecasting the genesis, motion and intensity of tropical cyclones; Tornadoes; Thunderstorms, Squall lines.

Course Outcomes:

1. The student will acquire an understanding of general principles of atmospheric motion and global circulation.
2. It helps to understand the techniques used to forecast the onset and evolution of tropical storms.
3. Students can gain knowledge of tropical climatic signals (monsoons and El Nino/La Nina) and the impact on global and regional weather patterns.
4. It motivates to provide the solutions to do further research on the challenges in tropical weather observations, analysis, and prediction over tropics.

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. Asnani GC: Tropical Meteorology, Vol 1-3,Willey.
2. Krishnamurti TN, Stefanova L, and Misra V: Tropical Meteorology: An Introduction*,* Springer.
3. Wang, B: The Asian Monsoon*,* Springer.
4. Ackerman SA, Knox JA*:* Meteorology: Understanding the Atmosphere, Jones & Bartlett Learning.

PATS102- General Circulation and Climate Modelling 4 Credits (60 Hrs.)

Course Description: This course is to introduce students for better understanding of the atmospheric motions, global circulation of atmosphere. Also this course aims to motivate the students to do future research using General Circulation Model (GCM), dynamics of Monsoon and representation of physical processes specific focused to GCM. Students will also gain knowledge how to improve regional and global atmospheric/climate modeling.

Course Prerequisite: Basic knowledge of Physics, Mathematics and Meteorology.

Course Objectives:

1. To familiarize students to the overview of general circulation of the atmosphere.
2. To give exposures to students on the dynamics and thermodynamics governing the ocean and atmosphere on spatial and temporal scales appropriate for climate systems.
3. To provide knowledge of the General Circulation Models and Regional Climate Models.

Course Content:

General Principles of Atmospheric Motion (Simplifications of Force Balances Important to Large-scale Motions, Large-scale Structures in the Atmosphere, Scale Analysis of the Tropics), General Circulation of the Atmosphere (Historical Evolution of Global Circulation Conceptual Models, Axisymmetric Hadley Cell: Theories and Assumptions, Walker circulation, Comparing the Tropics and Midlatitudes, Stratospheric Circulations), Surface ocean circulation, Atmospheric response to Equatorial Heating, Monsoons (Defining the Monsoon, A Conceptual Model of Monsoon Evolution, Evolution of the South Asian Monsoon System, Other Monsoons around the World, Australian-Maritime Continent Monsoon, West African Monsoon, Monsoons in the Americas), General Circulation Modeling (Basics of an atmospheric general circulation model, Representation of physical processes in GCMs, analysis of GCM simulations and comparison with observations, challenges for improving GCM simulations.

Course Outcomes:

1. The student will acquire an understanding of general principles of atmospheric motion and global circulation.
2. It helps to understand the techniques used of a variety of forecast verification tools and measures of forecast skill.
3. Students can gain knowledge of the principles underlying the creation and application of numerical models of the atmosphere
4. It motivates to provide the solutions to do further research on the climate modeling based on current observations with the different atmospheric phenomena to improve the numerical forecasts of the atmosphere.

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. Satoh M: Atmospheric Circulation Dynamics and General Circulation Models.
2. Randall D: An Introduction to the Global Circulation of the Atmosphere.
3. Chang J: General Circulation Models of the Atmosphere.
4. Randall D: An introduction to atmospheric modeling.
5. Neelin JD: Climate Change and Climate Modeling.

PATS103- Air-Sea Interaction 4 Credits (60 Hrs.)

Course Description: The atmosphere and the ocean form a coupled system, exchanging heat, momentum and water at the air-sea interface. The course introduces the basic concepts of the air-sea interaction: ocean circulation, surface fluxes, energy budgets, transfer of heat, water, and gases across the interface; Kelvin and Rossby waves; mixed layers and thermoclines; large-scale air-sea interaction.

Course Prerequisite: Basic Knowledge of physics and dynamics of atmosphere and Ocean.

Course Objectives:

1. To introduce students to the governing laws of air-sea teraction.
2. To impart knowledge of different coupled system
3. To understand different processes of coupled system and its impact on global climate

Course Content:

Ocean-atmosphere system, transfer properties between atmosphere and ocean, the transfer laws of Air -Sea Interface: Momentum transfer in laminar flows, Flux and Force in Air-Sea Momentum Transfer: Charnock's Law. Sensible and Latent Heat Transfer. Wind waves and the Mechanisms of Air -Sea Transfer: Instability Theory. The wind wave phenomenon, Momentum transfer in a breaking waves. Mixed Layers: Mixed layer Turbulence. Atmospheric and Oceanic Mixed layer mixed layer budgets. Bunker's Air -Sea Interaction Cycles, Different air-sea interaction systems: ENSO, PDO, NAO, SAM, AO

Course Outcomes:

1. Understand the methods for measuring key variables used to estimate air-sea fluxes
2. Understand the common methods of estimating air-sea fluxes from observations and in numerical
3. models
4. Ability to identify positive and negative local feedbacks within the coupled ocean-atmosphere boundary
5. Understand how large-scale circulations in the atmosphere and ocean modify local air-sea interactions, and how they are affected by them

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. Csanady GT: Air-Sea Interaction: Laws and Mechanisms, Cambridge University Press, ISBN: 0521796806.
2. Siedler G, Griffies SM, Gould J, Church JA.: Ocean Circulation and Climate, Elsevier, International Geophysics Series, Volume 103, ISBN: 978-0-12- 391851-2.
3. Gill AE.: Atmosphere-Ocean Dynamics, Academic Press, ISBN: 0-12-283522-0.
4. Talley LD, Pickard GL, Emery WJ, and Swift JH: Descriptive Physical Oceanography (An Introduction), 6th Edition, Elsevier, ISBN: 978-0-7506-4552-2.

PATS104 Atmospheric Chemistry: Measurements and modeling 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 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. Further, they will learn about measurement and modelling techniques to evaluate the role of atmospheric chemistry on air quality and climate

Course Prerequisite: Basic knowledge of physics, chemistry, mathematics and meteorology.

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 of the interlinkages of anthropogenic emissions, air pollution and climate
3. To develop an understanding about the measurement and modelling techniques used to estimate the impacts of atmospheric chemistry.

Course Content:

Atmospheric chemical constituents, 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**.**

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.

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 pollution, Sources of anthropogenic pollution, primary and secondary pollutants, transport of atmospheric gases and particles, Plume dispersion models, Gaussian puff diffusion.

Atmospheric effects- smog, acid rain, visibility, Ambient air quality standards.
Measurements of atmospheric trace gases, aerosols and radicals. Photochemical box 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 have a wider perspective during their research in different aspects of Atmospheric Sciences.

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

PATS105- Hydrology and Climate Change 4 Credits (60 Hrs.)

Course Description: This course gives an overview of the impact of changing climate on various components of the hydrological cycle and scholars will be introduced to various tools available to assess the impact of climate change on water resources.

Course Prerequisite: Basic Knowledge of water cycle, meteorology, remote sensing and geospatial information system

Course Objectives:

1. The aim of the course is to develop linkage between climate change and water resources, including understanding, modelling and projection of hydrological processes at river basin scale.
2. To develop capability of various tools and techniques to use climate data and various processing methods.

Course Content:

Elements of a watershed, hydrological cycle, hydro-meteorological variables and measurement, rainfall-runoff modelling, land capability classification, use of remote sensing and GIS tools in database preparation, hydrological models- calibration and validation, application of rainfall-runoff model, interlinking surface-groundwater, impact of landuse/landcover change on surface and groundwater resources, impact of climate change on hydrology, sources of future climate data from several global/regional climate models (GCMs/RCMs), pre-processing of climate data, bias-correction techniques, downscaling methods, uncertainity in hydrologic projections, hydro-climatic extremes, Application in water resources Management, Application of hydrological modelling-SWAT, HEC-HMS, WRF-Hydro

Course Outcomes:

Students will be

1. Able to understand of linkages between climate, hydrology for better water resources management.
2. Able to access/download, pre-process and downscale the projected climate data and generate hydrological scenarios using the hydrological models
3. Able to link the possible impacts of climate change on water resources and provide better solution for water management for society

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. Burrough PA and McDonnell RA: Principles of geographical information systems. Oxford University Press.
2. Chow VT : Applied Hydrology, Tata McGraw Hill Publishing Co., 1988.
3. Longley PA, Goodchild MF, Maguire DJ and Rhind DW: Geographic Information Systems and Science, Chichester, Wiley, 2nd edition, 2005.
4. Subramanya K: Engineering Hydrology, Tata McGraw-Hill, New Delhi, 2004.
5. Eslamian S: Handbook of Engineering Hydrology: Modeling, Climate Change, and Variability.
6. Srinivasa RK, Nagesh Kumar D: Impact of Climate Change on Water Resources with Modeling Techniques and Case Studies, 2018, 10.1007/978-981-10-6110-3

PATS106- Modeling of Clouds and Precipitation 4 Credits (60 Hrs.)

Course Description: This course provides an overview of the physics and dynamics of clouds. It will start with a short introduction to clouds and precipitation and a review of basic thermodynamics. The primary emphasis is placed on modelling of clouds & precipitation processes.

Course Prerequisite: Basic understanding of physics, thermodynamics and dynamical processes in atmosphere, cloud physics and dynamics.

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:

Theories of Cloud formation, classification, time scales, vertical velocities, cloud hydrometeors. Types of fog and formation mechanisms, Radiation fog and physics and dynamics, Valley fog, Marine fog, Stratocumulus clouds, Thermodynamic Variables: Various forms of potential temperature, Dry and moist static energy etc., Cumulus Clouds: Boundary layer cumuli – an ensemble view, 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, Theories of storm movement and propagation, Mesocyclones and tornadoes, Hailstorms, Models of hailstorms and hail formation processes, Rainfall from cumulonimbus clouds, Aerosol impacts on convective precipitation. Definition of mesoscale convective systems, Conceptual models of MCSs, Climatology of MCSs, Cumulus parameterization, cloud ensemble model, Orographic clouds: Theory of flow over hills and mountains, Effects of clouds on orographic flow, Orogenic precipitation, Distribution of supercooled liquid-water in orographic clouds, Clouds, Storms and Climate: Clouds and the global radiation budget, Hot towers and tropical circulations, Clouds and global hydrological cycle, Cloud Venting, Aerosol pollution impacts on global climate, Representing clouds in GCMs.

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 clouds and precipitation processes

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. Rogers RR and Yau Y: A Short Course in Cloud Physics, Pergamon Press, 3rdEdition, 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: Storm and Cloud Dynamics, 2nd Edition. Academic Press, 2011.
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.