IISER BERHAMPUR

Ph.D. Syllabus

Earth & Environmental Sciences

Ph.D. EARTH AND ENVIRONMENTAL SCIENCE

EES 601: ISOTOPE GEOCHRONOLOGY & GEOCHEMISTRY (4)

***Learning Objectives*:**

Isotope geochemistry is a powerful tool to explore a number of earth surface processes in both modern and ancient earth and environmental systems. Recycling of various elements in the Earth's upper crust, hydrosphere and atmosphere through various biogeochemical processes alters their physical states; however, their isotope compositions still retain clues on their source signatures and quantitative information on these cycling processes. Under closed system conditions, radiogenic isotopes additionally act as time clocks. Utilizing these characteristics study of isotopes can yield powerful insights into the physical and chemical evolution of thew Earth and its inter-connected systems.

Learning Outcomes:

This course will enable students to understand the evolutionary trajectories of various physical, chemical, biological processes in Earth systems, from the perspective of isotope systematics. After completion of this course students will be able to incorporate the tools and techniques of various radiogenic and stable isotope systems in solving various problems in Earth and Environmental sciences.

***Course Contents*:**

Isotopes and Radioactivity:
Basics of atomic and nuclear physics; Synthesis, relative abundances, and stability of various nuclides; Radioactivity, radioactive decay modes; Radiation detection and environmental protection.

Instrumentation:

Alpha, beta, gamma counters; Mass spectrometers; Methods of internal spike addition, isotope dilution and standard sample bracketing; Isotope fractionation correction by single/double normalization and double/triple isotope spiking.

Isotope Dating:

Growth and decay of radiogenic daughters; Basic assumptions of dating; Isochron dating, and related analytical uncertainties and geological errors; Dating using radioactive parent only(^{10}Be, ^{14}C and ^{36}Cl), parent–daughter couple (^{40}K–^{40}Ar, ^{87}Rb–^{87}Sr, ^{147}Sm–^{143}Nd, ^{176}Lu–^{176}Hf, ^{187}Re–^{187}Os, ^{238}U–^{206}Pb), decay series disequilibria (^{238}U–^{234}U–^{230}Th–^{236}Ra), radiogenicdaughter only (Pb–Pb and Ar–Ar) and extinct parent (^{26}Al, ^{41}Ca, ^{53}Mn, ^{60}Fe, ^{107}Pd, ^{129}I, ^{146}Sm, ^{182}Hf); Ages of crystallization and last metamorphism; Sediment depositional ages; Model ages; Exposure ages; Archaeological ages.

Radiogenic Isotope Geochemistry:
Compatibility; Crust–mantle differentiation; Crustal evolution; Crust recycling in subduction zones;

Pb-paradox; Chemical weathering versus physical erosion; Mixing theory; Sediment provenance; Zircon effect; Ocean circulation; Strontium isotope chrono-stratigraphy.

Stable Isotope Geochemistry:
Mass dependent and independent isotope fractionations; Use of traditional and non-traditional stable isotopes in exploration of Earth's climate, hydrology, oceanography, and other biogeochemical processes, Evolution of atmospheric gases.

Noble Gas Geochemistry:
Production and abundance; Isotope composition and behavior of noble gases; Noble gas–water interactions; Cycling in continental and oceanic crusts; Applications in oceanography and terrestrial rocks.

Suggested Readings:

1. Allègre, C. J., 2005, Isotope Geology, Cambridge University Press.
2. Faure, G., and Mensing, T. M., 2004, Isotopes – Principles and Applications, Wiley.
3. White, W. M., 2015, Isotope Geochemistry, Wiley-Blackwell.
4. Holland, H. D., and Turekian, K. K., 2011, Tretise or Geochemistry (2nd Edition), Elsevier Science.
5. Zeebe, R. E., and Wolf-Gladrow, D., 2001, CO_2 in Seawater: Equilibrium, Kinetics and Isotopes (1st Edition), Elsevier Science.
6. Hoefs, J., 2015, Stable Isotope Geochemistry (7th Edition), Springer.

EES 602: ADVANCED METAMORPHIC PETROLOGY (4)

Learning Objectives:

Metamorphism is a complex and nuanced subject which involves, physical and chemical processes operating over a wide range of P-T conditions, with the outcome depended on the cumulative involvement of all the factors. This course aims to develop a comprehensive understanding of the processes and conditions of metamorphism and their effects on rocks and to impart insights into classification, nomenclature, and terminology of metamorphic rocks and their mineral assemblages.

Learning Outcomes:

Students will get familiarized with analytical techniques used in metamorphic petrology, fieldwork techniques and the interpretation of metamorphic rock textures and structures. After completion of this course, students will develop critical thinking and a problem-solving approach to further their understanding about topics such as- metamorphism and how it is related to deformation, magmatism, and tectonics, geothermobarometry concepts and different software through modeling exercises, mantle petrology and processes

Course Content:

Review of Metamorphic Processes:
Review on agents and controlling factors, P-T conditions of metamorphism and variations in the Earth, geotherm & heat flow; metamorphic reactions, various chemographic projections, and Schreinemakers rules. Thermodynamics of metamorphic reactions, characteristic mineral assemblages under different P-T-X.

Crustal evolution and Metamorphism:
Tectonics and metamorphic styles through ages, ultrahigh-temperature (UHT) and ultrahigh-pressure (UHP) metamorphism, crustal anatexis and metamorphism, heat flow and thermal modeling of orogenic belts and cratons.

Modeling and Calculations:
Forward and backward modeling of mineral reactions; principles of geothermobarometryand its application. Principles and practical applications of P-T pseudo-section analysis.

Mantle petrology:
Mantle heterogeneity, the composition of the mantle, mantle processes, mantle metasomatism, ophiolites, and mantle xenoliths. P-T conditions and oxygen fugacity of mantle rocks, sub-continental lithospheric mantle (SCLM), mineralogy and architecture of the SCLM, stability of different mineral assemblages in the mantle,C-H-N-S fluids in the mantle, diamonds and their mineral inclusions. Recent advances in mantle petrology.

Eastern Ghats Mobile Belt:
Review on the metamorphic history of Eastern Ghats Mobile Belt

Lab work:
Petrography of Metamorphic rocks, Chemographic Projections, PTX problems

***Suggested Readings*:**

1. Winter, J. D., 2010, An Introduction to Igneous and Metamorphic Petrology (2nd Edition), Prentice Hall.
2. Philpotts, A. and Auge, J., 2009, Principles of Igneous and Metamorphic Petrology (2nd Edition), Cambridge.
3. Bucher, K., and Grapes, R., 2011, Petrogenesis of Metamorphic Rocks (8th Edition), Springer.
4. Orcutt, B., Daniel, I., & Dasgupta, R. (Eds.). (2019). Deep Carbon: Past to Present. Cambridge: CambridgeUniversity Press.
5. Steven B. Shirey and James E. Shigley (2013). Recent Advances in Understanding the Geology of Diamonds.Gems & Gemology, Winter 2013, Vol. 49, No. 4.
6. Metamorphic Phase Equilibria and Pressure-Temperature-Time Paths by Frank S. Spear Metamorphic Petrology by Bruce Yardley

EES 603: IGNEOUS PROCESSES AND VOLCANOLOGY (4)

Learning Objectives:

The study of igneous petrology and volcanology involves a wide range of concepts from- magma generation, ascent, storage, and diversification to understanding the crystallization mechanisms, interpretation of igneous textures and the influence of geodynamic settings. The primary objectives of this course are to develop a comprehensive and advanced understanding of the processes and mechanisms involved in the formation of igneous rocks, and introduce the fundamental concepts of volcanology.

Learning Outcomes:

Students will get familiarized with some igneous rocks-related problems and promote critical thinking and problem- solving skills through the interpretation of petrological data. This course will enable students to gain a deeper understanding of topics such as- tectono-magmatic association of igneous rocks and implications, igneous petrochemistry, magmatic diversification processes, phase equilibria of magmatic systems, mantle heterogeneity and field training in igneous terrain etc.

***Course Contents*:**

Review on Igneous rocks and processes:
Conventional and latest classification schemes, textural features of igneous rocks and their implications, petrology of basalts and related rocks, gabbros, ultramafics, andesites, granites. Alkalinerocks and their petrogenesis.

Petrological problems:
Charnockites and charnockites, eclogites and eclogites, granites and granites, magmas from the thermal and tectonic regime of Archean vs Proterozoic vs Phanerozoic, anorthosite problem.

Magmas and tectonic settings:
Formation of magmas in various tectonic settings, their petrological and geochemical characteristics with respect to different tectonic settings. Trace elemental and isotopic fingerprinting of the magmas, Critical review of petrogenetic models of Continental Flood Basalts (CFB) And Oceanic Island Basalts (OIB), Subduction-Related Igneous Activity, Continental Alkaline Magmatism, Granitoids and Anorthosites, ultramafics andultrapotassic rocks, layered rocks and magma chamber processes with examples from Skærgaard and Bushveld complex.

Magma and mineral modeling and phase equilibria:
Crystallization and melt-modeling of the magmas (e.g., timescales of magmatic ascent, magma resident time, fractional crystallization, assimilation-fractional crystallization, fractional and batch melting). Thermodynamic phase equilibria of magmatic systems and processes. Phase equilibriaof basaltic, granitic, and alkali systems.

Volcanology:
Various components and types of volcanic systems; dynamics of lava flows, pyroclastic falls and flows; emplacement of various types of intrusions; volcanic facies in subaerial and subaqueous environments; case studies around the world; important igneous provinces and events of India.

Lab work:
Physical and optical study of igneous rocks and minerals

***Suggested Readings*:**

1. Robin Gill. Igneous Rocks and processes, Blackwell, 2010.
2. Best, M. G. Igneous and Metamorphic Petrology, 2nd Edn., Blackwell, 2003
3. Winter, J. D., 2009, An introduction to Igneous and Metamorphic Petrology (2^{nd} Edition), Prentice Hall.
4. Carmichael, I., Turner, F., and Verhoogen, F., 1974, Igneous Petrology, McGraw Hill Publications
5. Anthony Philpotts and Jay Ague, 3^{rd} edi. 2022. Cambridge University Press.
6. Sigurdsson, H., Houghton, B., Rymer, H., Stix, J., McNutt, S. Encylopedia of Volcanoes, Academic Press, 2000
7. Schmincke, H.U., Volcanism. Springer, 2005
8. Parfitt, E. and Wilson, L. Fundamentals of Physical Volcanology. Wiley-Blackwell, 2008
9. McBirney, A. R., Igneous Petrology, 3rd Edn., Jones & Bartlett, 2006
10. Fisher, V. and Schmincke, H.-U. Pyroclastic Rocks. Springer Verlag, 1984

EES 604: AEROSOL SCIENCE (4)

***Learning Objectives*:**

The aerosols affect visibility, climate, health, and quality of life; at the same time their presence in atmosphere controls cloud formation. In this context, this course has been designed to understand physical and chemical properties of aerosols, which reflect upon their functional traits in affecting stated atmospheric processes. The primary objectives are to explain the general and optical properties of aerosols and related phenomenon, their role in climate issues and various experimental techniques of aerosol sampling.

Learning Outcomes:

Upon the completion of this course the students will be able to understand the importance of aerosols in the atmosphere, terminology used in aerosol science, fundamentals of the dynamics and mechanics of aerosols, size distributions, particle deposition and adhesion, and the theoretical basis for aerosol sampling and collection on to filter substrates.

***Course Contents*:**

Introduction and Aerosol Characterization:
Definitions and terminology, parameters for determining particle behavior, particle size, shape and density, aerosol concentrations, number, size, and mass distribution functions (moment distributions), log-probability graphs, Hatch-Choate conversion equations, statistical accuracy.

Uniform Particle Motion:
Newton and Stokes laws, settling velocity, mechanical mobility, slip correction factor, equivalent diameters, settling at high Reynolds numbers, stirred settling, and instruments based on settling velocity.

Straight Line Acceleration and Curvilinear Motion:

Relaxation time, stopping distance, curvilinear motion, impaction, cascade and virtual impactors, time-of-flight instruments.

Diffusion, Thermal and Radiometric Forces:

Diffusion coefficients, Brownian displacement, diffusion/diffusion batteries, thermophoresis, thermophoretic precipitators, radiometric forces.

Coagulation, Condensation, and Evaporation:
Monodisperse coagulation, polydisperse coagulation, kinematic coagulation, homogenous nucleation, Kelvin effect; Condensational growth – growth laws, transported limited growth, aerosol phase, reaction-limited growth, heterogeneous condensation, nucleated condensation evaporation.

Experimental Methods for Aerosol Sampling and Characterization:
Microscopy; Condensation particle counters; Filtration – single fiber efficiency, deposition mechanisms, filter efficiency, pressure drop, membrane filters; Optical measurement instruments-definitions, extinction, scattering, visibility - nephelometers, transmissometers; Electrical properties-based instruments – electric fields, mobility, charging mechanisms, corona discharge, charge limits, electrostatic precipitators, differential mobility analyzer.

Atmospheric Aerosols:

Biogenic and anthropogenic aerosols, general features of ambient aerosol size distributions background aerosol, urban aerosol, chemical composition of urban aerosols.

Suggested Readings:

1. Hinds, W. C., 1999, Aerosol Technology: Properties, Behavior, and Measurement ofAirborne Particles, John Wiley and Sons.
2. Friedlander, S. K., 2000, Smoke, Dust, and Haze: Fundamentals of Aerosol Dynamics, Oxford University Press.
3. Seinfeld, J. H., and Pandis, S. N., 2006, Atmospheric Chemistry and Physics: From AirPollution to Climate Change, Wiley-Inter science.

EES 605: INDIAN MONSOON AND ITS VARIABILITY (4)

***Learning Objectives*:**

This course is designed to provide a comprehensive knowledge of the Indian monsoon and its variability on different spatial and temporal time scales. The physics and dynamics of the monsoon variability involve a basic understanding of air-sea interaction, and their connection with oscillations such as the El Nino-Southern Oscillation (ENSO). An in-depth exploration of the background, the present understanding about nature of the system responsiblefor the monsoon mechanism, which leads to its variability, will be elucidated. State of the art models in simulating and predicting the variability of the monsoon will be assessed, and problems and prospects of improvement of predictions will be considered. In addition, the impact of the Indian monsoon on agriculture and the economy will be discussed.

Learning Outcomes:

After completion of this course, students will develop a comprehensive understanding on the factors influencing the onset, duration, and intensity of Indian monsoon. Students will also be able to use problem-solving skills to tackle problems related to prediction of monsoon. Understanding the global implications linked to ENSO and other related phenomenon will enable students to study holistic climate phenonmenon.

***Course Contents*:**

Introduction to Monsoon:
Indian summer and winter monsoon, nature of winter and summer monsoon variability, present understanding of the underlying mechanisms; Interannual variability, onset over Kerala and advances, active and break spells; Convection and rainfall in the tropics - Organization over different spatial scales, conditional instability of the first and second kind; Variation of temperature, pressure, and density with height in the atmosphere; Relationship between wind and pressure in rotating systems.

Basic System Responsible for the Monsoon:
Fundamental processes in seasonal cycle; Gigantic land-sea breeze, different hypotheses for the basic system responsible for the summer monsoon; Inter Tropical Convergence Zones (ITCZs) and the Indian monsoons; Role and characteristic behavior of ITCZ during summer and winter monsoon.

Variation of Convection/Rainfall over the Ocean:
Air-sea interaction; SST-rainfall relationship; Heat lows; ITCZ and monsoonal regions of the world; Seasonal transitions (onset and retreat)- spring to summer, advance and retreat on summer monsoon; Summer to winter transitions.

Intra-seasonal Variation and Intra-seasonal Oscillation:

Active-weak spells and breaks in the monsoon.

El Nino and Southern Oscillation:
Walker circulation, Hadley cell, Southern Oscillation index and its variability, Bjerknes theory and feedbacks; Definition of Nino regions, teleconnections, understating El-Nino, what causes El Nino and its underlying mechanism? Impact of the Asian Monsoon on ENSO.

Indian Ocean and the Indian Monsoon:
Role of SST on monsoon; Indian Ocean Dipole (IOD) mode variability and association with winter and summer monsoon.

Interannual Variation of the Indian Summer Monsoon Rainfall:

Links to events over the Indian and Pacific Ocean; Land surface processes; Circulation; IOD and ENSO link.

Monsoon Variability, Agriculture and Economy:

Effect of monsoon rainfall variability (droughts and floods) on agriculture production; Relationship between variation of rice production and variation of rainfall; Agriculture production link to Gross Domestic Product.

Monsoon Prediction: Problems and Prospects:
Short, medium, and long-range monsoon prediction using statistical approach; Coupled model prediction of monsoon and their skills, and limitations in monsoon forecasting.

Suggested Readings:

1. Fein, J. S., and Stephens, P. L., 1987, Monsoons, Wiley.
2. Hastenrath, S., 1991, Climate Dynamics of the Tropics, Kluwer Academic Publishers.
3. Wang, B., 2006, Asian Monsoon, Springer Praxis.
4. Asnani, G. C., 1993, Tropical Meteorology (3 Vol. set), Asnani Publishers.
5. Pant, G. B., and Rupa Kumar, K., 1997, Climate of South Asia, Wiley.

Reports:

1. Rao, Y. P., 1976, Southwest Monsoon. Meteorological Monograph (synoptic meteorology). No. 1, India Meteorological Department, New Delhi.
2. Asanani, G. C., De, U. S., Hatwar, H. R., and Mazumdar, A. B., 2011, Monsoon Monograph (vol 1) India Meteorological Department, Ministry of Earth Sciences Govt. ofIndia.

EES 606: GEOCHEMISTRY AND ANALYTICAL TECHNIQUES (4)

Learning Objectives:

This course aims to develop a detailed and comprehensive understanding of the inner workings of geochemistry, by building on the fundamental concepts. Students will get familiarized with application of geochemistry in understanding Earth materials, processes, and environmental systems and various analytical techniques and instruments used in geochemical research.

Learning Outcomes:

This course will help students to develop critical thinking, perform independent research and develop of scientific communication skills. On successful completion of the course, the students will be able to gain advanced knowledge of topics such as- modern analytical geochemistry, isotope systematics used in the geosciences and their myriad uses, radiometric dating techniques etc.

Course Contents:

Review on principles of geochemistry:

Principles and application of stable and radioisotope geochemistry in Earth and Environmental Sciences; introduction to stable and radiogenic isotope systems, various geochemical reservoirs, the composition of the crust and mantle, discrimination diagrams using major and trace elements and their applications, partitioning of trace elements during melting and magma crystallization, partition coefficients, application of multi-element spider diagram and normalized REE plots in petrology, geochemistry of low-temperature aquatic systems and their chemical thermodynamics and kinetics. Critical review on the mechanism of chemical weathering, dissolution and precipitation reactions, mineral stability diagrams, Eh-pH diagrams, oxidation-reduction reactions, and their advanced applications.

Stable isotope systems and their applications:
Carbon, oxygen, and sulfur isotopes, nontraditional stable isotopes(Mo, Ca, Fe, Sr). Stable isotopes and subduction process.

Radiogenic isotopes and geochronology:
Decay scheme of different radio-isotope systems (Rb-Sr, Sm-Nd, U-Pb, K-Ar, Lu-Hf), various methods of geochronology and their limitations, principles, and applications of K-Ar, U-Series dating, Rb-Sr, Sm-Nd and C-14.

Introduction to Cosmochemistry:
Geochemical perspectives on the formation of the Universe, solar system geochemical evolution, Meteorites and chemical diversities, geochemical constraints on the formation of Earth andMoon, isotopic evolution of the solar nebula, meteorites, and terrestrial planets

Analytical methods in geosciences:
Sample preparation and data interpretation, Quality control and data validation, Various modern analytical techniques in geosciences, XRF, EPMA, Laser Ablation Techniques, ICP-MS, XRD, LaserRaman, and SEM.

Geochemical modeling:
Principles of geochemical modeling, application of modeling software, predictive modelingof geochemical processes.

Presentations/Seminars:
Recent developments in geochemistry, isotope systems such as Re-Os, Lu-Hf, multiple-sulfur, transition metals, and Nobel gas.

***Suggested Readings*:**

1. White, M., 2013, Geochemistry, Wiley Publication.
2. Walther, J., 2009, Essentials of Geochemistry (2nd Edition), Jones and Bartlett Learning.
3. McSween, H. Y., Richardson, S. M., and Uhle, M., 2003, Geochemistry Pathways and Processes (2nd Edition),Columbia University Press.
4. Faure, G., 2012, Inorganic Geochemistry - Principles and Applications (3rd Edition), Wiley Publications.
5. Misra, K. C., 2012, Introduction to Geochemistry - Principles and Applications, Wiley-Blackwell Publications.
6. Rollinson, H., & Pease, V. (2021). Using Geochemical Data. In Using Geochemical Data: To UnderstandGeological Processes (p. I). Cambridge: Cambridge University Press.

7. Faure, G and Mensing, T. M., 2005, Isotopes: Principles and Application (3rd Edition), Wiley Publications
8. Sharp, Z., 2007, Principles of Stable Isotopic Geochemistry, Pearson Education, Inc.
9. Gill, R (Ed.)., 2014, Modern Analytical Geochemistry: An Introduction to Quantitative Chemical Analysis Techniques for Earth, Environmental and Materials Scientists, Taylor & Francis Group
10. Davis, A., Holland, H. D. and Turekian, K. K., 2014, Treatise on Geochemistry (2nd Edition) Volume 1:Meteorites and Cosmochemical Processes, Elsevier Ltd.

EES 607: ADVANCED REMOTE SENSING AND GIS (4)

***Learning Objectives*:**

This advanced level course will be helpful to develop technical skills and competence in data and information acquisition, extraction, management, and analysis; spatial and statistical modelling; mapping and visualization of satellite data. Additionally, the course will develop applications of environmental remote sensing and GIS which can contribute directly to service delivery on land use management, ground water management/prospects, agriculture, forestry, food and water security, and disaster management.

Learning Outcomes:

The students will be able to apply the understanding and knowledge of different aspects and information obtained from satellite imagery in the various fields of Earth Sciences. The course will enable the learners to apply the integrated knowledge of remote sensing, GIS, GPS and GNSS in different issues related to various branches of Earth Sciences.

***Course Contents*:**

Introduction:

Fundamental principles of photography, advantage, and limitations of remote sensing; Historical overview of remote sensing techniques.

Electromagnetic Radiation (EMR) and Color Science:
Electromagnetic radiation - nature, principle and source, classification, the blackbody radiation, scattering of EMR, EMR and interaction between atmospheric gases; Concept of color, the additive color scheme, the subtractive color scheme, representation of colors in viewing devices.

Spectroscopy of Rocks and Minerals:
Introduction, basic principles of spectroscopy, electronic process and vibrational processes, spectral reflectance of minerals, study of absorption spectra of different minerals at visible, infrared and thermal wavelength of EMR.

Multispectral Digital Imaging System:

Introduction to digital images, imaging sensors and tubes, different types of scanners - optical mechanical line scanners, CCD linear array scanner, description of space-borne image sensors; Introduction to the principles of digital camera, storage mechanisms, radiometric, spatial and temporal resolutions; Introduction to different multispectral satellite systems.

Thermal Remote Sensing:
The Earth`s radiant energy, surface, radiant temperature and kinetic temperature, Plank`s law and emissivity, Wien's displacement law, preparation of emissivity, temperature and thermal inertia images, interpretation of thermal imagery in the context of geological mapping, urban heat island and oil exploration.

Microwave Remote Sensing:
Introduction to microwave, passive and active microwave remote sensing, RADAR technology, SAR interferometry; Interpretation of SAR interferometry images and its applications.

Digital Image Processing:
Introduction to digital image processing, geometric distortion, factors affecting image quality; Projection, mosaic resampling of satellite images, atmospheric correction of satellite data, MODTRAN models, principle component analysis, band ratio (NDVI, NDWI, NDBI) and colour enhancement of images, supervised and unsupervised classification; Introduction to hyperspectral remote sensing using experimentally determined mineral spectra.

Geological Application of Remote Sensing Data:
Digital image processing and satellite imagery for geomorphology, tectonics, coastal and deltaic landforms, monitoring vegetation patterns and desertification, lithology and geological mapping, mineral and oil exploration using LANDSAT, MODIS, ASTER data

Integration of Remote Sensing Data with other Geo-data:

Introduction to GIS, transformation of remote sensing data and other data in GIS format; Preparation of thematic layers from the classified images.

Indian Remote Sensing Program:
Remote sensing program by Indian Space research organization. INSAT, IRS, Oceansat, Resourcesat and Cartosat data and their applications; Future directions.

Suggested Readings:

1. Sabins, F. F., 2007, Remote Sensing: Principles and Interpretation (3rd Edition), Waveland Press.
2. Rencz, A. N., 1999, Remote Sensing for the Earth Sciences- Manual of Remote Sensing (3rd Edition), Vol. 3. Wiley.
3. Gupta, R. P., 2013, Remote Sensing Geology (2nd edition), Springer-Verlag.
4. Jenson, J., 2007, Remote Sensing of the Environment: An Earth Resource Perspective (2nd Edition), Prentice Hall.

EES 609: ADVANCED SCIECNE OF SUSTAINABILITY (4)

Learning Objectives:

This course is to help (i) understand concepts of sustainability, (ii) its trans-disciplinary perspective, (iii) systems thinking, (iv) sustainability indicators and metrics, (v) sustainable development goals, (vi) sustainability assessment andanalysis, (vii) sustainability assessment and analysis methods, (viii) practices in resources management and conservation, (ix) policy and governance for sustainability, (x) sustainable technologies and innovations, (xi) ethical and social dimensions of sustainability, (xii) research methods in sustainability science and (xiii) communicating sustainability science.

Learning Outcomes:
This course will help the students to become equipped with the interdisciplinary skills and insights needed to develop solutions, and tackle sustainable transformation in many sectors. Students will also get familiarized with issues of security, health, climate and environmental change, global sustainability challenges and the interconnected nature of environmental, social, political, and cultural issues, and ultimately gain practical skills and apply academic concepts to real-world challenges.

***Course Contents*:**

Foundations of Sustainability Science:
Introductions to sustainability concepts and principles, systems thinkingand complex adaptive systems, and interdisciplinary approaches to sustainability research

Sustainable development and global challenges:
Overview of global sustainability challenges, sustainable development goals and targets, and social, economic, and environmental dimensions of sustainability

Ecological principles and conservation biology:
Ecological processes and ecosystem dynamics, biodiversity conservation and management, and ecological restoration and ecosystem services

Environmental and natural resources economics:
Economic principles and sustainability, valuation of ecosystem services, market-based instruments for environmental management

Energy and sustainable technologies:
Energy systems and transitions, renewable energy technologies, energy efficiency and conservation

Sustainable water resources management:
Water cycle and hydrological processes, water resource planning andallocation, and water quality and pollution control

Sustainable agriculture and food systems:
Sustainable agricultural practices, food security and resilience, agroecology and sustainable food production

Urban sustainability:
Sustainable urban planning and design, green infrastructure and urban ecosystems, sustainable transportation, and waste management

Social dimensions of sustainability:
Social equity and justice in sustainability, community engagement and participatory approaches, sustainable consumption, and behavior change

Sustainability assessment and indicators:
Sustainability assessment framework, Life cycle assessment andenvironmental impact assessment, Sustainability indicators and metrics

Policy and governance for sustainability:
Environmental governance and policy frameworks, multi-level governance and international agreements, policy implementation and evaluation

Research methodology and tools for sustainability science:
Research design and methods in sustainability science, data collection and analysis techniques, modeling, and simulation approaches.

***Suggested Readings*:**

1. Introduction to Sustainability by Robert Brinkmann and Sandra Zellmer
2. Sustainability Science: An Introduction by Harald Heinrichs, Pim Martens, and Gerd Michelsen
3. Sustainability: A comprehensive foundation by Tom Theis and Jonathon Tomkin
4. Sustainability Science and Engineering: Defining Principles by Martin A Abraham
5. Principles of Sustainability by Margaret Robertson
6. Sustainability: Essentials for Business by Scott T Yound and Katherine C N Smith
7. The Sustainable Learning Community: One University's Journey to the future by John Aber, Tom Kelly, and Bruce Mallory
8. Introduction to sustainable development by Peter P Rogers, Kazi F Jalal and John A Boyd.

EES 615: ADVANCED ENVIRONMENTAL CHEMISTRY (4)

Learning Objectives:

This course is aimed at understanding (i) concepts of environmental chemistry, (ii) environmental fate and transport, (iii) pollutant sources and pathways, (iv) analytical techniques, (v) pollutant monitoring and analysis, (vi) environmentaltoxicology, (vii) environmental regulations and policies, (viii) emerging contaminants, (ix) environmental chemistry modelling, and (x) communicating and collaborating on environmental chemistry issues and its social and environmental impacts.

Learning Outcomes:

After completion of this course students will gain a deeper understanding of the fundamentals of environmental chemistry and all its branches from soil chemistry, aquatic chemistry and atmospheric chemistry to environmental pollution, toxicology, and mitigation. Emphasis on the global aspects related to climate change will empower students to develop problem-solving skills to tackle emerging issues affecting our modern society.

***Course Contents*:**

Introduction to Environmental Chemistry:
Overview of environmental chemistry and its significance, environmental challenges, and concerns

Environmental analytical techniques:
Instrumental methods for chemical analysis in environmental samples, sample preparation and quality control

Chemical equilibrium and thermodynamics:
Equilibrium concepts and calculations, thermodynamic principles in environmental systems, phase equilibria and partitioning

Atmospheric chemistry:
Composition and structure of the atmosphere, pollutant sources, transport and fate, photochemical reactions, and air pollution

Aquatic chemistry:
Properties of water and aqueous solutions, chemical reactions in natural waters, nutrient cycles and eutrophication, Acid-base chemistry, and pH

Soil Chemistry:
Soil composition and properties, adsorption and desorption processes, soil fertility and nutrientmanagement, contaminant fate and remediation in soils

Environmental organic chemistry:
Fate and transport of organic pollutants, sources and pathways of organic contaminants, transformation processes and biodegradation

Environmental toxicology:
Introduction to toxicology and risk assessment, fate and effects of toxic substances in the environment, bioaccumulation and biomagnification

Environmental pollution and control:
Sources and types of pollution, environmental regulations and policies, pollution prevention and control strategies

Emerging topics in environmental chemistry:
Global climate change and greenhouse gases, nanotechnology and its environmental implications, environmental monitoring, and modeling

Research methodology and experimental design:
Scientific research methodologies, experimental design and statistical analysis, data interpretation and presentation, Methods for analysis of water, air, noise, and soil. GIS based spatial distribution of environmental parameters and hazards: temperature, salinity, biomass, floods, toxicwaste, water, organic pollutants, etc., Case study of pollution and presentations.

***Suggested Readings*:**

1. Environmental Chemistry by Colin Baird and Michael Cann
2. Environmental chemistry by Stanley E Manahan
3. Principles of Environmental Chemistry by James E Girard
4. Environmental Chemistry by Gary W VanLoon and Stephen J Duffy
5. Environmental Chemistry: A Global Perspective by Gary W VanLoon and Stephen J Duffy
6. Andrews, J. E., Brimblecombe, P., Jickells, T. D., Liss, P. S., and Reid. B. J., 2004, Introduction to EnvironmentalChemistry, Blackwell Publications.
7. Schlesinger, W. H., 1997, Biogeochemistry: An Analysis of Global Change, Academic Press.
8. Jacobson, M. C., Charlson, R. J., Rodhe, H., and Orians, G. H., 2000, Earth System Science: From BiogeochemicalCycles to Global Change, Elsevier.
9. Sawyer, C. N., McCarty, P. L., and Parkin, G. F., 2003, Chemistry for Environmental Engineering, McGraw-Hill

EES 616: RECONSTRUCTING QUATERNARY CONTINENTAL ENVIRONMENTS AND CLIMATES OF SOUTH ASIA (4)

***Learning Objectives*:**

This course aims to provide an inter-disciplinary perspective to studying past continental sedimentary environments and climates of the Indian Sub-Continent. Going beyond the instrumental records of historical time scales requires the use of proxy data that is embedded in natural archives such as ice cores (glaciers), lake sediments, tree rings, speleothems, and others. Apart from laying the foundations required for understanding multiple approaches to environmental and climate reconstructions of the continental sedimentary record, overviews of the stratigraphy and sedimentation patterns of some selected Quaternary domains of the Indian Sub-continent will be presented. Case histories from the Himalayan Lake sediments and glaciers, Thar Lake sediments, the large river systems of the Indo-Gangetic Plains, speleothems, and treerings shall be used to elucidate the paleo-climatology of the continental records of the South Asian monsoonal regime.

Learning Outcomes:

Students taking this course will become familiarized with the inter-disciplinary tools involved in recreating paleo-environments by utilizing various proxies. By gaining a deeper understanding of the detailed Quaternary sedimentological and stratigraphical record of South Asia, students will be able to identify and utilize various sources of information, essential for erecting an accurate paleo-climatic model.

***Course Contents*:**

Depositional Sedimentary Environments:
Sedimentary Environments, as a product of the complexity of earth surface processes, nature of changing sedimentary record through the Cenozoic, incompleteness of stratigraphic records; Tectonics, climate and eustasy – their role in sediment accumulation; Fluid flow and sediment transport, clastic sediments, sediment routing systems and concepts of sediment connectivity; Carbonate sediments and depositional settings; Lithification and diagenesis; Facies analysis, seismic facies analysis; Sedimentary basins- formation mechanisms and tectonic classification

Reconstruction of Quaternary Paleoclimates:
Overview of climate science; Climate archives, data and models; dating climate records; CO2 and the long-term climate; Orbital scale climate change; Insolation control on monsoons and ice sheets; Deglaciation, Last Glacial maximum (LGM) and climate since last deglaciation; millennial oscillations of climate; Humans and Pre-Industrial climate; Climate change in the last millennium.

Case Histories of Quaternary Climate Reconstructions:
Overview of the Cenozoic Sedimentary basins of India with a focus on Himalayan, Indo-Gangetic Plains (IGP) and Thar Quaternary Sequences; Review of monsoonal history over the last 18000 years; Himalayan lake and Ice core records; Lake records of Thar and its margins; Fluvial and Lake records of the IGP; Millennial scale monsoonal reconstructions from tree rings and speleothem records from the Indian Sub-continent; Inter-regional comparisons of Holocene climate changes in India and other Asian monsoonal systems.

Suggested Readings:

1. Nichols, G., 2009, Sedimentary and Stratigraphy (2nd Edition), Wiley – Blackwell.
2. Prothero, D. R., and Schwab, F., 2014, Sedimentary Geology – An Introduction toSedimentary Rocks and Stratigraphy (3rd Edition), WH Freeman and Company.
3. Jones, N. P., and Jones, B., 2015, Origin of Carbonate Sedimentary Rocks, Wiley.
4. Bradley, R. S., 2015, Palaeoclimatology: Reconstructing Climates of the Quaternary (3rd Edition), Elsevier
5. Ruddimann, W. F., Earth's Climate – Past and Future (3rd Edition), W H Freeman andCompany.

EES 617: ADVANCED SEDIMENTOLOGY AND BASIN ANALYSIS (4)

Learning Objectives:

The primary objectives of this course are to develop a comprehensive understanding of the processes and conditions of sedimentation and diagenesis, and to explore the classification, nomenclature, and terminology of sedimentary rocks and their components. Fieldwork techniques and analytical methods will be covered so that students will develop a critical approach for interpretation of sedimentary data.

Learning Outcomes:

Upon completion of this course, students will deepen their insight and knowledge in topics such as- Interpretation of primary sedimentary structures, facies analysis, provenance and tectonics of sedimentation, carbonate platform and stable isotope compositions from carbonate rocks, tectonic and eustatic controls on sequence development from surface and subsurface data from sedimentary successions etc. Students will get familiarized with analytical techniques used in sedimentary petrology, fieldwork techniques and the interpretation of sedimentary rock textures and structures.

***Course Contents*:**

Review on Sedimentary processes:
Controls on the origin and deposition of siliciclastic and carbonate sediments. Sediment transport mechanisms; Significance of primary sedimentary structures, diagenesis

Facies models and sequence stratigraphy:
Principles and applications, carbonate platforms

Sedimentary Geochemistry:
Geochemical signatures in reconstruction of provenance and tectonics. stable isotopes in sedimentary rocks.

Presentations/Seminars:
Examples of sedimentation history through ages from Indian rock record.

Lab work:
Sedimentary petrography, Determination of Provenance & Tectonics

***Suggested Readings*:**

1. Prothero, D. R., and Schwab, F., 2013, Sedimentary Geology (3rd Edition), Freeman Publishers.
2. Nichols, G., 2009, Sedimentology and Stratigraphy (2nd Edition), Wiley-Blackwell Publication.
3. Boggs, S., 2011, Principles of Sedimentology and Stratigraphy (5th Edition), Prentice Hall.
4. Miall, A. D., 2000, Principles of Sedimentary Basin Analysis (3rd Edition), Springer.
5. Leeder, M. R., 2011, Sedimentology and Sedimentary Basins – From Turbulence to Tectonics, Wiley-Blackwell.
6. Radhakrishnan & Vaidhyanadhan, 2008-2010, Geology of India (v 1 & 2), Geological Society of India

EES 628: INTRODUCTION TO CLIMATE AND CLIMATE CHANGE (4)

***Learning Objectives*:**

This course is designed for UG/PG students to provide with an introductory understanding of climate and climate change. The course is divided into two parts (i) climate system and (ii) climate change. The first part deals with the basic understanding of the climate system. The students will learn what is climate and weather, what is climate system, their characteristics and feedbacks. The course will also cover global and regional nature of climate system. The second part covers what is climate change, what factor cause climate change across different scales and how they interact. What is a climate model and how this tool is used for climate change studies. How climate models, observation and theory can be used to make prediction about future climate and possible consequences of climate.

Learning Outcomes:

Students taking this course will gain advanced knowledge how the climate system of the Earth functions and the factors that affect its short-term and long-term evolution. By emphasizing on the concept of climate change, this course will enable students to better understand the current situation of the global climate change crisis and utilize climate models to foresee future scenarios.

***Course Contents*:**

Introduction to the Climate System:

Definitions, weather and climate, Earth's Atmosphere, Earth' energy budget, role of greenhouse gases in atmosphere, greenhouse effect.

Introduction to General Circulation of Atmosphere:

Different wind types (mesoscale to macroscale, local winds etc), summer and winter monsoons circulation and its onset and withdrawal process, jet streams, ENSO, El-Nino, La-Nina. Effect of ENSO on Indian monsoon.

Introduction to Climate Change:
Observation of temperature trend in last century, natural climate change, anthropogenic climate change, climate feedback mechanism, climate change and global warming, future climate projections, extreme events, uncertainties associated with climate projections.

Introduction to Climate Modelling and Future Scenarios:

Elementary knowledge about climate modelling will be covered. Like its governing equations, how climate model works and their limitations.

Suggested Readings:

1. Essentials of Meteorology: An Invitation to the Atmosphere 7th Edition, Publisher Cengage Learning
2. Handbook of Weather, Climate, and Water: Dynamics, Climate, Physical Meteorology, Weather Systems, and Measurements, DOI: 10.1002/0471721603

EES 641: EARTH SURFACE PROCESSES (4)

***Learning Objectives*:**

The Earth’s surface consists of several interacting morpho-tectonic elements on which the climate system dynamics is superposed. This endogenic-exogenic coupling at different spatio-temporal scales exercises a first order control on the development of the Earth's surface and its gross characteristics. Against this backdrop, large scale physiographic and morpho-tectonic features, weathering and regolith development, sediment routing systems and drainage basins will be explored. Fundamental geomorphic concepts involving relationships between scale, pattern, and process will be introduced. Critical Earth surface processes related to hill-slopes, fluvial, aeolian, costal, and glacial geomorphic settings will be described. Lastly, the importance of human transformations of these process domains during the Anthropocene will be analyzed.

Learning Outcomes:

This course will help students to strengthen their understanding of geomorphological and tectonic processes and how that shapes the surface of the Earth. Upon completion of this course, the students will be able to utilize critical thinking to solve real-world issues related to weathering, drainage patterns, coastal management, glacial morphology etc.

***Course Contents*:**

Introduction to the Earth's Surface:

Sources of energy, energy flows and relative energy of surface processes, mass conservation and geomorphic transport laws (Bretherton Diagram).

Geomorphic Concepts:

Spatial and temporal scales; Hierarchy and multi-scale process, magnitude-frequency concepts; Sensitivity, equilibrium, threshold, equifinality, non-linearity and complexity; Diffusion equation, advection equation and application to modelling of Earth surface process.

Fundamentals of Earth Surface Systems:
Development of large-scale topography and its role in Earth surface processes; Tectonics-climate coupling; Weathering rates and the Critical Zone processes; Bedrock to sediment routing systems; Quantitative characteristics of drainage basins, sediment, and solute fluxes in drainage basins; Sediment yield and landscape models.

Specific Earth Surface Processes:

Hill slopes and catchment erosion processes; Fluvial, aeolian and coastal processes and landforms; Complexity of large riversystems.

Geosphere and Cryosphere processes:

Polar ice sheets, Himalayan cryosphere, ice melt dynamics, spatio-temporal considerations, glacial and periglacial processes, thermal structure, climate change impacts on the cryosphere.

The Anthropocene:

Human transformations of Earth; Atmosphere-Geosphere-Biosphere interactions, concept of Anthropocene and human impacts on oceans, rivers, and terrestrial biosphere.

Suggested Readings:

1. Anderson, R. S., and Anderson, S. P., 2010, Geomorphology: The Mechanics and Chemistry of Landscapes, Cambridge University Press.
2. Allen, P. A., 1997, Earth Surface Processes, Blackwell Publishing.
3. Pelletier, J., 2008, Quantitative Modeling of Earth Surface Processes, Cambridge University Press.
4. Summerfield, M. A., 2012, Global Geomorphology (2nd Revised Edition), Prentice Hall.
5. Wilcock, P. R., and Iverson, R. M., 2003, Prediction in Geomorphology, AGU Publications

EES 643: STRUCTURAL GEOLOGY AND CRUSTAL DEFORMATION (4)

***Learning Objectives*:**

This course is designed to understand the natural processes by which geological structures were developed in the lithosphere. Study of geologic structures provides the information necessary to understand the deformational history of rocks and regions from the micro-scale to the scale of tectonic plates.

Learning Outcomes:

After completion of the course, students will develop the skills necessary to recognize complex geological structures, and will gain an appreciation of analyzing the various deformational patterns of the lithosphere.

***Course Contents*:**

Introduction:

Structure of the course; Introduction to structural geology and tectonics; Interior of the Earth and other planetary bodies; Earth's crust and plate tectonics; Structure of the continental crust.

Stress and Strain:

Stress - definitions, different types of stress tensors, two- and three-dimensional stress, Mohr's diagram for graphical analysis of stress; Strain - definitions, measurement of strain, Mohr's diagram for strain calculation, rheology of rocks and minerals; Concept of brittle and ductile deformation.

Rock Failure:

Fracturing, Mohr-Coulomb criteria for rock failure, classification for fractures, geometry of fracture systems in three dimensions, microscopic features of fractured surfaces, effect of confining pressure on fracturing and frictional sliding, Griffith theory of fracture, deduction of fluid pressure from dykes and quartz veins.

Faults:

Different types of faults, recognition of faults, measurement of fault displacements, fault geometry, orientation of stress fields and fault kinematics, paleostress from the fault slip data, fault bend folds, fault propagation folds.

Folding:

Geometric descriptions and classification of folds, fold scale and attitude, the element of fold styles, order of folding, common styles and structures associated with folding.

Kinematics of Folding:

Folding mechanisms, buckling and shear folding of single layers, multilayer folding, formation of kink and Chevron fold.

Foliation and Lineation in Deformed Rocks:

Different types of foliations - compositional, disjunctive, crenulation and continuous; Lineation - structural and mineral, association of lineation and other structures.

Microscopic Aspects of Ductile Deformation:

Mechanisms of low temperature deformation, twin gliding, diffusion and solution creep, linear crystal defects; Microscopic criteria for identification of dislocation and diffusion creep.

Shear Zone and Progressive Deformation:

The nature of shear zone, mechanism of formation of shear zone, strain in shear zone, determining the sense of shear in shear zone, active tectonics.

Structural Geology and Plate Tectonics:

Introduction to plate tectonics, different types of tectonic boundaries, development of structures at active plate margins.

Suggested Readings:

1. Twiss, R. J., and Moores, E. M., 2007, Structural Geology (2nd Edition), W. H. Freeman and Company.
2. Ghosh, S. K., 1993, Structural Geology Fundamentals and Modern Developments (1st Edition), Pergamon Press.
3. Davis, H., Reynolds, S. J., and Kluth, F. C., 2012, Structural Geology of Rocks and Regions (3rd Edition), Wiley.
4. Jain, A. K., 2014, An Introduction to Structural Geology (1st Edition), Geological Society of India.

EES 645: REMOTE SENSING AND GIS LABORATORY (4)

***Learning Objectives*:**

Satellite remote sensing is a powerful tool to acquire information about the surface of any object. Thus, the information obtained through satellite imagery can be used for geological mapping, monitoring of natural resources and climate and weather prediction. In this course, the theory of electromagnetic radiation, principles of spectroscopy, data acquisition systems will be discussed in details. Emphasis will be given on the different image processing techniques and preparation of digital maps from the satellite data.

Learning Outcomes:

Upon completion of this course, students will learn the many powerful tools and techniques of remote sensing and GIS, to apply in real-world problem solving. Hands-on experience in software such as ArcGIS will equip the students to venture into inter-disciplinary fields to tackle various issues related to earth and environmental science.

***Course Contents*:**

Introduction:

Structure of the course, development of remote sensing techniques, fundamental principles, advantage, and limitations of remote sensing.

Electromagnetic Radiation:

The nature, principle and sources of electromagnetic radiation, the blackbody radiation, the electromagnetic spectrum, energy available for remote sensing, atmospheric window for remote sensing.

High Altitude Photography:
Interaction between light and matter, color science, film technology; Aerial photography - vertical and oblique photography.

Spectroscopy of Rocks and Minerals:

Introduction, basic principles of spectroscopy, electronic process and vibrational processes, spectral reflectance of minerals.

Multispectral Digital Imaging System:
Introduction to digital images, imaging sensors and tubes, optical mechanical line scanner, CCD linear array scanner, digital camera, description of space borne image sensors.

Thermal Remote Sensing:
The Earth`s radiant energy, surface, radiant temperature and kinetic temperature, Planck’s law and emissivity, interpretation of thermal imagery.

Microwave Remote Sensing:
Introduction to microwave, passive and active microwave remote sensing, RADAR technology,

interferometry.

Remote Sensing based on Gravity:
Gravity of Earth and other planetary bodies, GRACE mission; Space borne gravity data for hydrology, geodesy, and solid Earth science.

Distortion and Quality of Photographs and Images:

Geometric distortion, distortions related to a) sensors, b) spacecraft, c) Earth's rotation; Factors affecting image quality; Projection, mosaic resampling of satellite images.

Digital Image Processing of Satellite Images:

Introduction to digital image processing, radiometric and geometric corrections; Principle component analysis, band ratio and colour enhancement of images.

Geological Application of Remote Sensing Data:
Digital image processing and satellite imagery for geomorphology, tectonics, coastal and deltaic landforms, monitoring vegetation patterns and desertification, lithology and geological mapping, mineral and oil exploration.

Environmental Application of Remote Sensing Data:

Detailed description of SPOT and JERS images; Geobotany, geohydrology and water quality using remote sensing data; Remote sensing of the atmosphere.

Integration of Remote Sensing Data with other Geo-data:

Introduction to GIS, transformation of remote sensing data and other data in GIS format.

Indian Remote Sensing Program:
Remote sensing program by Indian Space Research Organization; INSAT, IRS, Oceansat, Resourcesat and Cartosat data and their applications; Future directions.

Suggested Readings:

1. Sabins, F. F., 2007, Remote Sensing: Principles and Interpretation (3rd Edition), Waveland Press.
2. Rencz, A. N., 1999, Remote Sensing for the Earth Sciences: Manual of Remote Sensing (3rd Edition), Wiley.
3. Gupta, R. P., 2013, Remote Sensing Geology (2nd Edition), Springer-Verlag.
4. Jenson, J., 2007, Remote Sensing of the Environment: An Earth Resource Perspective (2nd Edition), Prentice Hall.

EES 647: DATA ANALYSES AND STATISTICS FOR GEOSCIENCES (4)

***Learning Objectives*:**

This course will introduce the various data analysis tools, discuss the mathematical background behind these tools, and illustrate the choice and application of these tools in the analyses of geoscience data.

Learning Outcomes:

This course will help develop critical thinking skills, particularly in the use of quantitative data across different temporal and spatial scales.

***Course Contents*:**

Statistics and Data Analyses:
Description of data, directional data - circular data, spherical data; Vector and matrix notation, probability theory, probability distributions – common discrete and continuous distributions; Statistical concepts and paradigms, samples versus the population; Normality and error analysis, exploratory data analysis, estimation, bias, causes of variance.

Estimation and Hypothesis Testing on Means and other Statistics:
Introduction, independence of observations; Central limit theorem; Sampling distributions, t-distribution, confidence interval estimates on a mean, confidence intervalon the difference between means, hypothesis testing on means, Bayesian hypothesis testing; Nonparametric hypothesis testing, Bootstrap hypothesis testing on means; Testing multiple means via analysis of variance, multiple comparisons of means, nonparametric ANOVA; Paired data; Kolmogorov-Smirnov goodness-of-fit test.

Statistical Modelling:

Introduction, Steps in statistical modelling, model assumptions, designed experiments, replication.

Regression:

Correlation and covariance, simple linear regression, multiple regression, other regression procedures; Nonlinear models.

Multivariate Analyses:

Multivariate graphics; Principal component analyses; Factor analyses; Cluster analyses; Discriminant analyses.

Design of Experiments:

Sampling designs; Design of experiments; Field studies and design; Missing data.

Time Series:

Time Domain; Frequency Domain; Wavelets; Auto regressive model (AR1) and persistence.

Spatial Statistics:

Three-dimensional data visualization; Spatial association, the effect of trend; Semi-variogram models, Kriging, space-time models.

Suggested Readings:

1. Schuenemeyer, J., and Drew, L., 2001, Statistics for Earth and Environmental Scientists, Wiley.
2. Emile-Geay, J., 2014, Data analyses in the Earth Environmental Sciences, E-book accessible via http://dx.doi.org/10.6084/m9.figshare.1014336.
3. Ross, S. M., 2004, Introduction to Probability and Statistics for Engineers and Scientists, Elsevier.
4. Davis, J. C., 1986, Statistics and Data Analyses in Geology, John Wiley.

Hardle W., 2003, Applied Multivariate Statistical Analysis, Sprin