Term Information

Effective Term	Autumn 2023

General Information

Course Bulletin Listing/Subject Area	Earth Sciences
Fiscal Unit/Academic Org	School of Earth Sciences - D0656
College/Academic Group	Arts and Sciences
Level/Career	Graduate, Undergraduate
Course Number/Catalog	5757
Course Title	Artificial Intelligence in Earth Sciences
Transcript Abbreviation	AI in Earth Sci
Course Description	Develop an understanding of the current state-of-the-art in Artificial Intelligence (AI), Machine/Deep Learning (ML/DL) as applied in the Earth Sciences and Geodesy; code ML problems in Python, using Jupyter notebooks.
Semester Credit Hours/Units	Fixed: 3

Offering Information

Length Of Course	14 Week, 12 Week, 8 Week, 7 Week
Flexibly Scheduled Course	Never
Does any section of this course have a distance education component?	No
Grading Basis	Letter Grade
Repeatable	No
Course Components	Laboratory, Lecture
Grade Roster Component	Lecture
Credit Available by Exam	No
Admission Condition Course	No
Off Campus	Never
Campus of Offering	Columbus, Lima, Mansfield, Marion, Newark, Wooster

Prerequisites and Exclusions

Prerequisites/Corequisites	Math 1152; or Grad standing; or permission of instructor.
Exclusions	
Electronically Enforced	Yes

Cross-Listings

Cross-Listings	

Subject/CIP Code

Subject/CIP Code	40.0601
Subsidy Level	Doctoral Course
Intended Rank	Junior, Senior, Masters, Doctoral, Professional

Requirement/Elective Designation

The course is an elective (for this or other units) or is a service course for other units

Course Details

Course goals or learning objectives/outcomes

- Students will learn the current state-of-the-art in Artificial Intelligence (AI), Ma- chine/Deep Learning (ML/DL) as applied in Earth Sciences and Geodesy (2 hrs/week), and how to code ML problems in Python, using Jupyter notebooks (2 hrs/week).

Content Topic List

- Jupyter notebooks and Python basics, e.g., loading modules, working with arrays, common functions, plotting of figures.
- Univariate linear regression in Earth Sciences.
  Multivariate linear numerical regression in Earth Sciences..
  Classification by logistic regression in Earth Sciences.
- Overview of other supervised Machine Learning algorithms.
  Artificial Neural Networks (ANN).
  Remote sensing with satellite data.
  Convolutional Neural Networks (CNN) to classify satellite imagery.
- Overview of existing publicly available data products relevant to Earth Sciences and Geodesy.
  Fully Convolutional Neural Networks for Satellite Image Segmentation.

Sought Concurrence

No

Attachments

- EARTHSC 5757 Artificial Intelligence in Earth Sciences.docx: syllabus
  (Syllabus. Owner: Griffith,Elizabeth M)
- CURRICULAR MAP OF COURSES BS - updated with 5757.docx: curriculuar map for BS
  (Other Supporting Documentation. Owner: Griffith,Elizabeth M)

Comments

Workflow Information

Status	User(s)	Date/Time	Step
Submitted	Griffith,Elizabeth M	02/01/2023 06:13 AM	Submitted for Approval
Approved	Griffith,Elizabeth M	02/01/2023 06:13 AM	Unit Approval
Pending Approval	Vankeerbergen,Bernadette Chantal	02/01/2023 06:13 AM	College Approval

Artificial Intelligence in Earth Sciences

EARTHSC 5757, Fall 2023, 3 credit hrs
Time: Tue (lecture) & Thur (lab) 9.20 - 11.10 am
Location: Kresge Computer Lab, Mendenhall 356

Professor: Joachim Moortgat
Associate Professor
School of Earth Sciences
Office: Mendenhall Lab 303
Email: moortgat.1@osu.edu
Office hours: Thus 12.00 -- 2.00 pm

Catalog Description: Develop an understanding of the current state-of-the-art in Artificial Intelligence (AI), Machine/Deep Learning (ML/DL) as applied in the Earth Sciences and Geodesy; code ML problems in Python, using Jupyter notebooks.

Prerequesites: Math 1152; or Grad standing; or permission of instructor.

Course Overview & Goals

You will learn the current state-of-the-art in Artificial Intelligence (AI), Ma- chine/Deep Learning (ML/DL) as applied in Earth Sciences and Geodesy (2 hrs/week), and how to code ML problems in Python, using Jupyter notebooks (2 hrs/week).

Background and Course Content

Artificial Intelligence (AI), which encompasses Machine Learning (ML) and Deep Learning (DL), has revolutionized Big Data analytics, from Recommender Engines (think Netflix) to Natural Language Processing and Computer Vision as some of the most successful applications. Initially developed by some of the best computer scientists, many of these algorithms have matured and are available as open-source software with relatively easy-to-use interfaces. As a result, AI tools are increasingly adopted in the Sciences as well, where they will undoubtedly have equally consequential impacts.

In Earth and Geodetic Sciences, the simplest problems that take advantage of machine learning algorithms (in a broad sense) are simply the fitting of laboratory or field data to linear or non-linear models of one or more independent variables (say, how water, gas, or oil molar compositions vary as a function of temperature and pressure, or how seismic wave velocities depend on multiple rock and fluid properties). More interesting deep learning algorithms will change how we analyze the wide range of imagery that Earth Scientists work with. Instead of manually counting, e.g., grain-size-distributions, or identifying different mineral facies or types of fossils in (thin section) rock samples, or even (drone or regular camera) imagery of entire outcrops, computer vision algorithms can automate these processes, allowing for much larger datasets and thus more robust analyses.

Perhaps the Biggest Data that Earth Scientists and Geodesists work with are (climate models and) satellite images. When your professors were still (under)graduate students, the bottle- neck in advancing certain Earth Science and Geodesy problems would have been the lack of sufficient satellite imagery. For your generation, taming the truly mindboggling amounts of satellite data may be the bigger challenge. The School of Earth Sciences, and thus you, has access to petabytes of data from dozens of satellites, both commercial and publicly accessible. These range from extremely high resolution panchromatic ('grayscale' at ~ 40 cm) and multispectral (≥ 1 m) optical, to (interferometric) Synthetic Aperture Radar, gamma-ray, LIDAR, gravity, and magnetic field data. Automatically identifying various Earth Surface (and even sub-surface) Features, such as surface- and groundwater, snow, ice, forests, subsidence, continental motions, fires, coral health, you name it, and tracking those features over time at up-to global scales benefits tremendously from the latest state-of-the-art in AI and is often impossible without it.

Advanced deep learning (DL) algorithms are very powerful indeed, but with great power comes great responsibility. It can be notoriously difficult to interpret how and what exactly a DL model learns. The aforementioned easy-to-used pre-packaged software may perform, e.g., certain pre- or post-processing operations that a user may not be aware of. There is a risk in using such tools as a 'Black Box', and whenever one uses a back-box one has to worry about the scientific principle of 'garbage in, garbage out'. Because this is a higher-level course, it is important that you develop a deep understanding of how these tools work, not unlike having to properly appreciate the workings and limitations of a lab instrument before using it for scientific analyses.

In the first half of this course, we will therefore break down each fundamental ML algorithm to just basic linear algebra. In fact, you will learn how to program these algorithms yourself in hands-on lab sessions (more on that below). Once we have built up this solid foundation, you can choose to switch back-and-forth between your own ML codes or pre-packaged routines that are potentially more optimized/faster. Also, for the most complex fully convolutional deep neural networks for computer vision, you will understand and code the basic building blocks, but use convenient APIs (e.g., Tensorflow, Keras) to construct different neural networks for different applications.

Course Format and Reading Materials

Most weeks will consist of a lecture that covers theory and plenty of hands-on coding practice. Python has become the *de facto* standard language for most AI/ML/DL and data analytics applications. It is open source / free and has innumerable pre-packaged tools available. Interestingly, in recent years, a wide range of job advertisements have started to ask about Python proficiency. For all these reasons, lectures and labs will be based on

Python. No prior Python experience is assumed and even if you are already proficient in, e.g., Matlab, developing Python coding skills can only be helpful for your future careers.

To hit the ground running, we will use Google's free [Colaboratory environment](), which allows you to write and execute your codes on google's cloud compute hardware. By using this approach, you can work on codes from any computer without having to worry about hardware specs (CPU, GPU, RAM) or installing lots of Python packages yourself. More specifically, we will use Jupyter notebooks, which are an elegant way to blend code with marked-up text and interactive codes and figures, as shown below. All lecture and lab notes will be fully interactive Jupyter notebooks in which you can manipulate every line of code and see what happens, accompanied by detailed explanatory text. These notebooks are fully self-contained and comprehensive, with no additional textbooks or readings required.

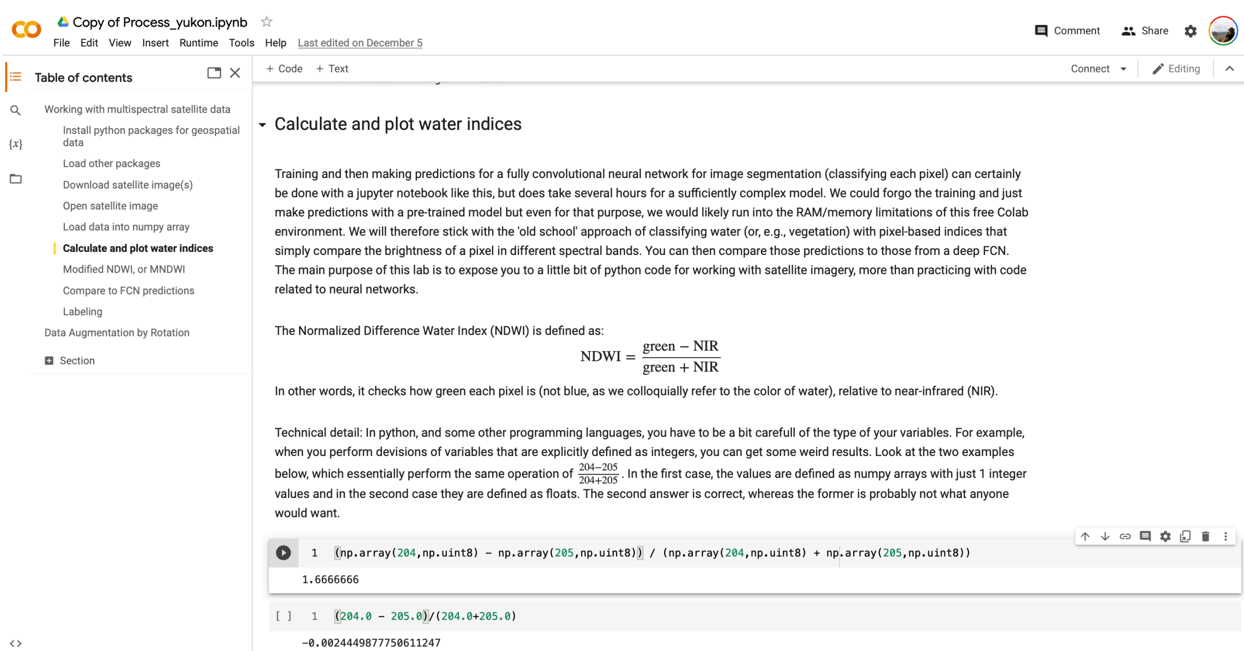

Figure 1: Illustration of a Jupyter notebook running Python code and LaTeX formatted markup.

Finally, you will also learn how to use OSU's Unity cluster to access more storage, memory, and compute power than available with a free Colab account. That way, you can access, e.g., satellite data that is already stored on Unity and train larger deep neural networks.

The hands-on lab sessions consist of Jupyter notebooks that include many steps early on but assume increasing levels of Python skills as the semester progresses. Some of the labs are a friendly competition of who can come up with the best machine learning model for a given problem. Most weeks, you will upload these lab assignments as Jupyter notebooks to Carmen/Canvas to be individually graded as pass/fail. In the final weeks, you will propose and work on a problem that is relevant to your own research/studies/career. In the last week of the semester, each student will give a 10-minute presentation of their project and upload the corresponding data and codes to Carmen/Canvas.

Course Grading

1. 80% Weekly Jupyter notebooks of lab assignments.
2. 20% Individual final project.
3. 10% Bonus for attendance (simple fraction of class sessions attended).

Letter grades correspond to the following percentages:

A: 93-100	B+: 87-89	C+: 77-79	D+: 67-69
A-: 90-92	B: 83-86	C: 73-76	D: 60-66
	B-: 80-82	C-: 70-72	E: < 60

Grades will be curved if the course median score drops below 80%.

Course Policies

Academic and Personal Integrity

It is the responsibility of the Committee on Academic Misconduct to investigate or establish procedures for the investigation of all reported cases of student academic misconduct. The term "academic misconduct" includes all forms of student academic misconduct wherever committed; illustrated by, but not limited to, cases of plagiarism and dishonest practices in connection with examinations. Instructors shall report all instances of alleged academic misconduct to the committee (Faculty Rule 3335-5-487). For additional information, see the Code of Student Conduct: http://studentaffairs.osu.edu/csc.

Students with Disabilities

The Americans with Disabilities Act (ADA) is a federal anti-discrimination statute that provides comprehensive civil rights protection for persons with disabilities. Among other things, this legislation requires that all students with disabilities be guaranteed a learning environment that provides for reasonable accommodation of their disabilities. If you believe you have a disability requiring accommodation, please contact me privately to discuss your specific needs. For additional information, visit http://ods.osu.edu.

Diversity Statement

As your instructor in this course, I most strongly support:

The Ohio State University affirms the importance and value of diversity in the student body. Our programs and curricula reflect our multicultural society and global economy and seek to provide opportunities for students to learn more about persons who are different from them.

We are committed to maintaining a community that recognizes and values the inherent worth and dignity of every person; fosters sensitivity, understanding, and mutual respect among each member of our community; and encourages each individual to strive to reach his or her own potential. Discrimination against any individual based upon protected status, which is defined as age, color, disability, gender identity or expression, national origin, race, religion, sex, sexual orientation, or veteran status, is prohibited.

If you experience any lack of respect in this context either by myself or any of your fellow students, please do not hesitate to reach out to me or a neutral party (e.g. the Office of Diversity and Inclusion: odi@osu.edu). Also, if you have a name and/or set of pronouns that differ from those apparent to me on Carmen, please let me know!

Mental Health

As a student you may experience a range of issues that can cause barriers to learning, such as strained relationships, increased anxiety, alcohol/drug problems, feeling down, difficulty concentrating and/or lack of motivation. These mental health concerns or stressful events may lead to diminished academic performance or reduce a student's ability to participate in daily activities.

The Ohio State University offers services to assist you with addressing these and other concerns you may be experiencing. If you or someone you know are suffering from any of the aforementioned conditions, you can learn more about the broad range of confidential mental health services available on campus via the Office of Student Life's Counseling and Consultation Service (CCS) by visiting ccs.osu.edu or calling 614-292-5766. CCS is located on the 4th Floor of the Younkin Success Center and 10th Floor of Lincoln Tower. You can reach an on-call counselor when CCS is closed at 614-292-5766 and 24-hour emergency help is also available through the 24/7 National Suicide Prevention Hotline at 1-800-273-TALK or at suicidepreventionlifeline.org.

Course Schedule

Week 1, August

Introduction and creating your Colab and Unity (OSU cluster) accounts.

Week 2, September

Jupyter notebooks and Python basics, e.g., loading modules, working with arrays, common functions, plotting of figures.

Week 3, September

Univariate linear regression. Numerical regression is the process of fitting a linear or nonlinear (next week) function of one or more variables to measurements / observations.

- Nomenclature: Features, targets, cost, cost function and cost gradient
- (Batch) Gradient Descent method
- Stochastic Gradient Descent
- Mini-Batch Gradient Descent
- Learning rates & learning curves

Lab: Use linear regression algorithms to model effects of precipitation on isotopic composition of rivers in Central Ohio and compare to Global Meteoric Water Line.

Week 4, September

Multivariate linear numerical regression.

Lab: Explore multivariate linear regression for large Earth Sciences dataset. Gentle introduction to feature engineering.

Week 5, September

Multivariate non-linear numerical regression.

Lab: Use multivariate non-linear numerical regression to predict missing geophysical well-logs from other existing ones, as used in the search for gas hydrates in seafloor sediments.

Week 6, September

Classification by logistic regression. Univariate and multi-variate, linear and non-linear.

Lab: Classify coral species based on morphological features.

Week 7, October

Nuts and bolts: machine learning algorithms generally require a pipeline of data pre- and post-processing. This week and the next you will learn a lot of additional concepts and how they all fit together.

Lab: Apply the aforementioned concepts to improve a pipeline for the non-linear multivariate regression problem from Week 5 regarding geophysical well logs.

Week 8, October

- Feature scaling,
- Feature selection,
- Ridge and Lasso regression,
- Categorical variables,
- One-hot encoding,

Lab: Explore Ridge and Lasso Regression

Fall break

Week 9, October

Brief overview of other supervised Machine Learning algorithms, such as

- Decision Trees,
- Random Forests,
- Support Vector Machines,
- K-Nearest-Neighbors.

Lab: Compare several of the aforementioned ML algorithms to a non-linear numerical regression for geophysical data problem.

Week 10, October

Artificial Neural Networks (ANN).

Lab: Explore basic linear algebra implementation of an ANN and apply to a computer vision problem, classifying Earth Science thin-section images.

Week 11, November

Remote sensing with satellite data

Lab: Getting started with satellite imagery in Python. Running Jupyter notebooks on OSU's Unity cluster.

Week 12, November

Convolutional Neural Networks (CNN) to classify satellite imagery. Overview of existing publicly available data products relevant to Earth Sciences and Geodesy.

Lab: Opening, pre-processing, and analyzing multispectral high-resolution satellite imagery. Compute (Modified) Normalized Difference Water Index and other indices (for vegetation etc.), compare to classification results by state-of-the-art fully convolutional neural networks.

Week 13, November

Fully Convolutional Neural Networks for Satellite Image Segmentation.

Continue labs from last week.

Week 14, November

Propose and discuss individual ML projects

Lab: Work on individual ML projects

Thanksgiving break.

Week 15, December

Lab: Work on individual ML projects

Week 16, December

Presentations of individual ML projects.

CURRICULAR MAP OF COURSES AVAILABLE IN EARTH SCIENCES B.S.

Course Number	Course Title	PLO A: Read/ evaluate Earth Sci literature	PLO B: Present Earth Sci info	PLO C: Apply Earth Sci data	PLO D: Apply appropriate techniques/ methods	PLO E: Identify Earth Sci problems, develop solutions	PLO F: Apply other sciences	BS program required /elective
Earth Sciences 1100	Planet Earth: How it works	B	B	B	B	B	B	O-prep
Earth Sciences 1105	Geology of the National Parks	B	B	B		B	B	O-prep
Earth Sciences 1108	Gemstones	B	B	B		B	B	O-prep
Earth Sciences 1121	The Dynamic Earth	B	B	B	B	B	B	O-prep
Earth Sciences 1151	Natural Hazards	B	B	B	B	B	B	O-prep
Earth Sciences 2203	Environmental Geoscience	B	B	B		B	B	O-prep
Earth Sciences 2205	The Planets	B	B	B		B	B	O-prep O-PS
Earth Sciences 2206(&S)	Principles of Oceanography	B	B	B		B	B	O-prep O-SS
Earth Sciences 1200	Introductory Earth Science Lab		B	B	B	B	B	O-prep
Earth Sciences 2000	Preparation for Thesis and Careers in the Earth Sciences	B-I	B-I	B-I		B-I		R-GS R-GP R-CWE
Earth Sciences 2122	Climate and Life over Billions of years on Earth	B-I	B-I	B-I	B-I	B-I		O-SS R-GS
Earth Sciences 2155	Energy and Environment	B-I	B-I	B-I	B-I	B-I		O-SS
Earth Sciences 2203	Environmental Geoscience	B-I	B-I	B-I	B-I	B-I		O-SS
Earth Sciences 2204	Exploring Water Issues	B-I	B-I	B-I	B-I	B-I		O-SS
Earth Sciences 2210	Energy, Mineral Resources, and Society	B-I	B-I	B-I	B-I	B-I		O-SS
Earth Sciences 2212	Intro to Earth Materials	B-I	B-I	B-I	B-I	B-I		O-CWE
Earth Sciences 3411	Water Security for the 21st Century	I	I	I	I	I		O-SS

Earth Sciences 2245	Introductory Data Analysis for Earth and Environmental Sciences	B-I	B-I	B-I	B-I	B-I		R-GS R-CWE R-GP
Earth Sciences 4194	Group Studies	I	I	I	I	I	I	
Earth Sciences 4194H	Honors Group Studies	I	I	I	I	I	I	
Earth Sciences 5310	Remote Sensing in the Earth Sciences	A	A	A	A		A	O-GP O-PS O-MS
Earth Sciences 4421	Earth Materials	I	I	I	I	I	I	R-GS O-CWE O-CWE O-MC
Earth Sciences 4423	Introductory Petrology	I	I	I	I	I	I	R-GS O-MC
Earth Sciences 4425	Energy Resources and Sustainability	I	I	I	I	I	I	O-SS
Earth Sciences 4450	Water, Ice, and Energy in the Earth System	I	I	I	I	I	I	R-CWE O-MS O-HG
Earth Sciences 4501	Paleontology	I	I	I	I	I	I	O-MC
Earth Sciences 4502	Stratigraphy and Sedimentation	I	I	I	I	I	I	R-GS O-CWE O-MC
Earth Sciences 4530	Structural Geology	I	I	I	I	I	I	R-GS R-GP
Earth Sciences 4560	Applied Geophysics	I	I	I	I	I	I	R-GP O-PS O-PG
Earth Sciences 4880	Seminar in Geophysics	I	I	I	I	I	I	
Earth Sciences 4998	Undergraduate Research in Earth Sciences	I - A	I - A	I - A	I - A	I - A	I - A	
Earth Sciences 4998H	Honors Undergraduate Research in Earth Sciences	A	A	A	A	A	A	
Earth Sciences 4999.01	Undergraduate Thesis in Earth Sciences	I - A	I - A	I - A	I - A	I - A	I - A	R-GS R-CWE R-GP
Earth Sciences 4999.01H	Honors Undergraduate Thesis in Earth Sciences	A	A	A	A	A	A	
Earth Sciences 5189.01	Field Geology I	I - A	I - A	I - A	I - A	I - A	I - A	R-GS R-PG O-MC

Earth Sciences 5189.02	Field Geology II	A	A	A	A	A	A	R-GS O-PG
Earth Sciences 5191	Internship in the Earth Sciences	I - A	I - A	I - A	I - A	I - A	I - A	
Earth Sciences 5191.01	Museum Internship	A	A	A	A	A	A	
Earth Sciences 5193.xx	Individual Studies	I - A	I - A	I - A	I - A	I - A	I - A	
Earth Sciences 5194	Group Studies	I - A	I - A	I - A	I - A	I - A	I - A	
Earth Sciences 5203	Geo-environment and Human Health	A	A	A	A	A	A	O-CWE O-HG
Earth Sciences 5205	Planetary Science	A	A	A	A	A	A	R-PS
Earth Sciences 5206	Advanced Oceanography	A	A	A	A	A	A	R-MS O-CWE
Earth Sciences 5268	Soils and Climate Change	A	A	A	A	A	A	O-CWE O-HG
Earth Sciences 5501	Museum Databases	A	A	A	A	A	A	O-MC
Earth Sciences 5550	Geomorphology	I-A	I-A	I-A	I-A	I-A	I-A	O-PS O-HG
Earth Sciences 5600	Siliciclastic Depositional Systems	A	A	A	A	A	A	
Earth Sciences 5601.01	Sedimentary Petrology: Sandstones	A	A	A	A	A	A	
Earth Sciences 5601.02	Sedimentary Petrology: Carbonate Rocks and Shales	A	A	A	A	A	A	
Earth Sciences 5602.01	Carbonate Depositional Systems I	A	A	A	A	A	A	
Earth Sciences 5602.02	Carbonate Depositional Systems II	A	A	A	A	A	A	O-MS
Earth Sciences 5603	Stratigraphy	A	A	A	A	A	A	
Earth Sciences 5604	Sequence Stratigraphy	A	A	A	A	A	A	
Earth Sciences 5605	Paleoceano graphy	A	A	A	A	A	A	
Earth Sciences 5613	Micropaleon tology	A	A	A	A	A	A	
Earth Sciences 5614	Paleobiology	A	A	A	A	A	A	
Earth Sciences 5615	Paleoecology	A	A	A	A	A	A	

Earth Sciences 5617	Petrology of Earth and Planets	A	A	A	A	A	A	
Earth Sciences 5618	Advanced Historical Geology	A	A	A	A	A	A	
Earth Sciences 5621	Introduction to Geochemistry	A	A	A	A	A	A	O-CWE O-HG
Earth Sciences 5622	Stable Isotope Biogeo chemistry	A	A	A	A	A	A	O-MS
Earth Sciences 5625	Igneous Petrology	A	A	A	A	A	A	
Earth Sciences 5627	Global Biogeochemical Cycles	A	A	A	A	A	A	
Earth Sciences 5628	Environmental Isotope Geochemistry	A	A	A	A	A	A	
Earth Sciences 5629	Principles of Petrology	A	A	A	A	A	A	
Earth Sciences 5636	Advanced Topics in Mineralogy and Crystallography	A	A	A	A	A	A	
Earth Sciences 5641	Geostatistics	A	A	A	A	A	A	O-GP
Earth Sciences 5642	Geomathe matical Analysis	A	A	A	A	A	A	
Earth Sciences 5644	Tectonic Evolution of Continents	A	A	A	A	A	A	
Earth Sciences 5645	Advanced Structural Geology	A	A	A	A	A	A	
Earth Sciences 5646	Geodynamics	A	A	A	A	A	A	O-GP O-PS
Earth Sciences 5650	Glaciology	A	A	A	A	A	A	O-CWE
Earth Sciences 5651	Hydrogeology	A	A	A	A	A	A	O-CWE O-GP R-HG
Earth Sciences 5655	Land Surface Hydrology	A	A	A	A	A	A	O-CWE O-HG
Earth Sciences 5660	Geology of Metallic Deposits	A	A	A	A	A	A	
Earth Sciences 5661	Petroleum Geology	A	A	A	A	A	A	O-PG
Earth Sciences 5663	Global Change and Sustainability in the Earth System	A	A	A	A	A	A	O-SS
Earth Sciences 5670	General and Economic Geology of Selected Areas	A	A	A	A	A	A	

Earth Sciences 5676	Elemental Chemical Analysis using Inductively Coupled Plasma Optical Emission and Mass Spectrometry	A	A	A	A	A	A	
Earth Sciences 5680	Deep Earth Geophysics	A	A	A	A	A	A	O-GP O-PS
Earth Sciences 5687	Borehole Geophysics	A	A	A	A	A	A	O-GP O-PG
Earth Sciences 5703	Principles of Biostratigraphy	A	A	A	A	A	A	
Earth Sciences 5713	Taxonomy and Phylogeny in the Fossil Record	A	A	A	A	A	A	
Earth Sciences 5714	Biometry	A	A	A	A	A	A	
Earth Sciences 5717	Critical Issues in World Freshwater Resources	A	A	A	A	A	A	
Earth Sciences 5718	Aquatic Geochemistry	A	A	A	A	A	A	
Earth Sciences 5719	Environmental Organic Geochemistry	A	A	A	A	A	A	
Earth Sciences 5746	Seminar in Rheological Properties of Solids	A	A	A	A	A	A	
Earth Sciences 5751	Quantitative Ground-Water Flow Modeling	A	A	A	A	A	A	O-PG O-HG
Earth Sciences 5752	Contaminants in Aqueous Systems	A	A	A	A	A	A	
Earth Sciences 5754	Risk Assessment and Management in Earth Systems	A	A	A	A	A	A	
Earth Sciences 5757	Artificial Intelligence in Earth Sciences	A	A	A	A	A	A	O-GP
Earth Sciences 5779	Seminar in Physical Properties of Minerals and Rocks	A	A	A	A	A	A	
Earth Sciences 5780	Reflection Seismology	A	A	A	A	A	A	O-MS O-PG
Earth Sciences 5781	Gravity Exploration	A	A	A	A	A	A	
Earth Sciences 5782	Magnetic Exploration	A	A	A	A	A	A	

Geod Sci 5781	Geodesy and Geodynamics	A	A	A	A	A	A	O-GP O-PS
Electives from other departments (Geog, AtmosSC, EEOB, ENR, Chem, Math, etc.)							I-A	

<u>Program Learning Goals:</u>
A) Students critically read and evaluate Earth Science literature

B) Students present Earth Science information in a clear and logical manner, both orally and in writing.

C) Students apply knowledge of Earth Science data to understand the dynamic physical, chemical, and biological processes of the Earth and its history.

D) Students apply knowledge of appropriate techniques, field methods, field mapping, and numerical methods to measure, portray, analyze, and interpret Earth Science data in specific subdisciplines.

E) Students identify Earth Science problems and develop solutions.

F) Students apply knowledge of modern applications from chemistry, physics, biology, mathematics, statistics, and computing to the solution of Earth Science problems.

<u>Key:</u> B = Beginning level; I = Intermediate level; A = Advanced level

<u>Program Course Listing:</u>
R- Required
O - one of multiple option
prep - preparation (all BS programs)
SS – science of sustainability (all BS programs)
GS – Geological Sciences subprogram
CWE- Climate Water Environment subprogram
GP- Geophysics subprogram
MS – Marine Science certificate
PS- Planetary Science certificate
HG- Hydrogeology certificate
MC – Museum Curation certificate
PG- Petroleum Geology certificate