POSTGRADUATE PROGRAM IN EARTH SYSTEM SCIENCE

Academic Coordinator

Kleber Pinheiro Naccarato, Ph.D., INPE, 2005

Faculty Members

Permanents

Ana Paula Dutra de Aguiar – Ph.D., INPE, 2006
Angélica Giarolla – Ph.D., UNICAMP, 2003
Carlos Afonso Nobre – Ph.D., MIT, 1983
Celso von Randow – PhD., Wageningen Univ. & Res. Centre, 2007
Dalton de Morisson Valeriano – Ph.D., Univ. of Califórnia, 1996
Daniel Andrés Rodriguez – Ph.D., INPE, 2011
Ênio Bueno Pereira – Ph.D., W. M. Rice University, 1980
Gilberto Câmara – Ph.D., INPE, 1995
Gilvan Sampaio de Oliveira – Ph.D., INPE, 2008
Javier Tomasella – Ph.D., UFRGS, 1995
Jean Pierre Henry Balbaud Ometto – Ph.D., USP, 2001
Laura de Simone Borma – Ph.D., UFRJ, 1998
Luciana Vanni Gatti – Ph.D., NOAA, 2003
Maria Cristina Forti, Doutora, USP, 1989
Maria Isabel Sobral Escada – Ph.D., INPE, 2003
Mariane Mendes Coutinho – Ph.D., Univ. of Reading, 2004
Pedro Ribeiro de Andrade Neto – Ph.D., INPE, 2010
Plínio Carlos Alvalá, Ph.D. – INPE, 1995
Regina Célia dos Santos Alvalá – Ph.D., INPE, 1993
Silvana Amaral Kampel – Ph.D., USP, 2003
Victor Marchesini – Ph.D., UFSCar, 2013

Colaborators

Antonio Donato Nobre – Ph.D., Univ. of New Hampshire, 1994
José Antônio Marengo Orsini – Ph.D., Univ. of Wisconsin, 1991
Gustavo Felipe Balué Arcoverde – Ph.D., INPE, 2014
Kleber Pinheiro Naccarato – Ph.D., INPE, 2005
Lincoln Muniz Alves – Ph.D., INPE, 2016
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Myanna Hvid Lahsen, Ph.D., Rice Univ., 1998

EARTH SYSTEM SCIENCE PROGRAMME

ANNUAL DISCIPLINES FOR DOCTORAL

1st Quarter

CST-201-4	Introduction to Earth System Science*	Dr. Antonio Donato Nobre, Dr. Carlos Afonso Nobre
CST-300-3	Foundations of the Social Sciences: Interdisciplinary Perspectives*	Dr. Victor Marchezini Dr. Diógenes Alves Sala
CST-311-0	Methods of Scientific Research*	Dr. Pedro R. Andrade, Dr. Gilberto Câmara
CST-501-0	Interdisciplinary Research Seminars*	Dr. Kleber Pinheiro Naccarato

2nd Quarter

CST-323-4	Introduction to Earth System Modelling*	Dra. Mariane Mendes Coutinho, Dr. Pedro R. Andrade, Dr. Gilberto Câmara
CST-328-3	Energy Transition and Development	Dr. Ênio Bueno Pereira
CST-308-3	Natural Disasters	Dra. Regina C. dos Santos Alvalá Dr. Daniel Andrés Rodriguez
CST-310-3	Population, Space and Environment	Dra. Silvana Amaral Kampel
CST-312-3	Land Use and Land Cover Change Patterns and Processes	Dra. Maria Isabel Sobral Escada
CST-329-3	Hydrological Processes and Ecohydrology	Dra. Laura De Simone Borma
CST-321-3	Paleoclimatologia	Dr. Gilvan Sampaio de Oliveira Dr. Manoel Ferreira Cardoso
CST-501-0	Interdisciplinary Research Seminars*	Dr. Kleber Pinheiro Naccarato

3rd Quarter

CST-324-4	Global Biogeochemical Cycles	Dr. Jean Pierre H. B. Ometto Dr. Plínio Carlos Alvalá Dra. Maria Cristina Forti
CST-330-3	Environmental Modeling for Biodiversity Conservation	Dra. Silvana Amaral Kampel Dr. Dalton de Morisson Valeriano
CST-313-3	Global Climate Change: Observations and Modeling	Dr. José Antônio Marengo Orsini, Dr. Gilvan Sampaio de Oliveira
CST-319-3	Hydrological Modeling	Dr. Javier Tomasella, Dra. Luz Adriana Cuartas Pineda
CST-320-3	Biosphere-Atmosphere Interactions	Dr. Celso von Randow Dra. Luciana Vanni Gatti
CST-401-3	Land change modeling	Dra. Ana Paula Dutra de Aguiar
CST-322-3	Soil Conservation: Importance for the Biodiversity	Dra. Angélica Giarolla
CST-325-3	Hydrologic Changes	Dr. Daniel Andres Rodriguez
CST-326-4	Global Electrical Phenomena	Dr. Kleber Pinheiro Naccarato
CST-501-0	Interdisciplinary Research Seminars*	Dr. Kleber Pinheiro Naccarato

* **Mandatory.** Other else are optative.

EARTH SYSTEM SCIENCE PROGRAMME

DISCIPLINES SYLLABUS

1st QUARTER

CST-201-4	Introduction to Earth System Science

The Intro to ESS course aims to introduce Earth System science to the students of the doctoral program. Presenting the larger picture of the Earth, it aims to understand its physical, chemical, biological and human systems, its origin, its evolution, its functioning and the interactions between the components and factors that make this planet habitable and resilient. Since admitted students come from disparate backgrounds, the course reviews the basic and applied sciences required as a foundation for the program's holistic approach, leveling an understanding that enables interdisciplinary dialogue, which is essential to understanding the Earth in all its complexity.

Syllabus

Philosophy - Cognition and neuroscience, learning, focus, scope, approaches, perspectives, imagination, intuition, knowledge, wisdom, experience. **Math** - Language of nature; meaning and search for a logical skeleton, symmetries and support in the construction of other sciences. **Physics** - Laws of nature, dimensions, organization, phenomena, action and reaction, entities. Time, space, energy, force, mass, fields, states of matter. **Chemistry** - Associations and combinations of entities, electrosphere, atom, molecule, substances, properties of entities and their changes. Scales. Periodic table, atomic and molecular architecture. **Astrophysics and Cosmochemistry** - Emergence and evolution of the universe, stars, nucleosynthesis, gravity, temperature, pressure, nebulae, emergence and evolution of the solar system, emergence and evolution of Earth, galactic and solar system habitability, environment and space climate, solar wind, asteroids and comets, cosmic objects and surface environments. **Geology** - Gravitation, density, buoyancy, magma, cooling, crystallization, minerals, rocks, Earth formation, composition, nucleus, mantle, crust, magnetism, surface compartments, lithosphere, continents, soil; hydrosphere; atmosphere; ecosphere, geochemistry. **Biology – Part 1:** The environments - planetary habitat, temperature versus pH, nutrients, radiation, comfort and stability. Life, scales, elements, origin, history, evolution. **Biology – Part 2:** Life, constitution and functioning; genes-proteins-functions, metabolism-gases-atmosphere, biogeochemistry; biogeophysics; respiration; photosynthesis. Thermodynamics. Webs of life. **Organisms and Ecossystems** – Cell, tissues, organs; organisms, populations, communities, biosphere; adaptation; homeostasis; symbiosis; persistence; habitat - climate; biotic relationships, ecosystems; food chain, production-consumption; ecophysiology - geophysiology; bigochemistry - bigeophysics; biogeography - landscapes - biomes. **Evolution and the Earth System** - Wallace & Darwin Natural Selection; evolution; genetics; tree of Life; selfishness - survival of the fittest Richard Dawkins; punctuated equilibrium; molecular biology - DNA self repair system - mutations; endosymbiosis Lynn Margulis, complexity and collaboration; the paradox of adaptation; biotic regulation and Darwinism. **Planetary Homeostasis** - Climate, paleoclimate, planetary stability. Lovelock, Margulis, Gaia. Parallels between astronomy and CST: Copernicus and the Gaia hypothesis. Keppler, Newton and Gorshkov et al, Biotic regulation theory. Liquid water - unstable equilibrium - climate oscillation. Feedback loops. Biogeochemical thermostat. Living planet, dead planet. Maturana, autopoiesis. E. Wilson, altruism controlling competition. Gorshkov and Makarieva, accumulation and flow of environmental regulation information. Interferences and disturbances. **Modelling I, Concepts** - What are models. Complexity. Flowchart, graphical, physical, empirical, and dynamic representations. Theory, physical model; phenomenon, nonphysical model, abstract, conceptual, mathematical, statistical, mechanistic, toy model. Modeling, possibilities and weaknesses. Predictions versus projections. Model versus theory, combination with data versus combination with fundamental laws. Imitative models versus germinative models. Predictability. Synthesis. **Modelling II, Preamble and Applications** - How to start from observations or theories and arrive at models? Defining and framing the problem /

system. Learning from observation. Exploring with theoretical thinking. Intuitive model; theoretical model, concatenating and inquiring. Examples and lessons from pre-modeling. **Modelling III, Mechanics** – Steps in building a model. Creating a conceptual model. Translating concepts, developing quantitative and formal logic, mathematical description. Building algorithms. Writing the program (executable). Compiling, running, testing sensitivity, calibrating, validating, perfecting. **Modelling IV, Environmental Models** - Has insufficient physics and insufficient data (the worst of both worlds). Lack of modularity and standardization, jungle of models, paths and solutions. Practice with some integrated models (DNDC, pNet, etc). **Conclusion** - Mysteries in Earth System Science. Example. Fields still unknown, opportunities for original studies. Climate Change, Anthropocene, Great Acceleration, Planetary Limits, Planetary Consciousness from Gaia; Common Global Goods; Diplomacy (climate convention) vs Nature; Sustainable Development Goals. Green varnish. Kyoto failure, carbocentrism. Thresholds and Tipping Points. **Aditional Activities**: We discuss movies and other topics relevant to the course. **Gravity** (Sandra Bullock): **Apollo 13** (Tom Hanks): **The Martian** (Matt Damon). **2001 Space Odyssey** (Stanley Kubrick). **Matrix 1** (Keanu Reeves). **Biosphere II** (experiment in Arizona). **International Space Station** (ISS).

References

Philosophy: Bosch, G., 2018. *Train PhD students to be thinkers* ... vol 554, Nature.
Math: Khan Academy Math; Frenkel, E. 2015, *Love & Math*
Physics: Khan Academy Physics
Chemistry: Khan Academy Chemistry
Astrophysics and Cosmochemistry: *The Big History Project*: 13.8 bilhões de anos de história; Kolb, V.M. 2019. Handbook of Astrobiology. Taylor & Francis.
Geology: *Earth Dynamic Systems, 2011, Christiansen E.H. & Hamblin, W.K.*
Biology: *E.O.Wilson's Life on Earth.* eBook
Organisms & Ecossystems: Ripple, W.J., Beschta, R.L., 2012. *Trophic cascades in Yellowstone: The first 15years after wolf reintroduction*. Biol. Conserv. 145, 205–213; Terborgh, J., Estes, J.A., 2015. *Trophic Cascades: Predators, Prey, and the Changing Dynamics of Nature* Chapter 3; Chapin III et al. 2011. Principles of Terrestrial Ecosystem Ecology. Springer, New York; *Como lobos controlam os rios* vídeo
Evolution and the Earth System: Jablonka, E., Lamb, M.J., 2018. *Evolution in Four Dimensions*; Gould, S.J., Eldredge, N., 1993. *Punctuated equilibrium comes of age*. Nature 366, 223–227.
Planetary Homeostasis: Gorshkov et al. 2000. Biotic Regulation of the Environment: Key Issues of Global Change. Springer Verlag; *The Biotic Regulation of the Environment;* Schneider et al. 2004. *Scientists Debate Gaia Chapman Conference on the Gaia Hypothesis*. MIT Press, Valencia.
Modelling: Edwards, D., Hamson, M., 2001. *Guide to Mathematical Modelling*, 2nd ed. Palgrave, Glasgow; Ekkehard Holzbecher, 2012. *Environmental Modeling Using MATLAB*; Wainwright, J., Mulligan, M., 2013. *Environmental Modelling Finding Simplicity in Complexity*. John Wiley & Sons, Ltd, Chichester, UK; Wellin, P., 2013. *Programming with Mathematica, An Introduction*, first. ed. Cambridge University Press, Cambridge.
Conclusion: Makarieva et al. 2013. *Where do winds come from? A new theory on how water vapor condensation influences atmospheric pressure and dynamics*. Atmos. Chem. Phys. 13, 1039–1056; Creutzig, F., 2017. *Govern land as a global commons*. Nature 546, 28–29; Steffen et al. 2015a. *The trajectory of the Anthropocene: The Great Acceleration*. Anthr. Rev. 2, 81–98; Steffen et al. 2015b. *Planetary boundaries: Guiding human development on a changing planet.* Science (80). 347.

CST-300-3	**Foundations of the Social Sciences: Interdisciplinary Perspectives**

The aim of this course is to introduce some of the social sciences' founding debates, as well as the foundations of politics and sociology, looking for references that would be of relevance, from the one hand, for the field of environmental change, and, from the other, for the variety of inter- and trans-disciplinary articulations in this field. In addition, the program will look for ways to put in evidence the methodological elements giving rise to the logical-conceptual frameworks of different social theories that take shape, in particular, in the context of environmental problems. Students will have the opportunity to read some of the classics of modern politics and sociology, selected for their representativeness and relevance for the course's matters.

Syllabus

1. Interdisciplinarity in environmental change studies (4h)

a) Interdisciplinary articulation in environmental change research programs. The International Conventions on the Ozone Layer, Biological Diversity and Climate Change, and the role of science and technology thereof. The case of the Intergovernmental Panel on Climate Change (IPCC).
b) Interdisciplinarity and General Systems Theory. Ecosystems, climate and social systems.
c) Environmental Sociology, Political Ecology, and cross-disciplinarity.
d) Transdisciplinarity, Postnormal Science, and Knowledge Coproduction.

2. Social Sciences' Founding Debates (2h)

a) Method in the Social Sciences: preliminary issues.
b) The society and the individual. Emergence. Individual and collective consciousness.
c) Origins of the social order. Consensus and conflict in social theory.

3. Foundations of Politics (14h + Seminar)

a) On the origins of modern political philosophy. Niccolò Machiavelli. Verità Effettuale. Forces opposing themselves giving rise to the instability of the social order. On method in Machiavelli.
b) Thomas Hobbes. State of nature. Equality among men and conflict. "Submission pact". The Sovereign's Rights. On method in Hobbes.
c) John Locke. Liberty, property, labour. Consent of the governed and their "Right to resume their Liberty". Locke and Charles de Secondat (Baron de Montesquieu) on the separation/distribution of powers.
d) Jean-Jacques Rousseau. Inequality and Social Contract. Government, sovereignty of the people, representation and liberty. On method in Rousseau.
e) Hobbes, Locke, Rousseau, Edmond Burke: on the institution of political power and representation.
f) The shaping of Brazilian political thought. On the insolidarity of the rural classes and the role of the State; lineages of Brazilian political thought.

4. Foundations of Sociology (14h + Seminar)

a) Auguste Comte. Social Physics in the context of Comte's categorisation of sciences.
b) David Ricardo. Value, wages, rent.
c) Karl Marx. Structure, superstructure and societal transformation. Theory of value, surplus value. Commodity fetishism. Consciousness, alienation. The thesis about metabolic rift.
d) Èmile Durkheim. Social fact and the sociological method. Mechanical and organic solidarity. The constitution of the collective consciousness.
e) Maximilian Weber. Ideal type and objectivity in the social sciences. Protestant asceticism and its affinity to the Spirit of capitalism. Status groups, classes, and parties. Bureaucracy. Social action. Power, domination, legitimation. Science as a Vocation, Politics as a Vocation.
f) Vilfredo Pareto. Pareto's Law. The circulation of the elites.

5. "Modern classics" and the present times (4h)

a) The origins and the conditions of possibility of the institutions.
b) Scarce resources and social order. Limits to Growth. Equity.
c) Violence, fear, pity, and guilty. The malaise of modern society.
d) Types of political representation. Social and environmental movements.
e) Science/technique and climate and environmental politics.
f) "Politics as a Vocation". "Science as a Vocation".
g) Marx, Durkheim and Weber in the field of environmental studies.

h) Marx and Weber and the formation of Brazilian political thought.
i) Transformation of the public sphere. Legitimation crisis. "The Crisis of Democracy".
j) Risk Society; Subpolitics; Cosmopolitics. The local and the global in environmental issues.

6. The land issue and the environmental issue in Brazil (6 h)
a) José Bonifácio. Land possession and forest conservation in the first Constituent Congress. The 1850 Law on Land. Land in the 1891 Constitution.
b) Forest Code.
c) The institutional framework concerning the biological diversity and climate change in Brazil.
d) Types of environmentalism and social movements. The local and the global amid environmental issues in Brazil.
e) Processes of territorialisation and deterritorialization.

References

The following references were selected based on their relevance and representativeness and can be found, in general, in a number of open-access internet classics portals, in their original language or in modern English. Throughout the course this selection will be commented and expanded, with the indication of translations and collected works when appropriate. The actual readings during the course will consist of selected parts of these works

Foundations of Politics
Burke, E. **Speech to the Electors of Bristol** [1774]
Hobbes, T. **Leviathan** [1651]
Locke, J. **Two Treatises of Government** [1689]
Machiavelli, N. **De Principatibus** [1513]; **Discorsi sopra la prima Deca di Tito Livio** [1517]
Montesquieu, C. de Secondat, baron de. **De l'Esprit des Lois** [1748]
Rousseau,J.J. **Discours sur l'origine et les fondements de l'inégalité parmi les hommes** [1755]; **Du contrat social** [1762]

Foundations of Sociology
Durkheim,E. **Les règles de la méthode sociologique** [1894]; **Les Formes élémentaires de la vie religieuse** [1904]
Marx, K. Preface, **In: A Contribution to the Critique of Political Economy** [1859] **Capital**, **volume 1** [1867], 3 [1894]
Pareto. P. **Manuel d'Économie Politique** [1897]
Weber. M. **Definition of Sociology** [c. 1897]; **"Objectivity" in Social Science** [c. 1897]; **The Protestant Ethic and the Spirit of Capitalism** [1905]; **Politics as a vocation / Science as a vocation** [1917/1918]

Monographs and collected works on the "classics"
Aron, R. **Les Etapes de La Pensée Sociologique**. Paris: Gallimard, 1976 (tradução brasileira: **As Etapas do Pensamento Sociológico**, São Paulo: Martins Fontes, 2000)
Brandão, G.M. Linhagens do Pensamento Político Brasileiro. **Dados**, **48** (**2**), p. 231-269, 2005
Cohn. G. (Org.) Cohn, G. Introdução, **In: Weber**. São Paulo: Ática, várias edições
Faoro, R. Existe um pensamento político brasileiro? **Estudos Avançados, 1 (1)**, p. 9-58, 1987
Fernandes, F. **Fundamentos Empíricos da Explicação Sociológica**. São Paulo: Companhia Editora Nacional, várias edições
Giddens, A. What is Social Science? **In: In Defense of Sociology**. Cambridge, U.K., Polity, 1996 (tradução brasileira: **Em Defesa da Sociologia**, São Paulo: UNESP, 2001)
Haesbaert, R. **O Mito da Desterritorialização: do "fim dos territórios" à multiterritorialidade**, 1ªed. Rio de Janeiro: Bertrand Brasil, 2004.
Nova, S.V. **Introdução à Sociologia**. São Paulo: Atlas, 2009
Rhoads, J. **Critical issues in social theory**. University Park: The Pennsylvania University Press, 1991
Veras, M.P.B. **Introdução à Sociologia: Marx, Durkheim, Weber, Referências Fundamentais**. São Paulo: Paulus, 2014

Weffort, F.C. (Org.) Vários Autores, **In: Os Clássicos da Política**. 2 volumes. São Paulo: Ática, várias edições.

Further reading

Acselrad, H. (2002) Justiça Ambiental e Construção Social do Risco. **Desenvolvimento e Meio Ambiente**, 5, 49-60.

Beck, U. **Risk Society: Towards a New Modernity**. London: Sage, 1992 (tradução brasileira: A Sociedade do Risco, São Paulo: Editora 34, 2010)

Bresciani, M.S. **O Charme da Ciência e a Sedução da Objetividade**. Oliveira Vianna entre intérpretes do Brasil. São Paulo: UNESP, 2008

Buckley, W. **Sociology and Modern Systems Theory**. Oxford: Prentice Hall, 1967 (tradução brasileira: A Sociologia e a Moderna Teoria de Sistemas, São Paulo: Cultrix, 1971)

Dunlap, Riley; Brulle, Robert. **Climate change and society: sociological perspectives**. Nova York: Oxford University Press, 2015.

Easton, D. **A Systems Analysis of Political Life**. Chicago: The University of Chicago Press, 1979

Furtado, C. **O Mito do Desenvolvimento Econômico**. Várias edições.

Hardin, G. **The Tragedy of the Commons**. Science, 162 (3859), p. 1243-1248, 1968.

Ostrom, E. **Governing the Commons: The Evolution of Institutions for Collective Action**. Cambridge, U.K.: Cambridge University Press, 1990.

CST-311-0	**Methods of Scientific Research**

The objective of the course is to prepare students to develop research activities such as writing scientific articles and thesis. The first part of the discipline presents the consensus view on the scientific method and shows how this view determines the structure of scientific works. Next, the classes deal with the main steps of a research project (definition of a research question, building arguments, preparing documents and presentations). The classes deal with the main aspects of scientific writing, showing how to structure texts for better readability and acceptance by peers. At the end of the course, the student is expected to master the basic techniques of writing articles and theses.

Syllabus

Foundations of the scientific method. Theses in applied research: the context of Brazil and INPE. Asking questions, finding answers. Makign a claim and supporting it. How to organise a scientific article: introduction, methods, results and discussions. Editing for readability and style. Learning how to evaluate third-part students' thesis. How to communicate your results. How will your thesis be?

References

Wayne Booth, Gregory Colomb, and Joseph Williams, “The Craft of Research**”**. University of Chicago Press, 1995.

Gerald Graff, Cathy Birkenstein, "They Say / I Say": The Moves That Matter in Academic Writing**”.** W. W. Norton & Company, 2014.

Joseph Williams, “Style: Toward Clarity and Grace**”.** University of Chicago Press, 1995.

Karl Popper, “Science: Conjectures and refutations”. In: Karl Popper, Conjectures and refutations: The growth of scientific knowledge. Basic Books, 1962.

Karl Popper, “Three Views Concerning Human Knowledge”. In Karl Popper, "Conjectures and Refutations: The Growth of Scientific Knowledge". London, Routledge, 1965.

CST-501-0	**Interdisciplinary Research Seminars**

The Interdisciplinary Research Seminars deal with several relevant and current themes, national or international, of interest to the course, always maintaining an inter, multi and transdisciplinary perspective. These seminars, complementary to the student's curricular formation, are usually given by professors and / or researchers - or even public managers – from Brazil or abroad, regularly invited, who contribute notoriously to the research topics covered. The participation of guests reinforces the integration of the course as a whole, consolidating existing research networks or creating new collaborations. This contributes to publicize its activities in the academic environment, consolidating it as a space of solid interdisciplinary reflection and scientific exploration and enabling a dialogue with managers concerned with thinking about public policies in the perspective of sustainability and global changes. In addition to external guests, the students and professors of the course are called upon to regularly present their work to colleagues, which will arouse mutual interest in ongoing research, creating a favorable environment for the formation of interdisciplinary teams. Other activities such as mini-courses, trainings, debates, round tables also allow students and teachers to get involved in discussions on important topics, nationally or internationally, expanding collaborations thus increasing student training.

ATTENTION: All students must attend the required minimum number of seminars in accordance to the current course regulations.

2nd QUARTER

CST-323-4	Introduction to Earth System Modelling

Prerequisite: Introduction to Earth System Science

Earth System Models are used to study natural systems (atmosphere, ocean, cryosphere, vegetation, global biogeochemical cycles, hydrology, atmospheric chemistry), human systems (economy, land use changes, greenhouse gases emissions, health, agriculture) and to simulate society-nature interactions. This course presents the main characteristics of these models and shows how they are built and used.

The first part of the course is focused on Systems Dynamics, with an emphasis on renewable and non-renewable resource models. Classical models, such as Predator-Prey and Daisyworld, are presented to discuss concepts such as equilibrium and feedback. Then, nonlinear and chaotic systems are presented, and their relationship to climate models is discussed. The second part of the course focuses on models of social dynamics, with an emphasis on complex systems. The third part of the course addresses aspects of natural systems modelling in the context of Earth System Models. The aim of the course is to develop an understanding of the fundamentals of systems dynamics and the physical and mathematical basis of Earth system modelling.

Syllabus

Structure and formulation of models. Concepts of systems dynamics: stocks and flows. Examples of dynamics of renewable and non-renewable systems. Concepts of mathematical modelling: dynamic systems, equilibrium, chaos, non-linearity. Parameterization, calibration and model validation. Concepts of social modelling: altruism, reciprocity, game theory. Examples of social models: complex systems, cellular automata, and agent-based modelling. Concepts of climate models and Earth System Models. Planetary energy balance and energy balance models. Historical evolution of the models: components of the earth system represented and their coupling. Causes and simulation of climate change, climate feedbacks. Fundamentals of the development of Earth System models, such as physical principles, discretization, coordinates, spatial and temporal scales and resolution, parameterizations.

References

Donnela Meadows, "Thinking in systems: a primer". Chelsea Green Publishing, 2008.
Andrew Ford, "Modeling the Environment". Island Press, 2009.
Kendal McGuffie, Ann Henderson-Sellers, "The Climate Modelling Primer", Wiley- Blackwell, 2014.
Emilio F. Moran, "Environmental Social Science: Human–Environment Interactions and Sustainability". John Wiley, 2010.
IPCC, "Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change", Cambridge University Press, 2013. Available from: www.ipcc.ch.
Joshua Epstein, Robert Axtell, "Growing artificial societies: social science from the bottom up". Brookings Institution Press, 1996.

CST-328-3	Energy Transition and Development

The growing demand for fossil energy has been responsible for the global warming effect, with consequent environmental and social impacts in the near future. In turn, these changes will also impact the energy sector, particularly that of renewable energy sources, such as hydroelectricity, wind and solar energy, and biofuels. This discipline aims to provide an integrated overview of the use and demand of energy resources and their relationship with the energy transition and development. Particular attention will be paid to renewable energy resources. Technical and social aspects of the issue will be addressed, particularly those related to the development policies of the economies of emerging countries. It is, therefore, an introductory and interdisciplinary approach, inserted in the context of the Earth System Sciences program.

Syllabus

1) Energy and development: Energy transition, main consumers; energy demand in developing countries.
2) Energy forms: Basic laws; energy efficiency and quality; conventional energy sources; renewable energy sources.
3) Impacts of climate and environment: Impacts on the chemistry of the atmosphere and hydrosphere; emissions of greenhouse gases and particulates; environmental and climatic scenarios; impacts on generation and distribution systems.
4) Climatic conditions and energy consumption: Climate, energy consumption and distribution; climatic effects and public lighting; thermal comfort.
5) Applications of short- and long-term meteorological forecasts in energy generation and distribution planning: Basic principles; energy and climate planning; climatic effects on energy generation and distribution.
6) The oil paradigm: Fossil fuel - non-renewable energy.
7) Solar energy: Basic principles; thermo-solar and photoelectric energy; survey and exploration of the energy resource; applications and implications.
8) Wind energy: Basic principles; wind turbines; survey and exploration of the energy resource; applications and implications.
9) Hydro energy: Basic principles; plants and small hydroelectric plants; survey and exploration of the energy resource, applications and implications.
10) Other forms of renewable energy.

References

Amarante, O.A.C., Brower, M., John, Z.; Leite, A. Atlas do Potencial Eólico Brasileiro, 45pp., Brasília, Fabrica de ideias, 2001.
Gasch, R.; Twele, J. Wind Power Plants. 390pp., Berlim, Editora Solarpraxis. 2002.
Goldemberg, J. e Lucon, O. Energia, Meio Ambiente & Desenvolvimento. 3a. de. São Paulo, EDUSP, 2012. ISBN 978-85-314-1113-7
Martins, F. R. e Pereira, E. B. Energia Solar: Estimativa e Previsão do Potencial Solar, Appris Livraria e Editora, 2019, 139p. ISBN 85-4732-70-88.
Pereira, E. B.; Martins, F. R.; Gonçalves, A. R.; Costa, R. S.; Lima, Francis J. L.; Rüther, R.; Abreu, Samuel Luna de; Tiêpolo, G. M.; Souza, J. G.; Pereira, S. V. – Atlas Brasileiro de Energia Solar. 2. ed. São José dos Campos: INPE, 2017. v. 1. 84p. ISBN 978-85-17-00089-8.
Steve, H. Revolução Energética. 229pp., Rio de Janeiro, Editora Relume-Dumará, 2003.
Trigueiro, A. Meio Ambiente no Século 21. Rio de Janeiro, Editora Sextante, 2003.
Vasconcellos, G.F.; Vidal, J.W.B. Poder dos Trópicos, 303pp., São Paulo, Editora Casa Amarela, 1998.ISBN 85-8621-01-2

CST-308-3	Natural Disasters

Natural disasters cause a large loss of human life and property worldwide. In the period from 1998 to 2017, most of deaths recorded as a result of disasters were associated with geophysical events, mainly earthquakes and tsunamis. However, 91% of all disasters were caused by floods, storms, droughts, heat waves and other extreme weather-related events (CRED-UNISDR, 2018). Information on the occurrence and severity of disasters has improved in recent years, mainly due to the implementation of the Sendai Framework for Disaster Risk Reduction 2015-2030 in several countries. The Sendai Framework, which prioritizes the connection between reducing risk and building resilience, has synergy with the 2030 Agenda for Sustainable Development, the Paris Agreement, the New Urban Agenda, the Addis Ababa Action Agenda and the Humanity Agenda.

In the past two decades, IPCC has reported evidence of changes in the frequency and magnitude of extreme events (IPCC, 1990, 2007, 2013, 2014), which are supported by observational data. Moreover, AR4 and AR5 reports highlight that the most vulnerable communities can be notably affected, mainly those that are concentrated in high-risk areas. These have a more limited capacity for adaptation and are more dependent on climate-sensitive resources, such as the local supply of water and food. Where extreme weather events become more intense and / or more frequent, the economic and social costs of these events increase and, consequently, these increases are substantial in those areas most directly affected.

In particular the growth of occurrences of natural disasters was observed in some regions of Brazil, because of either the intensification of geodynamic, hydrometeorological and climatic events, or the increase in exposure and risk due to areas of risk susceptible to natural disasters. The main natural disasters recorded arise from floods, flash floods, inundation, landslides, dry spell, droughts, forest fires, deaths by electrical discharges and destruction by gales. In this context, efforts have been made in the country to develop efficient systems for monitoring and forecasting extreme weather events in line with the Sendai Framework, which advocate investments for disaster risk reduction and not for disaster management.

Syllabus

1. Natural Disasters - definitions and databases of disasters in the world and in Brazil;
2. Precipitation: Types of precipitation - rain, snow, hail; Measurement - rain gauges, radar, satellites and other instruments; Modeling and application in hydrology and agriculture; Hydrologic cycle.
3. Meteorological phenomena (weather and climate) which trigger natural disasters: description and case studies. Modeling, forecasting and analyses: Severe storms; Flash floods; Tornado; Hurricane; Long-term South Atlantic Convergence Zones; heat waves, cold waves; El Niño, La Niña.
4. Disasters in agriculture (Crop failure): Monitoring, forecasting, uncertainties and planning. Dry Spells and Droughts; Floods; Frosts.
5. Disasters in hydrology (availability of energy and water resources): Monitoring, forecasting, uncertainties and planning. Droughts; Floods and Flash Floods.
6. Coastal disasters: effects of marine and terrestrial processes, coastal erosion, sea level and undertow regimes.
7. Forest Fires: monitoring and risk forecast.
8. Erosion and mass movement due to weather and terrain stability.
9. Studies of impacts, vulnerability and adaptation to climate change resulting from scenarios of increased greenhouse gas emissions.
10. Risks: Risk analysis related to natural disasters; local experiences and good practices in communities for disaster risk reduction; global strategies for communicating early warning of disasters.

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CST-329-3	Hydrological Processes and Ecohydrology

This course aims to present the basic concepts of Hydrological Processes and associated Ecohydrologic aspects that takes place in the Earth System, from rainfall formation to the recharge of surface- and groundwater reservoirs. In the context of the Hydrological Processes, the course covers the basic concepts of Ecohydrology, sub discipline of Hydrology and an interdisciplinary scientific research field that deals with the interactions between water and aquatic and terrestrial ecosystems. Ecohydrology as a science field can be seen as a two way track – in one way, it focus on the role of water in the maintenance of ecosystems; on the other way, it deals with the role of the ecosystems in the maintenance of the water supply, in terms of both, quality and quantity. In terrestrial ecosystems (e.g., forests, deserts and savannas), Ecohydrology deals with the water cycle in the soil-plant-atmosphere continuum. In aquatic systems (e.g., river, streams, lakes and wetlands), Ecohydrology deals with the role of the water in the maintenance of these ecosystem and, on the hand, with the importance of these system in the maintenance of water supply, i.e. the role of ecosystem in the provisioning of environmental services of water and climate regulation.

Syllabus

1. **Introduction to the Hydrologic Science**. Definition and scope of Hydrology. Hydrology as an interdisciplinary research field
2. **The hydrological cycle**. The classic model. Components of the hydrological cycle. The global hydrological cycle. Climate, soils and vegetation.
3. **Basic Hydrologic concepts**. Hydrologic Systems and the watershed
4. **Physical quantities and laws**. The conservation equations. The water balance equations
5. **Water and energy fluxes in the atmosphere**. The energy budget on the Earth. Latent and sensible heat
6. **Physics of precipitation**. The water vapour in the atmosphere. Cooling. Condensation. Droplet growth. Throughfall and stemflow
7. **Water in soils**. Soil physical and hydraulic properties. Soil-water status. Water infiltration, redistribution, drainage. Surface runoff.
8. **Evapotranspiration**. Physics of evaporation. Plant transpiration.
9. **Basic principles of groundwater flow**. Storage and transmissions properties of soils. Darcy's and Richards laws. Classification of groundwater flows. Preferential water flows and limitation of classics formulations
10. **Stream response to water input**.
11. **Basic hydrometeorological data**. Basic statistical analysis
12. **Overview of Ecohydrology**. Ecohydrology of terrestrial systems. Ecohydrology of Aquatic systems. Case studies.

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CST-321-3	Paleoclimatology

This course will cover aspects of Paleoclimatology with focus on studies of past global environmental change based on environmental data and Earth System modeling. It will discuss current climate dynamics, indexes for paleoclimate, paleovegetation and paleoceanography, paleostudies in South America and Earth System modeling applied to paleoclimatology. The course aims to provide theoretical basis for analyses related to the evolution of Earth climate, including climate variability at scales from years/months to centuries/milenia.

Syllabus

1. Present global climate dynamics: atmospheric circulation, atmosphere energy budget, climate variability in several temporal and spatial scales, and teleconnection patterns.
2. Indexes for paleoclimate, paleovegetation and paleoceanography: ocean data: sea surface temperature, salinity, ice cover, hidrology and ocean circulation; continental data: indexes for changes in precipitation, temperature, paleovegetation, ice sheets, and others. Icecores: indexes for air temperature, greenhouse gases, atmospheric circulation, and precipitation. Use of proxies for analyses of past climate.
3. Dynamics of climate change at the geologic time scale: climate change at the geologic time scale: sources of paleoclimate data at the millennial time scale: geologic, paleontologic and isotopic evidences. Climate change in the Quaternary period: solar radiation influence, variations in solar radiation and glacial cycles, climate patterns at year-century scale, paleoclimate records at high temporal resolution, natural climate variation in the Holocene. Paleoclimate studies in the South America. Evolution of ecosystems in the Amazon in the last 25 million years. Spatial and temporal scales of ecological relations and climate change.
4. Earth System modeling applied to paleoclimatology: Intermediate complexity models, high complexity models, international programs for numerical modeling applied to paleoclimatology, the Paleoclimate Modeling Intercomparison Project (PMIP).

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Additional papers:
– Biotic response to global change. The last 145 million years. Culver & Rawson.
– Ecology of Climate Change. The importance of biotic interactions. Eric Post
– Interpreting Pre-Quaternary Climate from the Geologic Record. judith Parrish
– Reconstructing Quaternary Environments. Lowe & Walker
– Global environments through the Quaternary. Anderson, Goudie, Parker
– Biologia & Mudanças climáticas no Brasil. M. Buckeridge
– Paleoclimates: understanding climate change past and present. Thomas Cronin

CST-310-3	Population, Space and Environment

The impacts of human activities on terrestrial systems imply significant modifications on the hydrological, ecological, geomorphologic, climatic and biogeochemical cycles. Working with quantitative and socioeconomic data predictions, represented in the geographical space, is a possible solution to promote successful interactions between social and earth system sciences. In this context, remote sensing (RS) data, geoinformatics and spatial analysis techniques are valuable tools to integrate different data sources, enabling social and the natural sciences interactions.

Landscape patterns and environmental profiles extracted from RS data can provide information to assist population dynamic elements studies, such as migration, family arrangements formation, as well as studies on the spatial distribution of the population. Estimates of population counting and projections are also good opportunities for the integrated use of RS and geoinformatics techniques. For instance, when studying urban population density, remote sensing is an indispensable tool for initially visualize the spatial extent of urbanized areas and their evolution pattern in time. Different mathematical models have been proposed to calculate density of urban population through high resolution remote sensing images. Also, some economic indicators, such as those reflecting quality of life, indices of development and sustainability, etc., can also be inferred or built from integration of remote sensing and census tracts data.

The objective is to train students in theories and technologies of geoinformatics, remote sensing, and spatial analysis appropriate for manipulation and processing of social sciences data represented in geographical space.

Syllabus

1. Socioeconomic and demographic data: origin, indicators and spatial indexing.
2. Spatial analysis applied to studies of socioeconomic and demographic processes.
3. Spatial data integration: socioeconomic, demographic and remote sensing data.
4. The Scale Effect: Inventory Scale and Integration Scale.
5. Data aggregation / disaggregation and data structure in Geographical Information System.
6. How to build Socio-spatial indicators.
7. Methods of data integration: from field data research to density probability surfaces.
8. Examples of applications in health, safety, urbanism, land use and land cover, demography, and others.
9. Socioeconomic and demographic variables for scenario analysis in global climate change studies.

Course Dynamics

There will be theoretical classroom presenting concepts and discussing articles about specific topics. Laboratories will be proposed to exercise data integration techniques in geoinformation software. Students will be evaluated by: 1) a seminar discussing a specific research topic of his/her interest considering a “population, space and environment” theme; 2) an article describing a study case (practical work) about his/her research interest, taking the relationships between population, space and environment into account.

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CST-312-3	Land Use and Land Cover Change Patterns and Processes

Concerning about land use change and land cover has emerged in global research agendas a few decades ago, mainly due to its influence on climate change at local and global scales. Human activities are largely responsible for changes in land use and land cover which often result in a mosaic of fragmented landscapes and a mixture of natural and anthropogenic patches, which vary in size, shape and spatial arrangement. Understanding human intervention on the landscape and the direct and indirect consequences of it in land use and land cover spatial patterns and in ecological processes, is fundamental for land management and planning issues and land use modeling. Remote sensing multitemporal data, coupled with the use of pattern recognition techniques, landscape ecology concepts and metrics and data mining techniques represent important tools for the study of land use and land cover spatial-temporal patterns. The aim of this course is to enable students to understand and discuss concepts and methodologies for studying patterns of land use and land cover change, not only as a result of human land surface processes, but also as a component of terrestrial systems, which modify and are modified by abiotic and biotic factors.

Syllabus

1. Patterns and processes of land use and land cover change: Conceptual and theoretical framework.
2. Land use and land cover classification systems.
3. Landscape Ecology: Concepts, methodological approaches and factors that influence landscape spatial patterns and change.
4. Use of landscape metrics to detect land use and land cover change (LUCC) patterns.
5. Change detection techniques in LUCC applications
6. Utilization of spatial tools and remote sensing data for detecting land use and land cover change patterns.
7.Use of pattern recognition and data mining techniques to link LUCC patterns to socioeconomic and ecological processes
8. Landscape stratification for computational modelling of patterns and processes in LUCC.

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3rd QUARTER

CST-324-4	Global Biogeochemical Cycles

The Earth System is constituted and modulated by interconnected "spheres" with diffuse boundaries in between, such as atmosphere, biosphere, hydrosphere and lithosphere. Considering the interconnectivity among these systems, mass and energy may flow and exchange between them. The transport and transformation of substances through the terrestrial system are collectively known as biogeochemical cycles. Biological processes play a fundamental role in regulating the planet's natural systems. The Earth functionality is, therefore, modulated by geophysical, geochemical and biological properties within these systems. This relationship can be expressed, among others, by processes such as physiological responses to changes in radiation, air temperature, CO2 levels, availability of water and nutrients, which can be directly affected and be affected by biology and Human activities. The conceptual basis for this discipline is founded in the interactions of physicals, chemicals and biologicals processes, with components in ecosystems and collectively in the biosphere.

Syllabus

Origins of the elements. Origin of life. Planetary compartments, geophysics, geochemistry. Structure, functioning and evolution of ecosystems. Natural ecosystems and biogeochemical cycles. Global carbon and nitrogen cycles, and current characteristics. Phosphorus and sulfur cycles. Cycles of other nutrients. Transfer of elements between terrestrial surface compartments. The biosphere - balance of flows and production. Atmosphere, its structure and constituents. Solar and terrestrial radiation. Atmospheric constituents: major and minor gases and greenhouse gases. Mechanism of the greenhouse effect. Stratosphere chemistry: ozone layer chemistry and the hole in the ozone layer, effects on ultraviolet (UV) radiation. Troposphere chemistry: clean troposphere, ozone precursors and pollution. Natural and anthropogenic changes in tropical ecosystems. Transfers at the interfaces of ecosystems, emissions and deposition in biogeochemical cycles. Global climate changes and effects on biogeochemical cycles. Aspects of biosphere modeling.

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CST-330-3	Environmental Modeling for Biodiversity Conservation

Brazil has a prominent global position due to its biological diversity; it is one of 15 countries called megadiverse, which together hold about 70% of the planet's biodiversity. However, biodiversity estimates based on species inventories are expensive and time-consuming. It is estimated that it would take at least eight centuries for a complete catalog of Brazilian species, given the current rate of descriptions - approximately 1500 species per year (Lewinsohn and Prado, 2002). Alternatives for estimating and locating priority biodiversity areas are necessary, mainly considering the speed of the conversion processes of natural areas, as deforestation rates of the Amazon forest, that was approximately 9,800 km2 for 2019 (INPE, 2020). Additionally, given the general climate change scenarios, the resilience of many ecosystems is likely to be overcome in this century by a combination of different factors, such as associated disturbances - floods, droughts, forest fires, insect outbreaks, ocean acidification - and other factors of global change, like changes in land use, pollution, overexploitation of natural resources. Thus, approximately 20-30% of the plant and animal species assessed so far are likely to face a greater risk of extinction if the average temperature rises for example, exceed 1,5-2,5 °C. In this context, this discipline proposes to present and discuss different possibilities for studying and modeling biodiversity. Among the models that are based on the ecological niche theory, for example, there are those dependent on the specie occurrence information and knowledge of the species physiology. Both of these are rare data considering the Brazilian case. Models of bioclimatic envelopes, in turn, are useful to understand the feedback between the interactions between climate and vegetation, but they have as drawback the factor of being static and do not consider biological interactions. By integrating climate forecasting models and species distribution models, we can interpret the landscape fragmentation, associated with climate change and land use and coverage changes, as an indicator of biodiversity losing. Understanding the different approaches to modeling biodiversity and analyzing the results is a basic tool for integrated studies where scenarios of global change are projected, especially regarding to the conservation of biodiversity and its associated resources. The final objective of this course is to enable students of Earth System Science to understand and discuss the different methodologies for studying biodiversity, as a basic and functional component of the terrestrial system.

Syllabus

1. Biodiversity - causes, patterns and importance of species distribution.
2. Ecological concepts associated with biodiversity.
3. Direct and indirect methods of assessing biological diversity.
4. Biotic and abiotic data for biodiversity estimation and modeling.
5. Species distribution models as tools for studying biodiversity.
6. Biogeography, historical aspects, and biotic interactions for biodiversity and community models.
7. Habitat Loss, spatial fragmentation and models in landscape ecology.
8. Computational tools for biodiversity modeling.
9. Modeling biodiversity and global changes interactions.

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CST-313-3	Global Climate Change: Observations and Modeling

Prerequisite: Introduction to Earth System Science

In this discipline, questions related to observations and modeling and of global climate change will be addressed. Basic concepts of climate modeling and an overview of the various components of the climate system will be covered: atmosphere, biosphere, cryosphere, hydrology. Observational aspects of various aspects of the climate system worlwide and in South America em partcular are doisciussed. In addition, climate change projections from IPCC models and downsacaling will be discussed. In here it is intended to go beyond detectimg climate change. Using the different climate modeling techniques (global and regional), we intend to analyze the different methodologies for analyzing impacts and vulnerability to climate change in sectors that are important to the national economy, such as: agriculture, agriculture, livestock, renewable energy, water resources, health, migration, economy, among other sectors. It is expected to develop practical experiences with various scenarios of climate change, including assessments of uncertainties and limitations.

Syllabus

Global warming and climate change. The natural and anthropogenic greenhouse effect. Greenhouse gases and the evolution of their concentrations in the atmosphere. History of the science of climate change. Climates of the past. Natural climate changes. Observations of climate changes in different parts of the globe. Climate modeling: bases and experiences at the global level. IPCC models and scenarios of greenhouse gas emissions and climate change. Changes in land use and global climate change. Impacts of anthropogenic climate change for the 21st Century and beyond. Assessments of uncertainties in future climate projections. Strategies for mitigating and stabilizing climate change. International programs: IPCC, UNFCCC. Protocols: Kyoto, Montreal, Post-Kyoto, Paris Agreement. Climate change in Brazil: progress since the IPCC AR5. Challenges of climate change modeling.

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CST-401-3	**Land change modeling**

Prerequisite: Introduction to Earth System Science

Spatially explicit land change models (LCM) quantify in time and space the relationships between determining factors (biophysical, socioeconomic, cultural and institutional) and the spatial and temporal patterns of change in land use and cover.

They aim to support the understanding of these change processes, decision making considering their impacts and the construction of future scenarios. In this course we cover the basic concepts and types of models to represent land change through a combination of lectures and practical exercises. The practical exercises will use the LuccME/TerraME modeling framework. LuccME/TerraME is an open source framework for spatially explicit Land Use and Cover Change (LUCC) modelling developed by the Earth System Science Center (CCST). Using the framework, the modeler can easily create deforestation, agricultural expansion, desertification, forest degradation, urban sprawl models and other process models at different scales and areas of study, combining existing model components and/or creating new ones. Basic GIS visualization skills are recommended, but no programming skills necessary. At the end of the course, the successful student is expected to: (a) acquire a general understanding about the different type of Land Change Models (LCM) and their applicability for different goals; (b) be able to analyze the drivers underlying land change processes at different scales and conceptualize LCMs and scenarios; and (c), be able to build alternative spatially-explicit models and scenarios using the LuccME/TerraME modelling framework. This course will be offered jointly for PhD students at INPE and Stockholm University

(Stockholm Resilience Centre). It will open to in-person and on-line participation (limited to 15 participants).

Syllabus

Part I: Land Change basic concepts
- **Lectures:** Land use and cover change concepts; Temporal and Spatial scales concepts; Land use trajectories; Drivers of change and examples; Feedbacks, SES, LUCC project to Land project; Perspectives of understanding, case studies and meta-analysis, archetypes, syndromes, LC theories.
- **Practical exercises:** discussion in groups (applying the concepts to case studies): direct and indirect drivers of change for selected case studies at different scales.

Part II: Land Change modeling approaches
- **Lectures:** Modeling goals and approaches; scenario concepts and typologies: Typologies of LC modeling approaches; Examples of different modeling approaches for the same problem.
- **Practical exercises:** discussion (applying the concepts to case studies): How you would model the case studies for your thesis problem?

Part III: Modelling process
- **Lectures:** From conceptual to quantitative modelling; TerraME overview: cellular spaces, neighborhood, modeling approaches; LuccME overview: discrete and continues components.
- **Practical exercises:** Setting the modelling environment; thinking about drivers and collecting spatial data; building a celular database using the FillCell tool to combine raster and vector data; temporal dimension; building data for your scenarios; analyzing how LC and driver spatial patterns relate to each other in your database.

Part IV: Discrete and Continuous LC models
- **Lectures:** Statistical analysis for LC processes; Potential, Allocation and Demand components for discrete and continuous models.
- **Practical exercises:** Building, calibrating and validating discrete and continuous LuccME models.

Part V: Alternative modelling approaches
- Invited Lectures about different modelling approaches, for example: Integrated Assessment Models (IAM), agent-based models, System Dynamics, Deep Learning, Spatial optimization models, etc. Presentation of projects.

Evaluation criteria: Practical project presentation (related to student´s thesis). Pass grade requires attendance, participation in practical exercises and discussion groups.

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CST-319-3	**Hydrological Modeling**

The goal of this course is to train and build capacity of the students on the use of distributed hydrological models, aiming to applications related to the assessment of the impacts of climate and land use and land cover changes on surface water resources.

Syllabus

1. Fundamentals of numerical analysis. Hydrological models classification (lumped, distributed, etc). Hydrological model parameters optimization.
2. Infiltration and soil water dynamics. Soil water models. Net rainfall calculation.
3. Saint Venant equations. Routing flow model classification.
4. Rainfall-runoff processes. Unit Hydrograph. Synthetic Unit Hydrographs. Kinematic wave models.
5. Hydrological modeling of small catchments: Topog, DHSVM, TopModel, etc.
6. River and reservoirs routing models: Pulz Method, Muskhingum, Muskhingum-Cunge. Introduction to Hydrodynamic models.
7. Large-scale processes representation and aggregation. Large Basin hydrological models: VIC, MGB-IPH, MHD-INPE. Application and use of large-scale models: Calibration and validation of parameters. Uncertainties.
8. Geoprocessing tools for input data preparation. Spatial Interpolation methods.
9. Climate and land use and land cover changes impacto n the surface hydrological cycle. Deforestation.

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CST-320-3	**Biosphere-Atmosphere Interactions**

The main objective of the course is to study the physical and biogeochemical processes through which terrestrial ecosystems affect and are affected by environmental conditions. The central theme of this discipline is that terrestrial ecosystems, through their cycles of energy, water, carbon, trace gases and nutrients, have an important influence on atmospheric processes. The coupling between the biosphere and the atmosphere is observed in spatial scales from the stomata of plants to the scale of large biomes, and in time scales from seconds (plant physiology), days to weeks (phenology), up to centuries to millennia (dynamic vegetation and biogeography).

Syllabus

1) Introduction: Principles of climatology, physical processes that control the global climate, variability on seasonal and interannual scales, and climate change on scales from centuries to millennia.
2) The role of the terrestrial biosphere in the global climate system.
3) Eco-hydrological processes of biosphere-atmosphere interaction.
4) Measurement and parameterization techniques
   a) Energy and water balances
   b) Physiological processes and carbon production (photosynthesis, primary production, limitations)
   c) Measurements of greenhouse gases and surface fluxes and limitations
   d) Land surface models
5) Phenology and vegetation dynamics in terrestrial ecosystems.

6) Feedbacks in the coupled system related to physical and biological processes in terrestrial ecosystems.
7) Regional Biosphere-Atmosphere Interactions: case study for the Amazon.

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IPCC AR5, Chapter 6: Carbon and Other Biogeochemical Cycles. https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter06_FINAL.pdf

CST-322-3	**Soil Conservation: Importance for the Biodiversity**

The soil is a finite resource in its extent and not renewable on a short time scale. The soil is one of the most significant natural resources for humanity, and its production capacity may be compromised mainly by anthropic action. Soil degradation is a real and growing threat caused by unsustainable uses and the sustainable management of the world's agricultural soils is paramount to global food security. This discipline was elaborated in order to promote discussions to improve the knowledge of interactions between soils in the current context of production and conservation and also, discuss the dynamics of the complex interaction of natural and social systems and the importance of biodiversity.

Syllabus

1. Soils in the context of biodiversity. Soil degradation and the risks to biodiversity. Concepts of the Planetary Boundaries, Sustainable Development Goals and global discussions on sustainability. Discussions of the soils in the social, environmental and economic context.
2. Soils physical and chemical properties and discussions concerning the importance of soil sustainability in the earth system. Pedology and concepts.
3. Brazilian Soil Classification System (historical and current). Brazilian soil types and their physical and chemical characteristics.
4. Soils in the context of desertification. Areas in the process of desertification in Brazil.
5. Soil erosion in the social context. Soils and Governance. Soils in the context of public policies in Brazil.
6. Soil erosion-environmental and economic context. Definitions of erosion processes. Soil erosion and the relationship with the loss of agricultural productivity - discussions. Soil degradation by erosion in Brazil. Fragile soils.
7. Soil erosion modeling. Models - types, concepts and examples. Universal Soil Loss Equation (USLE) - concept, applications, advantages and limitations. USLE - application in São Paulo state, Brazil (a case study).
8. Soil Conservation. Concepts and importance of soil conservation for biodiversity and society. Climate change and the relationship with soil conservation.
9. Soils and Ecosystem Services. Definitions. Importance of soils in the context of ecosystem services.
10. Environmental Indicators. Soils in the context of environmental indicators for sustainability.
11. The World in 2050 (TWI 2050) and Sustainable Development Goals (SDG). Soils in the context of The World in 2050 and the context of the Sustainable Development Goals (SDGs).
12. The Nexus Soil-Water-Energy-Food.

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CST-325-3	Hydrologic Changes

The availability of water resources has historically had a predominant role in the evolution of civilizations. Global demographic and land use patterns are constrained by the availability of water and the ability to appropriate the resource in order to sustain life and socioeconomic activities. Changes in the hydrological cycle produced by natural variability and anthropic action alter the storage capacity of the basin. The stress that world population growth and global changes exert on water resources has exacerbated the occurrence of conflicts related to these resources in recent decades and, according to IPCC projections, they will be more frequent and fiercer in the future.

The study of Hydrological Changes focuses on long-term dynamics. It seeks to understand the anthropic factor, through, for example, landscape and river modifications, the exploitation of surface and underground water resources; as well as the role of climate change and natural climate variability. Variability and climate change are understood as bidirectional processes, linked to anthropic activity and mediated by the hydrological cycle. The objective of this subject is to address the study of Hydrological Changes and their impacts on natural and anthropic systems, as well as methodologies used for their detection and projection of scenarios.

Syllabus and References

1) Concept of Hydrological Change at local, regional and global scales

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2) Methodologies for identifying hydrological changes. Statistical Methods and Numerical Modeling

a) McCuen, Richard H. Modeling hydrologic change: statistical methods. CRC press, 2002. 28
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3) Modeling Hydrological Changes, capabilities and limitations

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4) Climate Variability and Water Resources

a) Jhan Carlo Espinoza Villar, Jean Loup Guyot, Josyane Ronchail, Gérard Cochonneau, Naziano Filizola, Pascal Fraizy, David Labat, Eurides de Oliveira, Juan Julio Ordoñez, Philippe Vauchel, (2009). Contrasting regional discharge evolutions in the Amazon basin (1974–2004), Journal of Hydrology, 375, 3-4, 297.
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7) Effects of Hydrological Changes on water security, water resources management and management

a) Bakker, K. (2012) Water Security: Research Challenges and Opportunities. Science 337(6097), 914-915.
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CST-326-4	**Global Electrical Phenomena**

Earth has an intense and continuous electrical activity from the highest layers of its atmosphere (on the border with the interplanetary medium) to the center of the planet. These phenomena are directly related to solar activity, which continuously injects into the interplanetary medium, the so-called solar wind. It is a high-energy plasma that interacts with the magnetic field lines generated by the Earth's dynamo, thus modulating much of the electrical processes existing in the mesosphere and magnetosphere on the planet. In the lower atmosphere (troposphere), thunderstorm clouds, formed by the convection of humid air to the limits of the stratosphere, are controlled by thermal radiation from the sun as well as atmospheric emissions (natural and anthropogenic) from aerosol. Storm clouds electrify, mainly due to the colision of the ice particles inside, and produce lightning discharges, which are intense electrical currents that crosses the troposphere transferring charges within the clouds, between the clouds themselves and from the clouds to the ground. The latter discharges have a great impact on human activity, as they directly affect the structures on the surface causing damage and even culminating in the deaths of animals and humans. Thunderstorms in the troposphere and electrical processes in the mesosphere are tightly coupled to form the so-called Global Atmospheric Electrical Circuit. This circuit appears to be a "thermometer" that indicates how human action and global climate and environmental changes are affecting the planet's electrical balance. In addition, there is evidence that the continued occurrence of storms across the globe also has implications for the chemical balance of the lower atmosphere.

Syllabus

1. Electrical processes in the medium-high atmosphere. Coupling with the interplanetary medium and the Sun. The Earth's magnetic field and dynamo theory. Planetary energy balance.
2. Formation of the ionosphere. Ionization processes of the middle atmosphere
3. Electrical processes in the low atmosphere. Formation of thunderstorms and lightning discharges. Dynamic and thermodynamic systems.
4. Global Atmospheric Electrical Circuit (CEAG). Coupling between low and medium atmosphere
5. Direct and indirect measurements of planetary electrical activity. Satellite and on-board detection systems

6. Role of aerosol on the formation of thunderstorms. Anthropogenic effect on the spatial, temporal and electrical characteristics of lightning activity. Impacts of land use, urbanization and emissions.
7. Lightning discharges and their effects on the chemistry of the atmosphere. N_2 fixation and O_3 formation.
8. Effects of climate and environmental changes on the regime and intensity of thunderstorms. Changes in spatial, temporal and electrical patterns of lightning. Effects of pollution, heat islands, global warming, solar cycle, El Niño and La Ninã phenomena.

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CST-780-0	Doctoral Research on Earth System Science

Mandatory activity on each quarter for every student doing research. The Research Advisor will formalize it and will evaluate the student's performance in this activity. Mandatory also for the students who are not enrolled in any discipline. In this case, the orientation and evaluation must be done by an Advisor approved by the Academic Coordinator.

EST-00	Oriented Study on Earth System Science

Up to 4 credits

CST-800	Doctoral Thesis on Earth System Science

36 credits

Approved by CPG in 04/08/2020.