

Brian Arbic

Professor

Earth & Environmental Sciences

University of Michigan

Research and Teaching

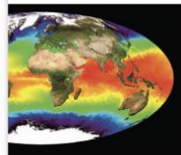
- Ocean Modeling
- Ocean Eddies
- Internal Gravity Waves
- Ocean/atmospheric coupling
- Tides
- Capacity Development

<https://arbic.earth.lsa.umich.edu/>



New Frontiers in Operational Oceanography

Edited by Eric D. Chassignet, Alexandre Pascual, Stjepan Varnet, and Jacques Verron



The implementation of operational oceanography in the past 10 years has provided many societal benefits and has led to new practices adopting a formal roadmap to providing ocean forecasts. Continuing the tradition of two very successful international summer schools held in Rome in 2004 (Chassignet and Verron, 2006) and in Australia in 2010 (Schiller and Branstetter, 2011), a third international school that focused on frontier research in operational oceanography was held in Rome in 2011.

In the coming years, graduate students and young scientists will be challenged by many new observations (GOOS, Sentinel, HRS, floats, etc.), complex high-resolution numerical models and data assimilation (high resolution, predictability, uncertainty, changing computing platforms, etc.) and the need to work on many scales (from research, operations, coupled ocean-atmosphere, biogeochemistry, etc.). The latter school brought together senior experts and young researchers (pre- and post-doctoral) from across the world and exposed them to the latest research in oceanography, specifically how it will impact operational oceanography. This book is a compilation of the lectures presented at the school and presents a summary of the current state-of-the-art in operational oceanography research.

Available at www.godae-oceanview.org and amazon.com

CHAPTER 13

A Primer on Global Internal Tide and Internal Gravity Wave Continuum Modeling in HYCOM and MITgcm

Brian K. Arbic^{1,†}, Mathieu St. Amand², Joseph E. Aouine³, Maxime C. Bellenger⁴, Robert B. Coiro⁵, J. Thomas Farrar⁶, Robert W. Hallberg⁷, Christopher E. Homan⁸, Christopher N. Hsieh⁹, Conrad A. Lankford¹⁰, Damien Menemenlis¹¹, E. Joseph Metzger¹², Mike Miller¹³, Ann D. Nofre¹⁴, Bruce C. Nofre¹⁵, Hans E. Ngodock¹⁶, Raj M. Posa¹⁷, James G. Richman¹⁸, Anne C. Savage¹⁹, Robert B. Scott²⁰, Jay F. Shinner²¹, Harpreet L. Summanu²², Isaacson Savoyev²³, Patrick G. Thacker²⁴, Alan T. Williams²⁵, Lisa Zandbergen²⁶, and Zhenqiang Zhao²⁷

¹University of Michigan, Ann Arbor, Michigan, USA; ²Currently on sabbatical at Institut de Géosciences et d'Environnement (IGE), Grenoble, France; and Laboratoire de l'Étude en Géographie et Océanographie (LEGO), Toulouse, France; ³University of California San Diego, La Jolla, California, USA; ⁴University of Ghent, Ghent, Belgium; ⁵University of Southern Mississippi, Hattiesburg, Mississippi, USA; ⁶NASA Ames Research Center, Mountain View, California, USA; ⁷Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, USA; ⁸Geophysical Fluid Dynamics Laboratory (GFDL), Princeton, New Jersey, USA; ⁹Massachusetts Institute of Technology, Cambridge, Massachusetts, USA; ¹⁰Star Program Laboratory, California Institute of Technology, Pasadena, California, USA; ¹¹Physical Sciences Laboratory, Sonoma Space Center, Mossburn, Australia; ¹²University of Oslo, Oslo, Norway; ¹³University of Florida, Gainesville, Florida, USA; ¹⁴University of Virginia, Charlottesville, Virginia, USA; ¹⁵University of Alabama, Fairbanks, Alaska, USA; ¹⁶University of Washington, Seattle, Washington, USA; ¹⁷Now at Wake Forest University, Winston-Salem, North Carolina, USA; ¹⁸Now at Wake Forest University, Winston-Salem, North Carolina, USA; ¹⁹Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²⁰Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²¹Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²²Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²³Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²⁴Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²⁵Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²⁶Now at Wake Forest University, Winston-Salem, North Carolina, USA; ²⁷Now at Wake Forest University, Winston-Salem, North Carolina, USA

In recent years, high-resolution (eddy-resolving) global three-dimensional ocean general circulation models have begun to include astronomical tidal forcing alongside atmospheric forcing. Such models can carry an internal tide field with a realistic amount of nonstationarity, and an internal gravity wave continuum spectrum that compares more closely with observations at model resolution increases. Global internal tide and gravity wave models are necessary for understanding the three-dimensional structure of ocean mixing for operational oceanography, and for simulating and interpreting satellite altimetry observations. Here we describe the most important technical details behind such models, including atmospheric forcing, bathymetry, astronomical tidal forcing, self-interaction and loading, quadratic bottom boundary layer drag, parametrically generated internal wave drag, shallow water tidal equations, and a brief summary of the theory of linear internal gravity waves. We focus on simulations run with two models, the MITgcm (MITgcm) and the MITgcm (MITgcm), and the MITgcm (MITgcm) of the Institute of Technology, Cambridge, Massachusetts (MITgcm). We compare the modeled internal tide and internal gravity wave continuum to satellite altimetry observations, second-order altimetry records, and the predictions of the Garrett-Munk (1975) internal gravity wave continuum spectrum. We briefly examine specific aspects of interest, such as tidal energetics, internal tide nonstationarity, and the role of nonstationarity in generating the modeled internal gravity wave continuum. We also describe our first attempt at using a Kalman filter to improve the accuracy of tidal altimetry using a general circulation model. We discuss the challenges and opportunities of modeling stationary internal tide, non-stationary internal tide, and the internal gravity wave continuum spectrum for satellite altimetry and other applications.

Arbic, B.K., et al., 2018. A primer on global internal tide and internal gravity wave continuum modeling in HYCOM and MITgcm. In "New Frontiers in Operational Oceanography", E. Chassignet, A. Pascual, J. Varnet, and J. Verron, Eds., GODAE OceanView, 307-350, doi:10.7177/godae2018.01.01

Joseph K. Ansong

Lecturer

Department of Mathematics

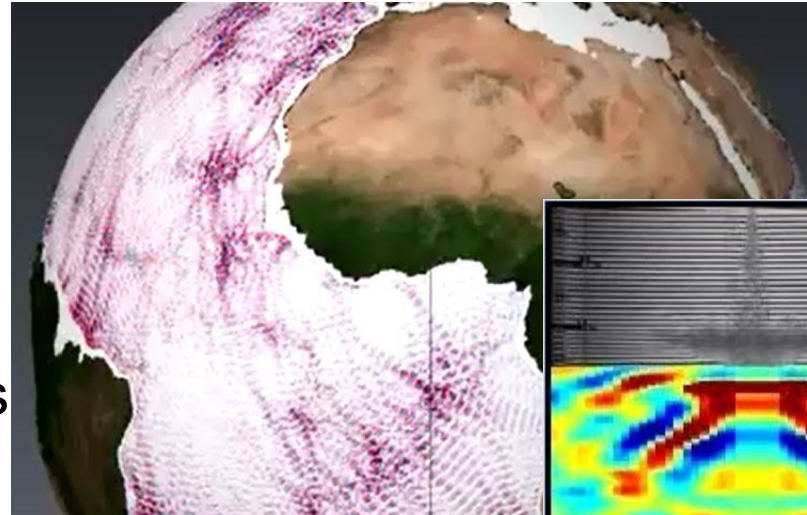
University of Ghana

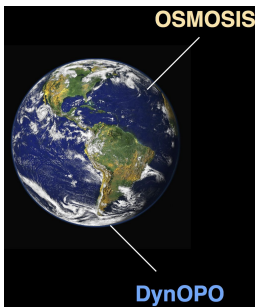
(jkansong@umich.edu; jkansong@ug.edu.gh)



Research and Teaching

- Applied mathematics: Fluid dynamics, Ocean modeling,
- Internal gravity waves
- Differential Equations, Calculus Algebra & Geometry, etc.
- www-personal.umich.edu/~jkansong/





Christian E. Buckingham

Marie Curie Postdoctoral Fellow

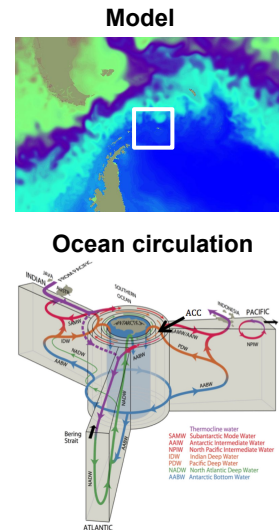
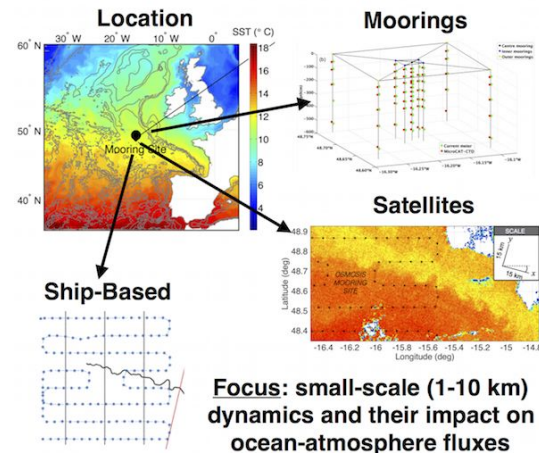
IUEM / LOPS / UBO

Plouzané, France



Research

- Ocean physics
- Examine small-scale (0.1-10-km) ocean phenomena that may have climate-scale impacts
- Use observations (e.g. from moorings, satellites, ships)
- And more recently ... models



Madelyn Cook

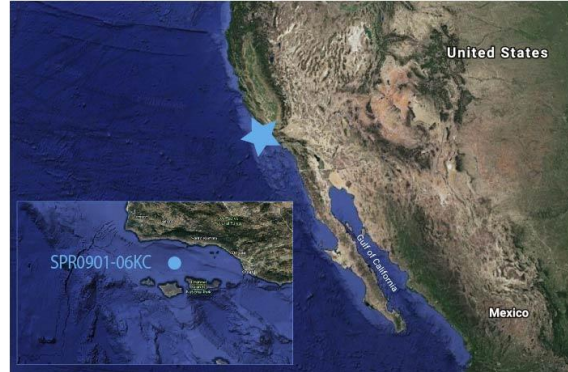
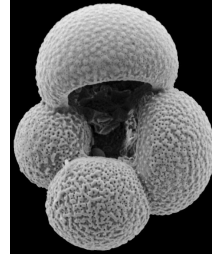
Graduate Student

Earth & Environmental Sciences

University of Michigan

Research

- Paleooceanography
- Chemical Oceanography
- Foraminiferal redox (O_2) proxies
- Speciation and distribution of iodine along the California margin
- Santa Barbara Basin, CA





Aline Cotel

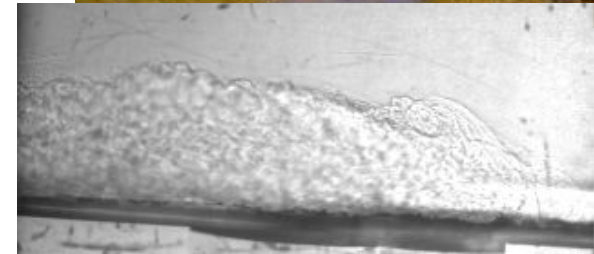
Associate Professor
Civil & Environmental Engineering
University of Michigan



Research and Teaching

- Biological/Environmental Fluid Dynamics
- Mixing and Turbulence
- Capacity building for women engineers in Liberia

<https://cee.engin.umich.edu/people/aline-cotel/>



Stephan Howden

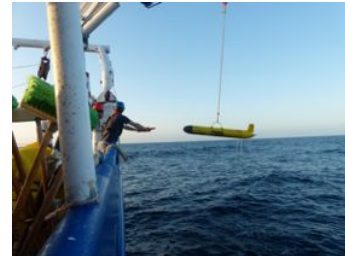
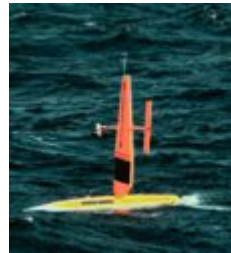
Professor



School of Ocean Science and Engineering
The University of Southern Mississippi

Research and Teaching

- Oceanography
- Ocean Observing Systems
- Hydrography
 - Tides
 - Geodesy



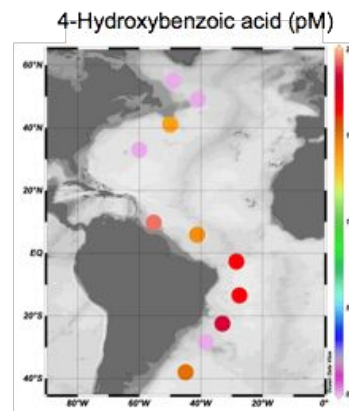
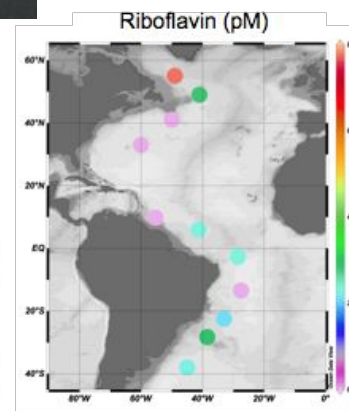
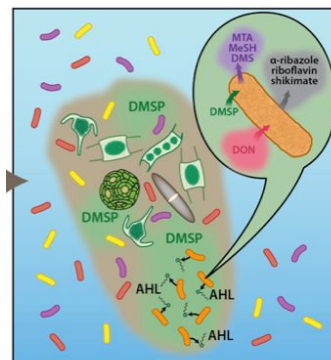
Winn Johnson

Postdoc

U.S. Naval Research Laboratory

Research

- Marine biogeochemistry
- Mass spectrometry
- Metabolomics
- Microbial ecology



Drew Lucas

Assistant Professor
Marine Physical Laboratory
Scripps Institution of Oceanography

Research and Teaching

- Observational oceanography
- Ocean technology design and development
- Small-scale ocean physics
- Interaction of ocean physics and life
- Human impacts on water quality



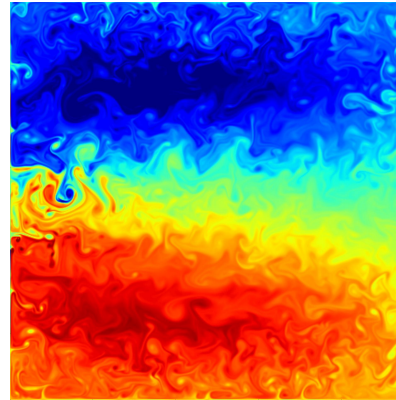
Paige E. Martin

Recent PhD Graduate
Physics/Earth & Environmental Sciences
University of Michigan



Research

- Idealized climate modeling
- Ocean-atmosphere variability
- Spectral analysis
- Python computing
- Science and the arts



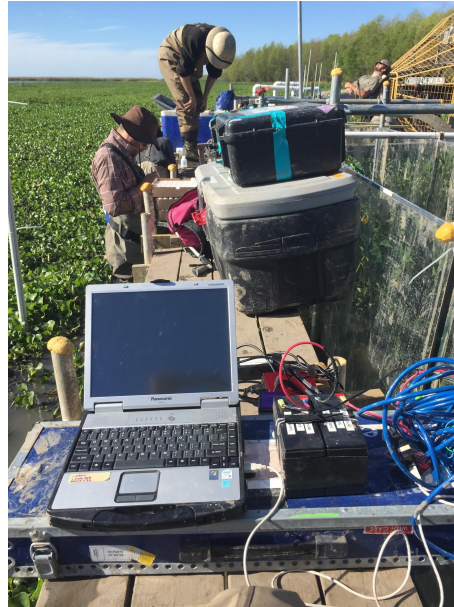
Maddie Foster-Martinez

Post-doc Research Associate

Pontchartrain Institute for Environmental Sciences
University of New Orleans

Research and Teaching

- Environmental Engineering
- Fluid Mechanics
(vegetation-flow interactions)
- Coastal marsh resiliency
- Fieldwork, fieldwork,
lab work, and modeling!



Dimitris Menemenlis

Research Scientist

Jet Propulsion Laboratory

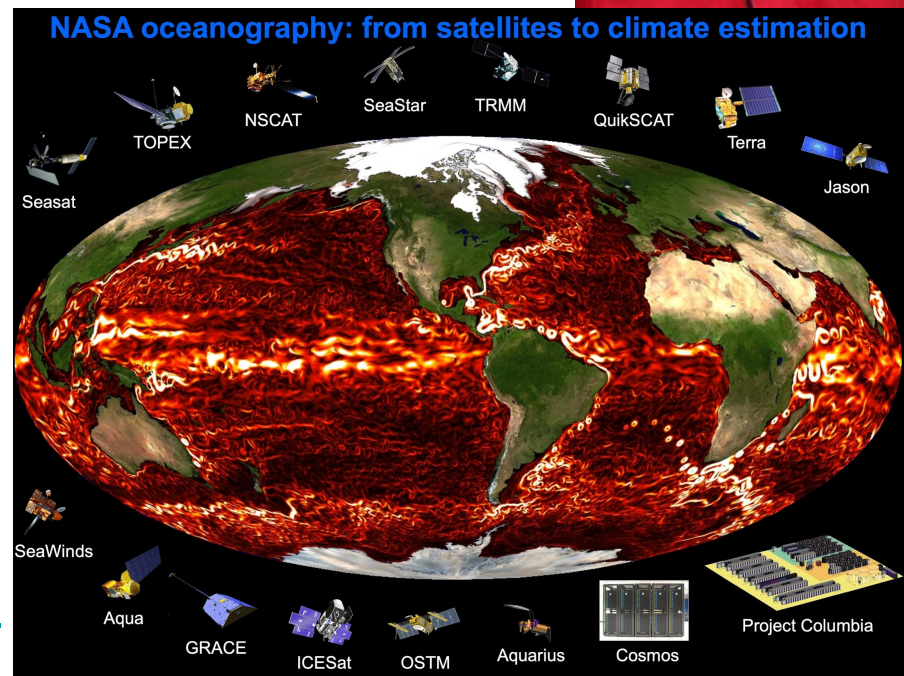
California Institute of Technology



Research

- Global ocean circulation and
- interactions with sea ice, land ice,
- atmosphere, ocean ecology, and
- biogeochemistry.

<https://science.jpl.nasa.gov/people/Menemenlis>



Julia E. Middleton

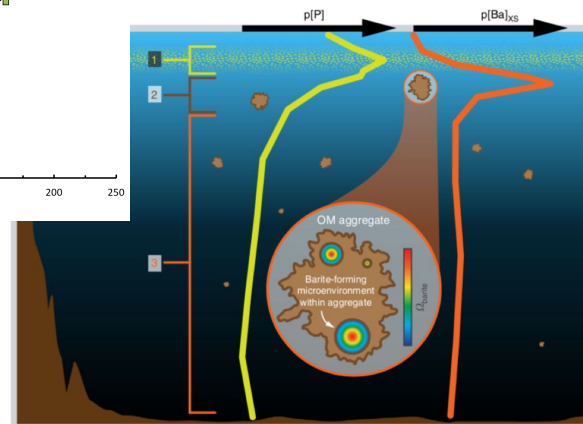
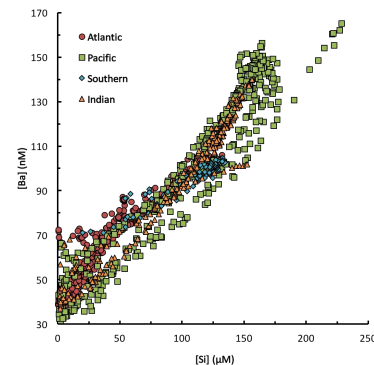
Graduate Student

Marine Chemistry & Geochemistry

Woods Hole Oceanographic Institution

Research

- Non-traditional stable isotopes
- Chemical oceanography
- Carbon export proxies
- Marine barium-isotope cycling and systematics



Ebenezer Nyadjro

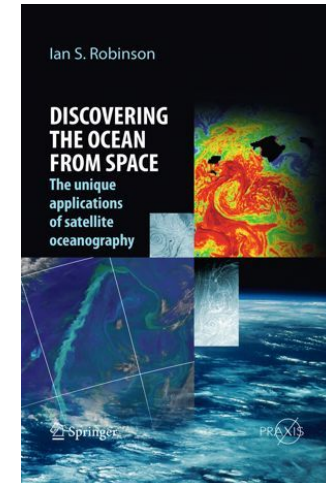
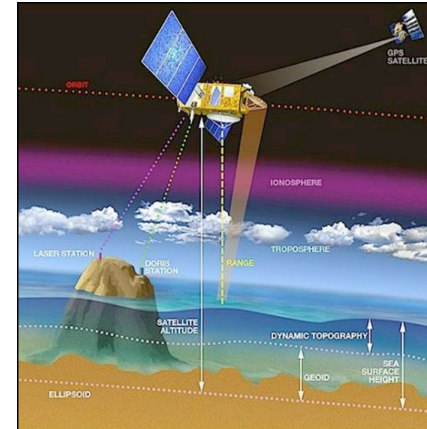
Asst. Research Professor

Dept. of Physics, University of New Orleans/
US Naval Research Lab
(enyadjro@uno.edu)



Research

- Satellite Oceanography
- Variability of ocean currents
- Ocean salinity & freshwater dynamics
- Air-sea interactions & tropical climate variability

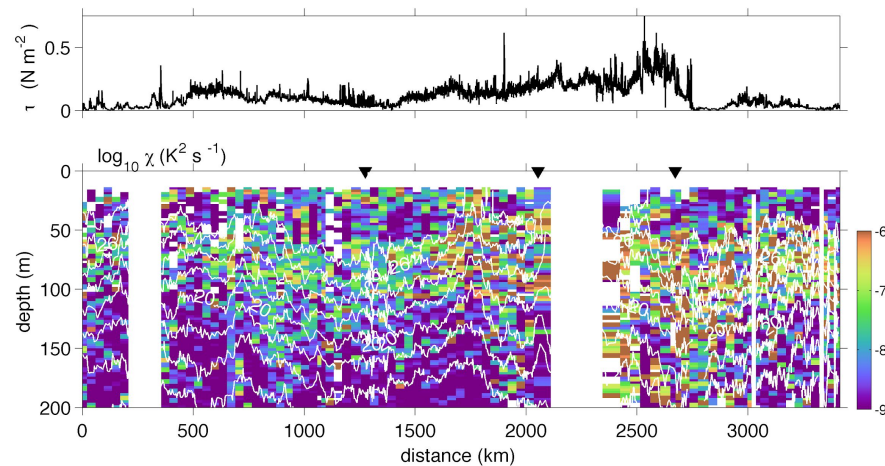
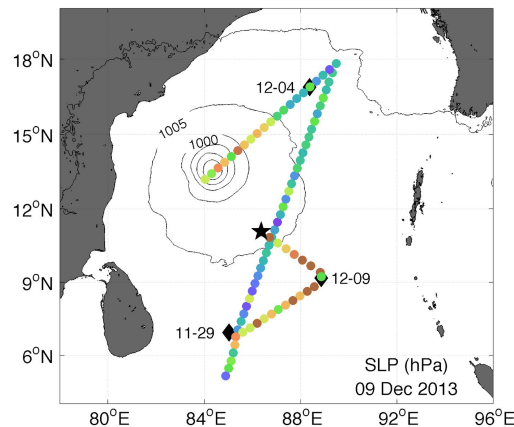


Emily Shroyer

Associate Professor
College of Earth, Ocean,
and Atmospheric Sciences
Oregon State University

Research and Teaching

- Physical Oceanographer
- physics at the interface of other disciplines (bio, ats, ice)
- Interplay between small & large-scale processes
- Observations and Modeling



Adam Simon

Professor

Earth & Environmental Sciences

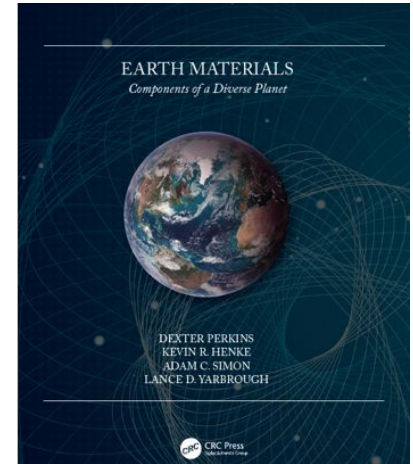
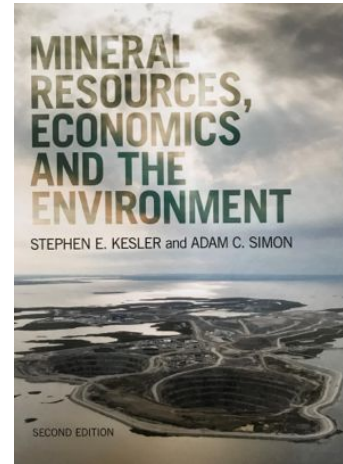
University of Michigan



Research and Teaching

- Formation of metal ore deposits
- Environmental science
- Sustainability

<https://sites.lsa.umich.edu/adamsimon/>



Jackie Wrage

Graduate Student

Earth & Environmental Sciences

University of Michigan



Research

- Geology & the environment
- Formation of metal ore deposits
- Magmatic evolution of Earth
- High T/high P geochemistry

