COSEG

Committee on
SOLID EARTH GEOPHYSICS

SOLID EARTH SCIENCE and SEA LEVEL CHANGE

November 12-13, 2020

Agenda Booklet

The National Academies of
SCIENCES • ENGINEERING • MEDICINE

AGENDA

IN THIS SECTION

Open Session Agenda

November 12-13, 2020

Solid Earth Science and Sea Level Change

Sea level change is one of the most critical environmental and socioeconomic problems facing modern society. It is of paramount importance to predict how much sea level will rise in the future and how it will impact coastal populations and infrastructure. Sea level change involves complex interactions among the atmosphere, oceans, and the land surface; each component must be understood to assess not only how sea level is changing now, but how it will change in the future. The role of the solid Earth and land surface is a vital piece of the puzzle. Vertical land motion can exacerbate relative sea level change in areas of subsidence or buffer against sea level change in areas of uplift. The solid Earth is still deforming in response to mass changes from ice that melted thousands of years ago, as well as ice that is melting today. This deformation changes sea level through the vertical land motion it causes and its changes to the gravity field of the Earth, which causes "imprints" of the ice sheets in the spatial patterns of sea level change. Measurements of sea level change can therefore be used to infer properties of the solid Earth that drive this deformation. This meeting will review the state of sea level science, discuss the role of solid Earth science in studying sea level change, and delve into the important questions that we need to answer in the future.

THURSDAY, NOVEMBER 12, 2020
(all times are EST)

	Open Session
12:00 PM	**Welcome and Introductions** *Thorsten Becker, COSEG Chair*
	Introductory Talks *Moderator: Steve Nerem, COSEG Member*
12:05 PM	**Mapping Sea-Level Change in Space and Time** *Ben Hamlington, NASA Jet Propulsion Laboratory*
12:40 PM	**Sea Level and the Solid Earth: Insights onto Ocean Circulation and Climate** *Christopher Piecuch, Woods Hole Oceanographic Institution*
1:15 PM	**Discussion and Q&A**

GIA Modeling and Solid Earth Deformation *Moderator: Mark Behn, COSEG Member*	
2:00 PM	**Neglected Processes: The Role of the Solid Earth in Controlling Ice Sheet Contributions to Sea Level Change** *Pippa Whitehouse, Durham University*
2:35 PM	**Using Paleo Sea Level Records to Image Earth's Internal Structure and Decipher Drivers of Sea Level Change** *Jacky Austermann, Lamont-Doherty Earth Observatory, Columbia University*
3:10 PM	**Discussion and Q&A**
3:30 PM	**Brief Wrap-Up of Day 1** *Steve Nerem, COSEG Member*

3:35 PM – Day 1 Adjourns

FRIDAY, NOVEMBER 13, 2020
(all times are EST)

Open Session	
12:00 PM	**Welcome and Summary of Day 1** *Thorsten Becker, COSEG Chair*
Vertical Crustal Modeling *Moderator: Jeff Freymueller, COSEG Member*	
12:15 PM	**Using GPS Networks to Measure Global Vertical Land Motion and its Impact on Sea Level Rise** *Bill Hammond, University of Nevada, Reno*
12:50 PM	**Monitoring, Modeling, and Projecting Vertical Land Motion: Implications for Relative Sea Level Rise and Coastal Flooding** *Manoochehr Shirzaei, Virginia Tech*
1:25 PM	**Discussion and Q&A**
1:45 PM	**Break**

Panel Discussion and Synthesis	
2:15 PM	**Discussion with All Speakers** *Moderator: Maya Tolstoy, COSEG Member*
2:55 PM	**Synthesis and Wrap-Up** *Steve Nerem, COSEG Member*

4:30 PM – Day 2 Adjourns

COMMITTEE INFORMATION

IN THIS SECTION

COSEG Statement of Task

The Committee on Solid Earth Geophysics (COSEG) provides independent advice to all levels of government and society on scientific, technical, and policy matters related to seismology, geodesy, and geodynamics.

Members are drawn from the public, academic, and private sectors and have a broad range of expertise and experience. The mission of the committee is as follows:

- To foster and encourage understanding of the structure, dynamics, and evolution of the Earth.
- To review and define basic and applied research activities in seismology, geodesy and geodynamics that contribute to federal agency missions.
- To address the transfer of seismological and geodynamics knowledge to areas of public welfare and national need including topics such as earthquake science; geological hazards; energy, mineral, and water resources; national security, global climate change; land-use planning; and public education.
- To foster long-term national efforts to collect, store and openly disseminate seismological, geodetic, and geodynamical data of all types.
- To foster long-term national efforts to monitor geodynamical events as well as nuclear testing treaties using geophysical technologies.
- To serve as the U.S. member of the International Lithosphere Program.

COSEG, formerly the Committee on Seismology and Geodynamics (name changed June 2020), was formed in 2001 as a standing committee of the Board on Earth Sciences and Resources. This committee succeeded three former entities: the Committee on Seismology, the U.S. Geodynamics Committee, and the Committee on Geodesy.

COMMITTEE BIOGRAPHIES

THORSTEN W. BECKER, Chair, is the Shell Distinguished Chair in Geophysics at the Institute for Geophysics and the Department of Geological Sciences, Jackson School of Geosciences, at the University of Texas at Austin. His main research interests are in geodynamics and seismology with a focus on interactions between mantle convection and surface tectonics—studying the inner workings of terrestrial planets and how their mantle and surface systems have co-evolved over time. He combines field, laboratory, and numerical approaches into dynamical models, focusing on the physics of plate tectonics from grain-scale deformation to plate-scale flow. Recent research projects include work on seismic anisotropy, mantle heat transport and the mechanics of plate tectonics, subduction dynamics, and fault system mechanics. He has co-authored more than 110 publications and was named an AGU Fellow in 2015. Dr. Becker holds an M.Sc. in physics from J. W. Goethe University, a Ph.D. in geophysics from Harvard University, and was a postdoctoral scholar at the Scripps Institution of Oceanography at the University of California, San Diego.

MARK D. BEHN is an associate professor in the Morrissey College of Arts and Sciences at Boston College. Dr. Behn's research investigates the dynamics of Earth deformation in glacial, marine, and terrestrial environments through the use of a wide range of geophysical techniques. These techniques include the development of geodynamic models that relate laboratory-based rheologic and petrologic models to the large-scale behavior of the Earth, which are then applied to a spectrum of problems from basic science to societally-relevant issues. His research interests include dynamics of faulting, magmatism, and surface processes at mid-ocean ridges and continental rifts; seismic anisotropy and imaging of sub-asthenospheric mantle flow; evolution of the continental crust; and ice-sheet dynamics. He is the co-chair of the Geodynamics Focus Research Group for the Community Surface Dynamics Modeling System, was active in the MARGINS/GeoPRISMS program, and is a former fellow of the WHOI Deep Ocean Exploration Institute. Dr. Behn received his B.S. in geology from Bates College and a Ph.D. in marine geophysics from the Massachusetts Institute of Technology/WHOI Joint Program.

CYNTHIA (CINDY) EBINGER is a professor and Marshall-Heape Chair in the Department of Earth and Environmental Sciences at Tulane University. Her current research aims to understand the partitioning of strain between faulting and magmatic processes within continental and oceanic rift zones over time scales of hours to millennia and the longer-term evolution of continental rift zones from initiation to continental rupture. Her interest in continental rifts and plate boundary deformation began as an undergraduate at Duke University when she took part in a National Science Foundation-sponsored research project in the volcanically and seismically active East African rift zone. Dr. Ebinger served as a former president of the Tectonophysics Section of the American Geophysical Union (AGU) and was recently named an AGU Fellow for her "fundamental work on the evolution of continental rifts toward seafloor spreading in East Africa and afar." Dr. Ebinger earned her B.S. in geology from Duke University, S.M. from Massachusetts Institute of Technology (MIT), and Ph.D. in oceanography from the MIT/Woods Hole Oceanographic Institution (WHOI) Joint Program.

JEFFREY T. FREYMUELLER is the Thomas A. Vogel Endowed Chair for Geology of the Solid Earth in the Department of Earth and Environmental Sciences at Michigan State University. Dr. Freymueller is an internationally recognized leader in the field of geodesy and utilizes satellites from the Global Positioning System (GPS) to make highly precise measurements of movement on the Earth's surface. In his far-reaching research activities, he has made discoveries in a wide range of topics including plate tectonics and plate boundary zones, faults dynamics, the continuing rebound of the Earth's surface from the melting of ice-age glaciers, inflation and deflation of volcanoes, and interpreting how changing water and ice levels deform the Earth. He is particularly well-cited for his work on using GPS to understand the crustal deformation in China related to the formation of the Himalayas and the Tibetan Plateau. In addition to his research, Dr. Freymueller is the director of the EarthScope National Office. EarthScope is a long-term, large-scale program funded by the National Science Foundation to study the structure and evolution of North America and associated hazards through the deployment of thousands of geophysical instruments throughout the country. Dr. Freymueller also has served the scientific community as the U.S. National Correspondent to the International Association of Geodesy

and its representative to the International Union of Geodesy and Geophysics, has served terms as an associate editor for the Journal of Geophysical Research and the Journal of Geodesy, and is currently Editor in Chief of the International Association of Geodesy Symposia Series. Dr. Freymueller received his M.S. and Ph.D. in geophysics from the University of South Carolina.

RENGIN GOK is a research seismologist at the Lawrence Livermore National Laboratory where she manages the Seismic Cooperation Program for the DOE/NNSA Office of Nuclear Verification. She is an expert in the development and improvement of seismic monitoring in international communities. Her interests include: seismic source behavior, Comprehensive Nuclear-Test-Ban Treaty verification technologies, velocity and attenuation structure of the Earth, and seismic hazard assessment and its engineering applications. She has published more than 35 peer-reviewed scientific papers. Dr. Gok earned her B.Sc. in geophysical engineering from Istanbul Technical University, and her M.Sc. and Ph.D. in geophysics from Bogazici University in Istanbul, Turkey.

DIEGO MELGAR is an assistant professor of geophysics in the Department of Earth Sciences at the University of Oregon where his research focuses on large earthquakes. He works on the physics of the rupture process and how to best image it by using many diverse kinds of on-shore and off-shore geophysical data. He also researches the hazards associated with these large events, working on tsunami modeling and coastal impacts, as well as studying how strong shaking is generated. Prior to joining the University of Oregon, Diego researched the role of global navigation satellite systems (GNSS) in seismology. He also spent three years at the University of California Berkeley's SeismoLab working on early warning systems. He continues to work on early warning systems to abate the societal impact of these hazards. Diego earned his B.Eng. in geophysics from the Universidad Nacional Autónoma de México and his M.S. and Ph.D. in geophysics from the Scripps Institution of Oceanography.

R. STEVEN NEREM is a professor in the Department of Aerospace Engineering Sciences and associate director of the Colorado Center for Astrodynamics Research at the University of Colorado at Boulder. Dr. Nerem's research interests include sea-level change, satellite altimetry, Earth's gravity field, planetary geodesy, precision orbit determination, and astrodynamics. He has served on two previous committees for the National Academies of Sciences, Engineering, and Medicine - the Committee on Earth Science and Applications from Space and the Committee on Evolving the Geodetic Infrastructure to Meet New Scientific Needs. Dr. Nerem is the recipient of numerous awards including the American Astronautical Society's Earth Science and Applications Award and the American Geophysical Union's (AGU) Geodesy Section Award. He is a fellow of the AGU. Dr. Nerem earned a B.S. in geology from Colorado State University and an M.S. and Ph.D. in aerospace engineering from the University of Texas, Austin.

MATTHEW PRITCHARD is a professor of geophysics at Cornell University. He is interested in how the Earth's surface deforms in response to earthquakes, magma movements, glacier dynamics, and human manipulation of subsurface fluids (e.g., carbon sequestration, hydrocarbon withdrawal). Dr. Pritchard uses a variety of tools including Interferometric Synthetic Aperture Radar (INSAR), GPS, and laser scanning to study deformation. He is a member of the American Geophysical Union, Geological Society of America, and the International Association for Volcanology and Chemistry of the Earth's Interior. He received the 2015 Geodesy Section Award from the AGU. He served on the UNAVCO Board of Directors from 2009 to 2012 and currently serves on the advisory board of the Carl Sagen Institute and the U.S. National Committee for Geodesy and Geophysics. He earned a B.S. in physics from the University of Chicago and an M.S. and Ph.D. in geophysics from the California Institute of Technology.

DONNA J. SHILLINGTON is an associate professor in the School of Earth and Sustainability at Northern Arizona University. Her research focuses on deformation, magmatism, and sedimentation at plate tectonic boundaries and in other interesting geological settings, which she studies using active-source seismology together with other geophysical, geological, and geochemical approaches. An important component of her research is the acquisition and analysis of novel geophysical data on land and at sea; she has sailed on 18 research cruises around the world and also led

major seismic data collection efforts on land. Her prior community service and leadership includes serving on the IRIS Board of Directors, the steering committees of GeoPRISMS and EarthScope and the Marine Seismic Research Oversight Committee; she currently serves on the steering committee of the SZ4D Research Coordination Network. Prior to joining Northern Arizona University, she was a research scientist and professor at Lamont-Doherty Earth Observatory of Columbia University and a postdoctoral research scientist and lecturer at the National Oceanography Centre in Southampton, UK. Dr. Shillington earned her B.S. in geology and A.B.J. in journalism from the University of Georgia and her Ph.D. in geophysics from the University of Wyoming.

MAYA TOLSTOY is a professor in the Department of Earth and Environmental Sciences at Lamont-Doherty Earth Observatory (LDEO) of Columbia University in New York. For the Academic Year 2018-2019, Dr. Tolstoy was the interim Executive Vice President and Dean of the Faculty of Arts and Sciences at Columbia University. She is a marine geophysicist specializing in seafloor earthquakes and volcanoes. She has worked extensively on the structure and seismicity associated with mid-ocean ridges and, in particular, how earthquakes in this environment can be used to illuminate hydrothermal and magmatic processes. In addition, she has done research on hydroacoustic signals and anthropogenic noise in the ocean. Dr. Tolstoy has extensive seagoing experience, having participated in 31 seagoing expeditions; on 18 of those she was chief or co-chief scientist. She currently helps oversee the LDEO Ocean Bottom Seismograph Instrument Pool (OBSIP), and serves on the Incorporated Research Institutions for Seismology's OBSIP management council. In 2009, she was one of 47 finalists for NASA's astronaut selection and is the recipient of the 2009 Wings Worldquest Sea Award honoring women in exploration. Dr. Tolstoy has also done extensive outreach work to communicate the excitement and importance of earth science to non-science audiences. She holds a B.Sc. Honors in geophysics from the University of Edinburgh and a Ph.D. in Earth science from Scripps Institution of Oceanography, University of California, San Diego.

WILLIAM (BILL) R. WALTER is a research geophysicist at the Lawrence Livermore National Laboratory where he leads the Geophysical Monitoring Programs. He is also the Chief Scientist for the DOE/NNSA Office of Defense Nuclear Nonproliferation sponsored Source Physics Experiments. His research areas include geophysics and seismology, seismic source physics, Earth structure, tectonics, treaty verification, and related policy issues. He served on the Seismic Subcommittee for the National Academies of Sciences panel that issued a 2012 report updating the technical issues related to the Comprehensive Nuclear-Test-Ban Treaty. He is the author or co-author of more than 75 peer-reviewed scientific papers. Dr. Walter received a B.A. in physics from Middlebury College, a M.S. in physics from the University of California, San Diego, and a Ph.D. in geophysics from the University of Nevada, Reno.

JESSICA M. WARREN is an associate professor in the Department of Earth Sciences at the University of Delaware. Dr. Warren's research focuses on the rheology and geochemistry of the Earth's upper mantle. She has worked extensively on the localization of deformation at plate boundaries with a focus on the transform faults that offset the global mid-ocean ridge system. She has also worked on the constraints provided by naturally deformed samples for interpreting seismic anisotropy. Dr. Warren has participated in 14 field expeditions including on-land expeditions to the western United States and Oman Ophiolite and seagoing expeditions in the Pacific, Atlantic, and Indian Oceans. In 2019, she served as chief scientist on the R/V Atlantis for a large ocean bottom seismometer (OBS) and dredging campaign on Gofar transform fault. Dr. Warren serves on the GeoPRISMS steering committee, the In-Situ Rock Deformation Research Coordination Network (RCN) steering committee, and previously on the Physical Properties of Earth Materials steering committee. Outreach by Dr. Warren includes work to improve the quality and accessibility of Earth Science education with a focus on field learning and the graduate experience. Dr. Warren is a recipient of a NSF CAREER award, Stanford Terman Fellowship, and Carnegie Postdoctoral Fellowship. She holds a B.A. First Class, M.A., and M.Sci. in natural sciences from the University of Cambridge and a Ph.D. in geochemistry and geophysics from the Massachusetts Institute of Technology/Woods Hole Oceanographic Institution Joint Program.

SPEAKER BIOGRAPHIES

Jacky Austermann

Jacky Austermann is an Assistant Professor in the Department of Earth and Environmental Sciences at Columbia University and works on better understanding how sea level and ice sheets have changed over the past hundreds, thousands, and millions of years. The goal of her work is to elucidate properties and dynamics of Earth's interior, understand the magnitude and rate of sea level change in response to warming temperatures, and unravel the interactions between solid Earth processes and the paleoclimate record over Earth's geologic past.

To reconstruct past local sea level, Austermann performs fieldwork to extract and interpret ancient sea level in the field, and works with collaborators to analyze and date sea level indicators. Austermann's specialty lies in performing large scale numerical simulations of various processes that can cause uplift or subsidence such as glacial isostatic adjustment and mantle convection. She uses forward and inverse modeling of these processes to combine the numerical models with new and existing sea level data.

Austermann is currently working on projects with field sites in the Bahamas and Argentina to better understand sea level changes during past warm periods. She's further an investigator on the Greenland Rising project, which includes working with local communities around Greenland to map habitat, bathymetry, and sea level change and make predictions of their future change. Other active projects include constraining changes in global groundwater over ice age cycles, understanding the dynamics and formation of cratonic basins, and mapping Earth's internal viscosity structure using Holocene sea level observations.

Austermann earned her Ph.D. in Earth Sciences from Harvard University in 2016 and conducted a short postdoc at Cambridge University before joining Columbia University in 2018. In 2019, Austermann was awarded the Jason Morgan Early Career Award from the American Geophysical Union for her outstanding and significant contributions to tectonophysics.

Dr. Ben Hamlington

Dr. Ben Hamlington is a Research Scientist in the Sea Level and Ice Group at the Jet Propulsion Laboratory. He studies global and regional sea-level changes with a particular focus on using satellite observations to understand sea level variability on interannual to decadal timescales. He has also done considerable work on understanding sea level during the 20th century, comparing historical in situ data to modern satellite observations. He is also interested in how sea level is responds to both natural and anthropogenic forcing, and what this will mean for coastal populations both now and in the future. This interest extends to bridging the gap between scientist and decision-makers, and the challenge of generating useful scientific information for planning purposes. Dr. Hamlington is a member of NASA's Ocean Surface Topography and GRACE/GRACE-FO science teams and is the current team lead of the NASA Sea Level Change Science team.

Bill Hammond

Bill Hammond is a Professor of Geodesy and Geophysics at the University of Nevada, Reno. He is a member of the Nevada Geodetic Laboratory a research group in the Nevada Bureau of Mines and Geology, the state of Nevada's geological survey. In his research Bill uses space geodesy to study active processes inside the solid Earth. These processes include tectonic and seismic cycle deformation, mountain building, mantle flow, geophysical loading of Earth's surface, tectonic controls on geothermal resources, and interactions between tectonic and magmatic systems. Recently he has published peer reviewed research papers on using GPS and InSAR to study vertical motion of Earth's surface, its interaction with the climate system and application to sea level studies. He currently manages the MAGNET GPS network in the western Great Basin and eastern California, a geodetic infrastructure for research in geodynamics and seismic hazards. His recent professional service includes chairing the Advisory Committee for the NSF-supported EarthScope Plate Boundary Observatory, acting as secretary of the geodesy section of the American Geophysical Union, and Associate Editor for the Bulletin of the Seismological Society of America. He currently serves on the National Academy of Science Board on Earth Science and Resources. He is author or co-author of ~90 peer reviewed and non-peer reviewed articles, book chapters, maps, conference proceedings, guidebooks, and reports. He earned degrees in applied mathematics and geophysics, and was a postdoc at the US Geological Survey in Menlo Park, CA.

Christopher G. Piecuch

Christopher G. Piecuch is Assistant Scientist in the Physical Oceanography Department at Woods Hole Oceanographic Institution (WHOI), where he has been since 2018. Before coming to WHOI, he was Staff Scientist at Atmospheric and Environmental Research, Inc. (2010-2017), and Volunteer with the United States Peace Corps (2006-2007). He holds a B.A. in Physics, Mathematics, and German Language and Literature (2006), a M.S. in Biological Oceanography (2010), and a Ph.D. in Physical Oceanography (2016), all from the University of Rhode Island. Dr. Piecuch studies the physics and statistics of coastal, regional, and global sea-level changes. His work quantifies how and why sea levels change across space and through time based on instrumental observations, proxy records, numerical models, and analytical theory. Dr. Piecuch's recent efforts focus on understanding how coastal sea level is related to large-scale ocean circulation, including the Atlantic Meridional Overturning Circulation (AMOC), and reconstructing the history of past coastal sea level changes. His work is supported by the National Science Foundation (NSF) and National Aeronautics and Space Administration (NASA). He is currently Principal Investigator on the NASA Sea Level Change Science Team (N-SLCT) and the NSF Paleo Perspectives on Climate Change (P2C2) Program. Piecuch serves on the United States Climate Variability and Predictability (CLIVAR) Program's Phenomena, Observations, and Synthesis (POS) Panel. His work is summarized in >50 peer-reviewed papers published in journals including Nature and the Proceedings of the National Academy of Sciences.

Dr. Manoochehr (Manoo) Shirzaei

Dr. Manoochehr (Manoo) Shirzaei is a geodesist/geophysicist who has made significant contributions to the field of crustal deformation monitoring and modeling from space. Dr. Shirzaei is specialized in space-borne synthetic aperture radar, groundwater hydrogeodesy, seismic and aseismic faulting processes, volcanos, induced seismicity and fracking, and impacts of relative sea-level rise on coastal areas. He has authored 60 publications in high-profile peer-reviewed journals.

Dr. Shirzaei has been a PI and Co-PI on several national-level programs such as the NASA Earth Surface and Interior, NASA Sea Level Change Science Team, NASA GRACE Satellite Science Team, DOE Office of Basic Science, and NSF Earthcube. He is also a member of the Center for Coastal Studies at Virginia Tech and the planning committee of the Southern California Earthquake Center.

Pippa Whitehouse

Pippa Whitehouse is an Associate Professor in the Geography Department at Durham University, UK. Her expertise lies in modelling the process of glacial isostatic adjustment (GIA), which considers feedbacks between ice dynamics, sea-level change, and solid Earth deformation. She collaborates with researchers in the fields of geophysics, geodesy, geology, and glaciology, drawing on data-model comparisons to better constrain model parameters and identify neglected processes.

For the last ten years, the main focus of Pippa's research has been the study of GIA in Antarctica, and she has taken part in three Antarctic fieldwork seasons during this time. Pippa has been involved in efforts to map out 3D Earth structure beneath Antarctica using seismic data, and she currently heads up a NERC-funded project that collects GPS data from ~30 bedrock sites across West Antarctica and the Antarctic Peninsula. She uses these data to improve our understanding of Earth rheology across Antarctica and investigate feedbacks between Earth deformation and ice sheet dynamics.

A second strand of Pippa's research focuses on interpreting records of past sea-level change, from locations in the near- and far-field of the major ice sheets, in order to determine Earth rheology and reconstruct global and regional ice sheet change.

Pippa is currently joint chief officer of the SCAR (Scientific Committee on Antarctic Research) scientific research program SERCE (Solid Earth Response and influence on Cryospheric Evolution). In recognition of her achievements in the field of GIA she was chosen to give the British Geophysical Association Bullerwell Lecture in 2016.