

Auroop R. Ganguly: Concise Summary of Prior Accomplishments

Climate-Driven Risks & Resilience of Natural-Built-Human Systems with Big Data

Auroop R. Ganguly works in climate and water complexity, predictive understanding of climate risks, and the resilience of natural and built systems such as water resources, ecosystems and lifeline infrastructures, with data and computational science methods. His research aspires to embed resilience in design, maintenance, and operations, provide guidance to adaptation and sustainability, and inform investments and policy.

PUBLICATIONS: Ganguly has published 2 books, 23 peer-reviewed book chapters, 48 peer-reviewed journal articles (with 3 more in review), and 28 peer-reviewed conference papers including in highly selective computer science (data mining) conferences (with 2 best paper awards) and 60 other conference papers or abstracts. Ganguly's research has been published in interdisciplinary journals such as *Nature*, *PNAS*, *Nature Climate Change*, *Nature's Scientific Reports* and *PLOS One*, with two others in review. His papers in climate or geophysics journals include those in *Journal of Climate*, *Journal of Geophysical Research*, *Geophysical Research Letters* and *Climate Dynamics*, water journals such as *Water Resources Research*, *Advances in Water Resources*, *Journal of Hydrology*, *Journal of Hydrometeorology*, *JAWRA*, and *ASCE J. Hydrologic Eng.* In the data sciences, he has published in nonlinear dynamics journals such as *Physical Review E*, and *Nonlinear Processes in Geophysics*, computer or data science journals such as *Statistical Analysis and Data Mining* and peer-reviewed data mining conferences such as *SIAM Data Mining* and *NASA CIDU*, organized and published in workshops of the *ACM KDD* and *IEEE ICDM*. His publications in IEEE journals are in *IEEE Transactions on Geoscience and Remote Sensing*, *IEEE Sensors*, and *IEEE Transactions on Intelligent Transportation Systems*.

Ganguly has published two edited books on *Knowledge Discovery from Sensor Data*. Currently he is under contract to write a textbook on *Critical Infrastructures Resilience* dealing with both the engineering and policy aspects, based on a graduate course he co-teaches with a professor of political science.

PATENTS: Ganguly has two US patents pending through Northeastern University (NU), one in climate risk management and the other infrastructural resilience. In addition, his research the Oak Ridge National Laboratory (ORNL) led to three invention disclosures in data science and decision sciences.

FUNDING: Over the last 5 years at Northeastern, Ganguly has been a PI or Co-PI in external grants totaling around \$13 Million. His research has been funded by NSF (e.g., Expeditions in Computing, Big Data, Cyber SEES), DOE including ORNL and ARPA-E, DHS, NRC, DOD including DARPA, and other private or public sector organizations. Funding agencies have reached out to him to solve problems, such as US DOE's ARPA-E when they wanted to solve a water-energy nexus (when stressed by climate and population) problem and the US NRC when they wanted to solve a problem related to precipitation extremes risks under climate variability or change. In addition, he has pending proposals and preproposals worth about \$12M in review, including a 5-year, \$10M (Ganguly share: \$2.25 Million) NSF Expeditions in Computing preproposal, just encouraged for full development.

Ganguly was the lead PI in a declined NSF Engineering Research Center proposal on coastal city resilience with a team that included NU (lead), USC (co-lead), GA Tech, MIT and Jackson State. He was also a Co-PI in an NSF INFEWS and an NSF CRISP proposal. Furthermore, he was the Co-PI and Deputy Director in a large DHS center lead proposal on critical infrastructure resilience, for which NU received partial funding.

RECOGNITION: He is a Co-Chair of NCAR's CESM (one of the most commonly used global climate model) societal dimensions working group. He is or has been an *Associate Editor* for two top journals, including AGU's *Water Resources Research* and ASCE's *Journal of Computing in Civil Engineering*. He is an editorial board member of the journal *Scientific Reports* from the Nature Publishing Group, and has reviewed papers both for *Nature* and for other Nature journals. He is a member of the Artificial Intelligence Committee of the American Meteorological Society, and has served on several distinguished panels, including twice serving on the *United Nations Environment Programme: Environmental Effects Assessment Panel*. He has also organized several international conferences, including serving as the Founding Organizer of the Workshop on Climate Data Mining as part of the *IEEE Conference on Data Mining* and the Founding Organizer of the Knowledge Discovery from Sensor Data Workshop as part of the *ACM Knowledge Discovery and Data mining* conference. The ACM KDD, IEEE ICDM and SDM are arguably the top three peer-reviewed venues in data mining (note: computer science communities often prefer to publish their best work initially in peer-reviewed conferences). Ganguly's leadership and participation across diverse professional societies speaks to the interdisciplinary appeal of his work. He received an outstanding reviewer award by ASCE, a faculty fellow award at Northeastern, an outstanding joint faculty award from the University of TN, Knoxville, and multiple scientific and mentorship awards from the Oak Ridge National Laboratory (ORNL) and the US Department of Energy (DOE).

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Ganguly has given over 20 invited lectures, including two at international conferences, as well as at national and international universities. He will present an invited talk at a NIST-funded workshop in DC entitled “Climate & Complexity: The Resilience of Natural-Built-Human Systems” while his PhD student will deliver a similar talk in Shenzhen, China, at a workshop organized by the US National Academy of Engineering and the Chinese Academy of Engineering (the two workshops are back-to-back), delivered multiple talks earlier this year at three campuses of the Indian Institutes of Technology, and a National Institute of Technology. He is slated to deliver an invited talk at the University of Massachusetts, Amherst later this year.

PUBLICITY: Ganguly and his group’s research at the SDS Lab has been written up as research highlights and as perspectives in *Nature*, NSF news (thrice for specific publications, once on their banner page for work related to the Expeditions in Computing project on data-driven climate understanding), Faces of NSF research (highlight of researchers in NSF’s magazine), Live Science interviews, as well as in *Science Daily*, NASA Tech Briefs and by editors of AGU and ERL. His papers have been cited by the 2013 Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC). In addition, his work has been reported and he has been quoted widely over the last decade in the mainstream national (e.g., USA Today and Washington Post) and international (e.g., Guardian and International Business Times) media, in all continents except Antarctica.

ADVISING: Ganguly has graduated five Ph.D. students, two at NU (as advisor), one while at NU via a university partner (as co-advisor), and two through partner universities while he was at ORNL (one as advisor and one as co-advisor). He is currently advising seven Ph.D. students and has advised several undergraduate research assistants and a high-school student. He has advised three post-doctoral associates at Northeastern, and is currently advising a research scientist. While at ORNL, he advised students at K-12, undergraduate, post-MS and doctoral levels as well as post-doctoral associates. Ganguly’s PhD students are in insurance (AIG), reinsurance (Tokio Marine), and data science (Verizon, Progeny Systems) companies, while one is the CEO of a startup (risQ Corporation) and another is an executive at AIG. Of his post-graduate associates, three are in academia (one is a tenure-track assistant professor at Santa Clara and another is a teaching faculty at Nebraska Lincoln), one is in insurance risk modeling industry (AIR Worldwide), three are research scientists (one is a team leader) at ORNL. While at ORNL, Ganguly won several awards for mentoring students.

TEACHING: Ganguly has created four new courses at Northeastern, including a new graduate course in Applied Time Series and Spatial Statistics, a new graduate course in Critical Infrastructure Resilience that is co-taught with the College of Social Science and Humanities, and a new pair of undergraduate Dialogue of Civilizations courses that are taught abroad, one on Climate Science and Engineering and another on Climate Adaptation and Policy. He also regularly teaches a required undergraduate course called Probability and Engineering Economy for Civil Engineers. His graduate courses are at the core of a new M.S. degree in Engineering and Public Policy with Concentration in Infrastructure Resilience within CEE, which he co-developed. His teaching scores have been generally above the department average in the graduate classes, originally a little below the department average in the required undergraduate class (but with steady improvement), and above the university average in the climate study abroad courses. The latter are tailored towards the elite University Scholars, and have consistently received high praise from students, including statements that they are life changing experiences.

IMPACTS ON BEST PRACTICES: Ganguly’s research has influenced key investments (e.g., on energy technologies by US DOE’s ARPA-E) and stakeholder decisions (e.g., the Massachusetts Port Authority), and advanced best practices (e.g., in the insurance and hazards modeling sectors), in the private sector (AIR Worldwide) as well as in cities/towns (Boston/Brookline). Mission-driven federal funding agencies (specifically, US DOE’s ARPA-E and US NRC) have funded him by first reaching out to him for solutions.

He is the Chief Scientific Advisor, and Co-Founder (with his former PhD student), of *risQ Corporation*, a spinout from his SDS Lab. The spinout, on climate risk management and infrastructural resilience with “Big Data”, was started with NSF SBIR funding and was originally based on two (pending) US patents generated from Ganguly’s SDS Lab at NU. The startup has now formed a business partnership with AIR Worldwide, a market leader and pioneer in natural catastrophe modeling, and is in the process of forming other partnerships and client relations.

Ganguly was the team lead (risQ was on the team) for one of four topical areas covered in the recently released *Climate Ready Boston* report commissioned by the *Mayor of Boston* and managed by the Green Ribbon Commission. His NU SDS Lab and spinout risQ are currently providing climate adaptation and mitigation solutions for *Brookline, MA*, under the aegis of the *Thriving Earth Exchange* of the American Geophysical Union.

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RESEARCH: Ganguly has tackled difficult and often highly controversial and challenging research topics to create fundamental science or engineering knowledge, develop new methods, and obtain novel stakeholder-relevant insights. He has published in high-impact science and engineering journals, as well as in top-tier methods venues such as physics and data mining. While science and engineering researchers tend to focus on their disciplines and adapt methods to generate (say) new predictive understanding, methods researchers tend to consider their research as most successful when the applications span disciplines. Ganguly has worked at disciplinary cores: climate extremes and uncertainty, natural hydrologic and ecological processes, infrastructure lifelines, sensors and supply chain. He has also worked in methods: extreme value statistics and sparse machine learning to network science and physics-guided data sciences (PGDS). His “Big Data” methods and applications have tended to focus on what he calls the “Big Data – small data” (BD-sd) challenge, where hidden, non-obvious, surprising, and unusual patterns need to be extracted from massive and heterogeneous data. Novel research in both methods and disciplines may not be easy, but has its own rewards. The disciplines benefit not just from tailored methods but also by learning from each other. Thus, Ganguly’s work on data science methods and their applications have benefited through lessons learned across disciplines, such as, rare events or extremes analysis in climate and security, or network science based restoration of lifeline infrastructures and ecological networks. The methods benefit through new domain challenges, while the domains benefit through cross-learning.

Ganguly’s research on climate has produced new surprising insights about geographic variability in heat waves, persistence of cold extremes in a warming environment, changes in hydraulic engineering design parameters related to attributes of (heavy) precipitation extremes, diverging patterns of mean versus extreme droughts, exacerbation of climate temperature extremes but reduced wind extremes in urban areas, uncertainties in wind extremes, increase in coastal upwelling under climate change but reduced latitudinal heterogeneity, growing spatial variability of monsoons and changes in onset and withdrawal. He has developed statistical and machine learning methods for downscaling of climate model outputs, characterizing hydroclimate extremes and their volatility, quantifying uncertainties and natural variability in climate models, and extracting dependence, and teleconnection patterns. The methodological advances include extraction of nonlinear dependence structures in short and noisy data and copula-based multivariate and spatiotemporal tail dependence, network-based interconnectedness and representation of dynamical data, network science based robustness and restoration, extreme value theoretic change analysis, sparse learning in high-dimensional systems, and hybrid physics and data-driven approaches. Ganguly’s work on data and computational sciences, often but not always originally motivated from climate and water, have proved their value in diverse disciplines like the sustainability of water-energy and urban-coastal systems, knowledge discovery from sensors for meteorology and logistics security, and the resilience of perturbed ecosystems or damaged lifelines under natural, man-made (including cyber-physical), and technological hazards. His work in climate, while agreeing with the basic scientific consensus, has continually refined our understanding of extremes, uncertainty, and regional processes, and addressed controversial topics to offer new insights and occasionally to overturn existing wisdom (e.g., about cold snaps, coastal upwelling and monsoon rainfall patterns). His data science methods, especially in nonlinear dynamics, have been adapted by diverse disciplines and continue to inform high-profile debates in the data scientific community. These include the delineation of chaos in time series signals with stochastic noise and seasonality, as well as the ability to find nonlinear associations among variables and the relationship thereof to the estimation of the mutual information.

CAREER THEMES: Ganguly’s dissertation at MIT CEE (supervisor: Rafael Bras) combined weather radar observations with numerical weather prediction (NWP) model outputs for short-term, distributed, quantitative precipitation forecasting. As a research associate at MIT Sloan, he co-developed an inventory optimization model for the demand-driven supply chain. The two had one unifying theme: the complex problem was partitioned into component processes, and time series statistics, neural networks and physics or process insights were developed for each process depending on what fit best. He was a Time Series Software Developer at Oracle Corporation for about a year, then a Product Manager of the demand forecasting and planning product associated with the supply chain suite. After 5 years at Oracle, he joined a semi-startup, best-of-breed time series and demand forecasting company, which was subsequently acquired by Oracle Corporation. Following a ten-month stint as visiting faculty in South Florida (USF), Ganguly was employed at ORNL for seven years (and simultaneously affiliated with the University of Tennessee at Knoxville as a joint faculty). When he left ORNL, Ganguly had risen to a Senior Research Scientist in the Computational Sciences & Engineering Division and Climate Change Science Institute. His research encompassed both weather extremes under climate change from observations and model simulations (funding: DOE, DOD), as well as threat analysis for transportation security from heterogeneous sensor data and process models (DOE, DHS, ONR). The first unifying theme was a focus on rare events and change from heterogeneous, spatiotemporal and massive data, which was in turn often generated by complex, stochastic and/or dynamical processes. Ganguly’s experience at Oracle and ORNL has made him strategically positioned for what is now called “Big Data”. His ongoing collaborations with ORNL and NASA, among others, has helped him and his research team develop familiarity with high-performance computing models in climate and water. Over the last five years at Northeastern, he has developed connections between climate risks and natural-built systems resilience, with data and computing advances as enabling technologies. Besides being a tenured Associate Professor in CEE, where he directs the SDS Lab, he is Co-founder & Chief Scientific Adviser of (SDS Lab spinout) startup risQ Corp.