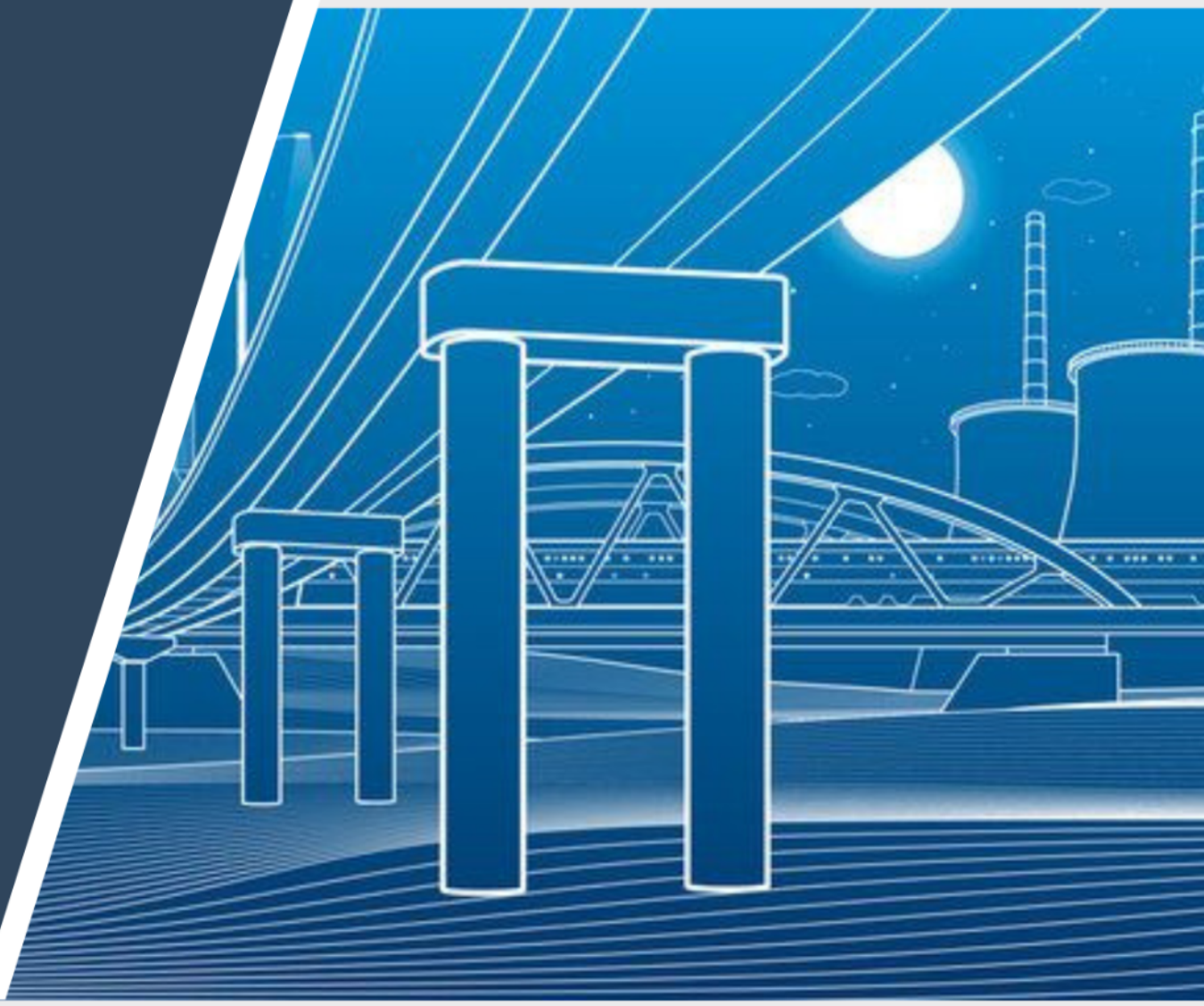
WORKSHOP 2022

UNITED STATES DEPARTMENT OF DEFENSE

STRATEGIC ENVIRONMENTAL RESEARCH AND DEVELOPMENT PROGRAM (SERDP)

PROJECT NO: RC20-1183



NETWORKED INFRASTRUCTURE UNDER COMPOUND EXTREMES

LEAD PI:
AUROOP R. GANGULY

TEAM

Northeastern University(Lead institution): Auroop Ganguly (PI), Stephen Flynn, Ashis Kumar Pal, Jack Watson, Puja Das

University of California Berkeley: Marta Gonzalez, Ariel Salgado

Pacific Northwest National Laboratory: Samrat Chatterjee, Robert Brigantic, Mahantesh Halappanavar, Alexandre Tartakovsky, Meenu Mohankumar

US Army Corps of Engineers: Kelly Burks-Copes, Himangshu Das, Edmond Russo, Benjamin Trump, Igor Linkov, Susan Wolters, Rumanda Young

Naval Research Laboratory: Satish Chikkagoudar

Workshop 2022

SERDP-NICE 2022 Virtual Workshop Agenda

Venue: Northeastern University, Boston, MA (all times US Eastern)

- **Day 1:** Tuesday, November 1 (Session 1: Setting the Stage)
  Session Chair: Ben Trump, United States Army Corps of Engineers
  - 1:00 – 2:00 PM: Edmund Russo, United States Army Corps of Engineers (Addressing Compound Threats: Army Installations Strategy as an Enabler to Army Modernization and Multi-Domain Operations)
  - 2:00 – 3:00 PM: Stephen Flynn, Northeastern University (Countering Emerging Threats and Hazards to Critical Infrastructure: The Resilience Imperative)
  - 3:00 – 4:00 PM: Igor Linkov, United States Army Corps of Engineers (Resilience and Efficiency Tradeoffs in Complex Systems)
  - 4:00 PM: Adjourn Day 1

- **Day 2:** Wednesday, November 2 (Session 2: SERDP NICE Projects: Part I)
  Session Chair: Sam Chatterjee, Pacific Northwest National Laboratory
  - 11:00 – 11:30 AM: Auroop Ganguly, Northeastern University (The state of the DOD SERDP NICE project at Year 1)
  - 11:30 – 12:00 PM: Ben Trump, United States Army Corps of Engineers (Compound Threats, Resilience, Methods, and Governance)
  - 12:00 – 12:30 PM: Marta Gonzalez, University of California, Berkeley (An interdisciplinary approach to managing natural hazards risk)
  - 12:30 – 1:30 PM: Lunch Break

- **Day 2:** Wednesday, November 2 (Session 3: SERDP NICE Projects: Part II)
  Session Chair: Marta Gonzalez, University of California, Berkeley
  - 1:30 – 2:00 PM: Sam Chatterjee, Pacific Northwest National Laboratory (Quantifying interdependent infrastructure network resilience)
  - 2:00 – 2:30 PM: Narmadha Meenu Mohankumar/Robert Brigantic, Pacific Northwest National Laboratory (Notional DoD installations and potential system failures)
  - 2:30 – 3:00 PM: Satish Chikkagoudar, United States Naval Research Laboratory (Assurance by design for cyber-physical data-driven systems)
  - 3:00 – 3:30 PM: Break and Mixer

- **Day 2:** Wednesday, November 2 (Session 4: SERDP NICE Futures)
  Session Chair: Auroop Ganguly, Northeastern University
  - 3:30 – 4:00 PM: Alexandre Tartakovsky, University of Illinois Urbana-Champaign (Physics-informed Gaussian process regression model for parameter estimation in groundwater models)
  - 4:00 – 4:30 PM: Mahantesh Halappanavar, Pacific Northwest National Laboratory (Graph analytics in the accelerator-enabled exascale era)
  - 4:30 – 5:00 PM: Himangshu Das, United States Army Corps of Engineers (Early Indicators of sudden collapse in infrastructure networks subject to concurrent extremes: Integrating data, physics, and complexity)
  - 5:00 PM: Adjourn Day 2

- **Day 3:** Thursday, November 3 (Session 5: External Perspectives)
  Session Chair: Steve Flynn, Northeastern University
  - 11:00 – 12:00 PM: Keynote Talk 1: Dan Eisenberg, Naval Postgraduate School (Infrastructure Vulnerability and Resilience Inside and Outside the Fence Line)
  - 12:00 – 12:30 PM: Invited Talk 1: Udit Bhatia, Indian Institute Of Technology–Gandhinagar (Early Indicators of sudden collapse in infrastructure networks subject to concurrent extremes: Integrating data, physics, and complexity)
  - 12:30 – 1:00 PM: Invited Talk 2: John Rowe, risQ/Intercontinental Exchange Inc (Managing physical climate risk in the Municipal bond market)
  - 1:00 – 1:30 PM: Invited Talk 3: Daniel Aldrich, Northeastern University (Social Capital's Critical Role in Disaster Mitigation and Recovery)
  - 1:30 – 2:30 PM: Lunch Break

- **Day 3:** Thursday, November 3 (Project Planning)
  - 2:30 – 4:00 PM: SERDP Team: Working Discussions on SERDP NICE Next Steps
  - 4:00 – 5:00 PM: Mixer
  - 5:00 PM: Adjourn Day 3 and Conclude Workshop

Name: Edmund Russo

Title: Addressing Compound Threats: Army Installations Strategy as an Enabler to Army Modernization and Multi-Domain Operations

Abstract: Incorporating sustainability and resilience into assessment and management of installation infrastructure systems enhances military mission advancement potential across a range of challenging conditions. Installations are subject to mission-impairing impacts under a variety of natural and anthropogenic compound threats, in combination with scenario drivers across the science, policy, and technology spectrum. These conditions result in spatiotemporally varying functionalities of natural and built installation assets according to their purposes and capacities. The array of challenges extends to competing uses across a diversity of interested and affected stakeholders, exacerbating system stresses and impacts. These situations pose technical difficulties for confident planning and execution of installation missions. Providing the tools for understanding complex relationships between networked installation assets, their services, and interdependencies, considering the spectrum of challenges, is an R&D opportunity for technically informing integrated and prioritized implementation actions under the Army Installation Strategy and Implementation Plan. The end state is for realizing adaptable, sustainable, and resilient, installations of the future that enable 2030-2040 Army modernization and Multi-Domain Operations in contested environments.

Bio: As a 30-year careerist with the US Army Corps of Engineers (USACE), Dr. Russo currently serves as the Director of the Environmental Laboratory for the US Army Engineer Research and Development Center, a position he assumed in September 2020. Dr. Russo leads the laboratory in providing relevant, value-added science and technology (S&T) supporting the missions of the USACE, US Army, Department of Defense, and the nation. The laboratory's diverse staff of over 300 engineers, scientists, technicians, and support personnel, plan and execute all phases of research and development, spanning from basic research to field implementation and commercialization of new S&T products. Partnering with federal and state agencies, academia, and the private sector, the laboratory uses its distinctive technical capabilities to resolve complex, multidisciplinary environmental sustainability and resilience problems.

Name: **Stephen Flynn**

Title: Countering Emerging Threats and Hazards to Critical Infrastructure: The Resilience Imperative

Abstract: A central reality of modern infrastructure is that it has become more interconnected and interdependent which places infrastructure systems at greater risk for cascading failures. This reality animates the imperative to embed resilience into the design and operations of infrastructure so that it is better able to withstand, respond, recover, and adapt to shocks and disruptions. The presentation will outline the barriers for accomplishing this along with recommended policy approaches for overcoming those barriers.

Bio: Dr. Stephen Flynn is Founding Director of the Global Resilience Institute at Northeastern University where he leads a major university-wide research initiative to inform and advance societal resilience in the face of growing human-made and naturally-occurring turbulence. He is a Professor of Political Science with affiliated faculty appointments in the College of Engineering and the School of Public Policy and Urban Affairs. Professor Flynn has previously served as President of the Center for National Policy and spent a decade as a senior fellow for National Security Studies at the Council on Foreign Relations. He has presented expert congressional testimony before the U.S. Senate and U.S. House of Representatives on 32 occasions. In 2022, Dr. Flynn was appointed by the National Academies of Sciences, Engineering & Medicine to serve as chair of a congressional-mandated committee to assess the strategies for managing the risk of Nuclear Terrorism. Dr. Flynn was an active duty commissioned officer in the U.S. Coast Guard for 20 years, including two tours as commanding officer at sea. He is co-author of the textbook, Critical Infrastructures Resilience: Policy and Engineering Principles (2018), and author of The Edge of Disaster: Rebuilding a Resilient Nation (Random House, 2007), and the national bestseller, America the Vulnerable (HarperCollins 2004). In September 2014, he was appointed by Secretary of Homeland Security to serve a member of the Homeland Security Science and Technology Advisory Council (HSSTAC) and by the President to the U.S. Coast Guard Academy Board of Visitors. Prof. Flynn holds the M.A.L.D. and Ph.D. degrees from the Fletcher School of Law and Diplomacy, Tufts University and B.S. from the U.S. Coast Guard Academy.

Name: **Igor Linkov**

Title: Resilience and Efficiency Tradeoffs in Complex Systems

Bio: Dr. Igor Linkov is Senior Science and Technology Manager with the US Army Engineer Research and Development Center (ERDC), and Adjunct Professor with Carnegie Mellon University. He develops methods and tools for measuring risk and resilience in interconnected networks and applies these tools to critical infrastructure, transportation, energy and cyber systems, supply chains and currently to manage response and recovery following COVID pandemic. He was part of several Interagency Committees and Working Groups tasked with developing resilience metrics and resilience management approaches, including the US Army Corps of Engineers Resilience Roadmap, Secretary of Deference Strategic Environmental Research and Development Program, and OSD Cyber Resilience Technical Committee. Dr. Linkov has organized more than thirty national and international conferences and continuing education workshops, including over twenty NATO events. He has published widely on environmental and technology policy, climate change, and risk and resilience analytics, including twenty five books and over 450 peer-reviewed papers and book chapters in top journals, like Nature, Nature Nanotechnology, Nature Climate Change, among others. Dr. Linkov is Elected Fellow with the American Association for the Advancement of Science (AAAS) and Society for Risk Analysis. Dr. Linkov has a B.S. and M.Sc. in Physics and Mathematics (Polytechnic Institute) and a Ph.D. in Environmental, Occupational and Radiation Health (University of Pittsburgh). He completed his postdoctoral training in Risk Assessment at Harvard University. Dr. Linkov has received multiple USACE, Army and DOD Awards and Civilian Service medals, including 2020 DOD Top Scientist Award. He received multiple awards from the Society for Risk Analysis (SRA), including Chauncey Starr, outstanding practitioner and distinguished educator awards. He is recipient of 2021 Arthur Flemming Award for outstanding public service and 2022 Edgeworth-Pareto Award from the International Society for Multi Criteria Decision Making (MCDM) for demonstrated a high level of creativity in developing novel areas of application of MCDM.

Name: **Auroop Ganguly**

Title: The state of the DOD SERDP NICE project at Year 1

Abstract: The "NICE: Networked Infrastructure under Compound Extremes" project funded by the US DOD Strategic Environmental Research and Development Program (SERDP) has entered the second year. I presented at this year's in-progress review (IPR) meeting to SERDP program managers and review panel on November 1, 2022. Our project has also been selected - for the second time - for a presentation at the SERDP/ESTCP symposium. Here I will provide an overview of the IPR presentation along with the comments we have received so far and discuss possibilities for the symposium presentation. For those who may not be familiar with the DOD SERDP project NICE, the funding was announced by DOD with a brief description here and by Northeastern there, and subsequently presented at a SERDP "Virtual Poster" here and a SERDP-ESTCP Symposium there. The project funding was slightly delayed initially owing to COVID and other issues but is now ongoing and in its second year.

Bio: Auroop Ganguly is a civil engineer and a hydrologist, a computational climate scientist, and a researcher in machine learning, extreme value theory, and nonlinear dynamics. He has 24 years of full-time professional experience spanning Northeastern University, Oak Ridge National Laboratory, and Oracle Corporation, along with publications in Nature, PNAS, and Nature Climate Change, award-winning papers in ACM KDD and SIAM Data Mining, and two US patents. He has been widely quoted in the national and global media, happens to be a Fellow of the American Society of Civil Engineers, has a PhD from MIT, and recently co-founded a successful startup company in urban climate resilience which has been acquired by a Fortune 500 company.

Name: **Ben Trump**

Title: Compound Threats, Resilience, Methods, and Governance

Abstract: Compounding threats present difficult to predict events that can impose potentially grave consequences from the household to global scales. While compounding threats inherently have lower probabilities of occurrence than singular threats, they can present multiplicative risks, which have been highlighted in the IPCC 2022 and Sendai Framework. While there has been increasing attention to modeling the probabilities and outcomes of compounding threats, there is a lack of framing to understand how compounding threats are parameterized and governed. Disaster risk prevention has made strides in establishing robust, transferable sociotechnical practices for predicting, responding to, and recovering from environmental hazards, but there are still significant gaps in compounding hazard management and resilience. This talk reviews perspectives of compound threat resilience, including the methodological and operational novelties posed by compounding threats to affected communities

Bio: Dr. Benjamin D. Trump is a Research Social Scientist for the U.S. Army Corps of Engineers. Dr. Trump's work focuses on decision making and governance of activities under significant uncertainty, and developing organizational, infrastructural, social, and informational resilience against systemic threats to complex interconnected systems. From March 2020 – March 2022, Dr. Trump led ERDC's engineering and public health research and communication for the SARS-CoV-2 pandemic. Dr. Trump was also a contributing author of the International Risk Governance Council's Guidelines for the Governance of Systemic Risks, as well as their 2nd Volume of the Resource Guide on Resilience. Co-authored with Dr. Igor Linkov, Dr. Trump's book The Science and Practice of Resilience (2019) includes a detailed discussion of the methodological, philosophical, and governance-related work behind the concept of resilience.

Name: **Marta Gongalez**

Title: An interdisciplinary approach to managing natural hazards risk

Abstract: Natural hazard risk management is a demanding interdisciplinary task. It requires domain knowledge, integration of robust computational methods, and effective use of complex datasets. However, existing solutions tend to focus on specific aspects, data or methods, limiting their impact and applicability. Here we present a general data-driven framework to support risk assessment and policy making illustrating its usage in the context of fire hazard by integrating three unique datasets of fire behavior, street network, and census data for the whole state of California. Through the innovative coupling of simulation, data-science, economic, and optimization methods, we unveil the vulnerability to fires in the region, suggest mitigation approaches, and analyze the trade-offs involved. These results open avenues for the future development of flexible interdisciplinary frameworks in natural hazards management using complex large-scale data.

Bio: Marta C. Gonzalez is an Associate Professor of City and Regional Planning and Civil and Environmental Engineering at UC Berkeley. She also is Physics Research faculty at Lawrence Berkeley National Laboratory. She has a PhD in Statistical Physics from the University of Stuttgart, Germany. With support from several companies, cities and foundations from around the world, her research team develops computational models to analyze digital traces to estimate the demand on urban infrastructure in relation to energy and mobility. Examples include: traffic gridlocks and the integration of electric vehicles in the power grid, policy of solar energy adoption, and habits in spending behavior. Her research has been published in leading journals such as Science, PNAS, Nature and Physical Review Letters.

Name: Samrat Chatterjee (Sam)

Title: Quantifying interdependent infrastructure network resilience

Abstract: This talk will present our research progress in FY22 under NICE project on infrastructure network resilience quantification. Analytical resilience framing in a submitted book chapter with NRL team members will be summarized first. Thereafter, three published papers from the 2022 IEEE Homeland Security Technologies conference will be briefly discussed. First paper focuses on urban rail transit network resilience under compound flooding and opportunistic failures. Second paper focuses on impact-driven and coverage-aware sampling strategies for hybrid attack graphs representing synthetic and real-world cyber-physical systems. Third paper focuses on disruption-robust community detection with consensus clustering in power grid networks. Finally, ongoing work on resilient communication-based control over an energy system network will be discussed.

Bio: Samrat (Sam) Chatterjee is a Senior Data/Operations Research Scientist and Team Lead with the Data Sciences and Machine Intelligence Group at U.S. Department of Energy's Pacific Northwest National Laboratory. He leads/co-leads security and computational science research projects in support of multiple sponsors (DHS, DOE, and DoD) and has over 12 years of experience in infrastructure network resilience modeling, security risk and decision analytics, and multi-agent learning and optimization. He is an Affiliate Professor at Northeastern University-Boston and has authored 2 books, 6 book chapters, and over 85 peer-reviewed journal articles, conference papers, and technical reports. He is a Senior Member of IEEE, member of SRA and MORS, and holds a Ph.D. in Civil Engineering from Vanderbilt University.

Name: **Narmadha Meenu Mohankumar**

Title: Notional DoD installations and potential system failures

Abstract: Military installation resilience is the capability of a military installation to avoid, prepare for, minimize the effect of, adapt to, and recover from extreme weather, and environmental conditions. Mapping failure and recovery pathways during extreme and compound events and examining the system functionality and resilience of military installations is essential for mission assurance and decision support of military operations. Data on notional military installations and simulated test cases of potential system failures can offer critical information on system functionality and resilience. Our objective is to simulate and model notional military installations, and potential impacts for system failures under compound extreme events (e.g., tornado, wildfire, etc.) to investigate power/energy use and energy resilience of interacting networks of components of military installation systems. We use the ERIN (Energy Resilience of Interacting Networks) model, a tool used by the Department of Defense (DoD) to simulate energy flows in military installation systems to test the reliability and resilience of the system to various scenarios. We investigate the energy demand and the corresponding energy availability at Ft. Illinois military base under various simulated scenarios. Our future work involves exploring the use of ERIN for simulating more complex compound events and impacts on larger installations/networks and generating data that can be used for Networked Infrastructures under Compound Extremes (NICE) algorithms. Further, we intend to explore access to other potential real-world DoD installation data.

Bio: Narmadha Meenu Mohankumar is a Data Scientist at the National Security Directorate of Pacific Northwest National Laboratory. Meenu graduated with a Ph.D. degree in Statistics from Kansas State University and her specialization involves data fusion, spatial and temporal statistical modeling, machine learning, hierarchical modeling, and data uncertainty quantification. Meenu works on a wide variety of applications that involve environmental remediation, ecological conservation, wildlife management, energy equity and environmental justice, renewable energy siting, material science, and installation resilience. Meenu enjoys working on innovative statistical modeling approaches to tackle challenging problems in science and technology.

Name: **Satish Chikkagoudar**

Title: Assurance by design for cyber-physical data-driven systems

Abstract: Currently, Cyber-Physical Data-Driven Systems (CPDDS) employ machine learning for the classification, data fusion, and control of our nation's infrastructure, such as the power grid, transportation networks (e.g., fuel distribution, air traffic control), and DoD long-duration collaborative autonomous platforms including unmanned underwater, ground, surface, space, and aerial systems. Many CPDDSs are system-of-systems that should be designed to communicate over disadvantaged networks. It is important to assure that the CPDDSs are resilient against physical and cyber threats by design. Additionally, their design should tolerate misclassification errors resulting from natural and/or adversarial distribution shifts within their data driven components. The all-domain nature of the problem of assuring the design of CPDDSs requires a multi-disciplinary perspective.

Bio: Dr. Satish Chikkagoudar is a Senior Researcher at the Navy's Center of Excellence in High Assurance Systems in Naval Research Laboratory (NRL). He has a decade of research experience tackling complex cyber security problems. At NRL, Dr. Chikkagoudar leads C5ISR projects in the areas of mission assurance, computer network defense, and infrastructure protection. Over the past decade, he has led and co-led several DoD funded mission assurance research efforts to model complex system dependencies and interdependencies. Dr. Chikkagoudar's research interests include devising novel resilience and sensing methods for interdependent and interconnected infrastructure networks.

Name: **Alexandre Tartakovsky**

Title: Physics-informed Gaussian process regression model for parameter estimation in groundwater models

Abstract: We propose a physics-informed machine learning approach for large-scale data assimilation and parameter estimation and apply it for estimating transmissivity and hydraulic head in the two-dimensional steady-state subsurface flow model of the Hanford Site. We term this method the physics-informed conditional Karhunen-Loeve expansion (PICKLE) method. We demonstrate that the PICKLE method is comparable in accuracy with the standard maximum a posteriori (MAP) method but is significantly faster than MAP for large-scale problems. We demonstrate that the computational cost of PICKLE increases nearly linearly with the problem size, while that of MAP increases faster than the power of 3 of the problem size. We also demonstrate that PICKLE is accurate as a surrogate model, i.e., it provides accurate estimates for a wide range of boundary conditions.

Bio: Alexandre Tartakovsky is a Professor in the CEE department at the University of Illinois Urbana Champaign and a Laboratory Fellow in PNNL's Advanced Computing, Mathematics, and Data Division. His research focuses on multiscale mathematics, uncertainty quantification, and physics-informed machine learning with application to complex natural and engineered systems. He earned a Master's degree in hydromechanics and applied mathematics from Kazan State University in Russia in 1994, and a Ph.D. in hydrology from the University of Arizona in Tucson in 2002. He started at PNNL in 2004 after a postdoctoral stint at DOE's Idaho National Laboratory.

Name: **Mahantesh Halappanavar**

Title: Graph analytics in the accelerator-enabled exascale era

Abstract: Combinatorial and graph algorithms play a critical enabling role in numerous scientific and analytics applications. The irregular memory access nature of these algorithms makes them one of the hardest algorithmic kernels to implement on parallel systems. I will present a brief overview of the latest work on multi-GPU systems for two prototypical graph problems — graph clustering and influence maximization — and demonstrate substantial gains in performance.

Bio: Dr. Halappanavar is a chief computer scientist at Pacific Northwest National Laboratory, where he serves as the group leader of the Data Science and Machine Intelligence group. He also holds a joint appointment as adjunct faculty in computer science at the School of Electrical Engineering and Computer Science at Washington State University in Pullman. His research has spanned multiple technical foci and includes combinatorial scientific computing, parallel graph algorithms, artificial intelligence and machine learning, and their applications in scientific computing, power grids, cybersecurity, and life sciences.

Name: **Himangshu Das**

Title: A Case Study to Enhance Flood Protection and Resiliency: Overview of Coastal Texas Mega Project

Abstract: The United States Gulf Coast cities including Houston, Corpus Christi, New Orleans, and many other coastal cities are vulnerable to periodic storm surges and rainfall extremes. Since 1900, hurricanes striking in this region have killed more than 9,000 people and caused tremendous economic damage to infrastructure. Recently, the U.S. Army Corps of Engineers (USACE), in partnership with the Texas General Land Office (GLO), began to explore viable solutions for coastal storm risk, management, and ecosystem restoration along the Texas coast. A "Multiple Lines of Defense" strategy was used in the Coastal Texas study to design cost-effective, environmentally friendly solutions that will reduce risks of storms impacting the coastal communities and restore important habitat at the same time. . The objective of the Coastal Texas Study was to improve our capabilities to prepare for, resist, recover and adapt to extreme flood events.

Bio: Dr. Himangshu Das is the Chief of Coastal Engineering who manages and provides expert guidance in science and engineering especially in hydrology and hydraulics at the US Army Corps of Engineers, Galveston District . He has been providing technical guidance to the District, capitalizing over 25 years of experience in academia and industry while performing "state of the art" technical studies in coastal and riverine engineering. Before joining the USACE, Galveston District, Dr. Das was a tenured Associate Professor in Civil and Environmental Engineering at Jackson State University from 2008 to 2017 mainly focusing on advanced studies related to hydraulic and coastal engineering. At JSU, he has secured and executed applied and research projects that focused on urban, coastal and near-shore processes, and ocean engineering. He has published over 40 peer reviewed articles.

Name: **Dan Eisenberg**

Title: Infrastructure Vulnerability and Resilience Inside and Outside the Fence Line

Abstract: Military missions depend on critical infrastructure systems found both on installations and in communities “outside the fence line.” This presentation overviews a SERDP funded project led by the Naval Postgraduate School Center for Infrastructure Defense advancing how to identify mission essential assets on installations and in surrounding communities. Efforts “inside the fence line” focus on network modeling methods to identify vulnerabilities across installation infrastructure systems and guide infrastructure management. Our methods help identify flaws in a common metric used to guide DoD planning decisions – the Mission Dependency Index (MDI) – and we discuss ways to overcome them. Efforts “outside the fence line” link civilian and military needs during disaster response to guide infrastructure projects for community resilience. We present case studies from Rhode Island and Hawaii that inform resilience for civilian and military communities alike. Overall, out work integrates the structure and function of infrastructure systems with the military missions they support.

Bio: Daniel Eisenberg is an Assistant Professor of Operations Research at the Naval Postgraduate School (NPS) and Deputy Director of the NPS Center for Infrastructure Defense. Dan’s research focuses on the design, operation, and adaptation of resilient infrastructure systems. He uses tools from operations research, engineering, and public administration to link built and social systems together and identify fragilities in existing practices. He currently leads projects on the design and management of resilient island and military installation infrastructure systems in the US Virgin Islands, Rhode Island, and Hawaii. Dan received his Ph.D. in Civil, Environmental, and Sustainable Engineering from Arizona State University (ASU) and a B.S. in Chemical Engineering from University of California, Davis. Prior to joining NPS, he was a research engineer with the US Army Engineer Research and Development Center. He has received several prestigious fellowships, including a Fulbright Fellowship and National Science Foundation Graduate Research Fellowship.

Name: Udit Bhatia

Title: Early Indicators of sudden collapse in infrastructure networks subject to concurrent extremes: Integrating data, physics, and complexity

Abstract: Natural and Man-made disruptions drastically affect the networked infrastructure systems, which further impacts regions' economies with rippling effects across the nations. Moreover, if subjected to successive disruptions, they may experience disproportionate losses in their functionality. In the presentation, I will discuss how integrating physical models and data with complex network representation helps us understand the robustness and recovery characteristics of built critical infrastructure systems subject to concurrent attacks, which can inform the resilient design and near-optimal restoration strategies for such systems. My talk will include specific examples from our work on finding early-warning indicators of the onset of a sudden collapse in networked systems with case studies on the national scale Indian Railways Network and US National Airspace Airport network, unfolding of concurrent hazards on regional transportation networks due to concurrent extremes at the regional scale, and the hydrodynamic response of urban infrastructures to pluvial floods.

Bio: Dr. Udit Bhatia is an Assistant Professor in the Civil Engineering Discipline at the Indian Institute of Technology, Gandhinagar. His research interests include the recovery and resilience of built and natural spatial systems, including complex networks, uncertainty assessment in hydroclimate extremes, and physics-guided data sciences. Udit received his Ph.D. in Interdisciplinary Engineering from Northeastern University, Boston (USA). National and international media have highlighted his research and publications, including major media houses in India, ScienceDaily, AAAS Eurekalert, R&D Magazine, Yahoo!, and Big Data Journal. He is co-author of the book" Critical Infrastructures Resilience: Policy and Engineering Perspectives," published by Taylor and Francis. His work in applied network science, uncertainty quantification, and extreme value analysis is currently being used by policymakers at various levels. Udit is a passionate teacher, and his online courses on various engineering topics are being used as part of the curriculum in Institutes within and outside India.

Name: **John Rowe**

Title: Managing physical climate risk in the Municipal bond market

Abstract: With extreme weather events on the rise there is increasing concern over how the municipal bond market - which is particularly vulnerable to physical climate events, will manage the financial risks of climate change. No other capital market encompasses so many issuers and so many securities. The differences among issuers are broad, as are the purpose of the offerings. Municipal bonds are a necessary instrument to fund basic governmental functions, including a variety of state, county, and city needs for infrastructure, such as schools, public facilities, transportation, utilities, health care, and housing, as well as some private purposes, such as to enhance economic development. The primary attractiveness of the municipal debt market is its tax-exempt status, where issuers can come to the market at more attractive yields for the purpose of developing American infrastructure. However, are we including all of the relevant risks in this market? We highlight here, an approach to assessing the likely impact of physical climate risk, both current and future, under different climate scenarios, on Municipal bonds.

Bio: John brings over 25 years of first-hand experience in catastrophe model development and use, both in the underlying science behind the models, and the techniques and technologies needed to ensure reliable model results that ensure models are fit for the intended purpose of understanding the impact of climate on the built environment. Prior to ICE, via acquisition of risQ Inc, John was Vice President of Research at AIR Worldwide where he directed the development of natural hazard models covering 120+ countries. These models included many types of wind hazard, storm surge, inland flood and wildfire. John was also instrumental in the development of a global pandemic model, covering the impact of influenza on the global population. Other responsibilities included the development, and annual updates to the AIR industry exposure databases, development of model QA/QC best practice procedures and many business development focused initiatives around the role of remote sensing related to real time hazard modeling and analytics. John has also contributed to many industry leading initiatives focused on using catastrophe models to outline alternate strategies for risk transfer and public education. These included the FEMA FIRS project, the precursor to FEMA's successful reinsurance of the NFIP, and earthquake and flood related projects for the Insurance Bureau of Canada, to name a few. These projects were of particular interest as they aimed to improve the public's awareness of the possible impact of various perils on the community at large.

Name: Daniel Aldrich

Title: Social Capital's Critical Role in Disaster Mitigation and Recovery

Abstract: While many continue to envision disaster mitigation and crisis response in terms of physical infrastructure (seawalls, fortifying beaches and hardening buildings, etc), effective disaster mitigation and then post-crisis recovery hinge instead on trust, horizontal, and vertical ties and the frameworks that build these resources. Using qualitative and quantitative data from shocks around the world, Aldrich demonstrates the importance of social connections in helping people survive and thrive during shocks and disasters. The good news: social ties can be maintained and strengthened, creating communities resilient to shocks we cannot even imagine now.

Bio: An award winning author, Aldrich has published five books including Building Resilience and Black Wave, more than 80 peer-reviewed articles, and written op-eds for the New York Times, CNN, HuffPost, and many other media outlets. He has spent more than 5 years in India, Japan, and Africa carrying out fieldwork and his work has been funded by the Fulbright Foundation, the National Science Foundation, the Abe Foundation, and the Japan Foundation, among other institutions and was the 2021 Klein Lecturer at Northeastern University.