U.S. DEPARTMENT OF ENERGY | Office of Science

CATALYST: A COOPERATIVE AGREEMENT TO ANALYZE VARIABILITY, CHANGE AND PREDICTABILITY IN THE EARTH SYSTEM

The Cooperative Agreement To Analyze variabiLity, change and predictabilitY in the earth SysTem (CATALYST) performs foundational coordinated research in a team-oriented, collaborative effort. It aims to advance a robust understanding of the modes of Earth system variability and change using models, observations, machine learning, and process studies.

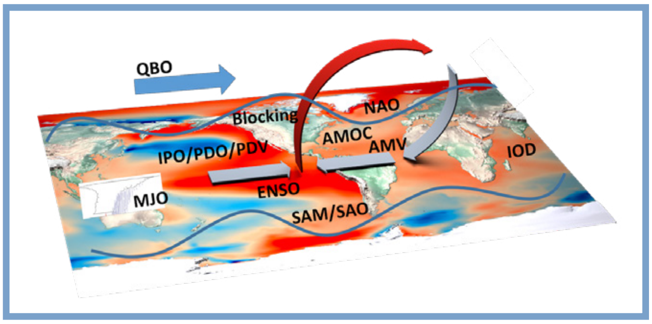
CATALYST RESEARCH TASKS

- Using machine learning (ML) and artificial intelligence (AI) methods, identify what types of synoptic weather features produce extreme precipitation, and quantify how those synoptic features are affected by modes of variability and possible future changes.
- Assess predictability of modes of variability; expand limits of predictability by applying machine learning methods.
- Quantify the interactions between the quasi-biennial oscillation and the Madden-Julian Oscillation (MJO).
- Identify interactions between MJO and El Nino-Southern Oscillation (ENSO).
- Examine teleconnections among ENSO, semi-annual oscillation, southern annular mode, and interdecadal Pacific oscillation (IPO).
- Benchmark modes of variability and climate states in the Energy Exascale Earth System Model (E3SM), Community Earth System Model (CESM), and other climate models.
- Quantify the role of external forcing in driving changes in modes of variability in E3SM and CESM using large- and single-forcing ensembles.
- Quantify the couplings between modes of variability in E3SM and CESM and tipping points in the climate system.
- Examine connections between modes of variability and atmospheric rivers.
- Quantify linkages between modes of variability and tropical cyclones.
- Connect modes of variability with precipitation extremes.

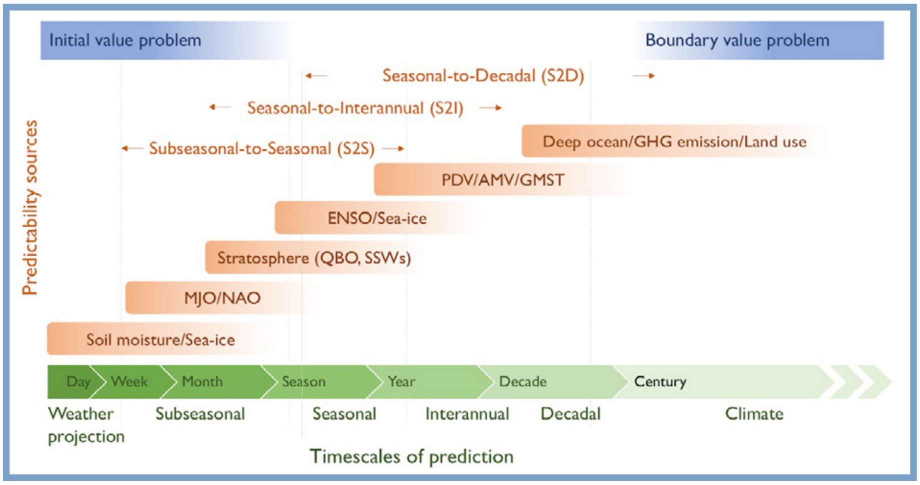
CATALYST RESEARCH OBJECTIVES

CATALYST research is characterized by four interrelated research objectives that address key science questions focusing on modes of variability:

Research Objective 1 sets the groundwork for the rest of the research objectives and addresses the limits of predictability of modes of variability on subseasonal-to-decadal timescales using E3SM, CESM, and machine learning methods. It provides the research themes that tie together the other three research objectives, using state-of-the-science modeling tools and machine learning methods to quantify the limits of predictability for different modes of variability to address the processes and mechanisms that contribute to the predictability of those modes on different timescales.



Modes of variability addressed by research tasks in CATALYST. MJO = Madden-Julian Oscillation; NAO = North Atlantic Oscillation (and the related Arctic Oscillation (AO) that is characterized by zonal wind and temperature variations across the mid-and high northern latitudes); ENSO = El Niño/Southern Oscillation; IPO/PDO/PDV = Interdecadal Pacific Oscillation/Pacific Decadal Oscillation/Pacific Decadal Variability (used interchangeably in the literature); QBO = Quasi-Biennial Oscillation; IOD = Indian Ocean Dipole; SAM/SAO = Southern Annular Mode/Semi-Annual Oscillation; AMV = Atlantic Multidecadal Variability (also known as Atlantic Multi-decadal Oscillation, AMO); AMOC = Atlantic Meridional Overturning Circulation; blocking = long-lived areas of high atmospheric pressure. Sea-surface temperature (SST) anomaly pattern in schematic represents the positive phase of IPO/PDO/PDV with connections through the atmospheric Walker Circulation to the Atlantic.



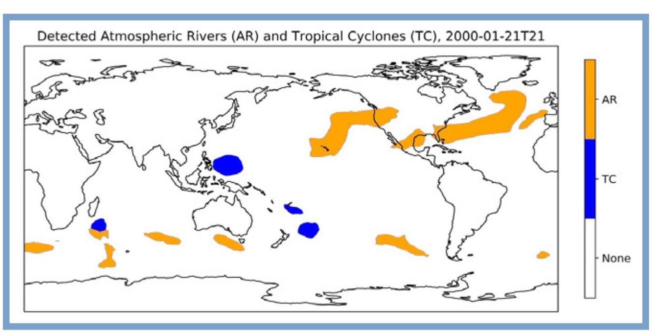
Predictability sources and timescales of prediction for seasonal-to-seasonal, seasonal-to-interannual, and seasonal-to-decadal. Lighter green shading indicates larger uncertainty.

Research Objective 2 uses a hierarchy of models to inform predictions, and it addresses relevant processes and feedbacks related to modes of variability and how they interact with each other.

Research Objective 3 benchmarks model representations of modes of variability in Earth system models, examines the role of external forcing in changes of modes of variability and their interactions, and addresses the likelihood and predictability of tipping points and irreversible changes.

The interconnected research in the first three research objectives (1. limits of predictability of modes of variability, 2. key processes involved with understanding and predicting modes of variability, and 3. evaluating and understanding the representation of modes of variability and tipping points, and connections between them) leads to research objective 4.

Here, predictability and the processes and mechanisms of modes of variability delineated in the first three research objectives are brought to bear where high-impact events are related to modes of variability. This objective focuses on high-resolution simulations and utilizes feature detection and machine learning techniques across all the proposed tasks.



A novel application of machine learning feature detection to identify atmospheric rivers and tropical cyclones in CESM simulation output. This machine learning technique is used to connect such synoptic weather features with precipitation extremes.

Research Objective 4 investigates the relationships between the modes of variability addressed in the other research objectives and high-impact events—such as flash droughts and precipitation extremes, atmospheric rivers, tropical cyclones—and how these might change in future climate through model analyses, process studies, and innovative application of machine learning methodologies.

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