Exploring Frontiers in Earth System Modeling with Machine Learning and Big Data
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Climate Observations and Monitoring Program
Outline

NOAA and Climate Program Office Landscape

- Organization and NOAA-wide strategies
- CPO/ESSM contributions

Opportunities for Research Community Engagement:

- Examples of Extramural AI/ML Research Supporting NOAA Priorities
- Untapped ESSM Research Areas for AI/ML

Value of and Applications for ESSM-supported Research
• **Understand & predict** changes in climate, weather, oceans, & coasts
• **Share that knowledge** and information with others
• **Conserve & manage** coastal, marine ecosystems & resources

**ADMIN PRIORITIES:** Climate Services, Equity, Blue Economy
NWS Production Suite (2016)

Closely related GFDL models:
- SHIELD – hi res weather prediction
- CM4 – higher resolution ocean
- ESM4 – earth system model

OAR/GFDL SPEAR S2D Prediction

Atmospheric circulation and radiation
Chemistry - CO₂, NOₓ, SO₄, aerosols, etc

Earth System Model
- Ocean ecology & Biogeochemistry
- Ocean circulation
- Sea Ice
- Plant ecology & land use
- Land physics & hydrology
Through the NOAA AI Strategy, expansion of AI is accelerated … to make transformative improvements in NOAA mission performance and cost effectiveness.

Sign up for the new NCAI Community of Practice
Earth System Science and Modeling Division Scope: Advance understanding, modeling, prediction, and projection of the Earth’s atmosphere, ocean, land, and cryosphere as an integrated system.

### ESSM Competitive Research Programs

<table>
<thead>
<tr>
<th>Program</th>
<th>Description</th>
<th>Contact</th>
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<tbody>
<tr>
<td><strong>AC4</strong></td>
<td>Atmospheric Chemistry, Carbon Cycle, and Climate</td>
<td>Monika.Kopacz</td>
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<tr>
<td><strong>COM</strong></td>
<td>Climate Observation and Monitoring</td>
<td>Virginia.Selz</td>
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<tr>
<td><strong>CVP</strong></td>
<td>Climate Variability and Predictability</td>
<td>Sandy.Lucas</td>
</tr>
<tr>
<td><strong>ERB</strong></td>
<td>Earth’s Radiation Budget</td>
<td>Victoria.Breeze</td>
</tr>
<tr>
<td><strong>MAPP</strong></td>
<td>Modeling, Analysis, Predictions and Projections</td>
<td>Daniel.Barrie</td>
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Support Competitive Research for NOAA Priorities

- Process studies and field campaigns
- Observation and model-based dataset development and monitoring
- Predictability studies of climate phenomena
- Model improvements of key processes
- Applying Earth system and climate models to societally-relevant challenges
- Projecting future climate variability & change
- R&D toward transitions of R2O and R2A

Coordinate joint federal research activities

Lead national assessments

Facilitate NOAA line office and lab collaboration
Extramural AI/ML research supporting NOAA Priorities

- Joint Climate & Weather Program Offices Competition encouraged ML/AI (CVP)
- Climate and Fisheries
- Innovative Ocean Obs Synthesis Datasets
- Climate Science for Sanctuaries (COM, CVP, MAPP)
- Decadal Var, Pred.
- CMIP5/6 Analysis
- Drought Task Force
- Climate Process Team
- Process-Oriented Model Diagnostics (CVP, MAPP)
Extramural AI/ML research supporting NOAA Priorities

ESSM-funded research is utilizing AI/ML to develop datasets, understand earth system processes through obs-model analysis, and improve models.

<table>
<thead>
<tr>
<th>Challenges Addressed:</th>
<th>Methods employed:</th>
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<tbody>
<tr>
<td>● Spatiotemporal data sparseness</td>
<td>● Neural networks and NN ensembles, Self-organizing maps &amp; feed-forward neural networks</td>
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<tr>
<td>● Difficulties using spatiotemporal observations to constrain processes in ESMs (nonlinearity, domain-dependent)</td>
<td>● Neural Network Visualization Tools</td>
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<td>● Method-related uncertainties</td>
<td>● Supervised machine learning algorithms</td>
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<td>● Model resolution</td>
<td>● Causal Networks</td>
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<td>● Clustering Analyses, Constructed Analogues</td>
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Evaluating and improving pCO$_2$ reconstructions using multiple ML approaches

- Enables improved obs-model comparison and air-sea CO2 flux variability analyses, and informs targeted modeling improvements

Demonstrating the use of NNEs in separating BGC vs. physical drivers of phytoplankton in ESMs

- Adds new methodological tools for model-model, model-obs comparison and evaluation
- PI: Gnanadesikan, Johns Hopkins [Holder et al. 2022] (CVP)

Value to NOAA Mission: Supports advancing accurate representation of BGC in NOAA models for Climate, Ecosystems, and Fisheries Initiative
Examining the contribution of natural variability and anthropogenic forcing to fire risk and characteristics

- Advances separating anthropogenic forcing from other factors impacting exposure and vulnerability

Identifying weather types and circulation patterns associated with North East heat waves

- PI: Barlow, UMASS Lowell [Coe et al. 2021, Agel 2021] (MAPP/NIDIS)

Value to NOAA Mission: Supports advancing understanding, monitoring, and prediction of Drought-related events - Fire, Heatwaves in partnership with NOAA NIDIS
Datasets for Monitoring Climate Variability & Change

Exploring ML algorithms that can reconstruct AMOC using surface data that works well across models (CVP)

- Potential to apply algorithm to observations to improve observation-based AMOC record
- PI: DelSole, George Mason University [Figure from DelSole and Nedza 2020] (CVP)

Value to NOAA Mission: Supports ability to understand climate variability and monitor for change and contributes to U.S. CLIVAR AMOC science
AI/ML for Modeling Analysis and Improvements

Ask Laure and Libby about their work!

Identifying patterns of change over the 21st century with neural networks

- Method improves understanding of nonlinear combinations of anthropogenic forcing
- PI: Barnes, Colorado State University [Barnes et al. 2020, Labe and Barnes 2021] (MAPP)

Climate Process Team: Ocean Transport and Eddy Energy

- Improving representation of ocean eddies and role in the ocean energy cycle in models

Value to NOAA Mission: Enhances cross-agency investments
Untapped areas for AI/ML in ESSM Research

**Atmospheric Chemistry, Carbon Cycle and Climate Program (AC4)**

- Research determining processes governing atmospheric concentrations of trace gases and aerosols in Earth System context

**Earth Radiation Budget (ERB)**

- Improving modeling of stratospheric aerosol processes and atmospheric response, interactions, and assessing SAI, MCB with models

**Process-understanding and Field Campaigns**

- Tropical Air-Sea Interactions, Fully coupled system, Fire-smoke, Air Quality and Climate
Potential applications for ESSM-supported research

NOAA Rapid Event Attribution Capability

Authoritative climate information for stakeholders across NOAA’s priority areas

Improvements to NOAA obs/models; Enhanced observation-based, monitoring products

Explaining Extreme Events of 2020 from a Climate Perspective

Development of a Rapid Response Capability to Evaluate Causes of Extreme Temperature and Drought Events in the United States

Joseph J. Barsugli, David R. Easterling, Derek S. Arndt, David A. Coates, Thomas L. Delworth, Martin P. Hoerling, Nathaniel Johnson, Sarah B. Kapnick, Arun Kumar, Kenneth E. Kunkel, Carl J. Schreck, Russell S. Vose, and Tao Zhang
References