



# NOAA

## National Weather Service

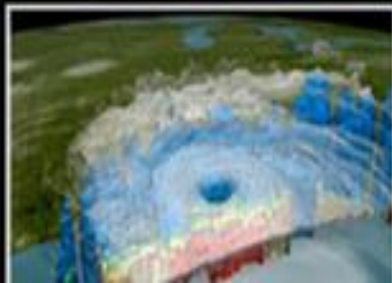
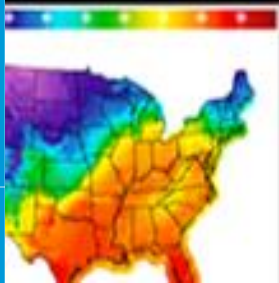
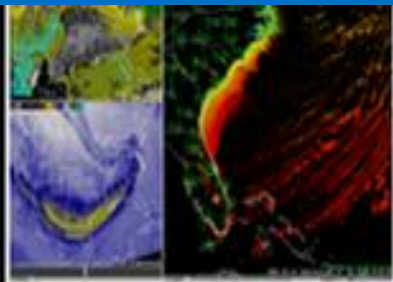
# *The growing importance of AI in weather, water and climate applications: dual perspectives from the American Meteorological Society (AMS) and the U.S. National Weather Service (NWS)*

**Dr. Mike Farrar**

*Director, National Centers for Environmental Prediction (NCEP), NOAA/NWS  
2021 President of the American Meteorological Society (AMS)*

August 30, 2021

Third ITU/WMO/UNEP Workshop on AI for Natural Disaster Management



# Outline

- **American Meteorological Society (AMS)**
  - Brief overview of the AMS
  - AI/ML in AMS publications
  - New AMS AI/ML Journal
- **National Weather Service (NWS)**
  - Broad NOAA & NWS perspective
    - National Centers for Environmental Prediction (NCEP)
  - AI/ML uses in modeling
    - Past AI/ML Activities at Env. Modeling Center (EMC)
    - Current AI/ML Activities at EMC & CPC + Sample Results
- **Summary**

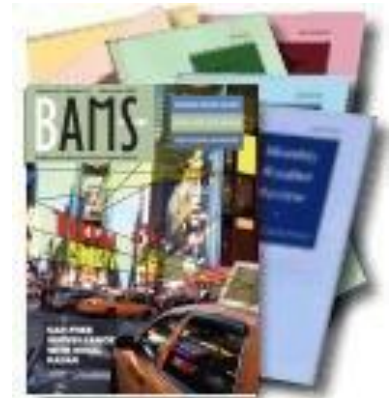


# Part 1: American Meteorological Society (AMS)

# American Meteorological Society (AMS) Overview

***AMS Mission: To advance the atmospheric and related sciences, technologies, applications, and services for the benefit of society.***

- **Founded in 1919**
- **~12,500 members**
- **Publishes 11 leading scientific journals**
- **Organizes over a dozen conferences annually**
- **Has many student and educational programs**
- **Certifies consultants, broadcasters, and teachers**
- ***Community triad of Government, Academia & Industry***



***AMS is a trusted voice and committed advocate for weather, water, and climate science and service.***

# American Meteorological Society (AMS)

## AMS Core Values

As part of the centennial (1919-2019) activities, the AMS updated our Strategic Goals, which included the AMS Core Values:

- *We value the integrity of science and the scientific process.*
- *We believe that a diverse, inclusive, and respectful community is essential for our science.*
- *We believe that decisions affecting society should be made in a transparent, evidence-based manner.*
- *We are committed to excellence, relevance, and agility in all our activities.*

*The full document with all 9 Strategic Goals found in BAMS (April 2019)*

American Meteorological Society

**Strategic Goals:  
Centennial Update**

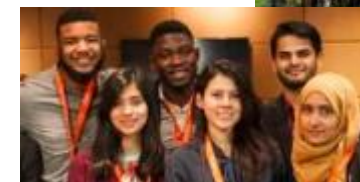
(Adopted by the AMS Council on 6 January 2019)



# American Meteorological Society (AMS) Programs & Activities



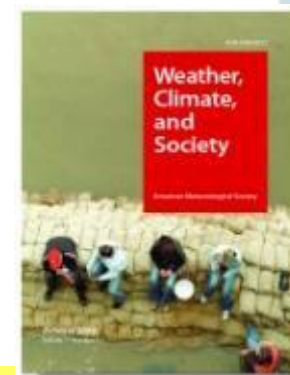
- Meetings
- Awards
- Statements & Letters
- Annual Reports
- Journals
- Certifications
- Local Chapters
- Student Support
- K-13 Programming
- Policy Program





# American Meteorological Society (AMS) Journals

- *Bulletin of the AMS (BAMS)*
- *Journal of the Atmospheric Sciences*
- *Journal of Applied Meteorology and Climatology*
- *Journal of Physical Oceanography*
- *Monthly Weather Review*
- *Journals of Atmospheric and Oceanic Technology*
- *Journal of Climate*
- *Weather and Forecasting*
- *Journal of Hydrometeorology*
- *Earth Interactions*
- *Weather, Climate and Society*

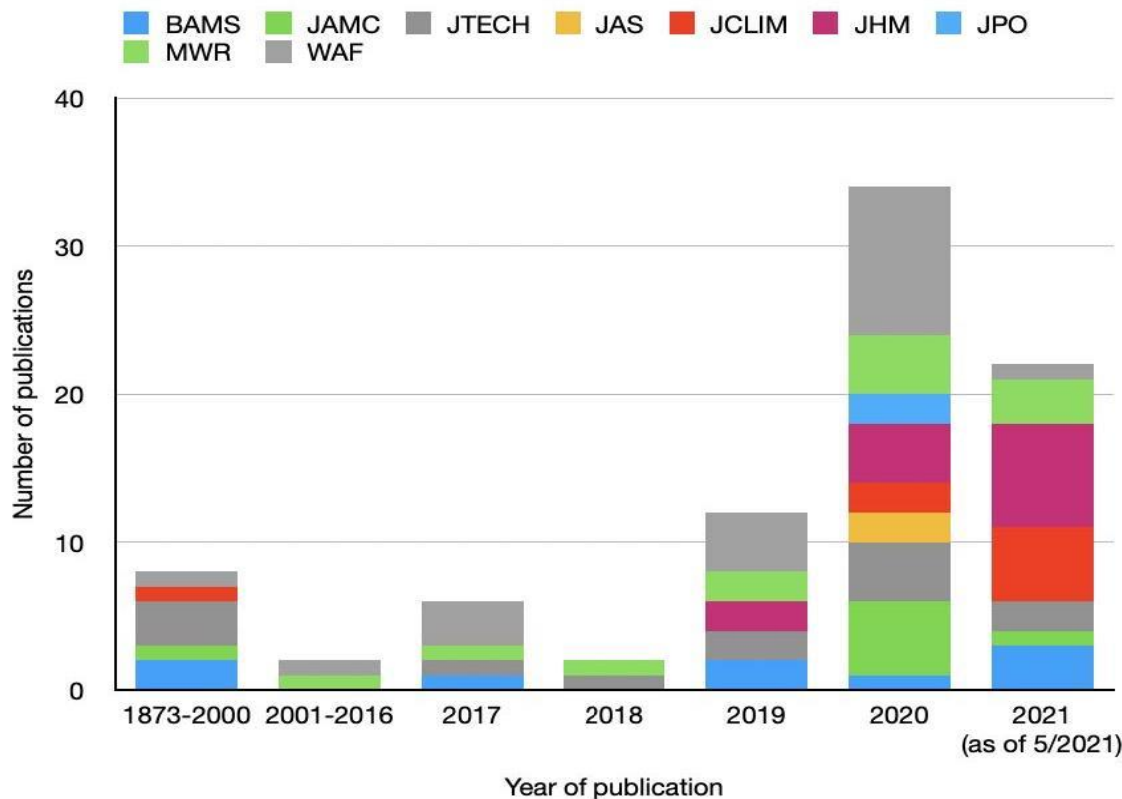


**While several existing AMS journals publish articles related to the application of AI/ML and statistics, none focus on the development of novel AI/ML methodologies...**

# American Meteorological Society (AMS)

## The growth of AI content in AMS Journals

To illustrate the growth of AI within AMS publications, this graphic shows the number of papers that have AI or ML as a keyword or in the title.



- Exponential growth over the past few years, going from just a few per year to over thirty in 2020.
- This figure was created in May 2021, so 2021 is on track to surpass 2020.

Figure from 'Proposal for an AMS Artificial Intelligence Journal', Amy McGovern & Tony Broccoli

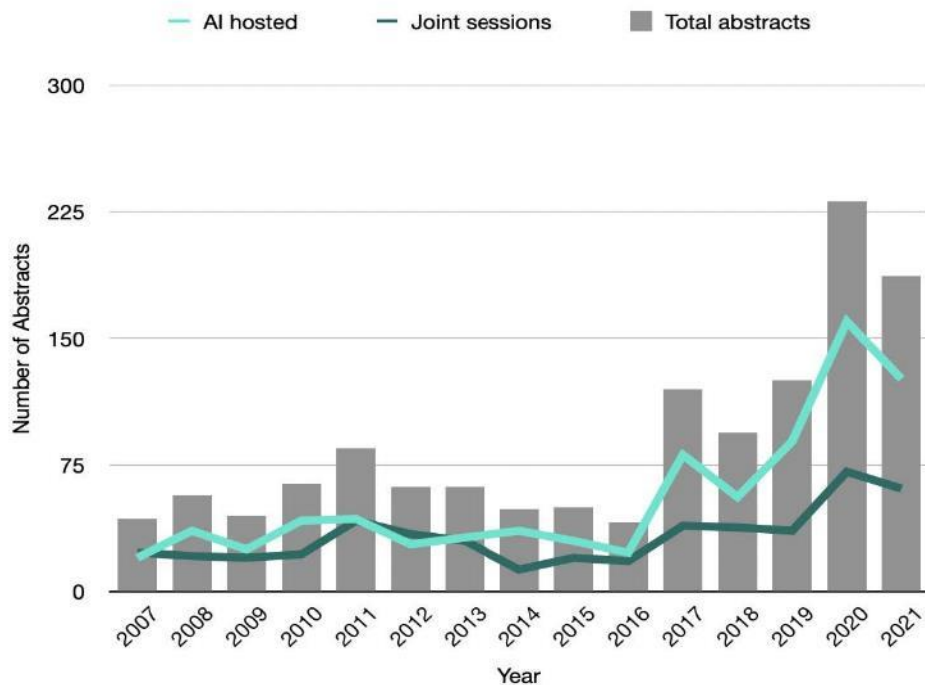


# American Meteorological Society (AMS)

## The growth of AI content in AMS Conferences

The AI conference is now one of the largest contributors to the AMS annual meeting. This is evident from the dramatic increase in the number of papers submitted to the AI conference in the past few years, where the number of presentations tripled from 2015 (average 50 presentations) to 2019 (almost 150), reaching over 225 in 2020.

The figure below shows the history of AMS AI presentations.








- While 2021 had fewer presentations than 2020, author feedback indicated this was due to the virtual nature of the conference rather than to any decline in interest.
- Because AMS AI has a history of holding joint sessions, we have included both the joint sessions and the sessions hosted by AI.

Figure from 'Proposal for an AMS Artificial Intelligence Journal', Amy McGovern & Tony Broccoli



# American Meteorological Society (AMS)

## The case for a new AMS Journal for AI

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- AI/ML are a rapidly growing sector of the atmospheric, climate and water related sciences.
    - Nine of the ten existing AMS journals have seen *rapid growth* in terms of publications on this topic, with more than 30 publications in 2020 alone (see prior slides).
    - In addition, there is a *rapid proliferation of AI conferences*, including a recent focus on weather and climate applications.
    - ***This suggests both a need and opportunity to provide a journal to attract new authors, subscribers, and potential members to the AMS.***
  - This rapid growth has posed editorial challenges to the existing AMS journals, requiring editors with specialized knowledge across journals to meet the *growing demand*.
    - Manuscript evaluation is more difficult, leading to some publications being out of place in existing journal offerings.
    - The proposed journal would be appropriate for novel AI/ML and statistical methods focused on AMS related sciences, as well as the application of AI/ML and statistics. Currently AMS journals primarily publish applications of AI/ML and statistics, *rather than the development of novel methodologies*.
    - ***By developing a journal for both methods and application, we create a community of AI/ML practice for the AMS sciences.***

Info from 'Proposal for an AMS Artificial Intelligence Journal', Amy McGovern & Tony Broccoli

# American Meteorological Society (AMS)

## New AI Journal from AMS

*Artificial Intelligence for the Earth Systems (AIES)* will publish research on the development and application of methods in AI, ML, data science, and statistics that is relevant to meteorology, atmospheric science, hydrology, climate science, and ocean sciences. Topics include:

- Development of AI/ML, statistical, and hybrid methods and their application
- Development and application of methods to further the physical understanding of earth system processes from AI/ML models (e.g., physics-based AI)
- Use of AI/ML to emulate components of numerical weather and climate models
- Incorporation of AI/ML into observation and remote sensing platforms
- Use of AI/ML for data assimilation and uncertainty quantification
- Societal applications of AI/ML for AIES disciplines, including ethical and responsible use of AI/ML and educational research on AI/ML



<https://www.ametsoc.org/ams/index.cfm/publications/journals/artificial-intelligence-for-the-earth-systems/>



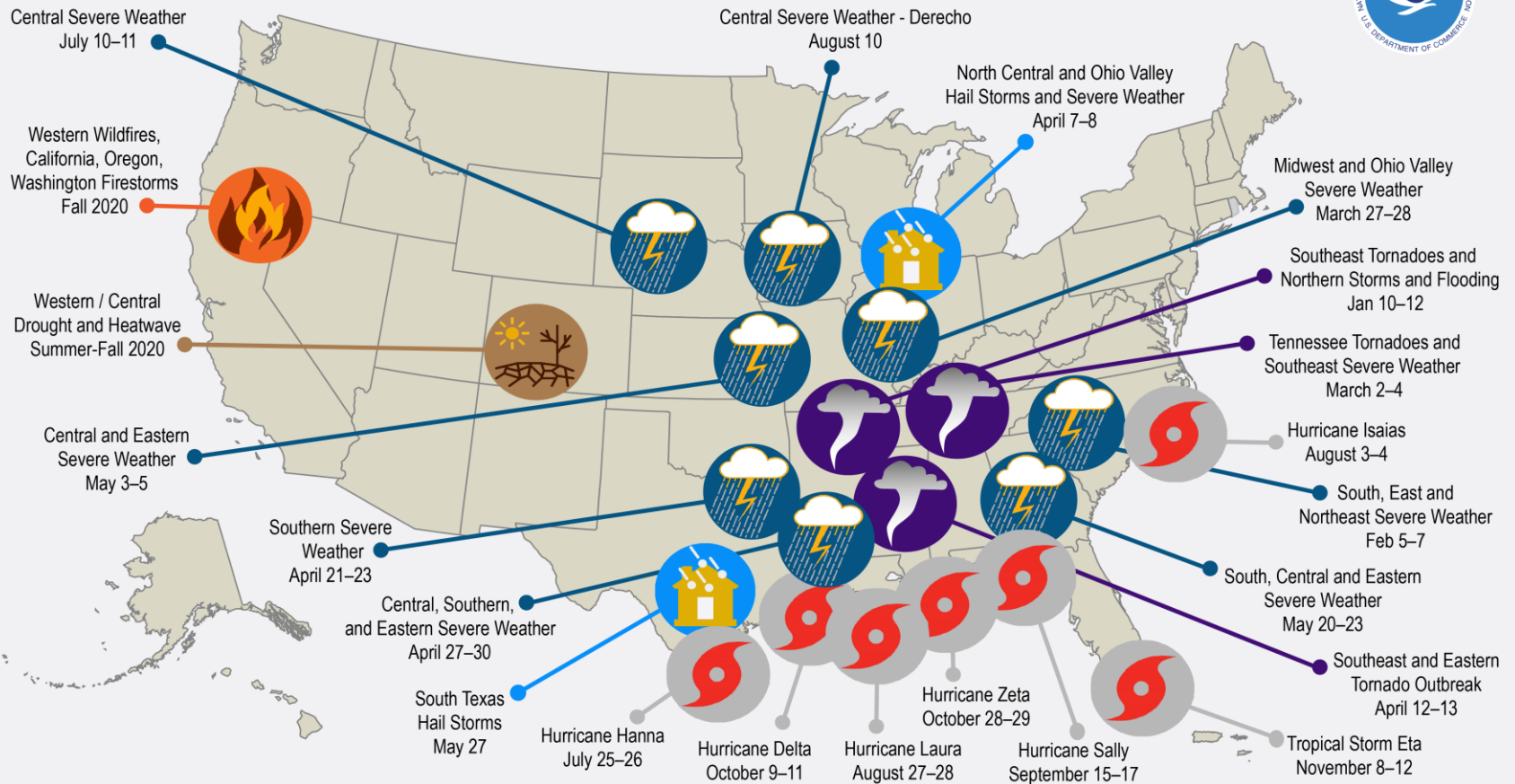
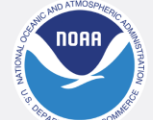
# **Part 2: National Weather Service (NWS) and National Centers for Environmental Prediction (NCEP)**

# National Weather Service (NWS)

## Our Fundamental Role in Disaster Management

**Weather and climate disasters are directly relevant to the NWS mission**

### U.S. 2020 Billion-Dollar Weather and Climate Disasters



*This map denotes the approximate location for each of the 22 separate billion-dollar weather and climate disasters that impacted the United States during 2020.*





# National Weather Service (NWS) Vision and Mission

## Vision



Build a Weather-Ready Nation where Society is prepared for & responds to Weather-Dependent Events

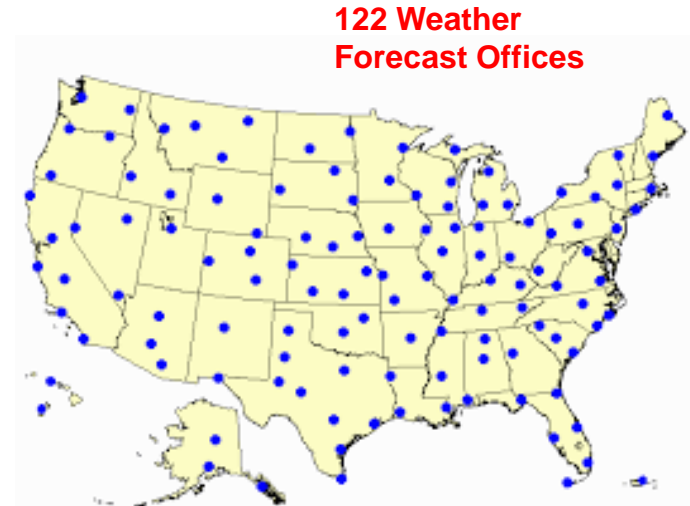
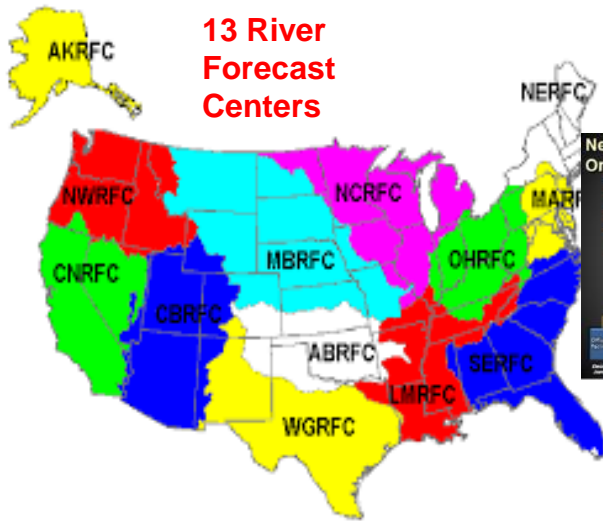
## Mission



The National Weather Service (NWS) provides weather, water, & climate forecasts & warnings for the United States, its territories, adjacent waters & ocean areas, for the protection of life & property & the enhancement of the national economy. NWS data & products form a national information database & infrastructure which can be used by other governmental agencies, the private sector, the public, & the global community.



# Connecting the NWS Organization to Deliver Accurate & Consistent Products and Services



## 9 National Centers (NCEP)



**National Water Center**

<ul style="list-style-type: none"> <li>&gt; 480 FTE</li> <li>&gt; 237 Contractors</li> <li>&gt; 40+ Visiting Scientists</li> <li>&gt; 6 NOAA Corps Officers</li> <li>&gt; \$137M Budget</li> </ul>	<p><b>Aviation Weather Center</b> Kansas City, MO</p>	<p><b>Climate Prediction Center</b> College Park, MD</p>	<p><b>Environmental Modelling Center</b> College Park, MD</p>	<p><b>National Hurricane Center</b> Miami, FL</p>
<p><b>NCEP Central Operations</b> College Park, MD (Supercomputers in Boston &amp; Orlando)</p>	<p><b>Ocean Prediction Center</b> College Park, MD</p>	<p><b>Space Weather Prediction Center</b> Boulder, CO</p>	<p><b>Storm Prediction Center</b> Norman, OK</p>	<p><b>Weather Prediction Center</b> College Park, MD</p>

## 21 Central Weather Service Units (Aviation)



# National Centers for Environmental Prediction (NCEP) Vision and Mission

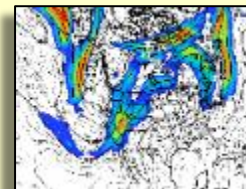
490 FTE  
237 Contractors  
40+ Visiting Scientists  
6 NOAA Corps Officers  
\$137M Budget



**Aviation Weather Center**  
Kansas City, MO



**Climate Prediction Center**  
College Park, MD



**Environmental Modeling Center**  
College Park, MD



**National Hurricane Center**  
Miami, FL



**NCEP Central Operations**  
College Park, MD



**Ocean Prediction Center**  
College Park, MD



**Space Weather Prediction Center**  
Boulder, CO



**Storm Prediction Center**  
Norman, OK



**Weather Prediction Center**  
College Park, MD

## Vision

The trusted source for environmental predictions from the sun to the sea, when it matters most.

## Mission

NCEP delivers national and global operational weather, water and climate products and services essential to protecting life, property and economic well-being.

# NCEP Modeling: Operational *Numerical Guidance* Supports the NOAA/NWS Mission (includes disaster response)

– *Forecasts* are made by *people*:

- Weather Forecast Offices (WFOs).
- Service Centers within the National Centers for Environmental Prediction (NCEP).

– *Models* provide *guidance*.

- Prediction is now inherently linked to numerical models.
- Most models are run at NCEP.
  - More than 20 major simulation codes.
  - More than 1600 support codes and scripts.
  - Billions of data ingested daily.
  - Millions of products delivered daily.
- Sharing with world wide partners:
  - DoD, ECMWF, UK Met Office, JMA, ...

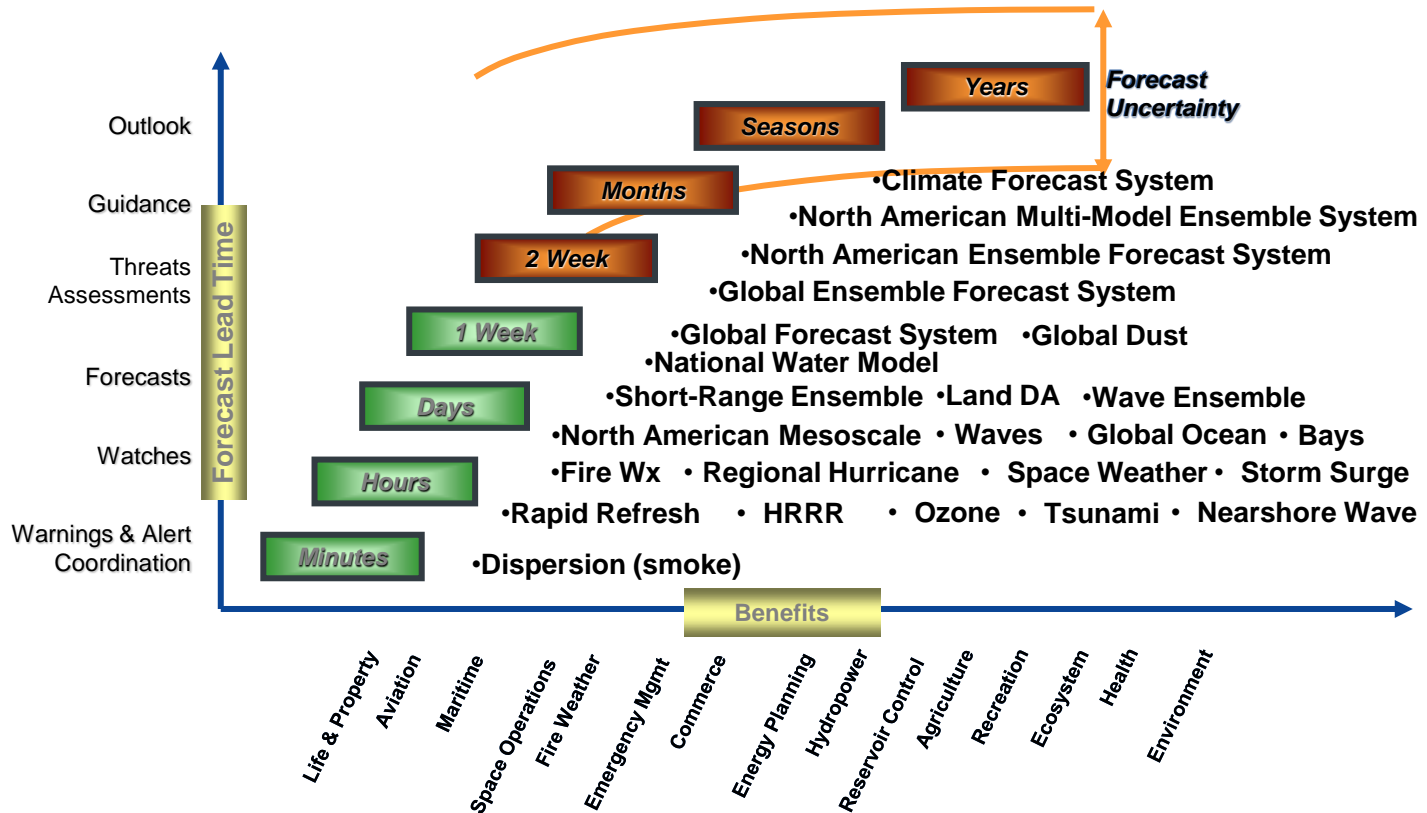
# NCEP Modeling: Operational *Numerical Guidance* Supports the NOAA/NWS Mission

- **Numerical Weather Prediction at NOAA**
    - Required for agency to meet service-based metrics
  - **National Weather Service GPRA\* Metrics**  
(\* Government Performance & Results Act)
    - Hurricane Track and Intensity
    - Winter Storm Warning
    - Precipitation Threat
    - Flood Warning
    - Marine Wind Speed and Wave Height

Lead Time and Accuracy critical for disaster response ops!
- **Operational numerical guidance:**
    - Foundational tools used by government, public and private industry to improve public safety, quality of life and make business decisions that drive U.S. economic growth

# NCEP Modeling: Seamless Suite of Operational Numerical Guidance Systems

## NCEP model span Weather and Seasonal/Climate time scales



NCEP models managed by the Environmental Modeling Center (EMC)



# Past AI/ML Activities at NCEP/EMC

- **1995 - 1998** - SSM/I multiparameter NN retrieval algorithm
- **2002** - NN nonlinear wave-wave interaction for wave model
- **2003 - 2010** - NN emulations of Long- and Short-wave radiative parameterization for NCAR CAM, NCEP GFS and CFS
- **2012** - NN averaging of multi-model ensemble for precipitation.
- **2013** - New NN moisture parameterization learned from data simulated by CRM
- **2014** - NN observation operator for assimilating SSH
- **2017** - NN biological model for assimilating ocean color data
- **2018** - NN for NCEP Global Wave Ensemble System
- **2019** - Using NN to Improve CFS Week 3-4 Forecasts



# Current AI/ML Activities at NCEP/EMC (1)

Project	Status	PI	Collaborators
<b>AI-based emulator for accelerated transport of atmospheric chemical species and aerosols</b>	Funded by NOAA's HPCC IT Incubator Call, work started	J. Sleeman	JHU/APL, UMBC, NASA/GMAO, OAR/ARL
<b>AI-based bias correction for air quality predictions</b>	Funded by NOAA, work started	M. Halem	UMBC, JHU/APL OAR/ARL
<b>Development of a ML emulator for CAM-CMAQ to improve wildfire smoke forecasts.</b>	Funded by NOAA's FY19 Disaster Supplemental, work started	C. Keller	USRA, OAR/ARL, NASA/GMAO
<b>NN emulation of GFS physics suite</b>	Pilot study completed and published	V. Krasnopolsky	IMSG, GOOGLE

# Current AI/ML Activities at NCEP/EMC (2)

Project	Status	PI	Collaborators
<b>NN emulations of LW and SW radiation parameterizations for GEFS</b>	in progress	V. Krasnopolsky	IMSG
<b>NN emulation of GFS physics for use in DAS and calculating adjoint for 4D-Var</b>	in planning	D. Kleist	
<b>Post processing using k-means clustering to identify spatially and temporally consistent wave systems from the output of NWPS v1.3</b>	Implemented in 2021	A. van der Westhuysen	IMSG
<b>Investigate replacing unstructured WW3 in the Great Lakes with (i) a Recurrent neural network and (ii) a boosted ensemble decision tree</b>	Published in Ocean Modelling	A. van der Westhuysen	GLERL, CIGLR, IMSG
<b>Joint Research on NN-scheme to Emulate NWP Physics parameterizations</b>	in progress	V. Krasnopolsky	KMA, NIMS

# Current AI/ML Activities at NCEP/EMC (3)

Project	Status	PI	Collaborators
<b>Use of a convolutional neural network (CNN) to relate the directional wave spectrum produced by NWPS to observed rip current events.</b>	in progress	A. van der Westhuysen	MDL, NOS/CO-OPS, IMMSG
<b>Machine learning for the pre-processing of radiosonde observations for NWP at EMC</b>	in progress	D. Kleist	UMD
<b>Satellite thinning, data selection, and quality control for the global data assimilation system leveraging AI/ML</b>	planning	D. Kleist	
<b>Calibration of the new Multigrid/Beta filter-based background error covariances using AI/ML</b>	Planning & preliminary testing	J. Carley	Potentially UMD and MIT
<b>Improvement of the background fields in 3D-RTMA using AI/ML</b>	Planning & preliminary testing	J. Carley	Potentially UMD and MIT

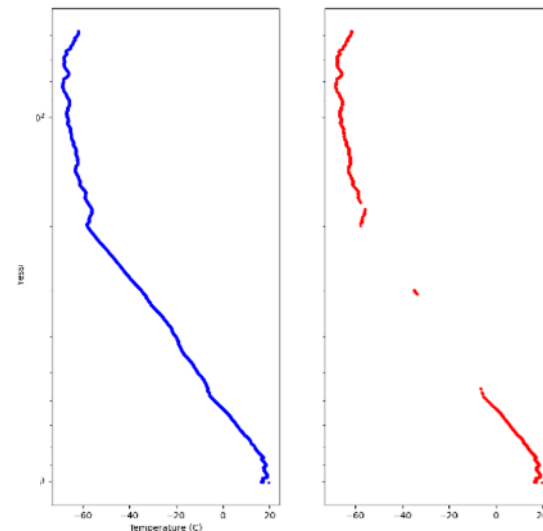
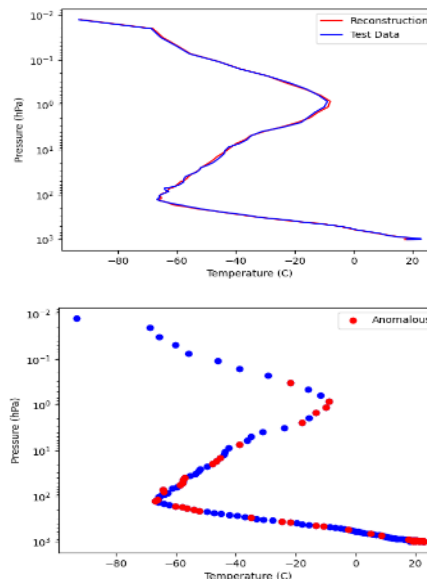
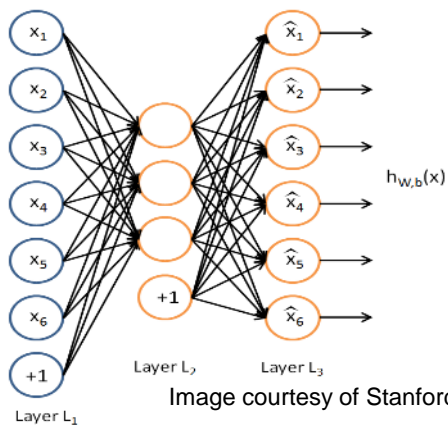


# NCEP/EMC and NCEP/CPC AI/ML applications Sample Results

# Machine learning for the pre-processing of radiosonde observations for NWP at EMC

## Autoencoders

- Identify important data points
  - Important points: deviate from expectations
- Autoencoder
  - Unsupervised machine learning
  - Bottlenecked neural network
  - Compress the data
  - Reconstruct the data for evaluation
- Anomaly detection (AD)
  - Locates where the reconstruction is poor
  - Poor reconstruction means the data is anomalous
  - Identifies and outputs points from the original dataset

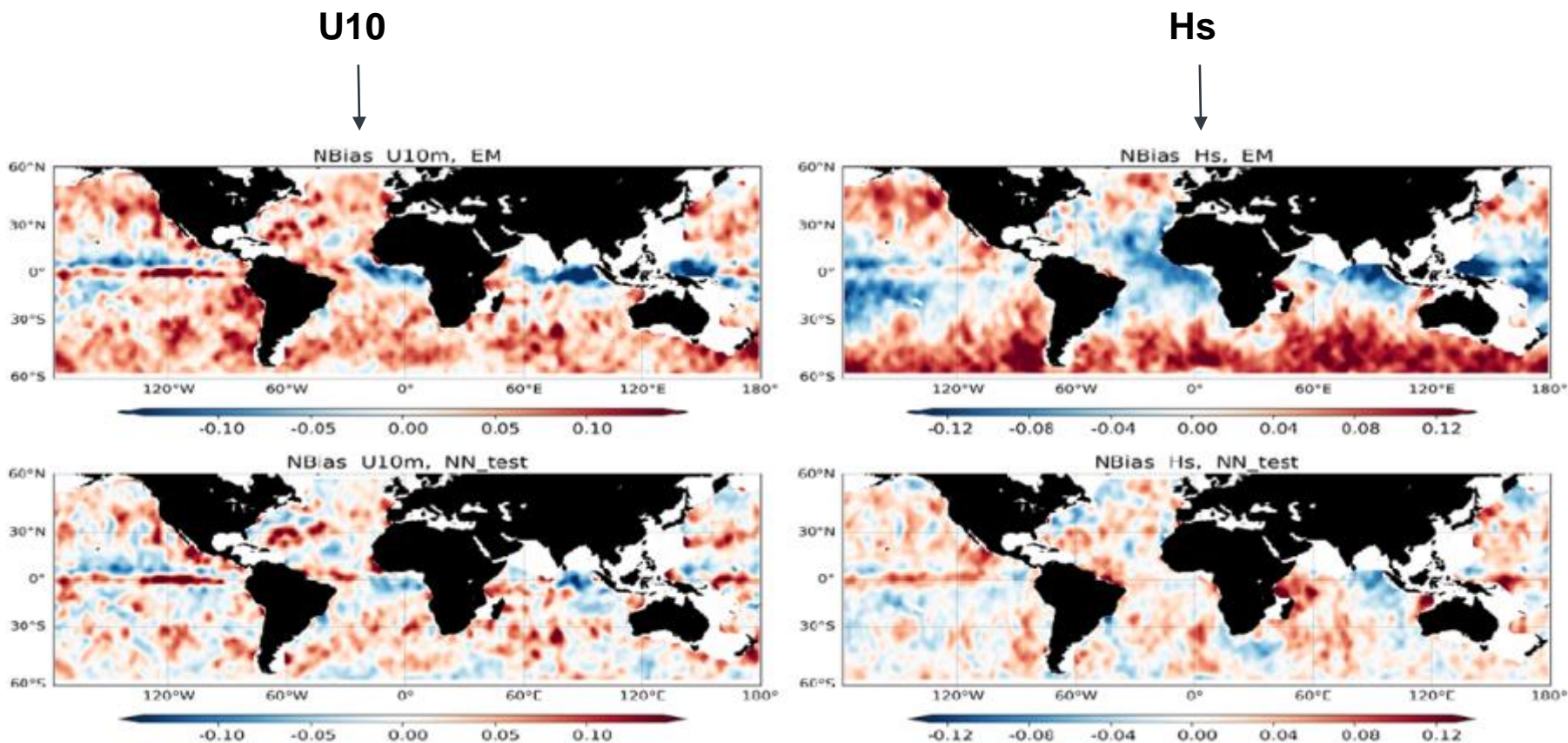


Anomaly detection can be used to find points in a vertical profile that deviate from a climatological training dataset

**Goal: Reduce size of input radiosonde dataset while retaining the original structure of the profile**

Work performed by Sam Varga, University of Maryland and a 2020 NOAA Hollings Scholar

# NN Bias Correction in Global Wave Ensemble System



**Upper row: U10 and Hs biases, GWES ensemble mean vs. altimeter data**

**Lower row: Biases after NN bias correction**

**U10 - wind speed at 10 m**

**Hs - significant wave height**

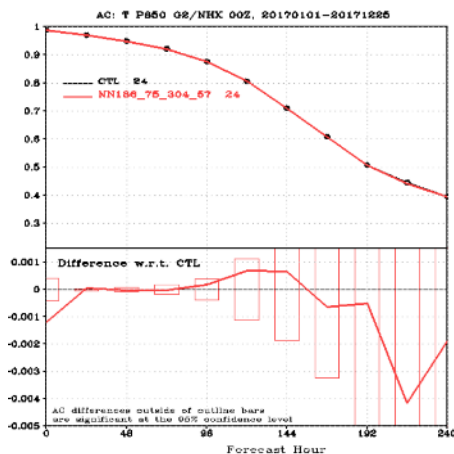
Campos, R. M., V. Krasnopolsky, J.-H. G. M. Alves, and S. G. Penny, 2020: Improving NCEP's Global-Scale Wave Ensemble Averages Using Neural Networks, *Ocean Modeling*, 149, 101617



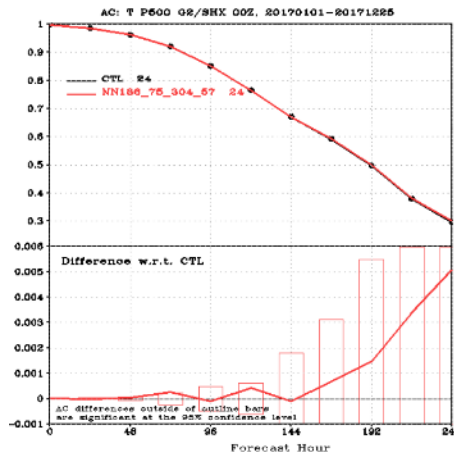
# NN Emulation of the GFS Physics Suite

Anomaly Correlation and RMSE of 850 hPa Temp. 24 10-day forecasts spanning 2017  
Control run - black, NN run - red

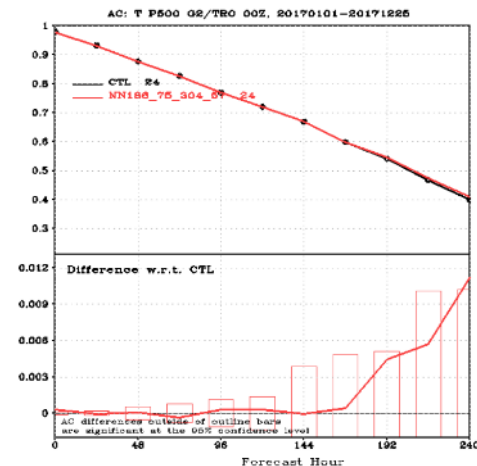
AC →



Northern Hemisphere



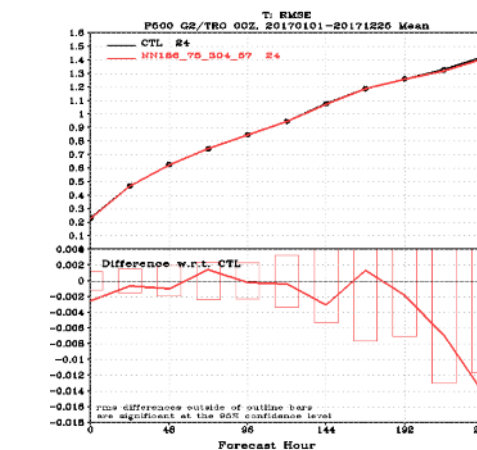
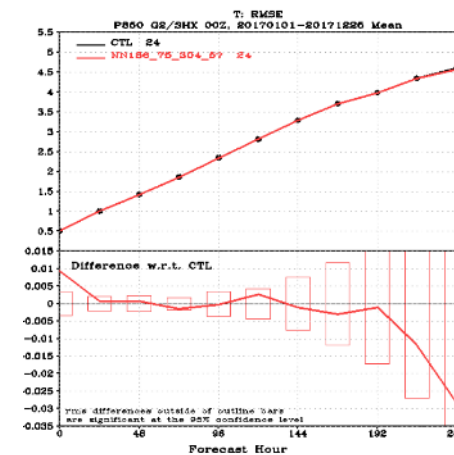
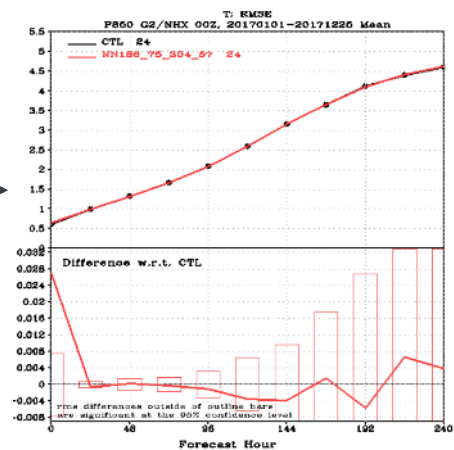
Southern Hemisphere



Tropics

NN physics  
~5 times faster

RMSE →



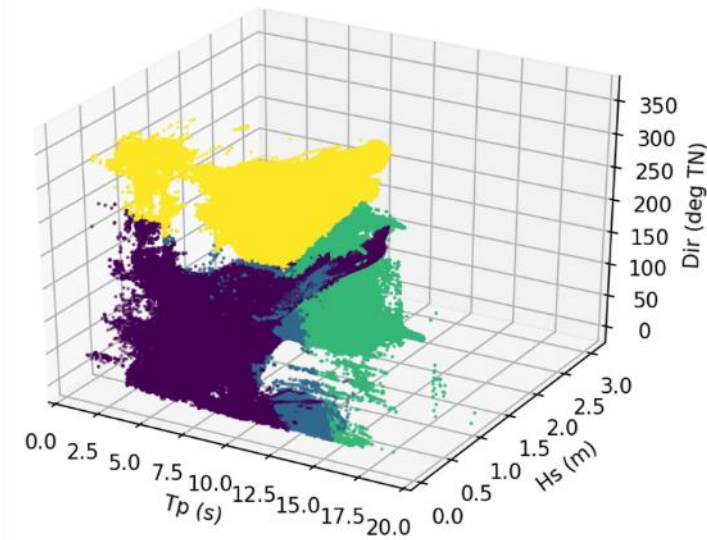
A., Belochitski,  
V. Krasnopolsky,  
2021, JAMES, submitted



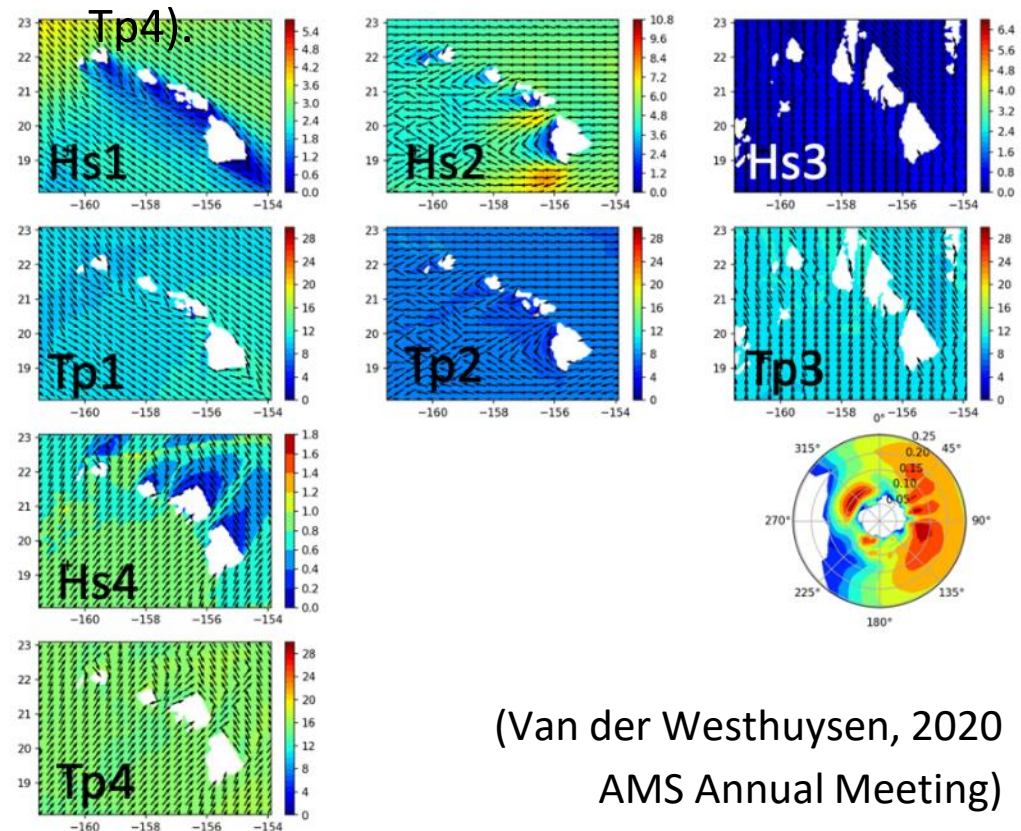
# Wave System Identification Using Clustering

Using *k*-means clustering to identify spatially and temporally consistent wave systems from the output of Nearshore Wave Prediction System v1.3

*k*-means clustering in wave parameter space



Clustered wave systems in geo space with heights (Hs1-Hs4) and periods (Tp1-Tp4).

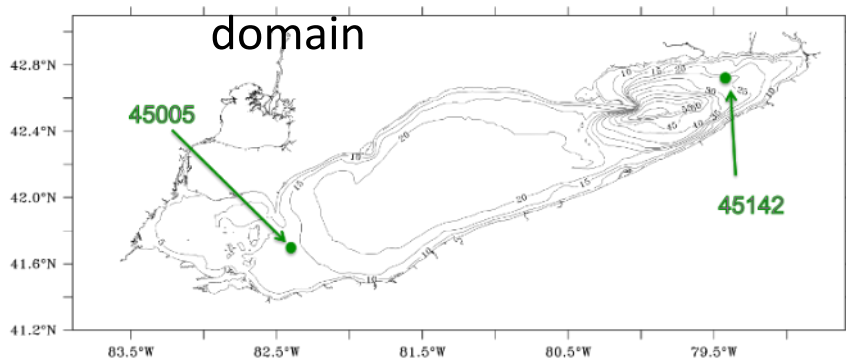


(Van der Westhuysen, 2020  
AMS Annual Meeting)

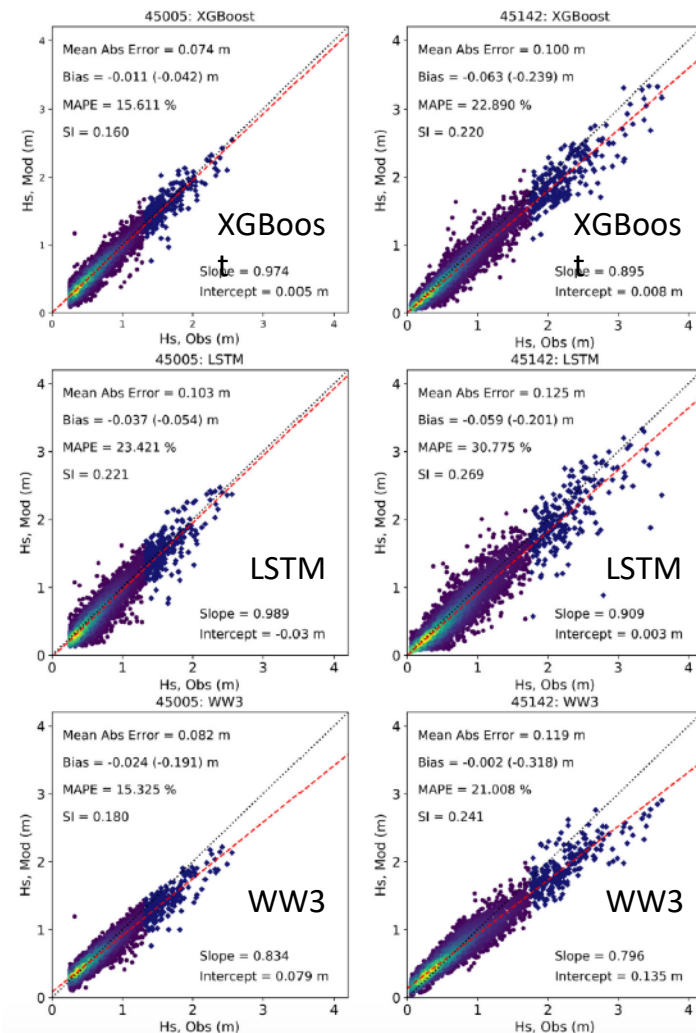
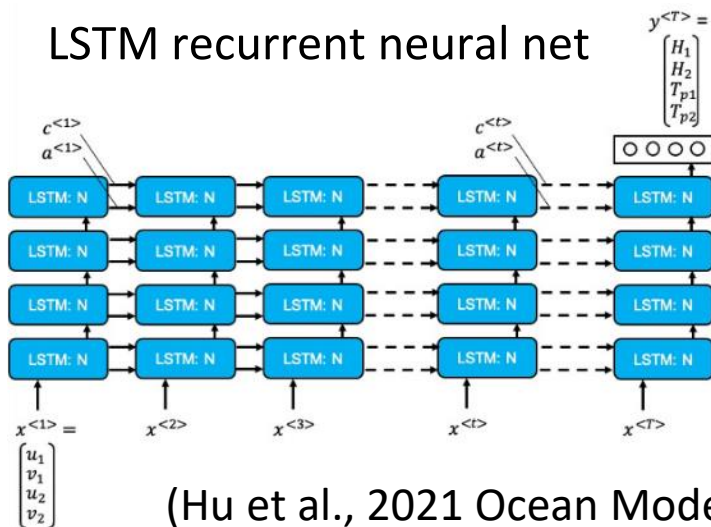
# Replacing WW3 in the Great Lakes with AI/ML

Investigate performance of (i) a Recurrent Neural Network and (ii) a Boosted Ensemble Decision Tree (XGBoost) against the WW3 numerical wave model.

## Lake Erie study



## LSTM recurrent neural net



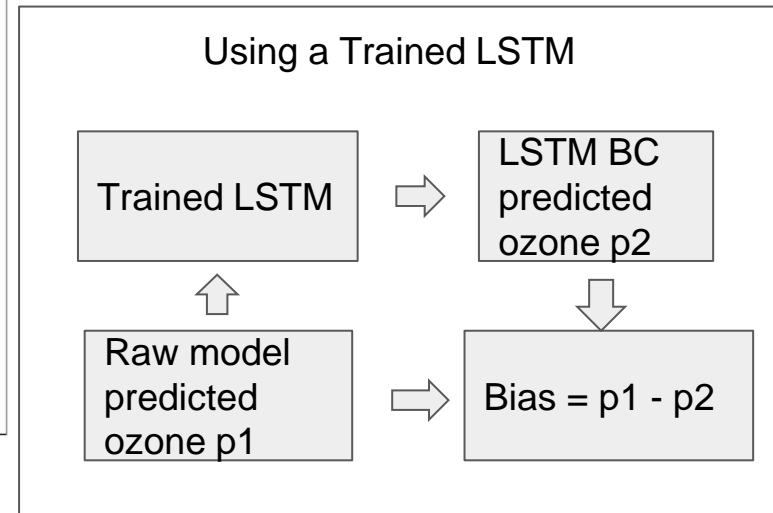
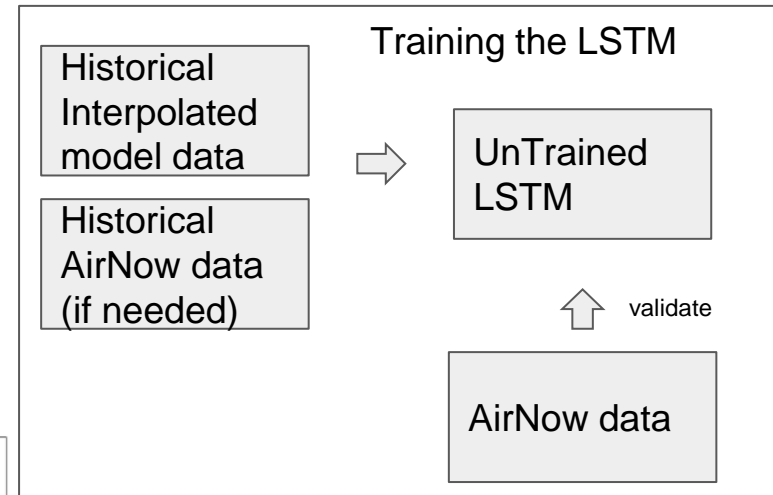
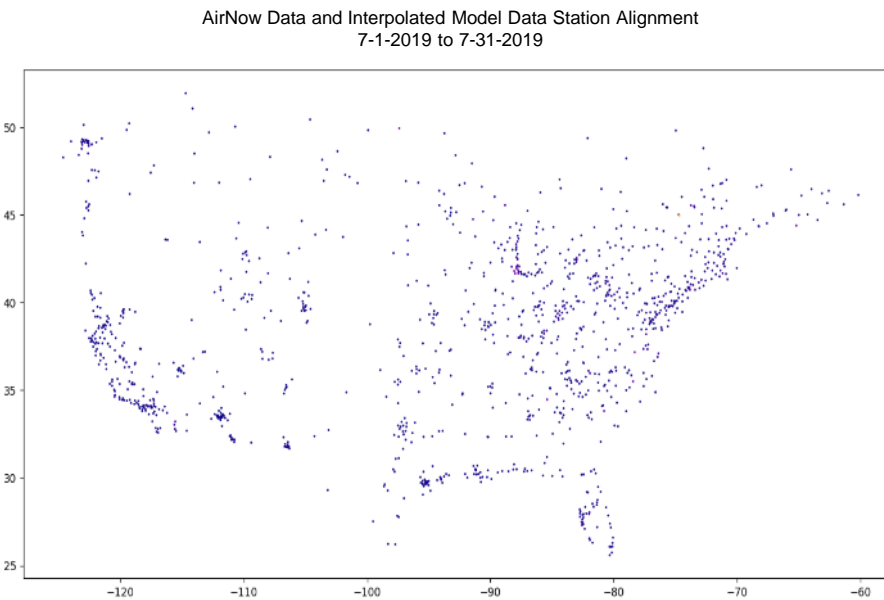
# Long Short Term Memory (LSTM) Bias Correction Deep Learning Network for Extreme Events

*Investigate the use of deep learning to augment existing bias correction methods for extreme air pollution events*

Input: Historical AirNow and Interpolated data

Output: LSTM learned bias corrections for predicted ozone

Geographic coverage: CONUS



*Work in progress by Halem et al*



# AI Emulator for Accelerated Transport of Chemical Species

*Evaluate the use of AI-based emulators for accelerated transport of atmospheric tracers: chemical species and aerosols.*

Input: 3D tracer concentrations for transported species, pressure, temperature, wind, humidity, grid information (lat/lon/height, date, time)

Output: 3D tracer concentrations for transported species, grid information (lat/lon/height, date, time)

Format: netcdf

Geographic coverage:

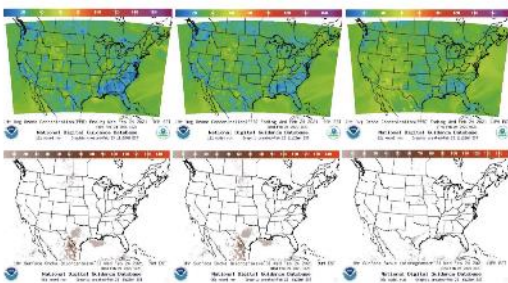
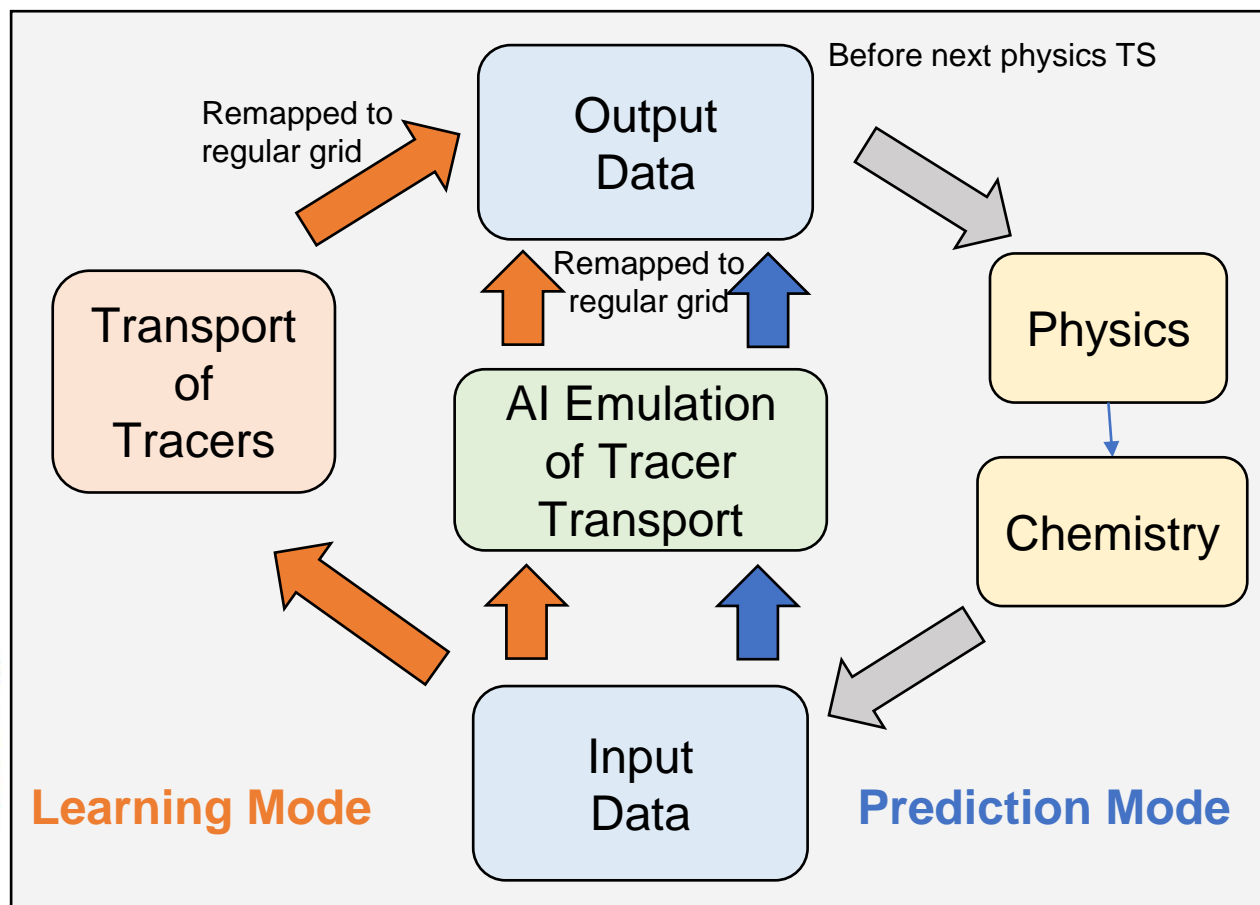


Figure 1: Concentrations of ozone (top) and smoke (bottom) over 4 hours in the lowest model layer in the operational NWS AQI predictions for 7 am (left), 9 am (middle) and 11 am EST (right) on 2/24/2021. Ozone increases, but smoke is dispersed as sun rises (source: <https://airquality.weather.gov/>)



Work in progress by Sleeman et al

# NCEP Climate Prediction Center (CPC) AI/ML Project for Drought Monitoring and Outlooks

**Objective:** Drought monitoring and outlooks using ML methods

## Benefits:

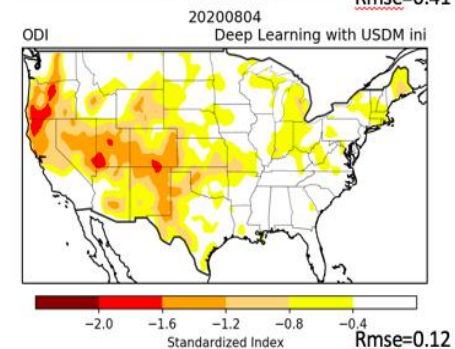
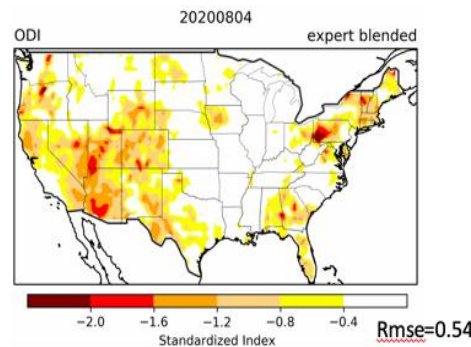
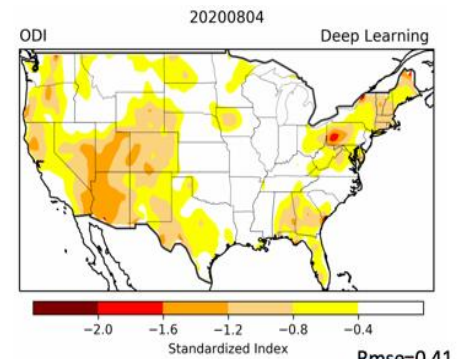
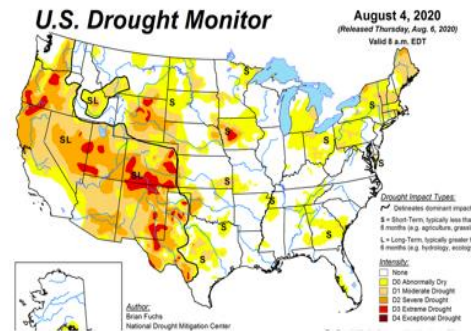
- Improved drought monitoring and outlooks can better inform water resource planning.
- More refined drought monitoring can help with targeted relief actions and specific mitigation actions.
- For the outlooks, the monthly and seasonal timescales exhibit low signal to noise ratio, and machine learning methods may enhance that ratio above other methods.

## Predictors:

- Standardized Precipitation Index
- Standardized Runoff Index
- Soil Moisture
- Evaporative Stress Index
- Standardized Precipitation-Evapotranspiration Index

**Predictand:** Standardized index of drought – Drought Category

Principal investigator: Yun Fan/Li Xu, CPC  
AI tools: hierarchical machine learning and Restricted Boltzman machines





# NCEP Climate Prediction Center (CPC)

## AI/ML Project for ENSO Prediction

**Objective:** Develop a new ENSO prediction tool using NN techniques with ECMWF Ocean Reanalysis and NCEP GODAS

**Question:** Since state of the art NWP systems often have failures wrt ENSO outlooks beyond a couple months, can reanalysis datasets be mined for new empirically based tools to give better estimates of uncertainty/more realistic spread?

### Predictors:

SST\_anom, SST\_clim,  
SSHT\_anom, SSHT\_anom(t-1),  
SSH\_anom

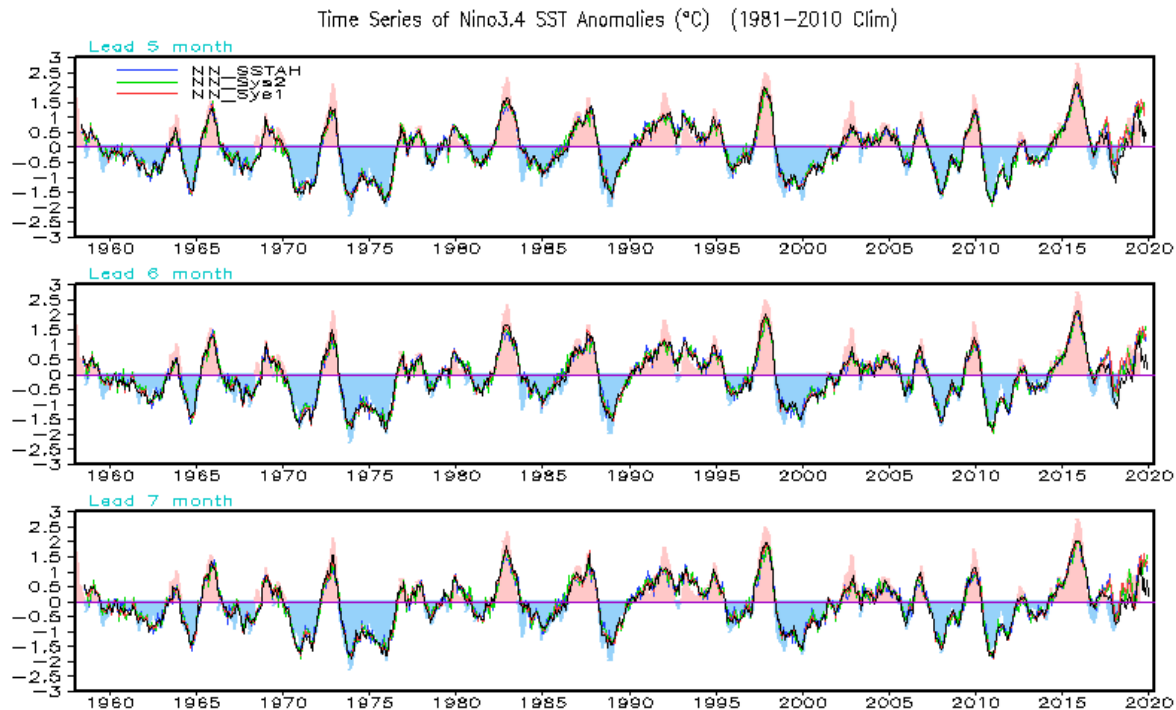
### Predictand: SST\_anom

SST: ERSST\_v5  
Heat content, Sea Height:  
1958-2016: ECMWF S4,  
2017-pres GODASS

Training: Jan1958 - Dec2018  
Verif: Jan2019 - Apr2020

*Principal investigator: Yun Fan (NCEP/CPC), in partnership with NCEP/EMC*

*AI tools: NN, one hidden layer, 180 neurons*





## Q&A

If you'd like to follow up on any item, feel free to contact me via:

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