Innovations in Weather Forecasting for a Changing Climate

Thursday, February 15, 2024

Materials will be available at: www.eesi.org/021524weather
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About EESI

Non-partisan Educational Resources for Policymakers
A bipartisan Congressional caucus founded EESI in 1984 to provide non-partisan information on environmental, energy, and climate policies.

Direct Assistance for Equitable and Inclusive Financing Program
In addition to a full portfolio of federal policy work, EESI provides direct assistance to utilities to develop “on-bill financing” programs.

Commitment to Diversity, Equity, Inclusion, and Justice
We recognize that systemic barriers impede fair environmental, energy, and climate policies and limit the full participation of Black, Indigenous, people of color, and legacy and frontline communities in decision-making.

Sustainable Solutions
Our mission is to advance science-based solutions for climate change, energy, and environmental challenges in order to achieve our vision of a sustainable, resilient, and equitable world.
Policymaker Education

**Briefings and Webcasts**
- Live, in-person and online public briefings, archived webcasts, and written summaries

**Climate Change Solutions**
- Bi-weekly newsletter with everything policymakers and concerned citizens need to know, including a legislation and hearings tracker

**Fact Sheets and Issue Briefs**
- Timely, objective coverage of environmental, clean energy, and climate change topics

**Social Media (@EESIOnline)**
- Active engagement on Twitter, Facebook, LinkedIn, and YouTube
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www.eesi.org/survey

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Tweet about the briefing:
#eesitalk  @eesionline

Thursday, February 15, 2024
NWS: 154 Years Young

NWS runs 168 operational units, most of them 24/7

NWS has ~4450 employees, of whom 86% are in the field

NWS issues ~1.5 million forecasts and ~50,000 warnings each year

NWS costs each person in the US about $4.00/year

Supporting national security and public safety in every community, every day.
Why the National Weather Service Matters

U.S. 2023 Billion-Dollar Weather and Climate Disasters

- Drought/Heat Wave
- Flooding
- Hail
- Hurricanes
- Severe Weather
- Tornado Outbreaks
- Wildfire
- Winter Storms/Blizzards

Annual Average for weather/climate disaster events increasing

- 2000-2009: 6.7/year
- 2010-2019: 12.8/year
- 2020-2023: 22/year

Impact-Based Decision Support Services

Our forecasts & warnings: confidence, context, social science + Tabletops, feedback, engagement: connections with decision-making partners = Impact-based Decision Support Services

Actionable Environmental Intelligence

February 4-7, 2024 Historic Southern California Rains

Two weeks Prior  4-7 Days Prior  1-3 Days Prior  EVENT

Emergency Operation Centers

NATIONAL WEATHER SERVICE

Building a Weather-Ready Nation // 3
NWS Transformation Commitment

Becoming a more nimble, flexible, & mobile agency providing indispensable mission services eye to eye with decision makers

Observations/Data => Models/Guidance => Forecasts / Services => IDSS

Enable Prepared, Weather Ready, and Responsive Communities
Thank you!
michelle.m.mainelli@noaa.gov
Overview

Tomorrow.io

Climate Adaptation Platform, powered by Weather Intelligence.
Tomorrow.io at a glance

- Started in 2016 in Boston; over $300M in capital raised to-date
- Locations in U.S., Israel, and India
- Deploying groundbreaking LEO smallsat constellation of weather radars and sounders
- Partnering with the U.S. Air Force, NASA, JetBlue, Uber, Ford, and more
- Approximately 240 employees (~50% in R&D)

Scaling SaaS Weather Intelligence Globally

Weather Intelligence Alert
- De-ice planes between 10 AM - 11 AM

Weather Intelligence Alert
- Hail will start in 60 minutes. Move car to covered area and check road conditions
West & Central Kenya
Rainfall next 7 days from October 17 (October 17-24) at 3.5 km resolution

Good rains expected in the short term forecast.

It is time to plant.

6M Farmers Reached (and growing!)

SMS agri-advisory program with KALRO, powered by high-resolution weather intelligence:

- **Rapid scale** - up to 6M farmers reached in 1 year
- **High impact** - Farmers more likely to report successful germination and less likely to report pests or damage to maize
Tomorrow.io Created Weather Intelligence™

Weather Intelligence isn’t focused on the weather, it’s focused on the predictive impact of the weather, automated decisioning, and operational optimization.

12°

Mostly cloudy with a 40% chance of rain on Tuesday for New York City.

VS

Suspend rail service on the 5 line south of Wall St on Tuesday from 1-4 PM due to rain expected to exceed flooding threshold.
Operationalizing the Forecast
Empowering organizations to standardize and automate operating protocols

Build protocols that monitor for impact

Get signaled when impact will occur

Drive business outcomes
Tomorrow.io Differentiated on 3 Fronts

Comprehensive Global Weather Observations & Measurements

Proprietary Weather Modeling. Powered by Physics, Supercharged with AI/ML.

Weather Intelligence SaaS/API
Quality Weather Information is Not Universal

Decades after the first weather radar was installed, 5 billion people still live outside of reliable radar coverage.

No radar coverage over oceans, where most high-impact weather originates.

Existing satellites do not offer a solution for global high-revisit precipitation monitoring.
The Global Radar Gap

More than 70 years after radar was invented, more than 5 billion people still live outside of radar coverage making even the most basic forecasts a dream for the vast majority of humanity.
Meet the Tomorrow.io Constellation

Tomorrow.io’s constellation of 20 small satellites will provide:
- Full Global Coverage
- <1 hour average revisit rate
- World’s first near real-time precipitation measurements and 3D atmospheric profiles
- Dramatic improvement in real-time weather forecasts, tropical cyclone warnings and flood alerts

Hybrid constellation of 30 small satellites in Low Earth Orbit
- 12 Ka-band radars
- 18 MW radiometers

Timeline:
- Launched in Q2/23
- Constellation fully operational by EOY 2025
Radical Cost Reduction for Spaceborn Weather Radar

- Leveraging NASA/JAXA proven science and investing in massive cost reduction to enable operational utility and cost-effective science continuation
- 160X improvement in cost per scan from existing state-of-the-art
“A new [active radar] instrument architecture that is compatible with low-cost satellite platforms...will enable constellation missions and revolutionize climate science and weather forecasting.”
Pathfinder Results: Higher correlation to US NEXRAD precipitation product (MRMS) than NASA's current state-of-the-art GPM satellite
Full Atmospheric and Oceanic Observation System

- Drought monitoring
- Flood alert
- Tropical cyclone forecasts
- Real-time global precip
- Storm structure and intensity
- Real-time disaster warnings
- Marine wind/Wave warnings
- Tides and sea level rise
- Coastal erosion
- Sea heights
- Storm moisture structure
- 3D Temperature Profiles
- 3D Humidity Profiles
- 3D Clouds & Precipitation
- Radar
- Microwave Sounders
Global Wx radar gap | Data required where DoD operates
In April ‘23, China launched FY-3G which is a derivative of the NASA/JAXA GPM architecture. FY-3G features the following payloads:

- Dual-frequency (Ku+Ka) band radar w/ 300 km swath
- Microwave imager (conical scan) w/ 26 channels (~900 km swath)
- Vis/IR imager with 8 channels and 500m resolution
- GNSS-R/RO receiver
- SWIR polarimeter

The article states that an identical satellite will be launched in 2028, followed by an FY-5 “constellation” consisting of 2 additional precipitation measurement satellites and an atmospheric dynamics satellite to measure wind (possibly wind lidar).

<table>
<thead>
<tr>
<th>MWRI-RM channels (GHz)</th>
<th>MERSI-RM channels (μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>V/H:</strong> 10.65, 18.7, 23.8, 36.5, 50.3, 52.61, 53.24, 53.75, 89.0</td>
<td><strong>0.65, 0.865, 0.940, 1.38, 1.64, 3.8, 10.8, 12.0</strong></td>
</tr>
<tr>
<td><strong>V only:</strong> 118.75±3.2, 118.75±2.1, 118.75±1.4, 118.75±1.2, 165.5±0.75, 183.31±2.0, 183.31±3.4, 183.31±7</td>
<td></td>
</tr>
</tbody>
</table>
The Traditional Weather Enterprise

- Most of the work done by government agencies
- Private market focused on repackaging data, few contributions to underlying technology
- Access to reliable and useful weather/climate information - still a dream for most of the world
Weather Enterprise 2.0

- Urgent need for improvement requires “whole-of-nation” approach
- Private market can and should take a much more significant role to augment and support government mission
- Industry is innovating across the value chain
Key structural changes

- Industry is not reliant on government as a customer (dual use technologies benefit industry and gov agencies)
- Leveraging private capital to develop and deploy new technologies
- Taking on risk of deployment (launch), replenishment, and will continue to innovate on new payloads, sensing modalities, modeling systems, and more

The result is that **industry will likely surpass government** in observations and modeling in the next few years. Industry and government must **develop better mechanisms for public-private partnership** in the weather enterprise.
USG has limited mechanisms for purchasing commercial weather data

- **CWDP**: So far limited to limited scope of technologies and data types
- **CSDA**: Limited to scientific applications not operational meteorology
- **CWDP**: Zeroed out in FY24 NDAA and Appropriations bill

Other agencies like USDA, DOE, DOI, etc. have unique needs which may not fit within the purview of these entities and yet have limited purchasing power for commercial weather solutions.
A coalition of 11 commercial weather companies dedicated to promoting public-private partnership and industry collaboration to innovate across the entire U.S. weather and climate enterprise value chain
Legislative Opportunities

- Weather Act 3.0
- NASA Reauthorization
- Farm Bill
- NDAA
AI for weather and climate forecasting

Pierre Gentine
Columbia University
Director, LEAP center
CTO, Tellus AI
Climate change is happening now ... but we are too unprepared
Current gap: Climate Adaptation is Needed

... and their associated cost.
How can AI help? 1. Resilience

Flood forecasting with machine learning models in an operational framework

Short-term, fast, flood prediction

Example Google flood forecasting
How can AI help? 1. Resilience

Monitoring: flood mapping
Using deep learning to map inundation, using meter-scale resolution satellite imagery.
How can AI help? 1. Resilience

Monitoring: wildfire progression
Using deep learning to track wildfire progression:
RADR - FIRE/ DOE PNNL
Rapid Analytics for Disaster Response
How can AI help? 2. Improved prediction

Weather: up to 2 weeks
AI can have similar or better skill than weather centers prediction. Europe is leading the way (integrating AI in weather forecasting)

GraphCast: Learning skillful medium-range global weather forecasting

Better Wind accuracy
AI model Lead time (days)

and Nvidia, Huawei, ECMWF etc
How can AI help? 2. Improved prediction

After two weeks no accuracy from AI models (nor from physical models)

Subseasonal to seasonal prediction is a major challenge
Critical for agriculture, insurance etc
Limited data: How many droughts or El Niño have we seen?
How can AI help? 3. Improved projections

AI can post-process climate models to correct them and provide better estimate of climate change (here, temperature).

Machine learning projections

Physical model projections

More pessimistic greenhouse gas scenario
AI can help climate change adaptation & resilience in many ways

- Real-time Monitoring
- Prediction
  - Short-term weather forecasting
  - Short-term climate predictions (a few weeks to year)
  - Climate projections (>10 years)

Still some gaps:
- Seasonal to multi-year predictions, empirical indices for risks...
- Training data!

But we are in a much better place to face risks than a few years ago.

Not just academic work, tremendous private interest, boundaries are porous.

Feel free to reach out: pg2328@columbia.edu
How can AI help? 2. Improved prediction

Seasonal to yearly **climate** prediction: El Niño

Deep learning for multi-year ENSO forecasts
Current gap: Climate Adaptation is Needed but Requires Reliable Predictions and Projections

Current climate models are too uncertain

Climate models’ forecasts do not translate into actionable adaptation
How can AI help? 3. Improved projections

AI can help improve climate models: unresolved physical processes cause model errors

- Clouds
- Ocean Eddies
- Photosynthesis

Physical + Biological Processes

Climate model Grid ~100km

TAS, global, CMIP6.

Model Spread

Ocean heat content CMIP5

Model Spread

Cumulative uptake (PgC)

RCP8.5

ocean

land

Model Spread
How can AI help? 3. Improved projections

Example of deep clouds (convection)
Deep learning to emulate physical processes at coarse resolution
How can AI help? 3. Improved projections

Step-change improvements in extremes
→ critical for inundation and flood projections

Rasp et al., 2018 PNAS; Shamekh et al. PNAS 2023
Weather Forecasting Challenges, and Efforts to Address Them

Dan Stillman,
Co-Founder and Meteorologist
The Washington Post’s Capital Weather Gang

EESI Congressional Briefing
February 15, 2024
➢ Jan. 26: Highest January temperature in D.C. since record keeping began in 1872

➢ Earliest 80-degree day by several weeks; previous earliest was Feb. 21 in 2018

➢ Occurred during worldwide warm spell with record warmth on nearly every continent

➢ Just a week after snow and arctic cold blast

➢ Intense cold snaps still happen in a warming world, but they are becoming less extreme

➢ Warm spells becoming more extreme

➢ Warm records outpacing cold records; 31,611 warm records in 2023 compared to 10,493 cold-weather records

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Forecasts were as much as 10 to 15 degrees too low.
Contributing Factor: Strong, Stable Polar Vortex

When polar vortex is strong and stable, cold air is locked up near Arctic
Contributing Factor: El Niño

Ongoing Strong El Niño

Warmest Years Are El Niño Years

El Niño increases the chance of breaking warm temperature records
Contributing Factor: Record-Warm Oceans

Last year was warmest on record, even warmer to start 2024.
Hurricane Otis forecast an ‘epic fail’

Most models kept Otis below hurricane strength. A day later it catapulted to a Category 5.

- Hurricane Otis made landfall on Acapulco Oct. 25, 2023
- First Pacific hurricane to make landfall at Category 5 intensity
- Winds increased by 90 mph, from a tropical storm to Category 5 hurricane, in 12 hours
- More hurricanes are rapidly intensifying due in part to warmer ocean waters and slower-moving storms
- Harder to predict, harder to prepare for
Feb. 13, 2024, Nor’easter confounds meteorologists

➢ Huge shift in snowfall forecasts the day before storm as models abruptly shifted storm significantly southward

➢ Boston forecast dropped from 7-13” to 4-8”; final total at Logan Airport was 0.1”

➢ Albany forecast dropped from 8-12” to 1-2”; final total: no accumulation

➢ Hartford forecast dropped from 8-12” to 4-8”; final total was 15”

➢ Forecast for portions of SE Mass jumped from 1-3” to 6-8”; final total was 4-6”
Large-scale weather pattern accuracy

Precipitation forecast accuracy

Rate of forecast improvement has slowed, especially for precipitation, but efforts to improve models continue.
NOAA and other government satellites, radars, weather balloons, aircraft, ground sensors, buoys, serve as backbone of global observation network

International collaboration because local forecasts depend on global data

Forecast models limited by incomplete, relatively scarce observations of surface and lower atmosphere

NOAA continuing to explore and/or operationalize use of private-sector satellite, radar, buoy, and other data
Big Tech, including Google, Microsoft and Nvidia, have made rapid advances in AI weather modeling in the last 2 years

AI models now as accurate, in some cases even more accurate, than traditional models

AI models are less expensive and much faster to run than traditional models; could enable more confident forecasts and better capture extreme conditions

But it’s a symbiotic relationship. AI models are trained on traditional models and use their data as starting point to make forecasts

Government weather agencies, including NOAA, accelerating AI modeling activities and collaborating with private sector
➢ Social science is key to turning forecasts into well informed decisions

➢ Forecasts for low-probability, high-impact events especially challenging

➢ Experimental National Hurricane Center forecast cone this coming season; will highlight inland threats, not just on the coast

➢ NWS emphasis on better communication with, and embedding forecasters with, emergency managers

➢ NOAA Weather Program Office projects looking at how people understand probabilities, interpret weather risk graphics, and respond to severe weather
Messages to Congress

- More accurate forecasts, earlier warnings, better characterization of extreme scenarios, and more effective communication will save thousands more lives and provide millions to billions of dollars in economic benefit.

- When you properly fund weather and climate agencies, you are investing in the entire U.S. weather and climate enterprise—the public, private, and academic sectors.

- When you underfund any one component of forecasting, you undercut the end-user forecast and potential for personal, organizational, and economic benefit.
The Frontline of Climate Communication

How to effectively communicate the impacts of climate change on extreme weather events & global disasters
People Trust Meteorologists

Research shows that Broadcast Meteorologists are highly trusted sources of information about climate change.

Source: Climate Matters
The Frontline of Climate Communication

Coverage of climate’s impact on **local weather** is a strong reason to watch T.V.

Coverage of the climate’s impact on **major weather events and disasters** is a strong reason to watch T.V.
What Can We Do?

1. **USE OUR PLATFORM**
   - Access to the public through broadcast, digital and social media

2. **EXPAND OUR ROLE**
   - Cover stories about how climate change is impacting our community

3. **CLOSE THE GAP**
   - Helping the public understand climate science will lead to greater understanding, acceptance and action
How We Present Information

Meet our audience where they are

- Television
- WUSA9 app/website
- YouTube
- Instagram
- X
- Facebook

Make the big picture smaller

- Wildfire impacts on air quality
- Rising sea levels inundating the tidal basin
- Warming global temperatures & cherry blossoms
- Excessive rainfall and algae blooms
- Health impacts of extreme heat
Organizations We Partner With

- The National Weather Service
- NASA
- The National Oceanic and Atmospheric Administration
- Local Universities
- Covering Climate Now
- Yale Program on Climate Change Communications
- Climate Central
Solutions Journalism
Fruit Trees Need Winter

CLIMATE CENTRAL DATA

**CHILL TIME NEEDED**
Hours required before spring growth

- **Apple**: 800-1,100 hours
- **Blueberry**: 900-1,000 hours
- **Peach**: 400-1,050 hours
- **Cherry**: 1,000+ hours

Source: Alabama Cooperative Extension

**An apple a day may be harder to come by in our changing climate**

A local scientist is working with Virginia farmers to help protect fruit trees from late spring frosts.
Solutions Journalism
The Power of Trees

CLIMATE CENTRAL DATA

The power of trees in urban areas
How Casey Trees is enhancing the tree canopy in our nation's capital
Using Climate Data in Weather Forecasts

A Climate Central Product

Change in annual days above 90° based on rate of change since 1970.
Source: RCC-ACDB.org
Climate Shift Index
A Climate Central Product

- CSI compares how often a given temperature will occur in our current climate, with the frequency of that temperature in a climate without global warming.
- The scale used details how likely a temperature is in today's altered climate.
## Climate Shift Index

A Climate Central Product

Temperatures that are more likely get a positive value, negative values indicate conditions that are less likely

<table>
<thead>
<tr>
<th>Descriptor</th>
<th>CSI level</th>
<th>Interpretation</th>
<th>CSI level</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>No effect</td>
<td>0</td>
<td>The influence of climate change on the conditions (i.e., the daily high or low temperature) is not detectable. These conditions could occur about as often with or without climate change.</td>
<td>0</td>
<td>The influence of climate change on the conditions (i.e., the daily high or low temperature) is not detectable. These conditions could occur about as often with or without climate change.</td>
</tr>
<tr>
<td>Moderate</td>
<td>1</td>
<td>Climate change made the conditions at least 1.5 times more likely. A CSI level of 1 indicates a detectable climate influence.</td>
<td>-1</td>
<td>Climate change made the conditions at least 1.5 times less likely.</td>
</tr>
<tr>
<td>Strong</td>
<td>2</td>
<td>Climate change made the conditions at least twice as common. CSI levels of 2 and higher indicate a dominant climate influence.</td>
<td>-2</td>
<td>Climate change made the conditions at least 2x less common.</td>
</tr>
<tr>
<td>Very strong</td>
<td>3</td>
<td>Climate change made the conditions at least 3x more likely</td>
<td>-3</td>
<td>Climate change made the conditions at least 3x less likely</td>
</tr>
<tr>
<td>Extreme</td>
<td>4</td>
<td>Climate change made the conditions at least 4x more likely. These conditions would be extremely rare without climate change.</td>
<td>-4</td>
<td>Climate change made the conditions at least 4x less common. These conditions are becoming extremely rare with climate change.</td>
</tr>
<tr>
<td>Exceptional</td>
<td>5</td>
<td>Climate change made the conditions at least 5x more likely, potentially far more. This is an exceptional event driven by climate change.</td>
<td>-5</td>
<td>Climate change made the conditions more than 5x less likely. These conditions are becoming exceptionally rare with climate change.</td>
</tr>
</tbody>
</table>
Climate change made the conditions at least twice as common. CSI levels of 2 and higher indicate a dominant climate influence.
Thank you

Questions?
Let’s connect!
kmcgrath@wusa9.com
Resources

- Climate Central
- Covering Climate Now
- The National Weather Service
  - National Website
  - Local Office
- NASA
- The National Oceanic and Atmospheric Administration
- George Mason Center for Climate Change Communications
- Yale Program on Climate Change Communications