Predicting Weather-Driven Impacts in the Current and Future Climate

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- Introduction
- Science of weather and climate predictive models
- Coupled models for weather-driven impact forecasts
- Example business use cases of mitigation of weather risk
- Potential implications of climate change

Introduction to IBM Research

and

The Weather Company, an IBM Business

IBM's global research capability

The world is our laboratory

Foundational breakthroughs have made us famous

6

Nobel Laureates

10

National Medals of Technology

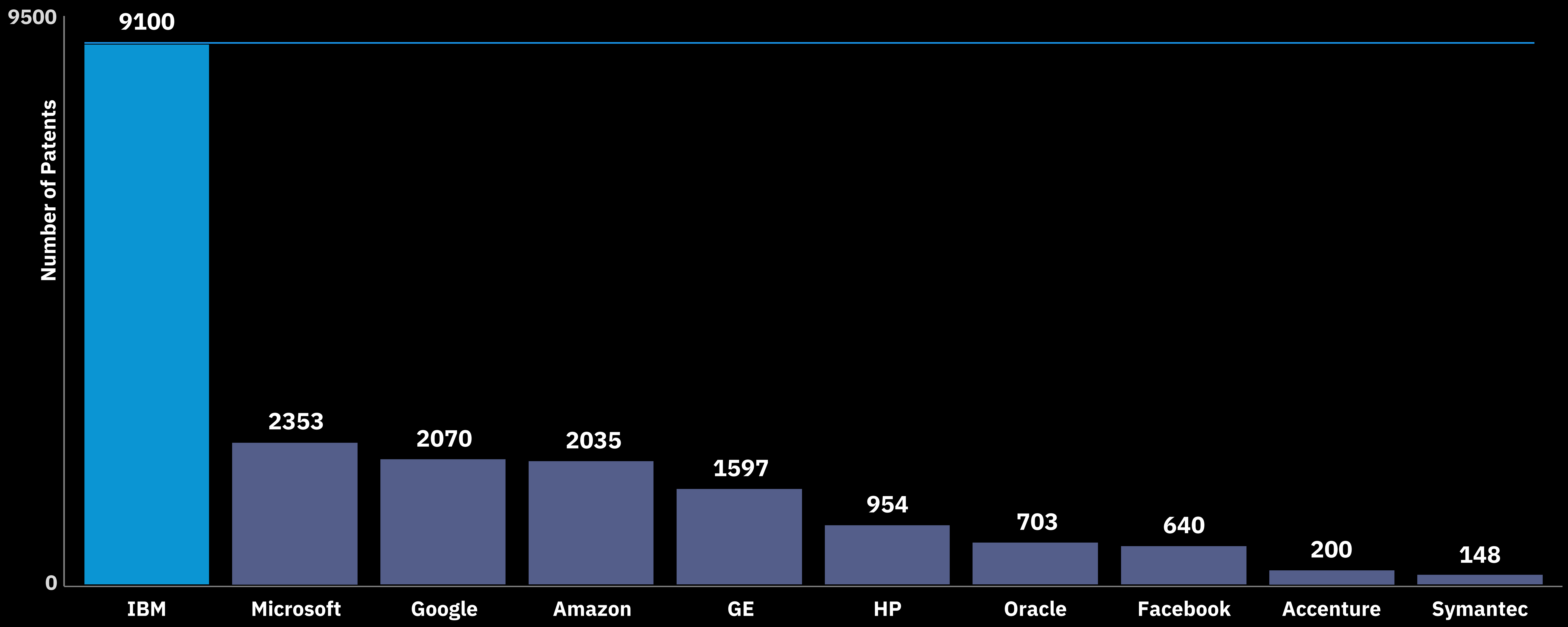
5

National Medals of Science

6

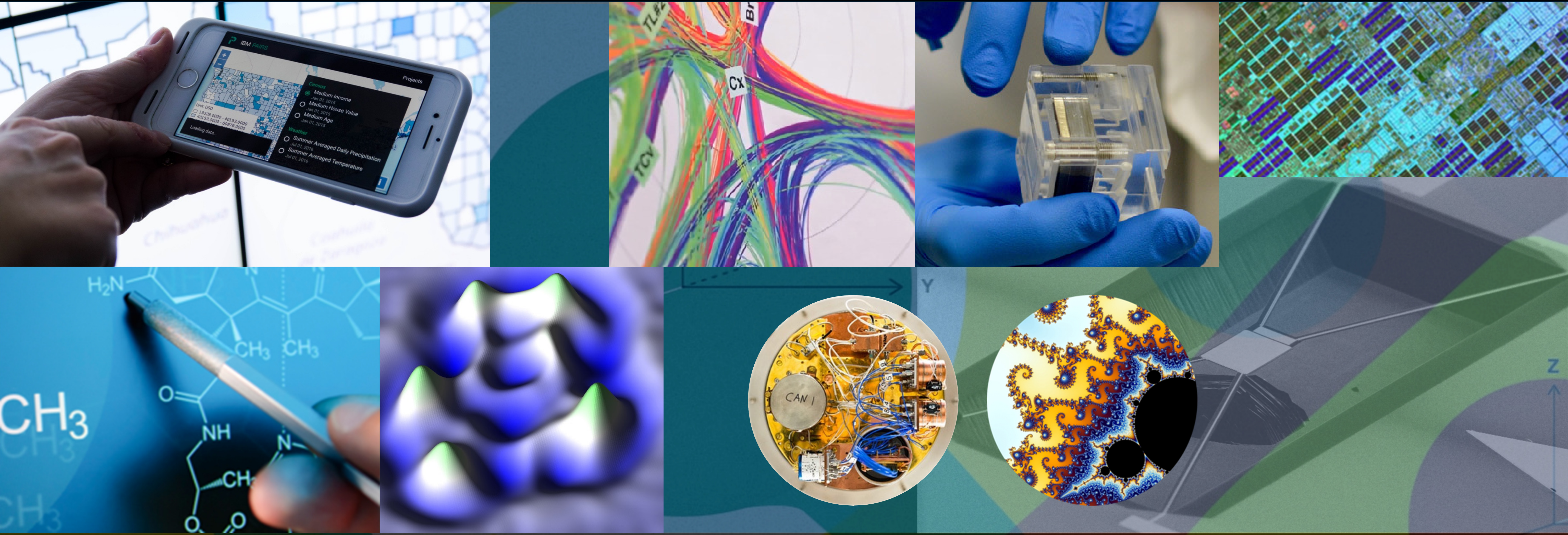
Turing Awards

2018 patents:
IBM vs. competition



2018 patent data sourced from IFI Claims Patent Services

Our scientists have deep skills in a range of core disciplines



Behavioral Science

Electrical Engineering

Biology

Materials Science

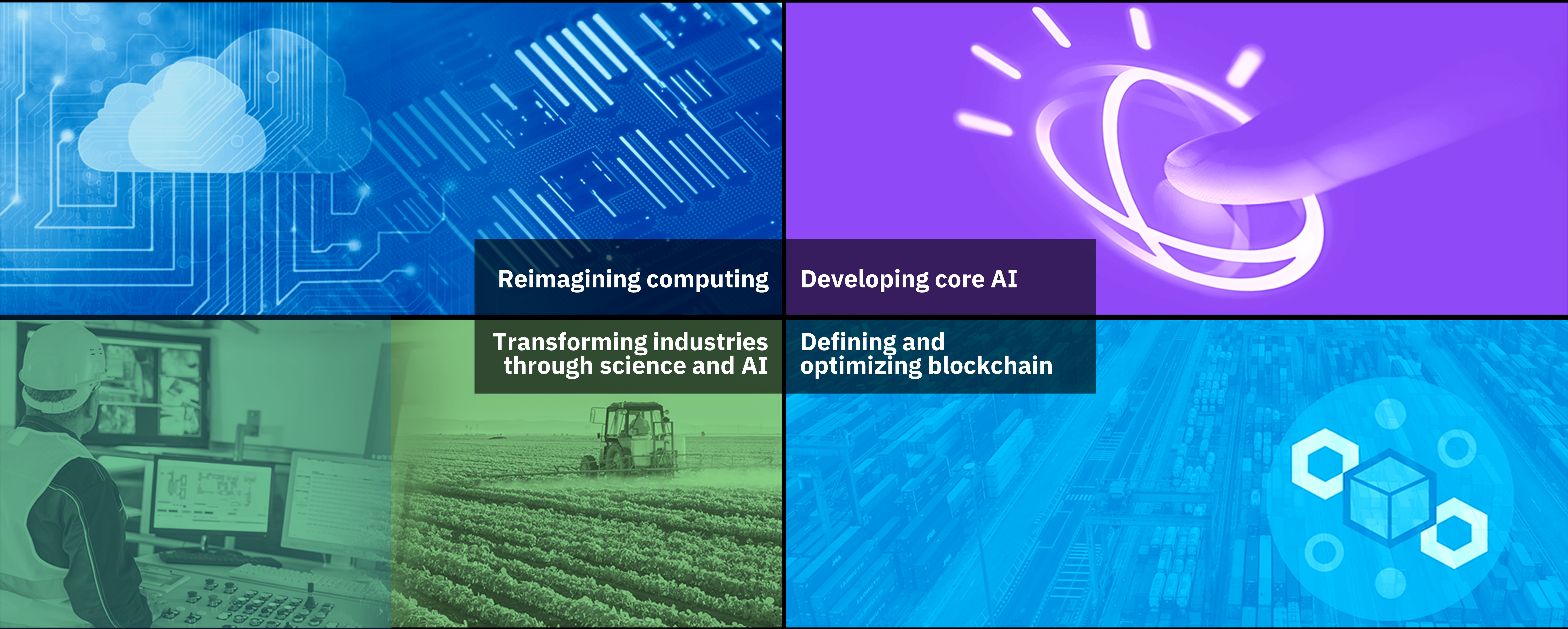
Chemistry

Mathematics

Computer Science

Physics

IBM Research strategic focal areas



IBM and The Weather Company (TWC)

IBM delivers 15 billion forecasts on average per day

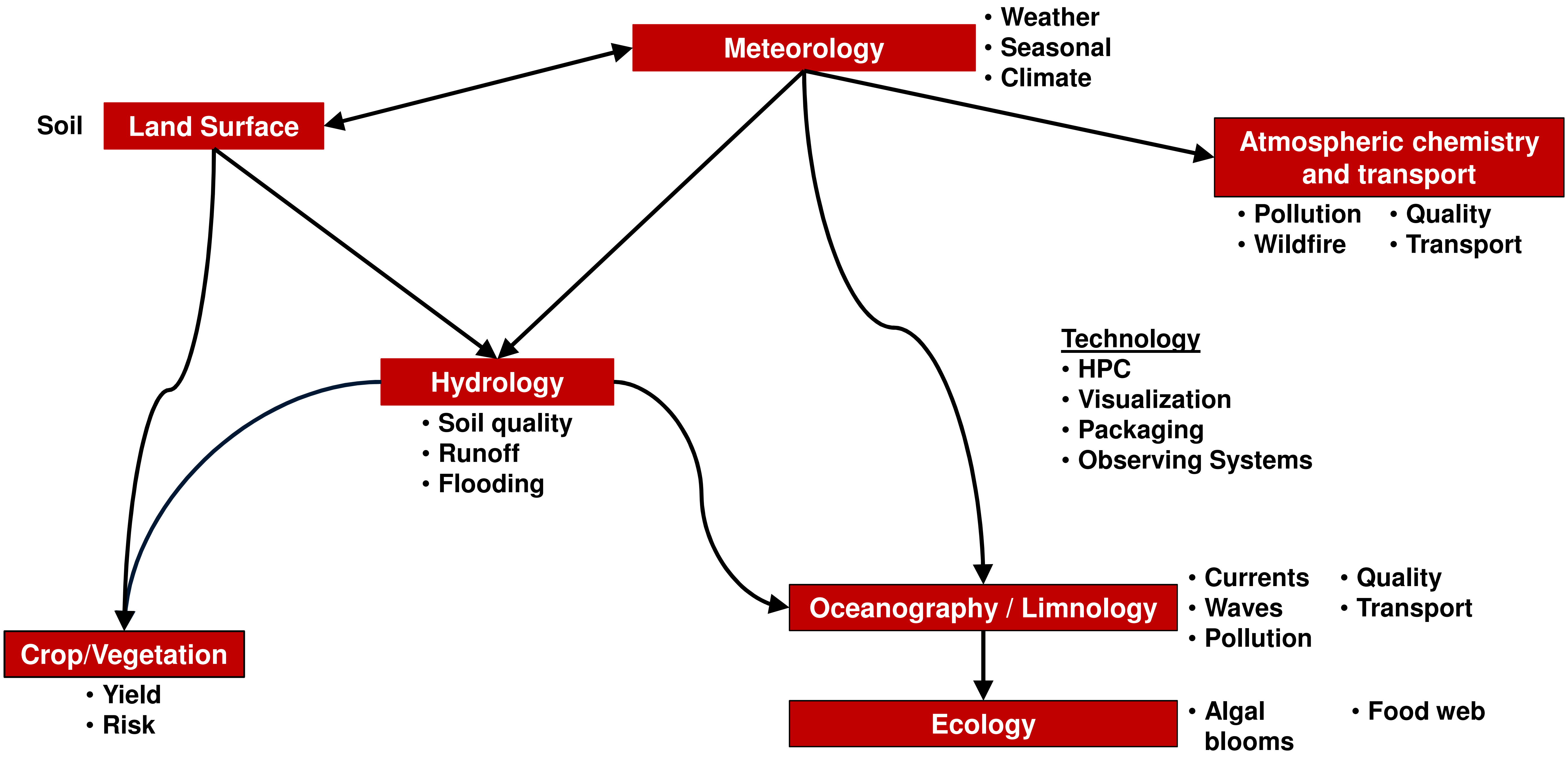
Up to 2.2 Billion weather forecast locations every 15 minutes (4GB/second)	15 Million pressure readings from mobile devices	Atmospheric data from 50,000 flights per day	~ 275,000 worldwide weather stations	> 150 forecast models serve as inputs to forecast

- Scalable data delivery via cloud-based APIs
- Content serves all TWC consumer forecast services, and powers many distribution portals including Apple, Google, Yahoo, Samsung, Facebook, local media outlets, and more
- Consumer business: weather.com, Weather Underground, mobile apps (The Weather Channel)
- Industrial customers: insurance, media, aviation, energy, retail, advertisement, agriculture, finance, surface transportation
- For example, delivers content to almost all of the television stations in the US
- 24 x 7 globally staffed operations: 70 forecasters in eight global office locations

Global Weather and Environmental Sciences Research and Development Team (TWC and IBM Research)

We have environment-related research and development activities around the world

Environmental Science Research Areas at IBM



Basic Scientific Principles and How We Create Weather Forecasts

A mathematical model that describes the physics of the atmosphere

Numerical Weather Prediction (NWP) uses finite difference methods to solve coupled partial differential equations that model the physics as an initial (and boundary) value problem

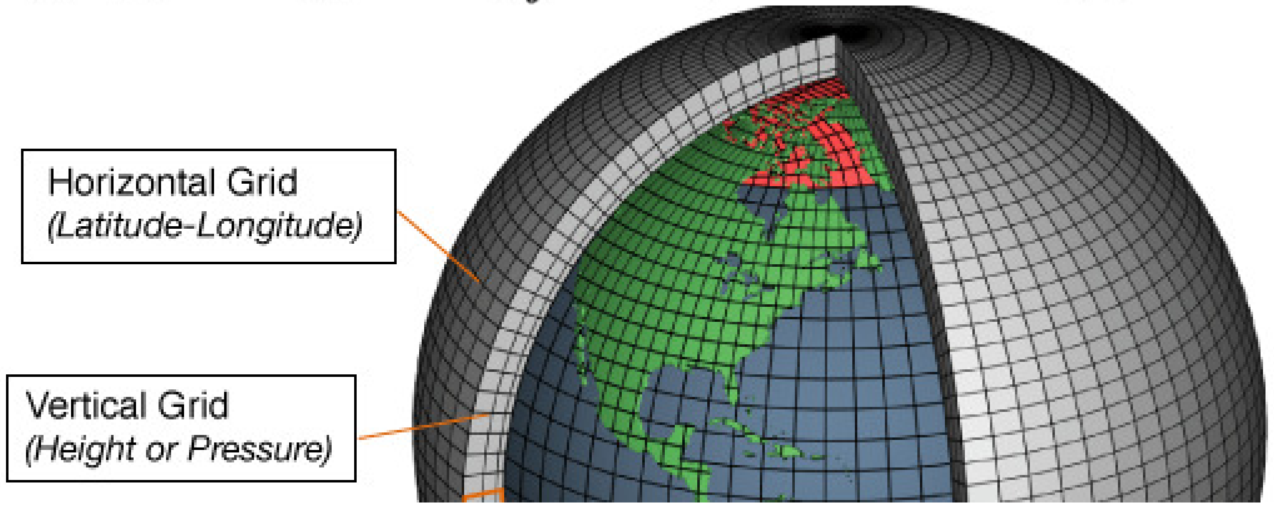
$$\frac{\partial u}{\partial t}+\dot{\sigma}\frac{\partial u}{\partial \sigma}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}-fv-\frac{uv}{r}\tan\phi+g\frac{\partial z}{\partial x}+c_p\theta\frac{\partial \pi}{\partial x}+F_x=0$$

$$\frac{\partial v}{\partial t}+\dot{\sigma}\frac{\partial v}{\partial \sigma}+u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+fu+\frac{u^2}{r}\tan\phi+g\frac{\partial z}{\partial y}+c_p\theta\frac{\partial \pi}{\partial y}+F_y=0$$

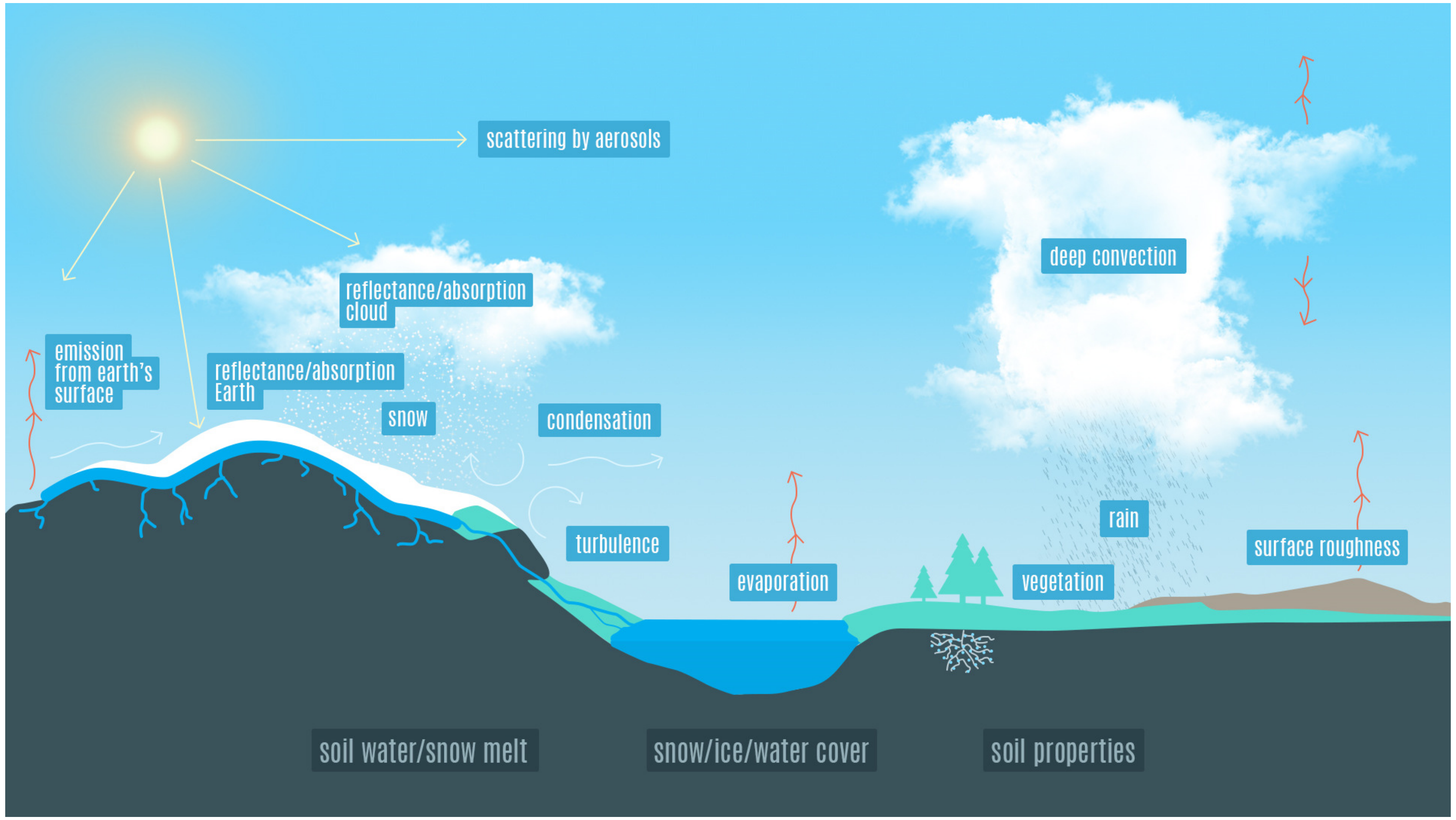
$$\frac{\partial (gz)}{\partial \sigma}+c_p\theta\frac{\partial \pi}{\partial \sigma}=0,$$

$$\frac{\partial \theta}{\partial t}+\dot{\sigma}\frac{\partial \theta}{\partial \sigma}+u\frac{\partial \theta}{\partial x}+v\frac{\partial \theta}{\partial y}+H=0,$$

$$\frac{\partial p_\sigma}{\partial t}+\frac{\partial}{\partial \sigma}(\dot{\sigma}p_\sigma)+\frac{\partial}{\partial x}(up_\sigma)+\frac{\partial}{\partial y}(vp_\sigma)-\frac{vp_\sigma}{r}\tan\phi=0, \qquad \pi=\left(\frac{p}{P}\right)^{\kappa}.$$

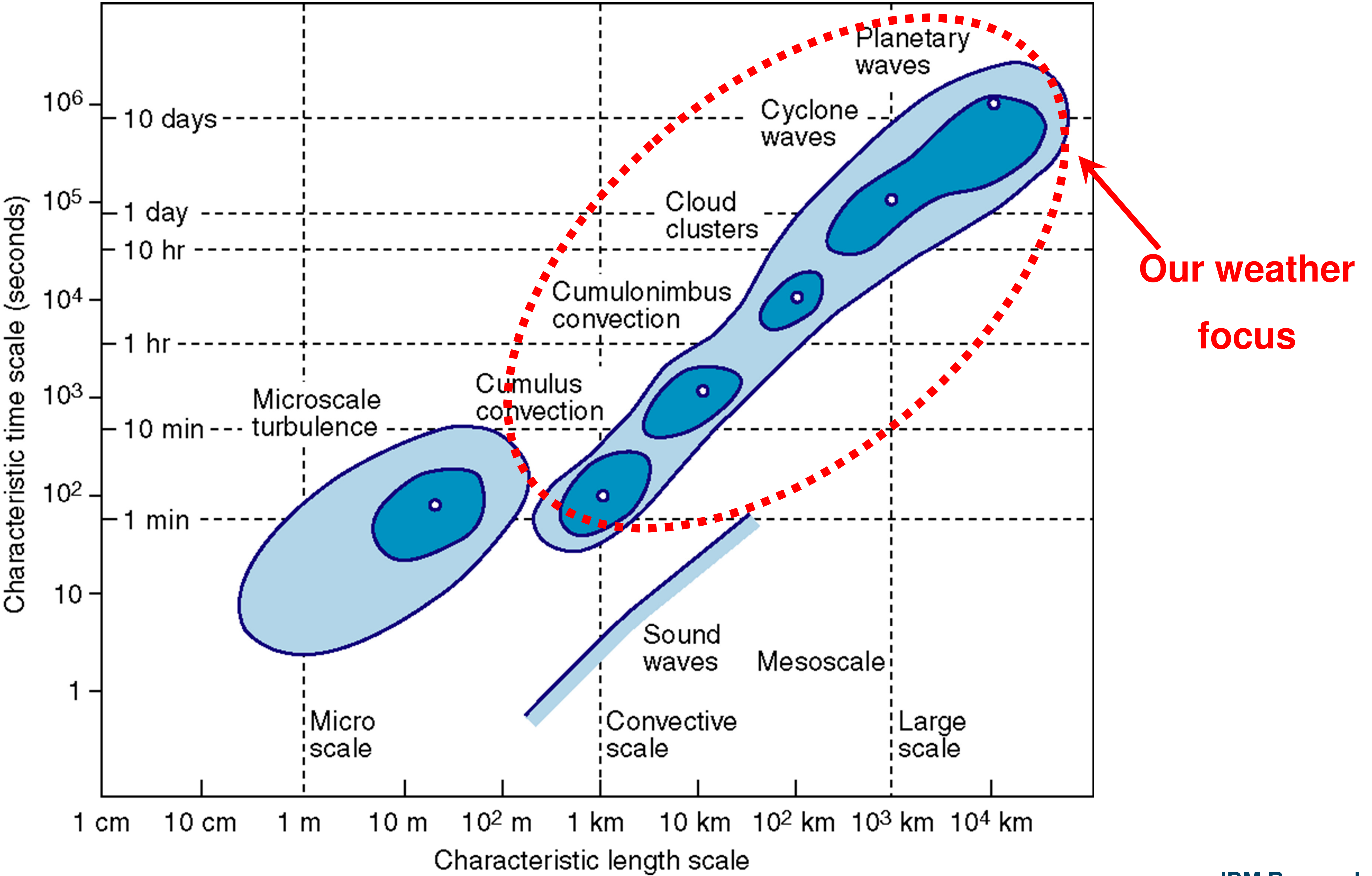


The equations are solved on a 4-dimensional grid (e.g., latitude, longitude, altitude, time)



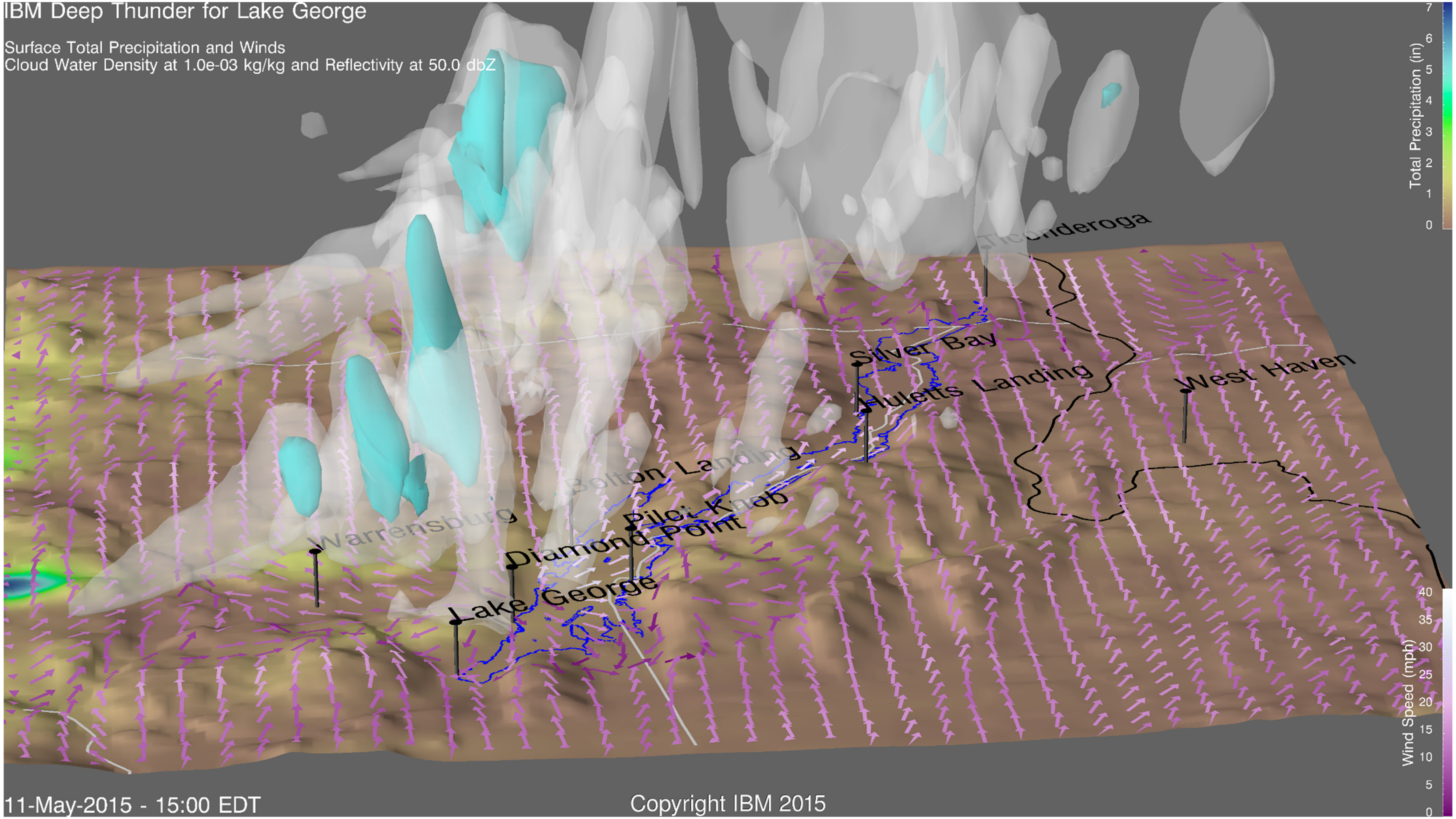
- **The sun adds energy, gases rise from the surface resulting in convection**
- **Unequal heating of the surface causes temperature and pressure differences which drives winds**

The typical lead time for reliable predictability is two to three times the time scale.



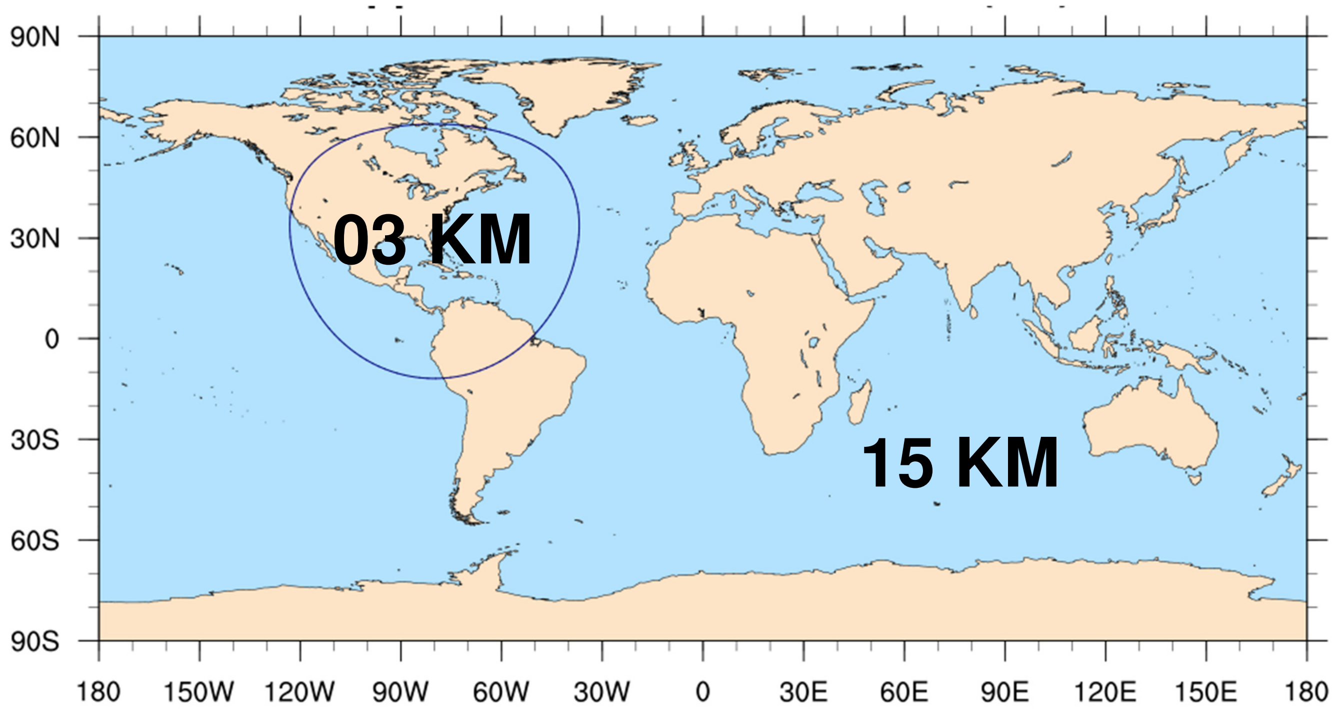
Example Targeted Forecast for Lake George, NY

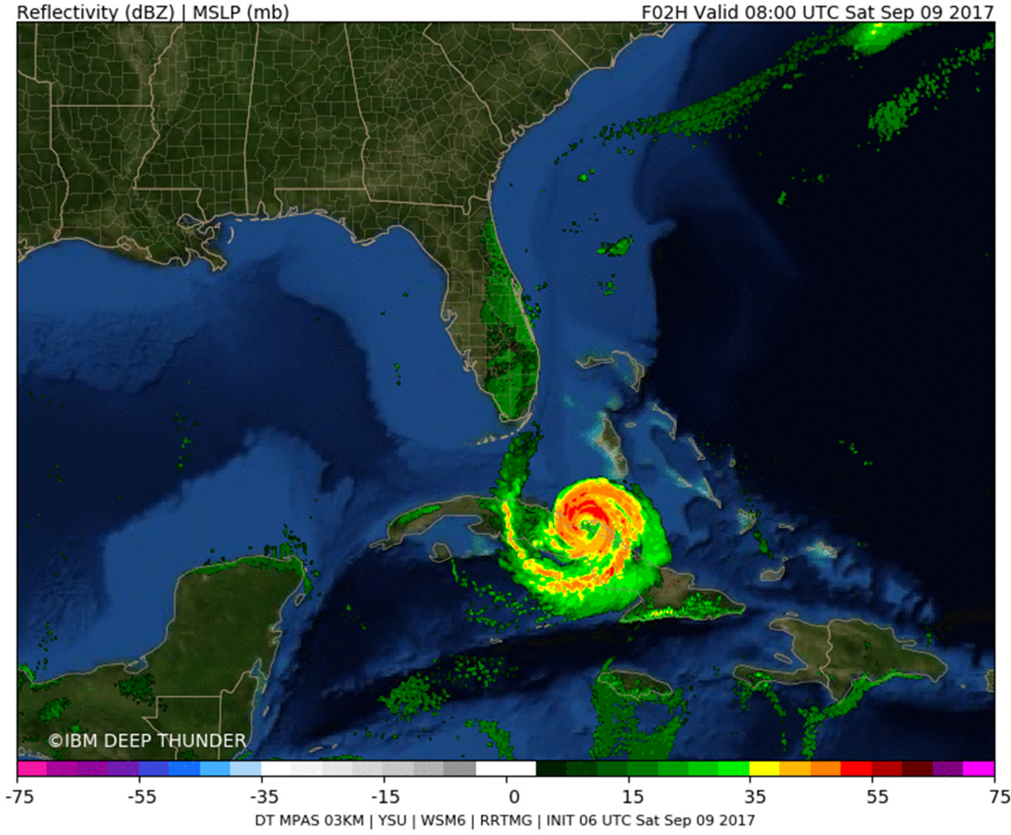
48-Hour Model Run at 333m Horizontal Resolution

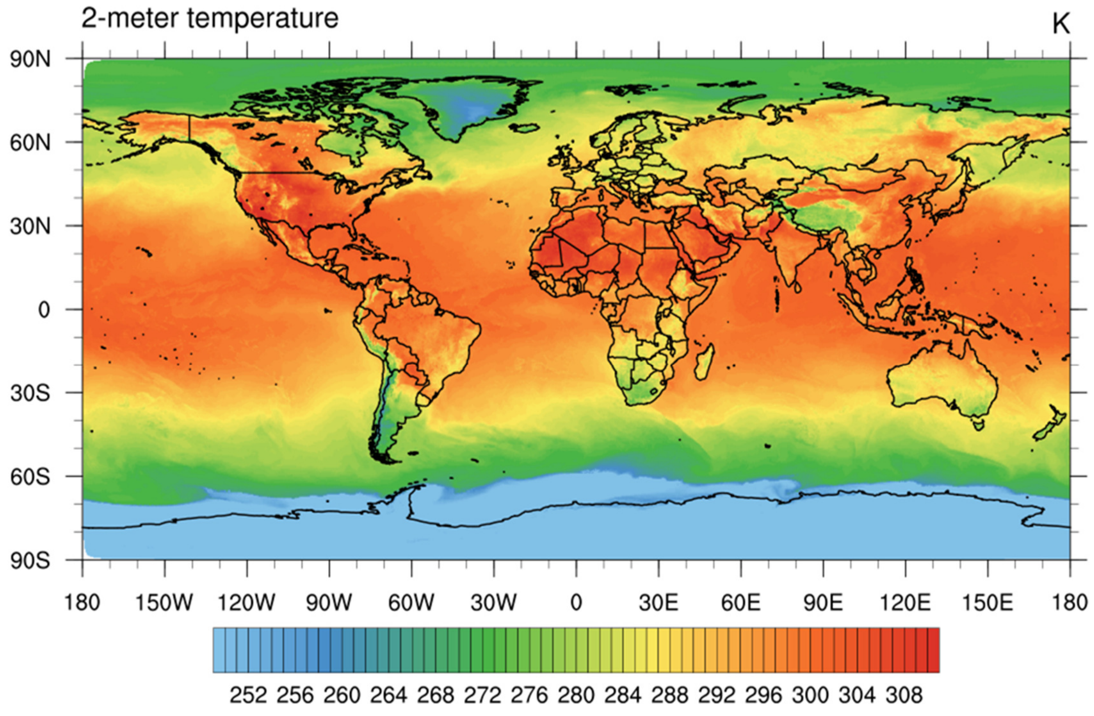


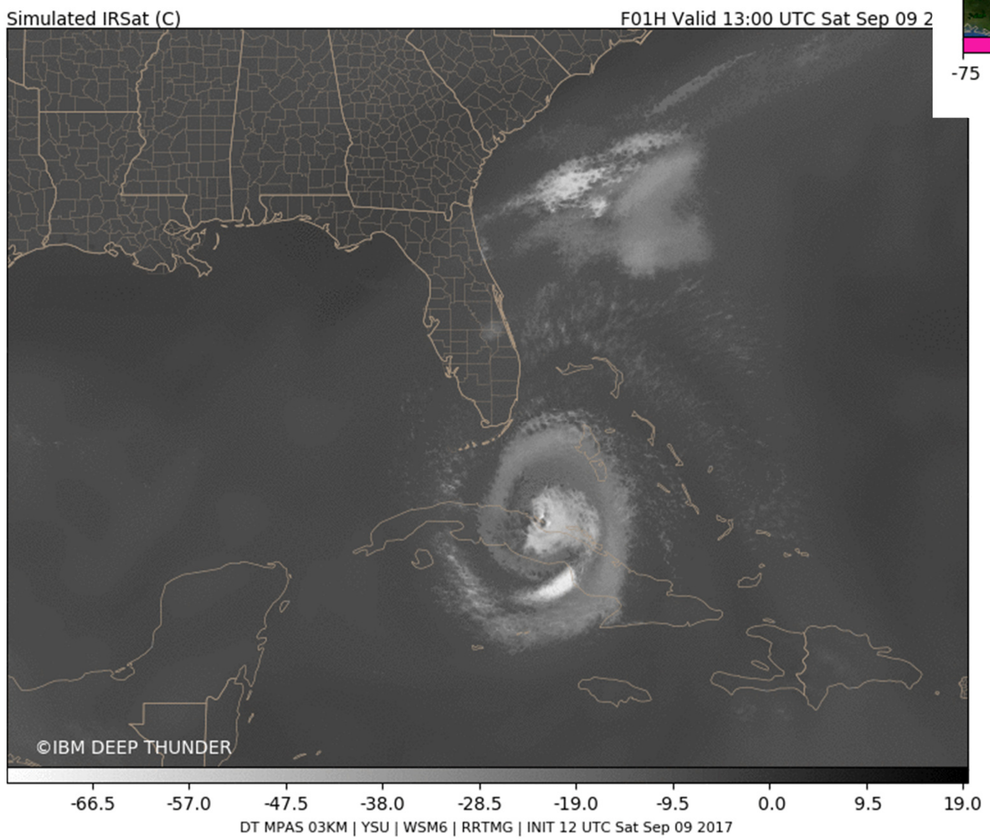
IBM Research

True Global Modelling







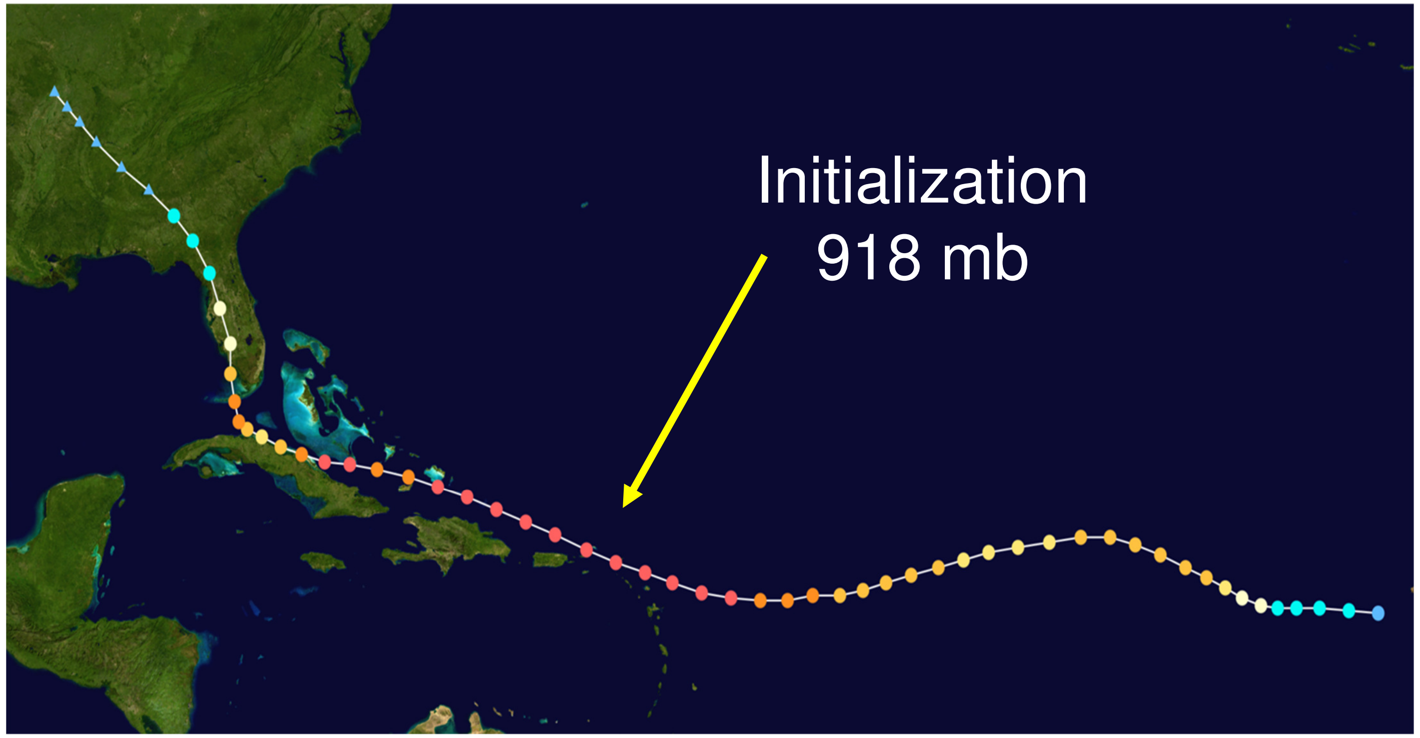


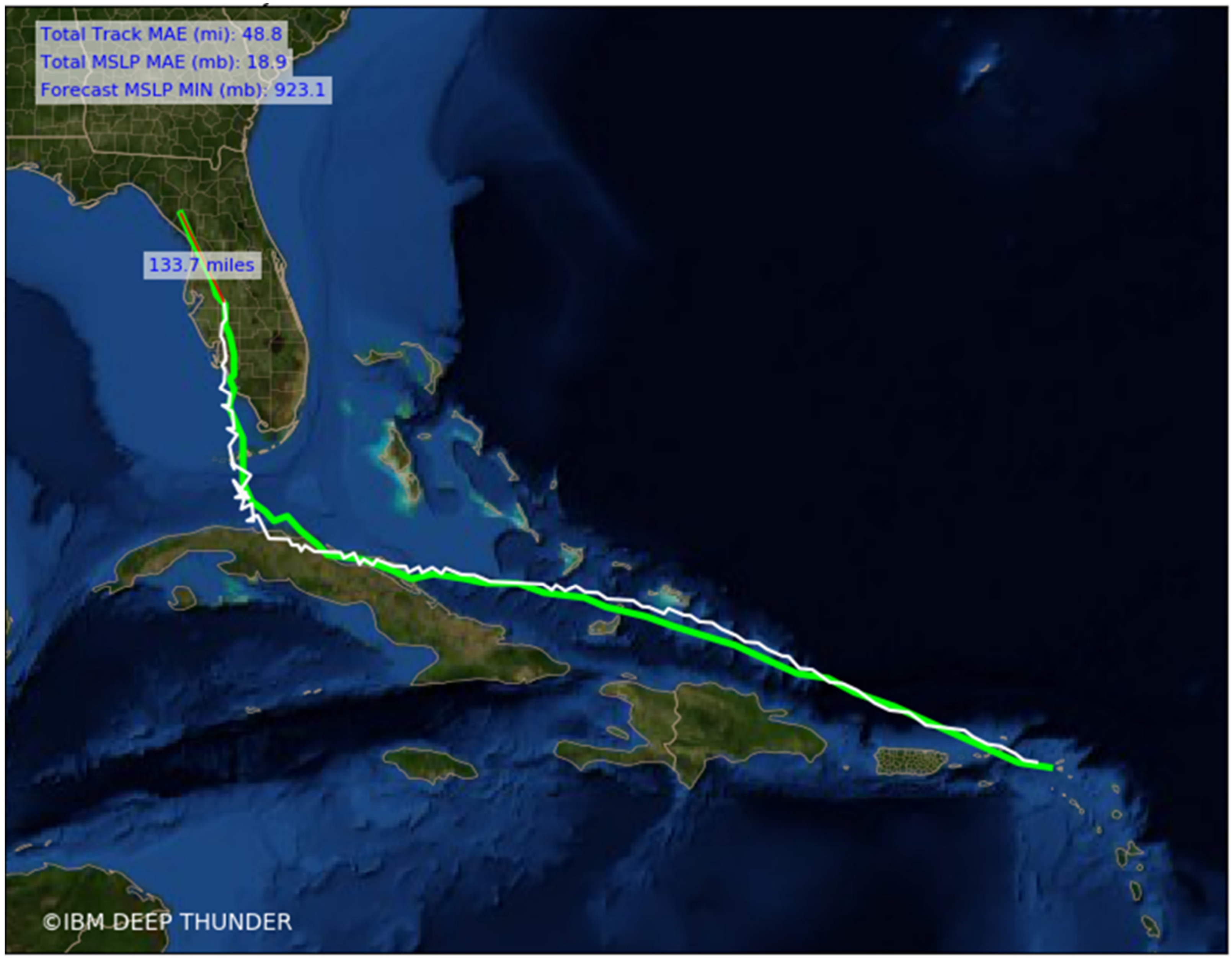
Hurricane Irma Forecast from 9 September 2017 (06 UTC)

Hurricane Irma Simulation

Five-Day Forecast Started at 0800 EDT, 6 September 2017

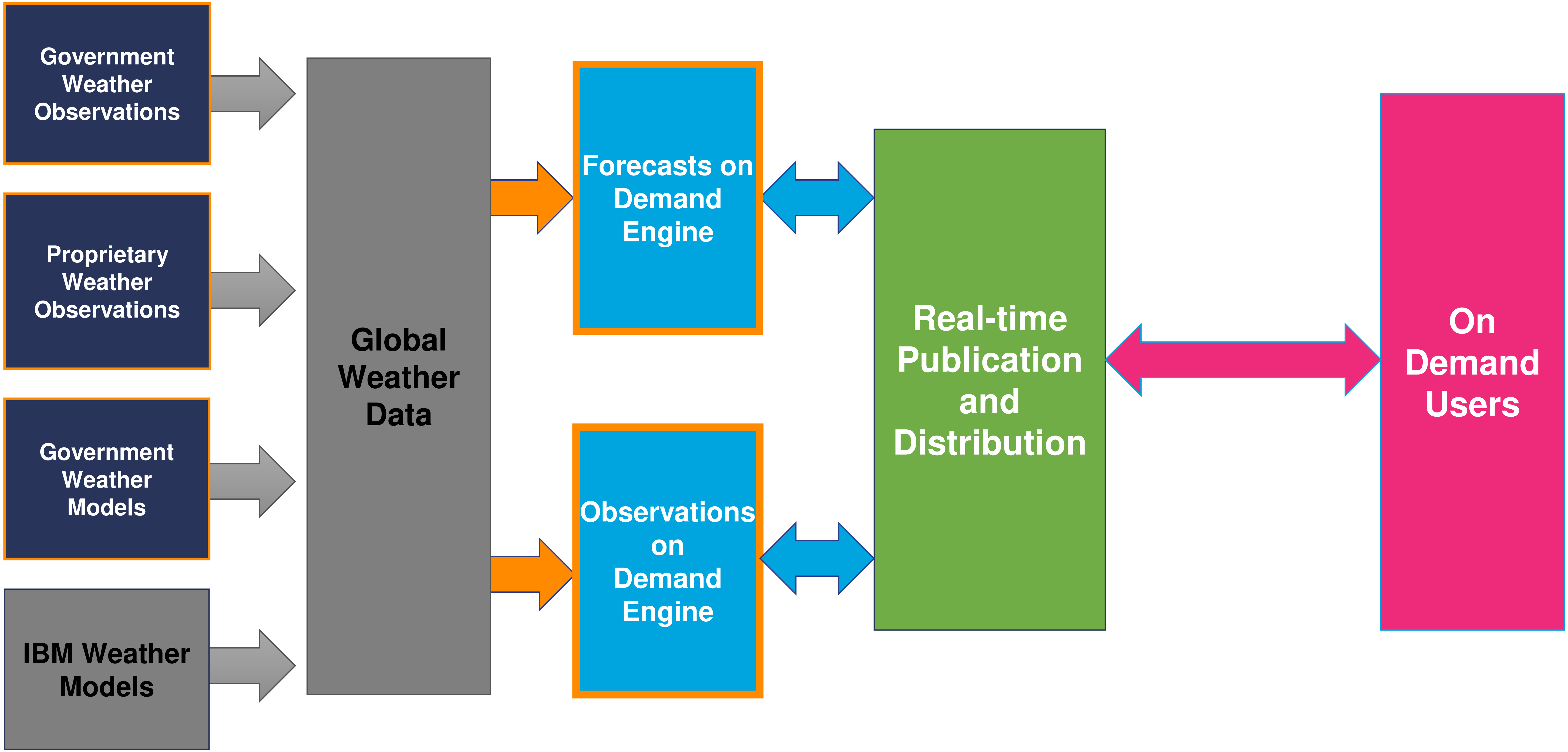
Observed Irma Track





Simulated Irma Track

IBM-TWC Weather-on-Demand Ecosystem

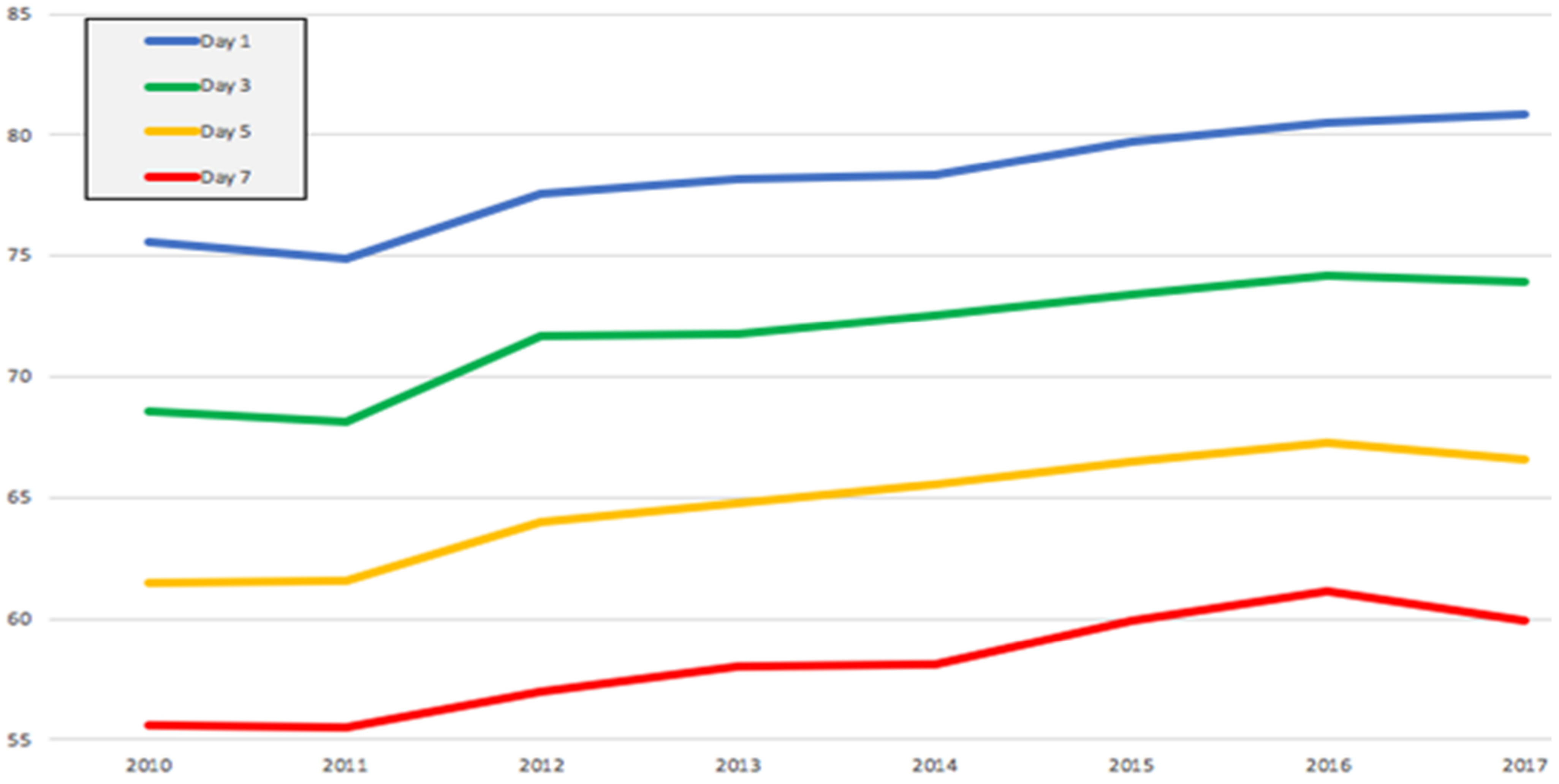


Approach to Overall Forecast Accuracy

IBM is a pioneer of multi-model ensemble science

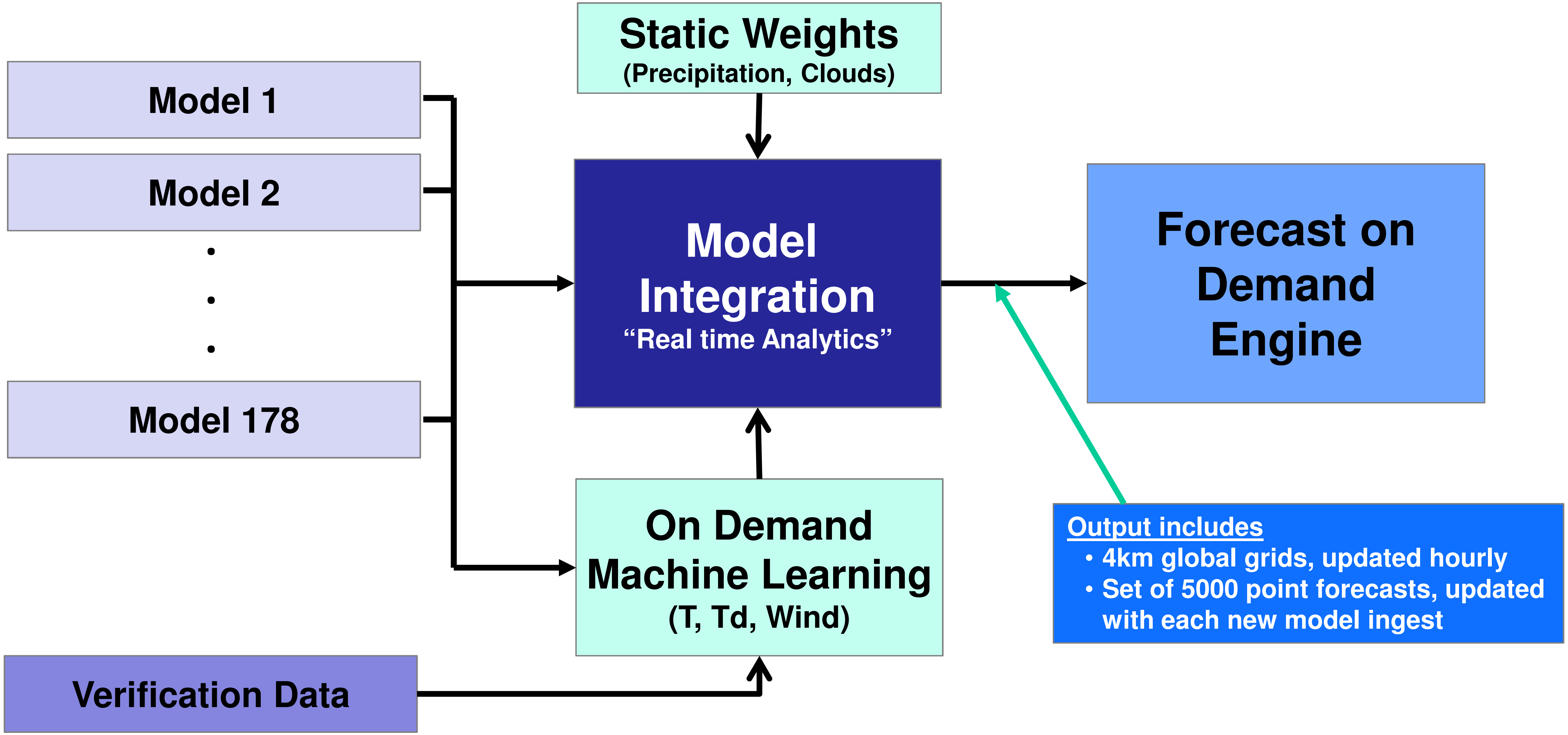
- **Statistically optimized mix yields the best forecasts**
- **IBM's forecast skill is improving at two days/decade or better**
  - For example, a day 3 forecast now is nearly as accurate as the day 1 forecast was in 2010
  - That is roughly twice the rate of improved skill in weather forecasting models by others

Trends in Forecast Accuracy: Percent Correct (US)



Concept for Consensus Weather Forecasting

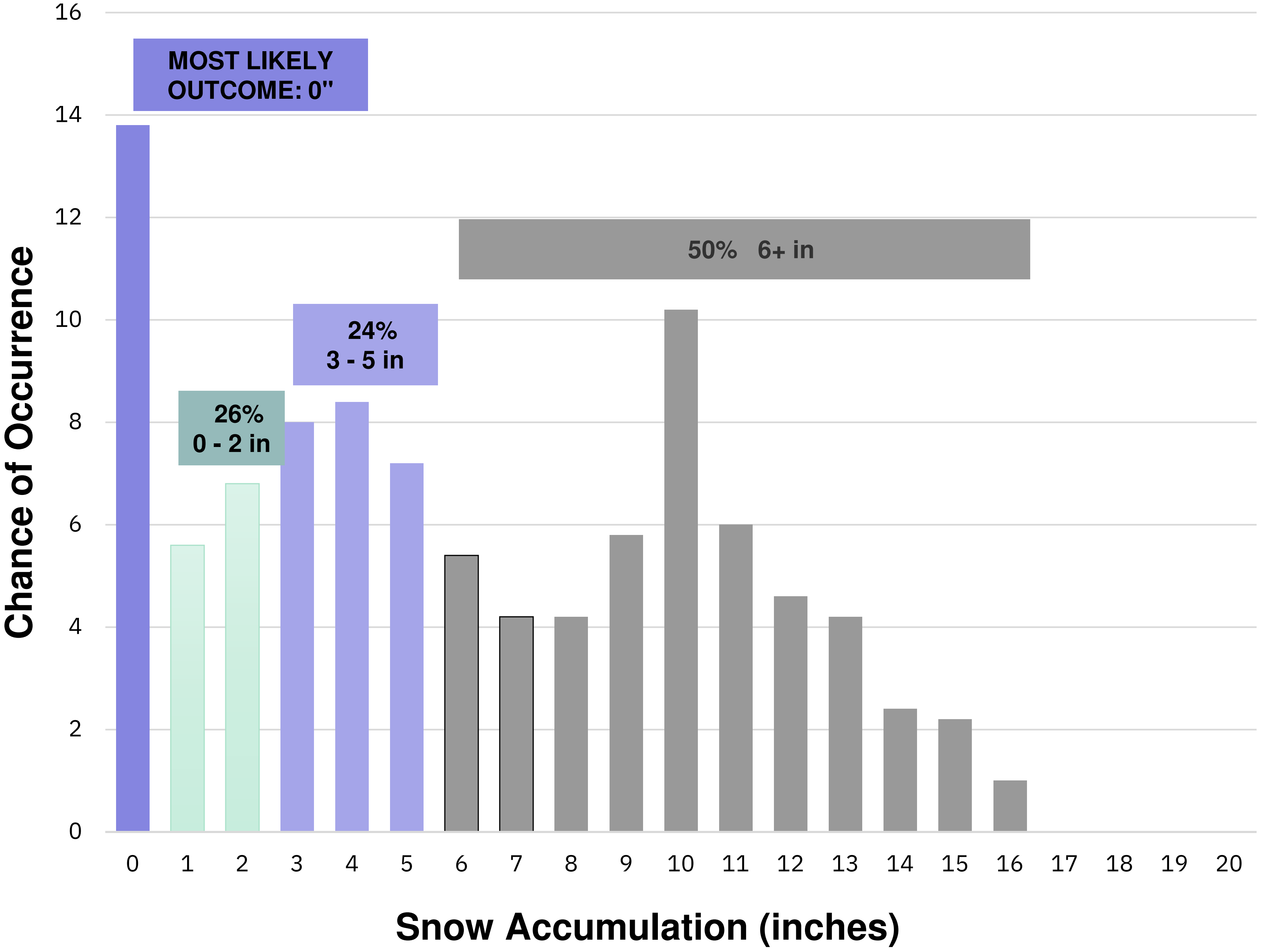
A combination (ensemble) of bias-adjusted models can have superior skill to any individual model or human forecast



Probabilistic Forecasts

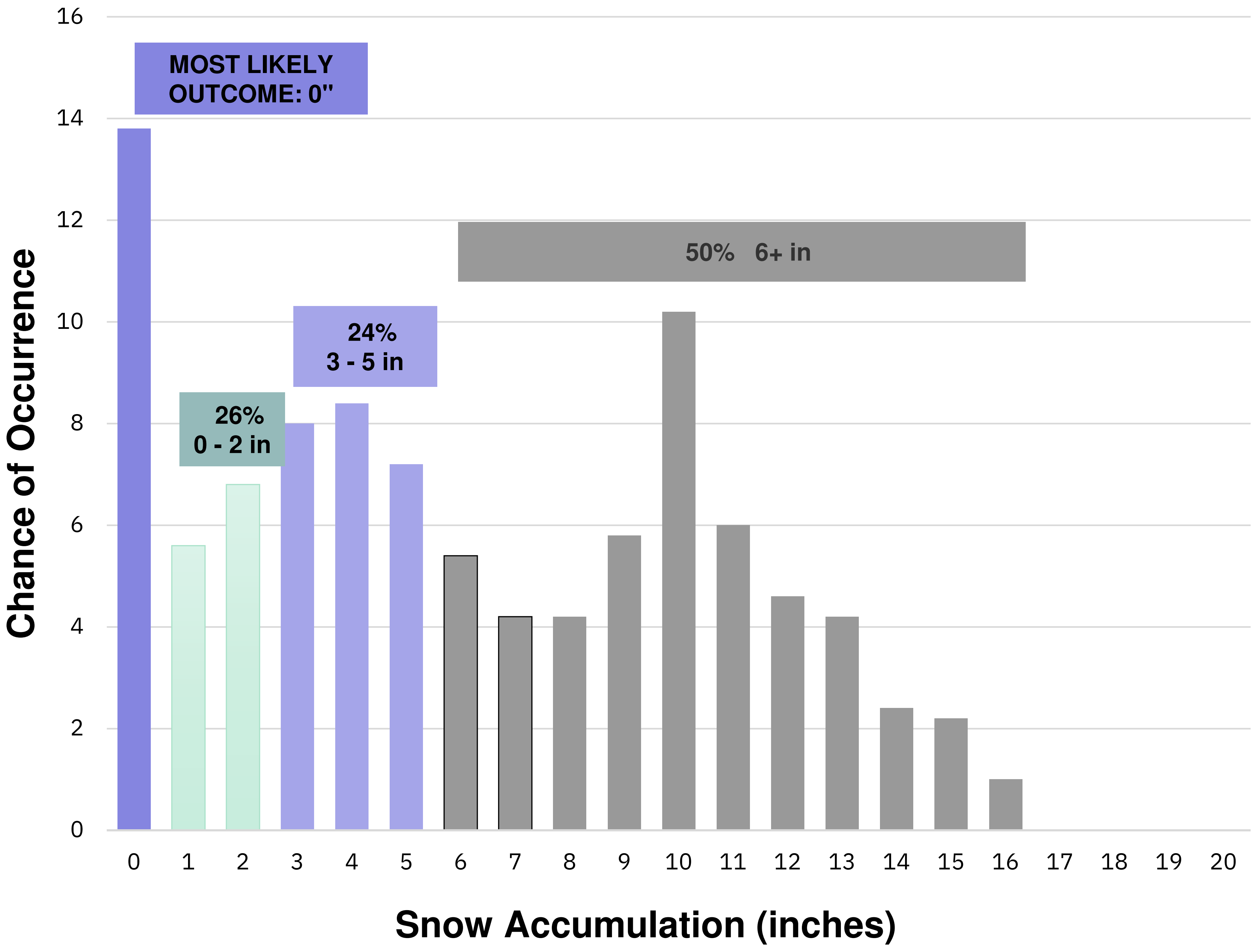
All of those models provide rich information about the possible weather

- **Here is the actual set of forecast probabilities of a snow storm a few years ago in Boston**
- **The "least error" forecast of 4.8" is what feeds the consumer forecast**
- **But there is a whole range of possibilities**
  - **For example, if you want the most likely amount, it would actually be zero**
  - **The second most likely is 10"**
  - **And there's a 50.7% chance of at least 6"**



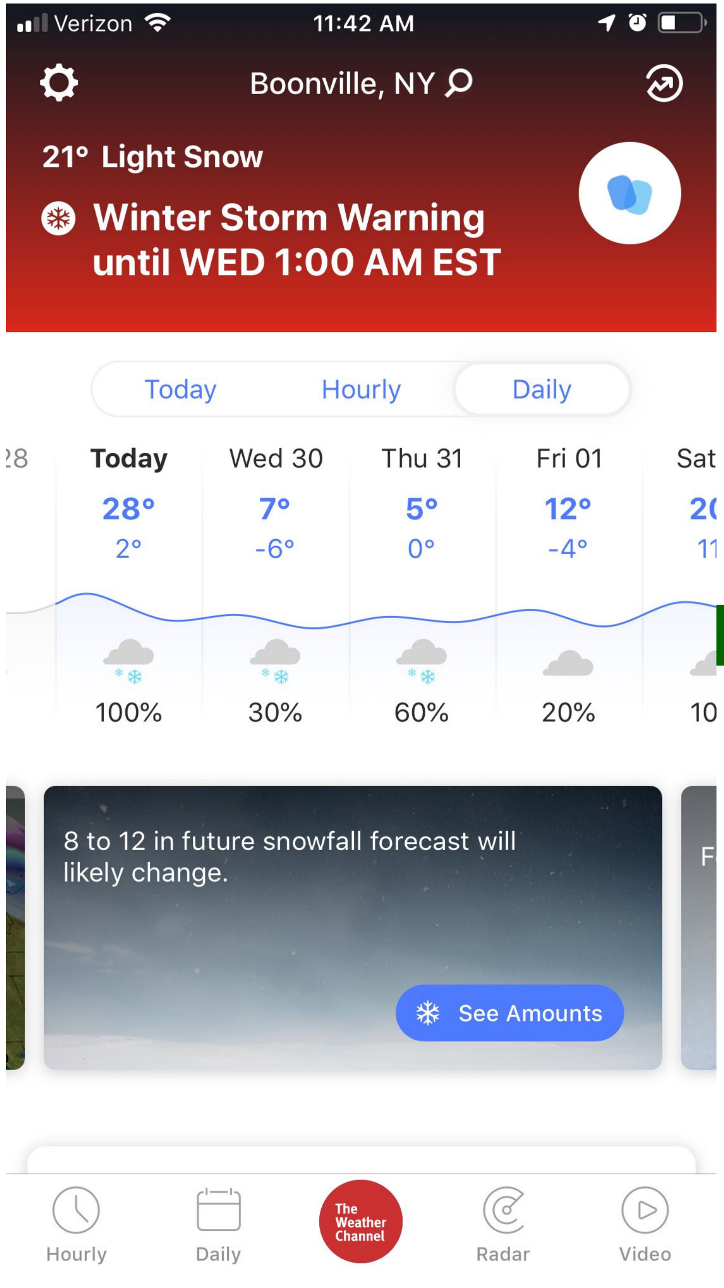
All of those models provide rich information about the possible weather

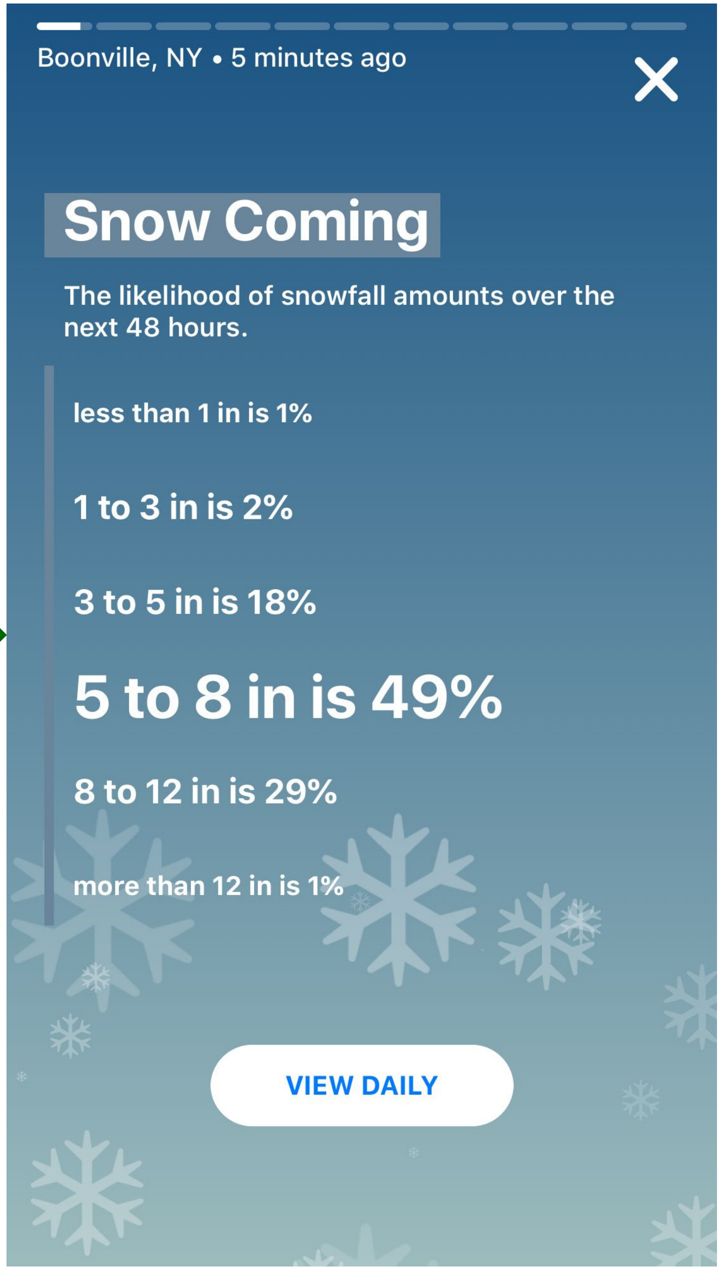
- **What's useful to one decision maker is not useful for another**
  - If you're making decisions about road crews in Atlanta, you care about "what's the likelihood it's going to snow at least an inch"
  - If you're in charge of declaring a state of emergency in Boston, you care about the likelihood of at least 15"
  - In between, there's a range of other thresholds that are key to other decision makers



Probabilistic Snowfall Forecasts

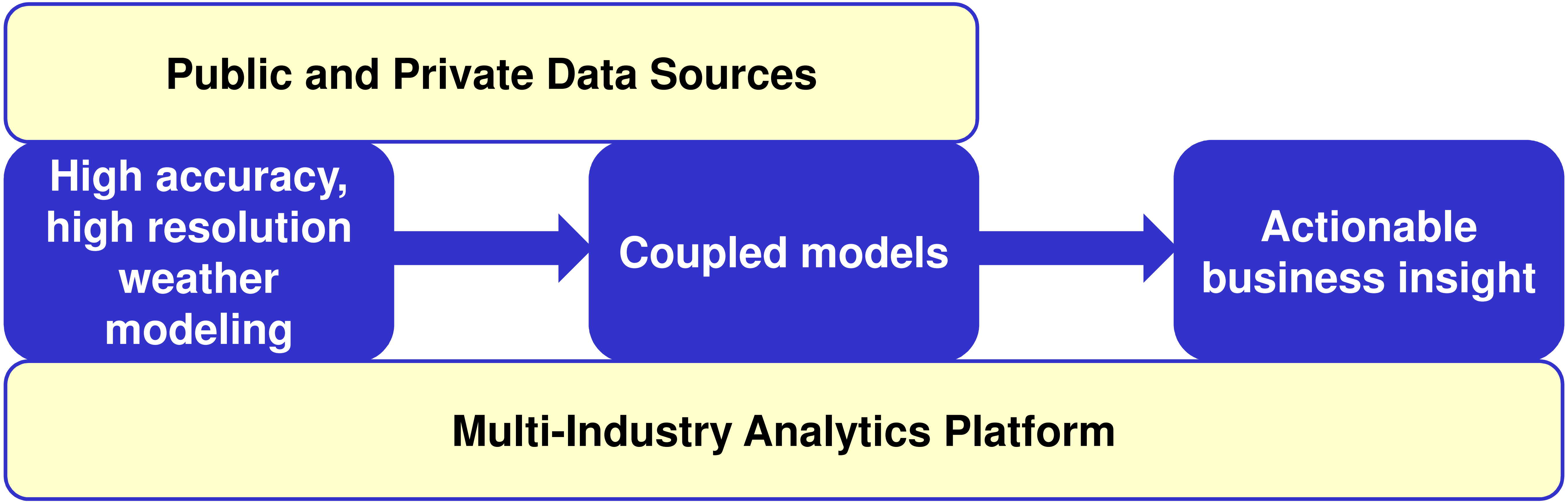
- Produce snowfall forecasts from available input models
- Calibrate snowfall forecasts using machine learning
- Ensure consistency with human forecasting expertise
- Calculate snowfall exceedance percentiles, boom and bust amounts, confidence metric
- Available in the The Weather Channel mobile app





Coupled Models for Weather-driven Impact Forecasts

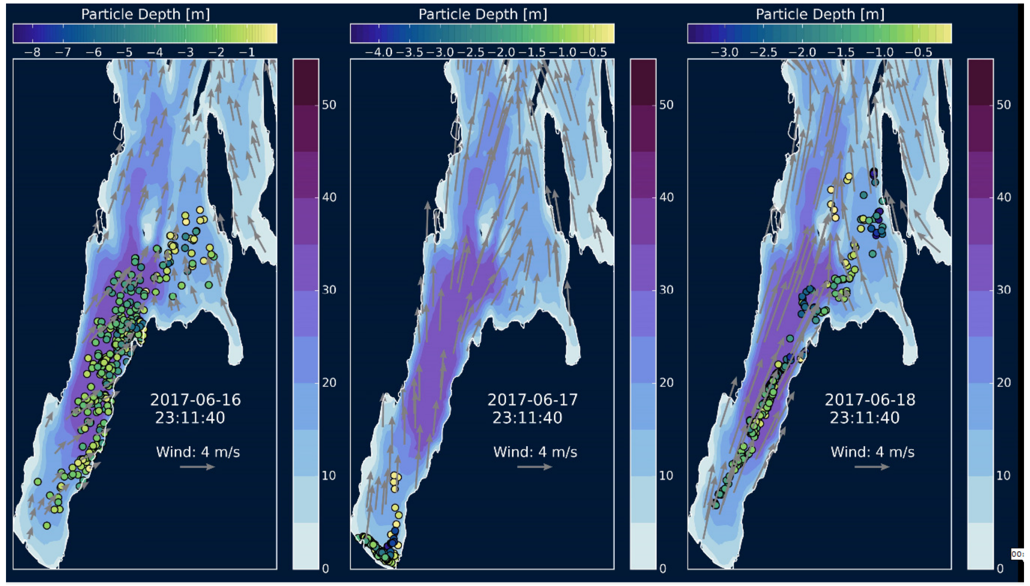
Coupled Models: Where Is the Business Value ?



"*You don't get points for predicting rain.*
You get points for building arks."

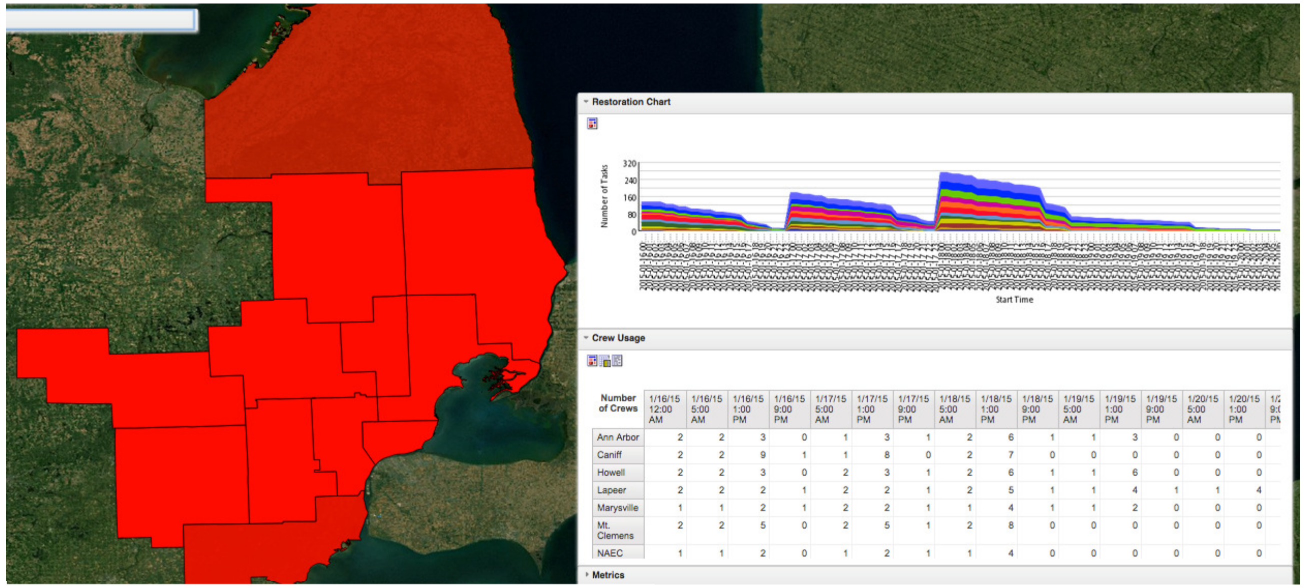
Former IBM CEO, Lou Gerstner

Example Results of Coupled Models

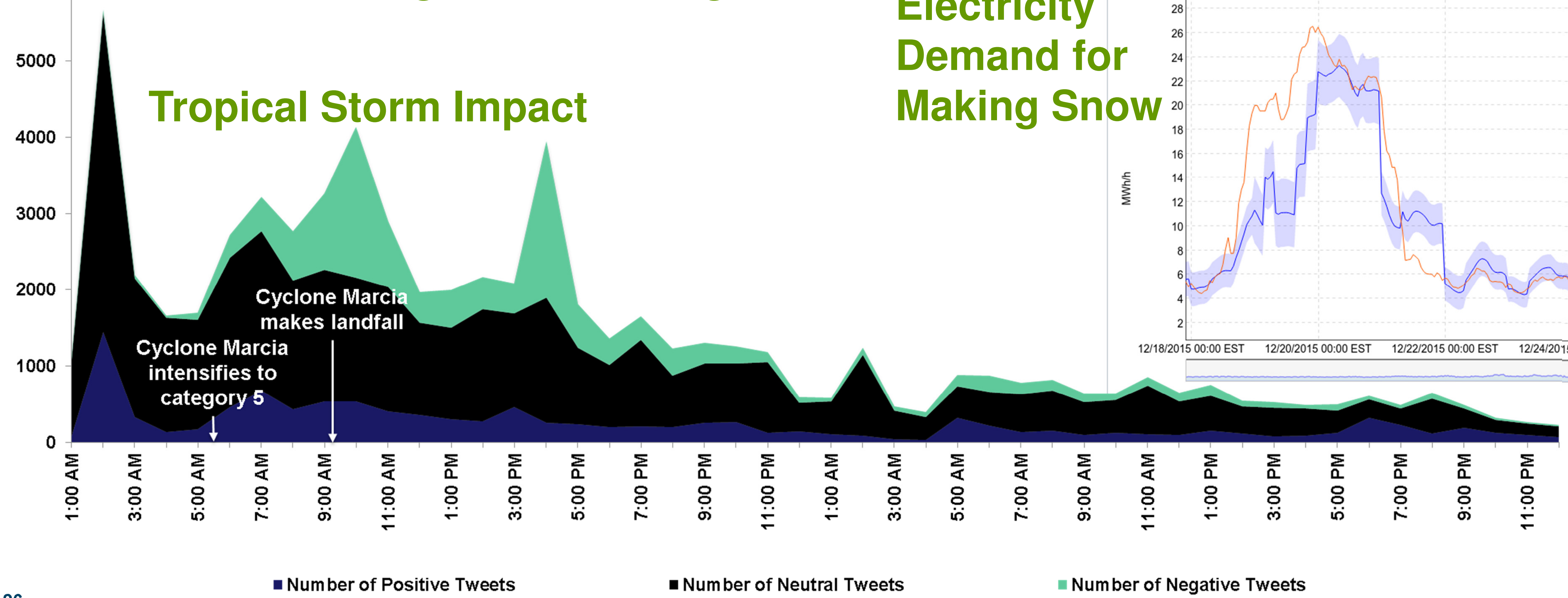


Pollution Tracking in Lake George, NY

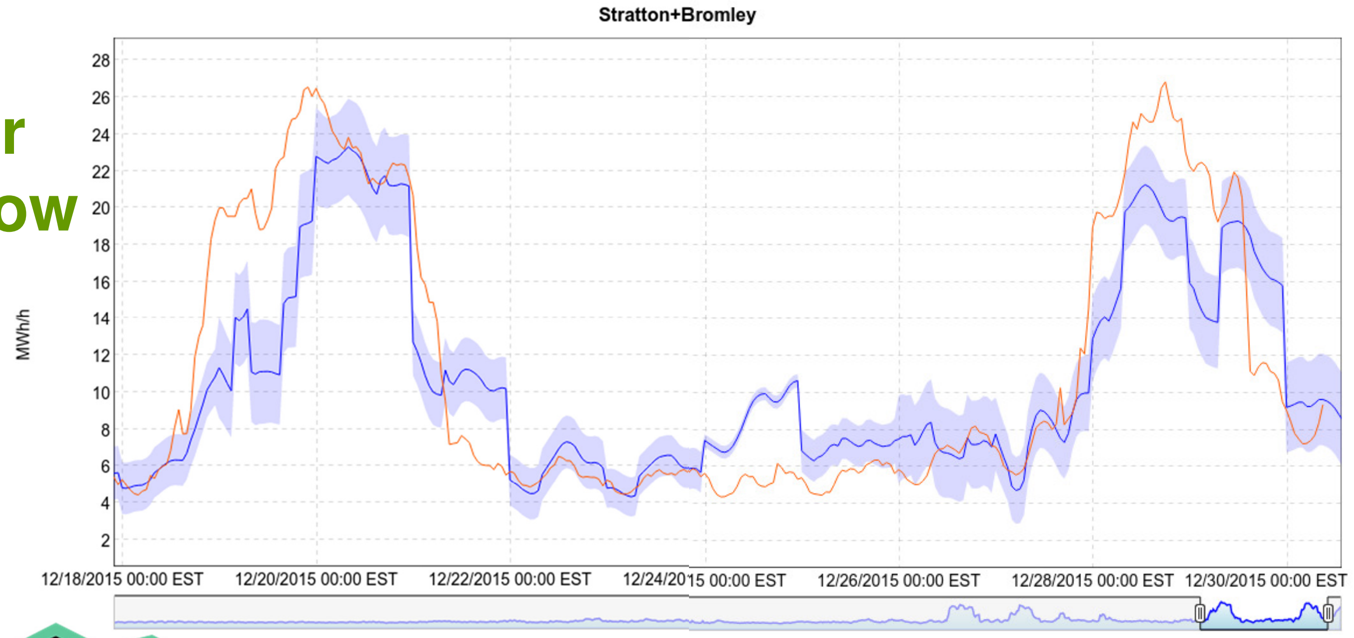
Restoration Scheduling for Storm-Driven Utility Outages



Tropical Storm Impact



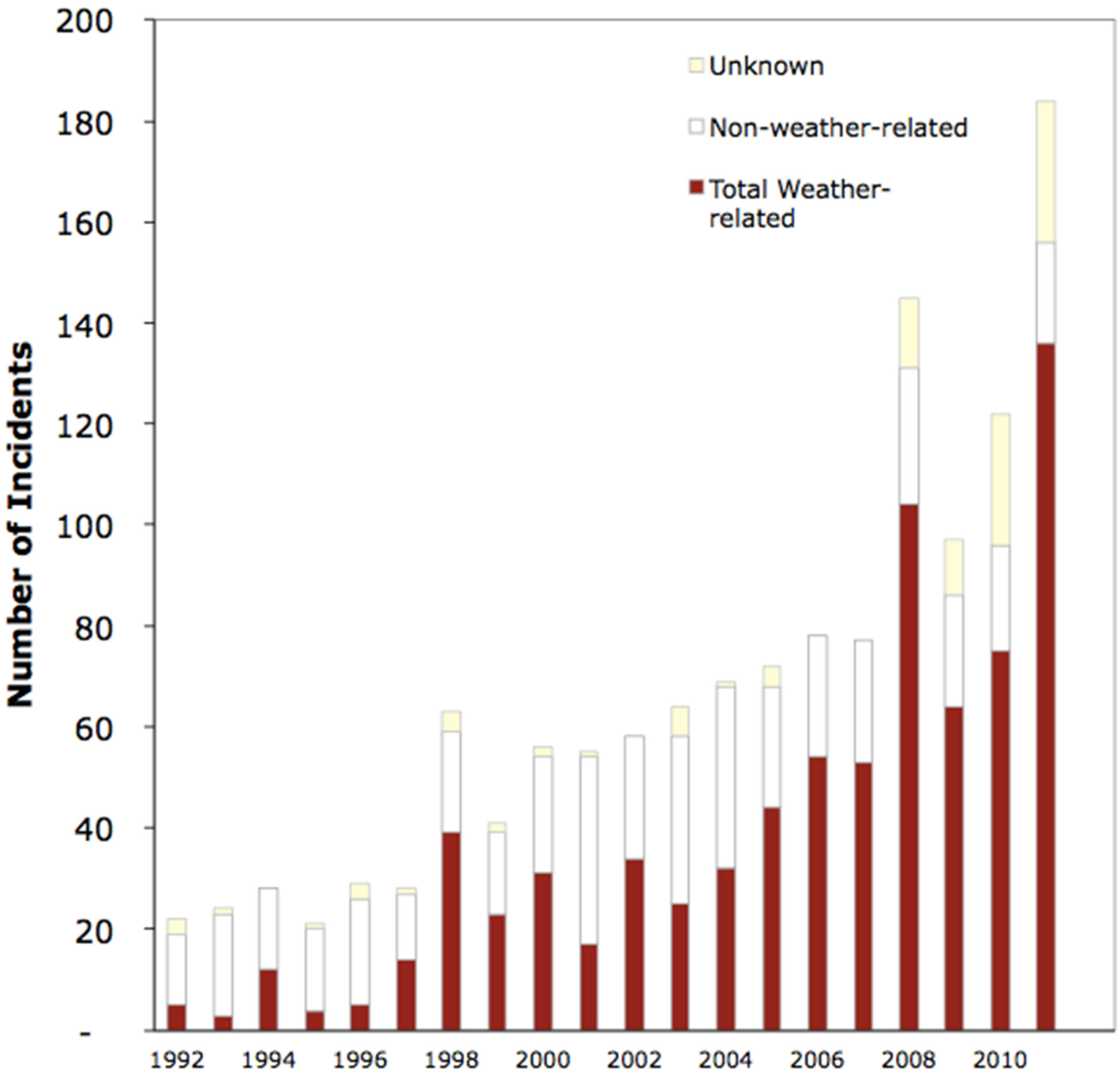
Electricity Demand for Making Snow



Example Business Use Cases of Mitigation of Weather Risk

Electric Power Outages Have Been Increasing

- **Aging infrastructure**
- **Frequent impactful weather**
- **Growing energy demand**



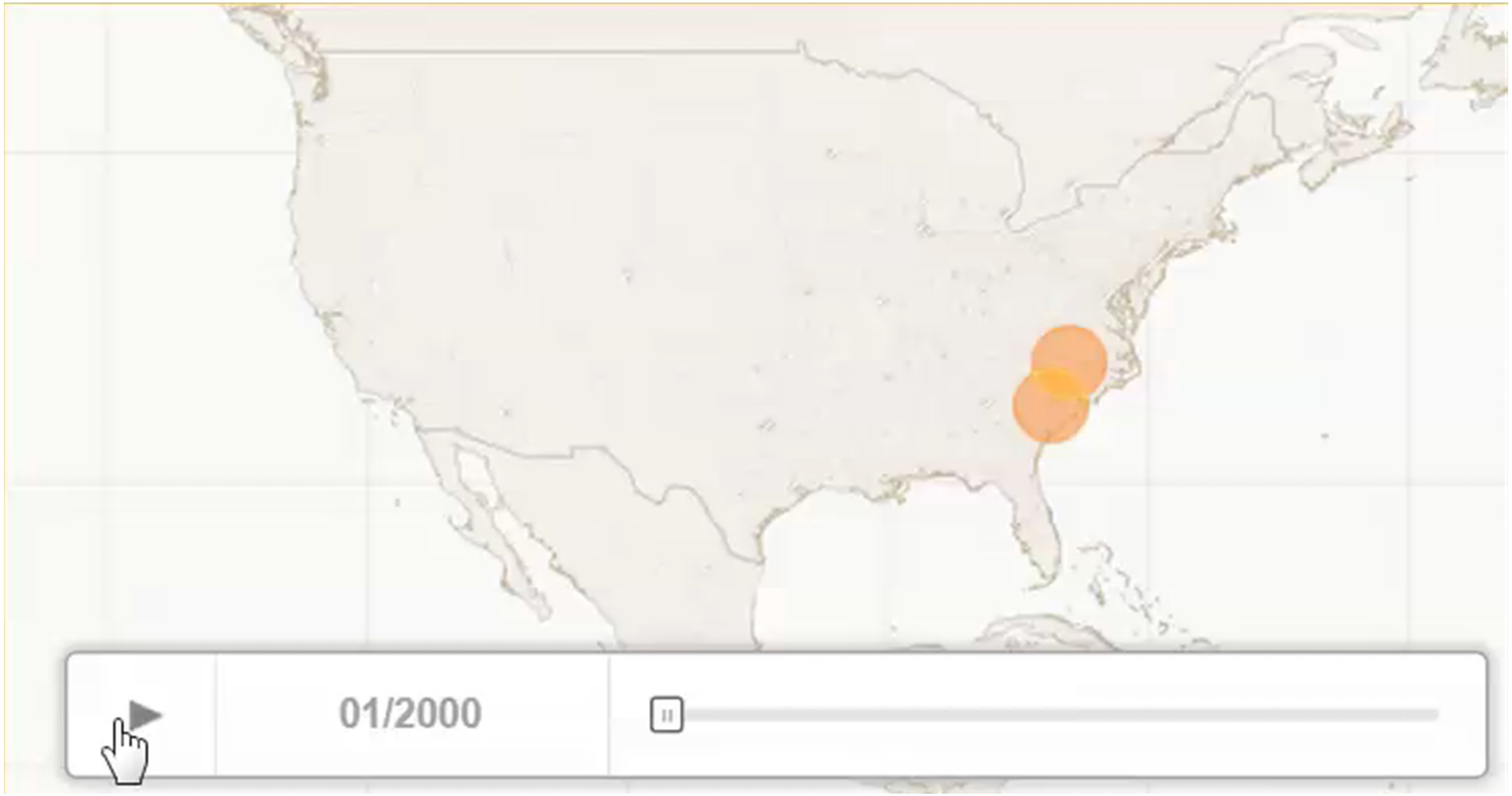
Significant US Electric Grid Disturbances (1992-2011)

Weather- and Non-Weather-Related (1333) Incidents

Source: Electric Grid Disruptions and Extreme Weather, http://evanmills.lbl.gov/presentations/Mills-Grid- Disruptions-NCDC-3May2012.pdf

Electric Power Outages Have Been Increasing

- **More than 70% of all outages are weather-related**
- **Major US power outages cost $20B to $55B annually**
- **Smaller, more frequent weather events pose preparation and response challenges**
- **Major events in 2017 doubled outage duration compared to 2016**



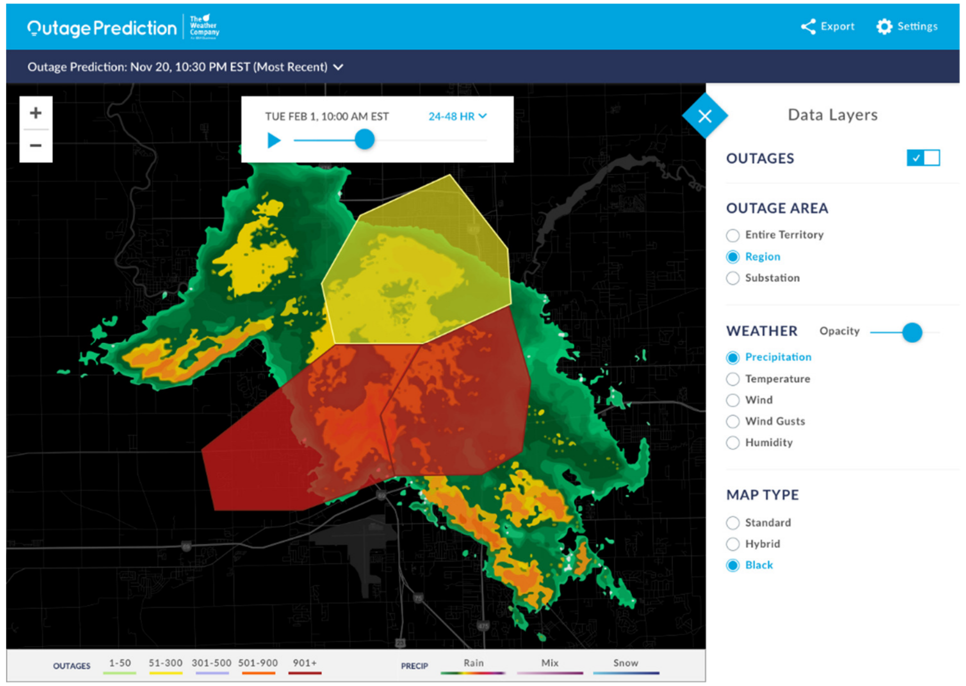
2000 - 2014: 19 weather-related outages affected more than 1M people

What If You Could Predict Outages?

Proactive preparedness and response

✓ Open emergency HQ ✓Call mutual assistance ✓Preposition crews ✓Faster restoration ✓Customer and regulatory satisfaction

Outage/Damage Prediction 3 Day Lead Time



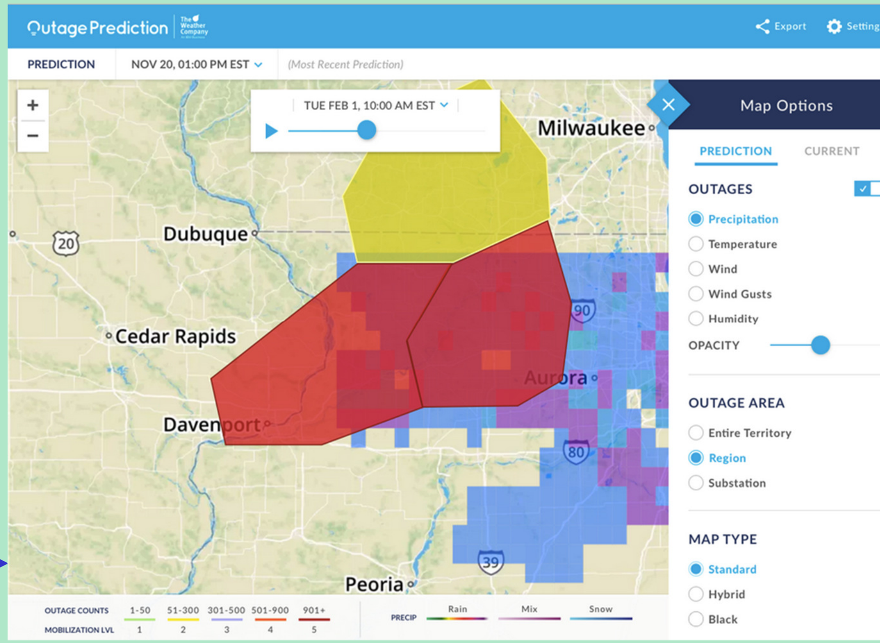
Predicted damage locations and timing

Connected to Utility Mobilization Procedure

Level	Customers	Outages
1	0 – 10,000	0-50
2	10,001 – 25,000	51-150
3	25,000 – 50,000	151-300
4	50,001 – 100,000	300-600
5	>100,000	>600

Minimize Storm Mobilization $$$ Optimize Efforts to Restore

- Crew Mobilization
- Time of Restoration
- Damage/Outage Type
- Call Center Mobilization
- Supply Chain for Repairs
- Reduced Customer Outage Times
- Customer Satisfaction
- Political Satisfaction
- Minimize Lost Revenue



Outage Model → Storm Mobilization Plan →

How Do We Predict Outages ?

Coupling physics (weather prediction) plus AI (machine learning)

Historical Data

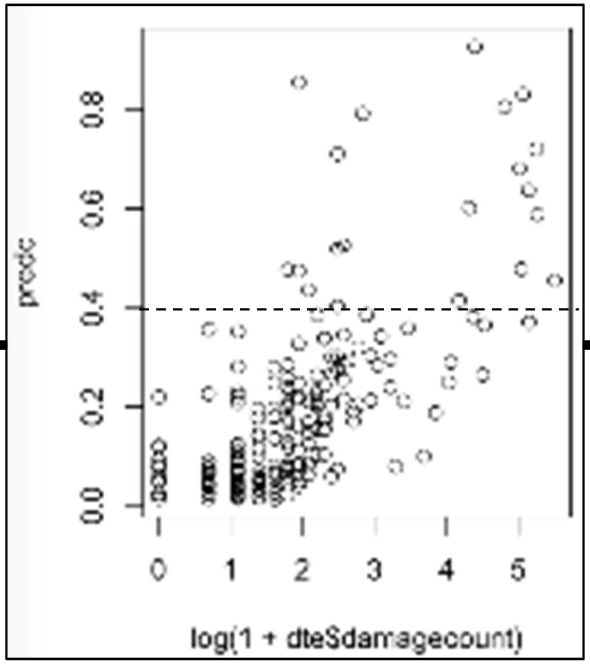
Weather

Outages

Apply machine learning techniques to derive relationships between outages and weather in the utility service territory

Data-driven Modelling

Classifier

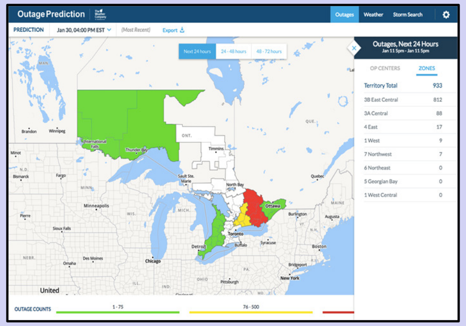


Outage model (Major Events)

Outage model (“Routine” storms)

Results

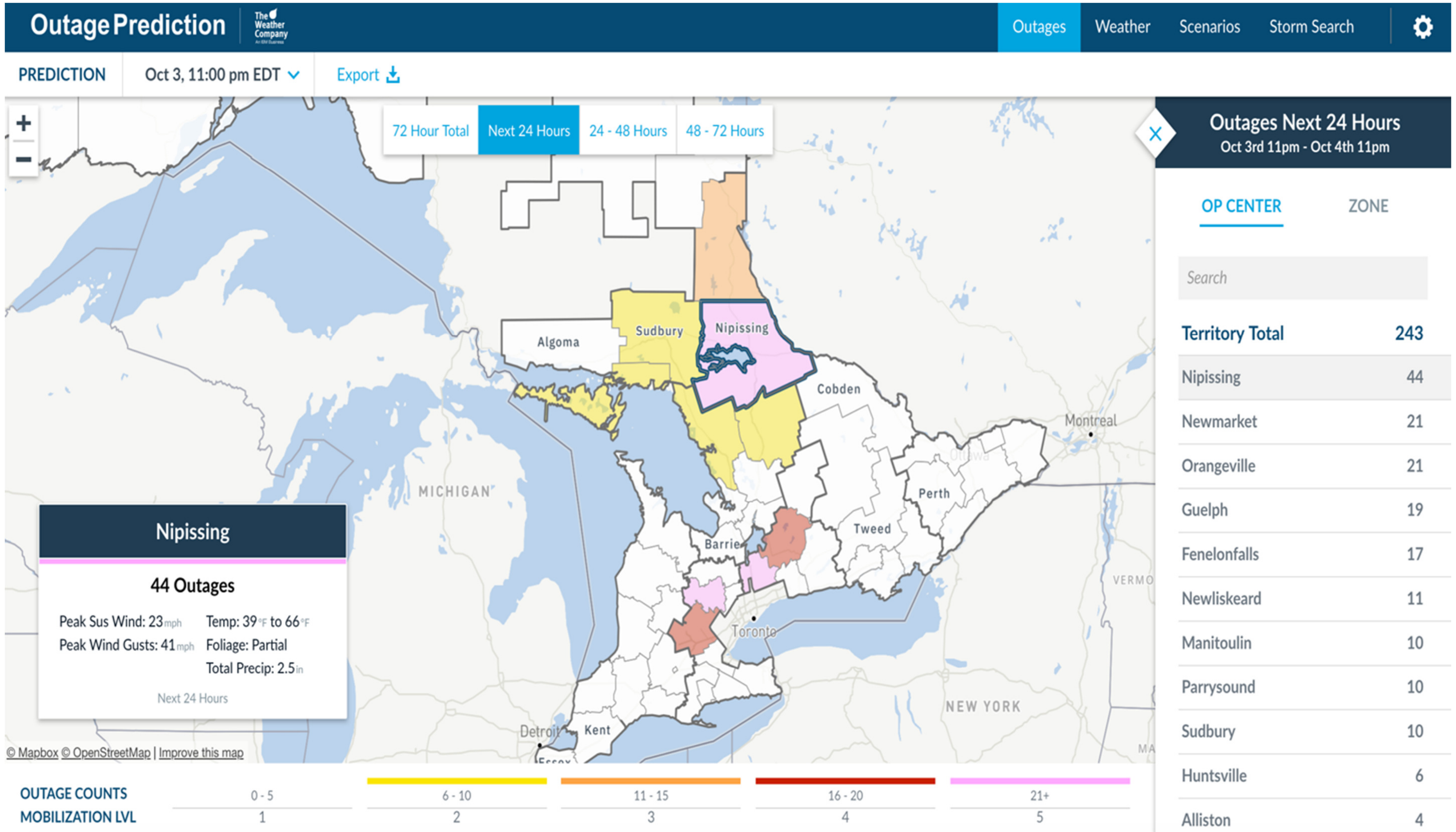
Prediction



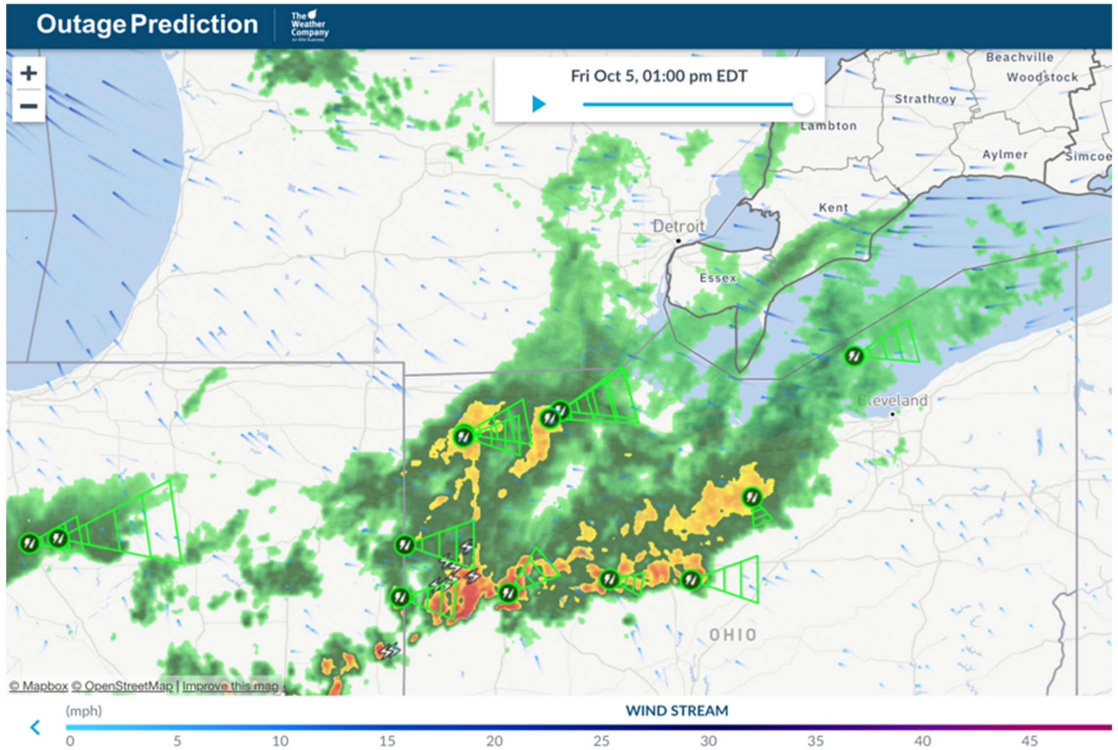
Customized prediction relevant to utility mobilization strategy

Through the use of a classifier, the outage model can intelligently qualify and quantify the predicted weather to optimize the prediction of outages by choosing the appropriate statistical model

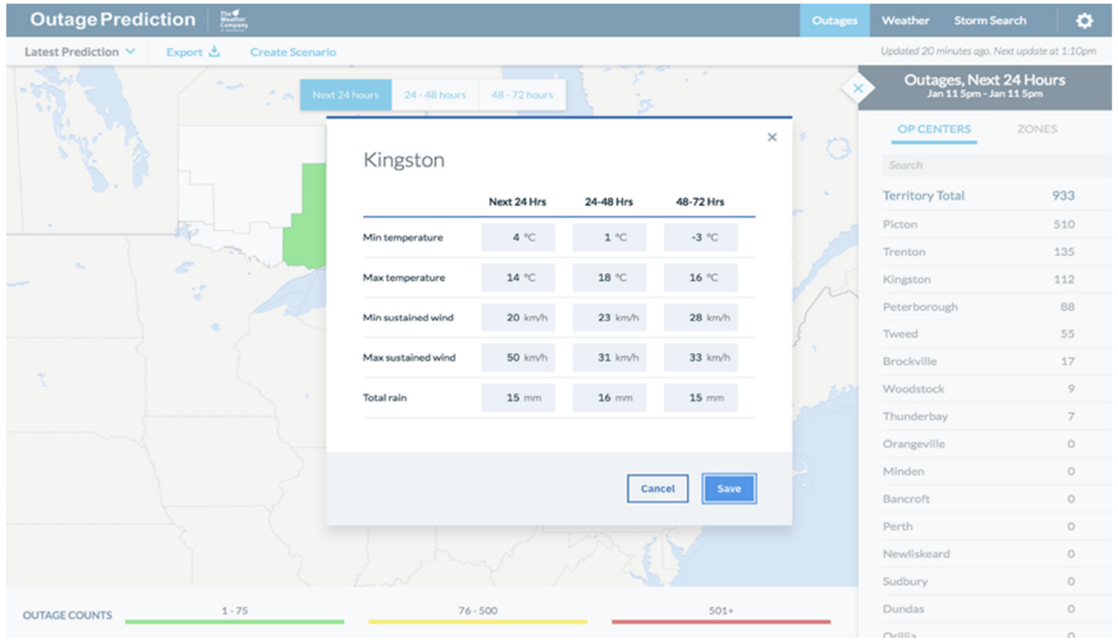
Outage Prediction Solution Screenshots



Outage Prediction Dashboard



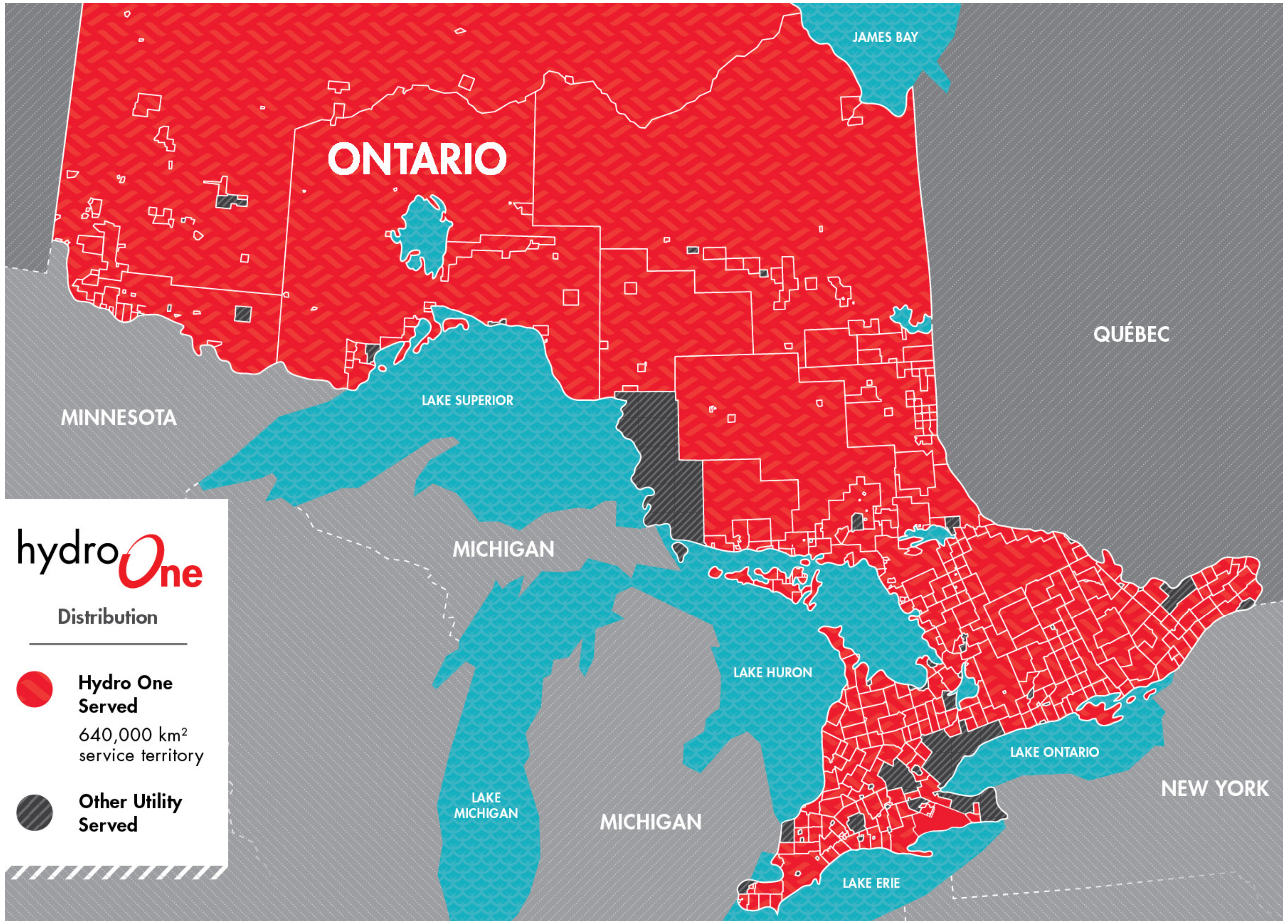
Observed/Forecasted Weather Layers



Scenario Planning Tool

Customer Example: Hydro One

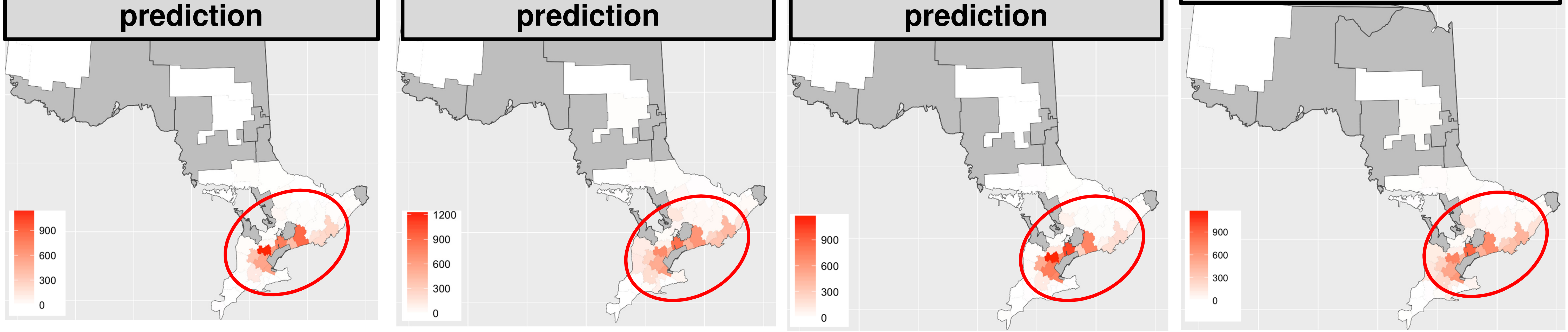
- **In April 2018, Hydro One was able to restore power to approximately half a million customers in just four days**
  - Torrential rain, an inch of ice and wind gusts up to 60 miles an hour
  - Positioned 1400 front-line staff who were needed to restore power and to handle the nearly 130,000 customer calls
- **By contrast, after a major storm in 2016, it took six days to restore power**



Ontario's Largest Distribution Utility

Business Value For Hydro One Customer Communications

72 hour lead outage prediction	48 hour lead outage prediction	24 hour lead outage prediction	Actual Outages



Starting at 72 hours lead time outage prediction model forecast significant outages in the central and southern part of Hydro One's service territory

Proactive customer and stakeholder messaging

- Incident command center activation (done in real-time today as storm is hitting)
- Restoration calls with key stakeholders
- Customer care and media relations call for customer awareness
- Outage website messaging updated prior to storm
- IVR messaging
- Social media

Estimated Time of Restoration (ETR) calculation and communication

- Calculate ETR in advance based on outage predictions rather than wait for damage assessment post-storm (can be 6-12 hour lag)
- Communicate ETR and put in system in advance of storm
- Future implementation – predict damage type for additional ETR and mobilization efficiency

Role of Weather Information Prior to Damaging Events

PREDICT

- Use historical and short-term forecast data for calculating risk exposure
- Match in-force policies to weather risk

Reduce Costs and Improve Safety

PREVENT

- 52% of policyholders take action
- Email, SMS, and in-app push notifications for contextual action-based messaging
- Valued Digital Engagement: 97%

Alerting

- **Engage Digitally**
  - Improved retention up to 6%
  - Retaining policy holders improves profit
- **Reduce Claims**
  - $3500 USD per average auto hail claims avoided
  - Mitigate property water damage claims which average over $8000 USD
- **Satisfaction and Safety**
  - Improves safety of policyholders
  - A proactive and improved claims experience leads up to 18% satisfaction improvement

- **Timely, accurate, targeted**
- **Customized messaging**

Role of Weather Information After Damaging Events

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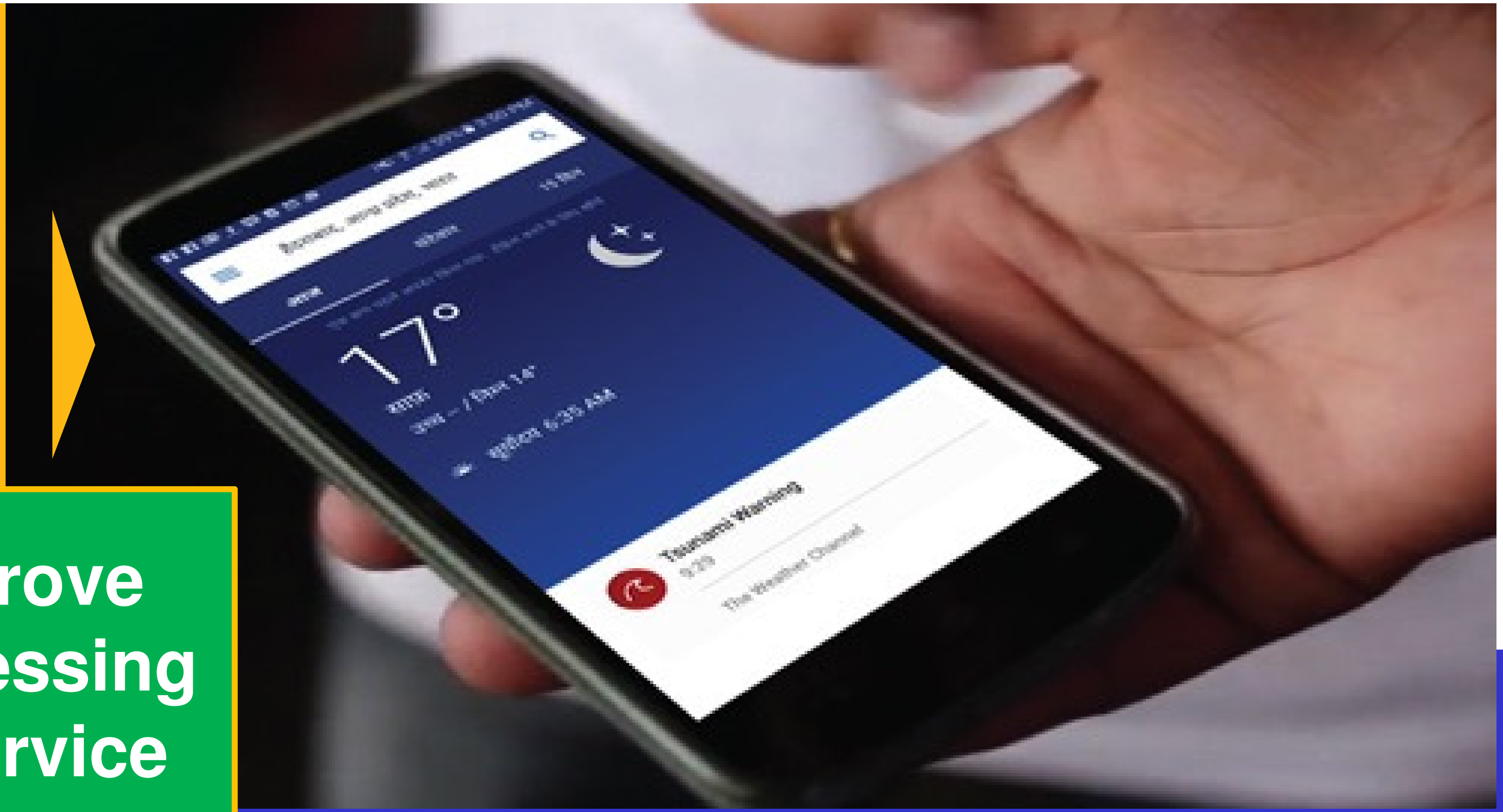
RESPOND

- Proactively spool up your call centers
- Optimize operational response
- Drive self-service claims



Improve Processing & Service

ANALYZE

- Process claims more efficiently through early fraud detection
- Target marketing campaigns to historically vulnerable policyholders

Customer Example: USAA

- **Challenge**: Continue to innovate to find new ways to enhance the experience of members
- **Solution**: Initial alerting pilot
  - Warn members of approaching disruptive or dangerous weather, based on location, preferences, and assets
- **Results**
  - Improved customer satisfaction
  - Better engagement with membership (1.5M)
  - Reduced claims although that was not the primary goal
- **Expanded rollout underway**

Customer Example: Desjardins

- Challenge: Accelerate adoption of a mobile app

- Solution: Addition of mobile alerts for approaching severe weather to enrich app's digital experience
  - Warn members of approaching disruptive or dangerous weather based on location, preferences, and assets, especially hail
  - Create a "safety eco-system"

- Results
  - Effective adoption of mobile app
  - Better engagement with policyholders
  - Reduced claims

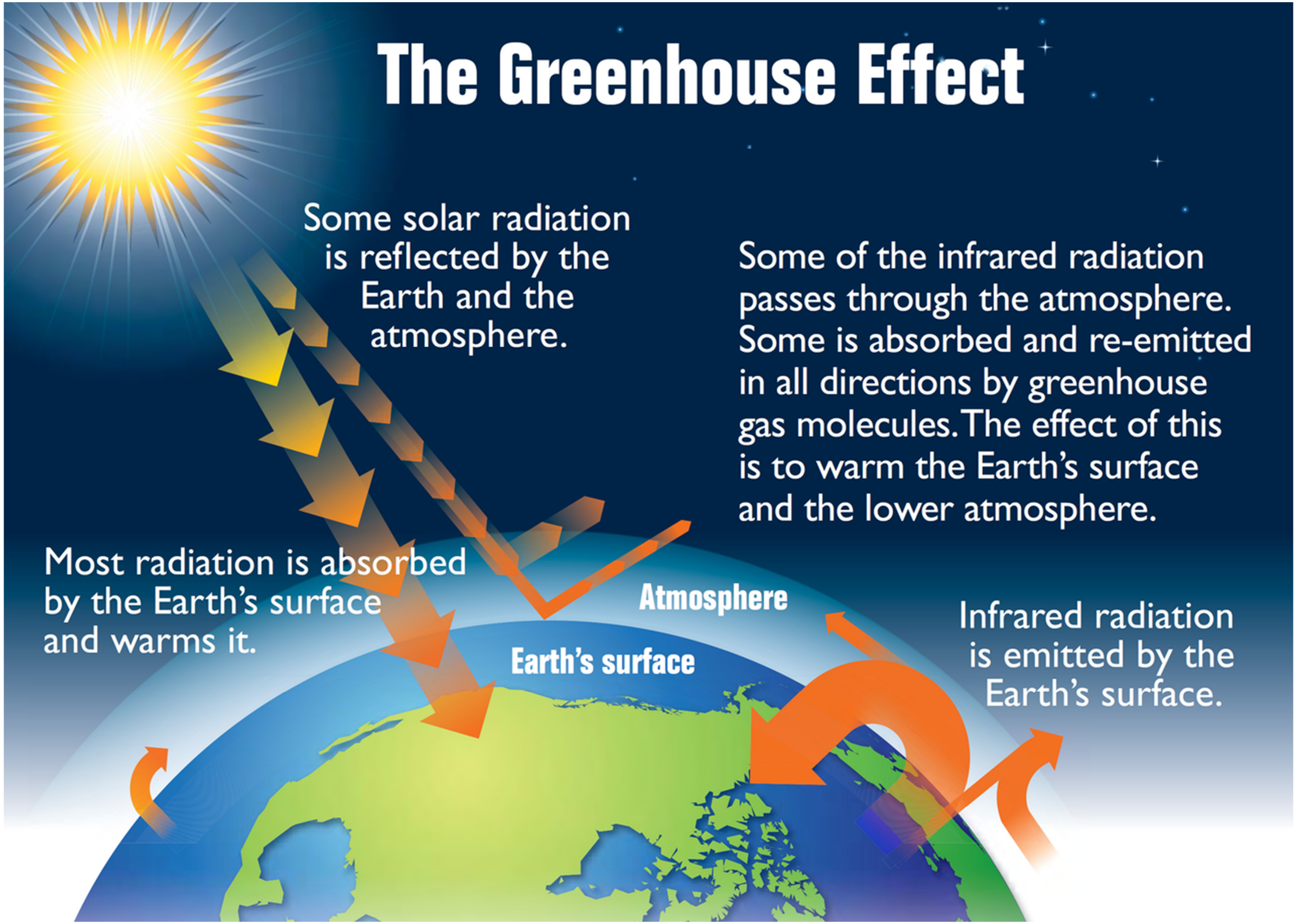
Customer Example

- **Challenge**: More efficient scheduling of claims operations team and reduction of claims for automobile insurance
- **Solution**: Apply methods used for outage prediction and response
  - Focus on hail for an internal application
- **Results**
  - In process
  - Using hail alerting with policy holders as well
  - Also evaluating seasonal-scale and probabilistic forecasts for catastrophe management

Potential Implications of Climate Change

Additional Scientific Principles Related to Climate Change

The “Greenhouse” Effect



Source: U.S. Environmental Protection Agency

The atmosphere can hold 4% more water with each increase of temperature of 1°F, on average.

A Few Facts about the State of the Climate and the Science

What Can Be Attributed to a Changing Climate?

Many temperature and precipitation extremes are becoming more common in the United States

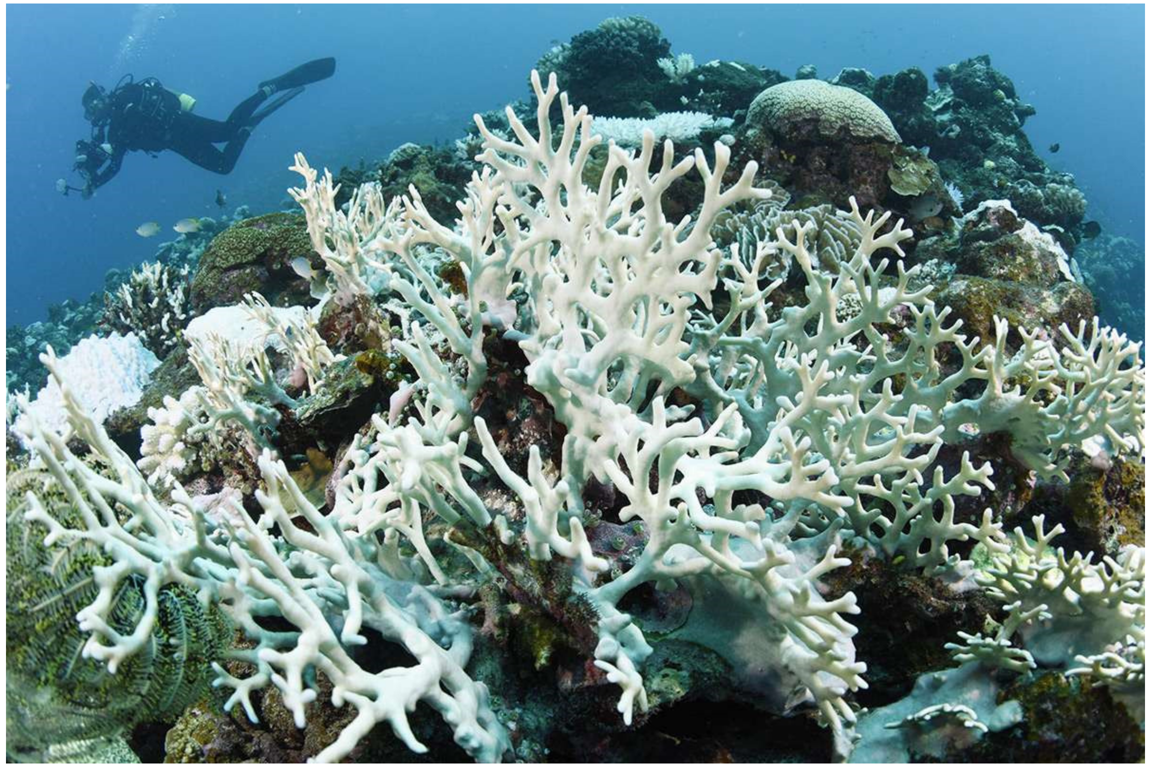
1. The frequency of cold waves has decreased since the early 1900s
2. The frequency and intensity of heat waves has increased since the mid-1960s
3. The frequency and intensity of heavy precipitation events have increased since 1901, especially in the northeast

Sources: U.S. Global Change Research Program, New England History Society, Time Magazine, ABC News

What Can Be Attributed to a Changing Climate?

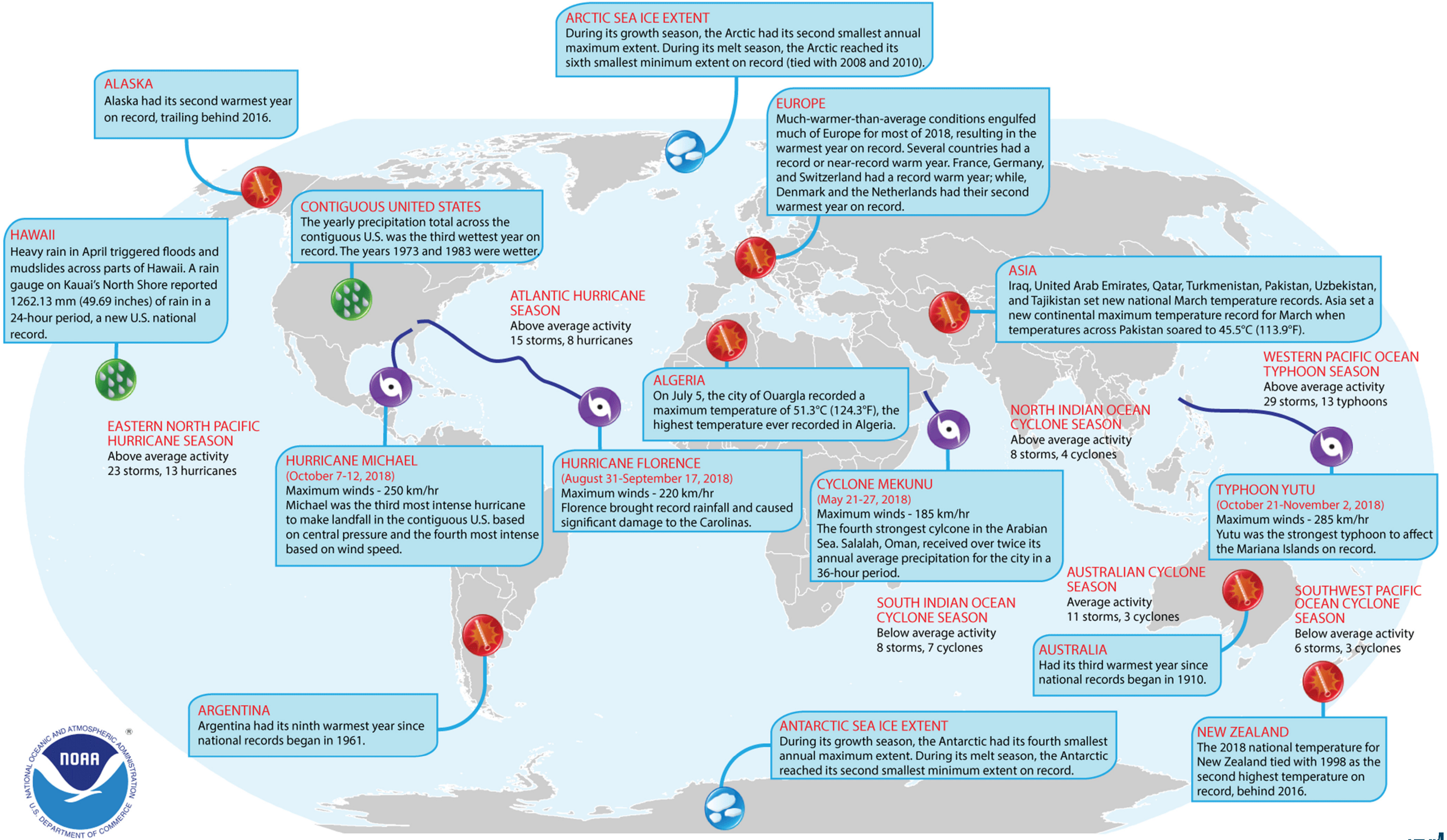
The oceans are not just rising, they are warming and changing

- The world's oceans have absorbed about 93% of the excess heat caused by greenhouse gas warming since the mid-20th century
- The world's oceans are currently absorbing more than a quarter of the carbon dioxide emitted to the atmosphere annually from human activities, making them more acidic
- Oxygen levels are expected to decrease by as much as 3.5%



Sources: Mario Hoppmann, via imaggeo.egu.eu, U.S. Global Change Research Program,https://science2017.globalchange.gov/; Kyodo News via Getty

Selected Notable Climate-Related Events in 2018



16 Events in 2017 with Cumulative Impact of $306.2B

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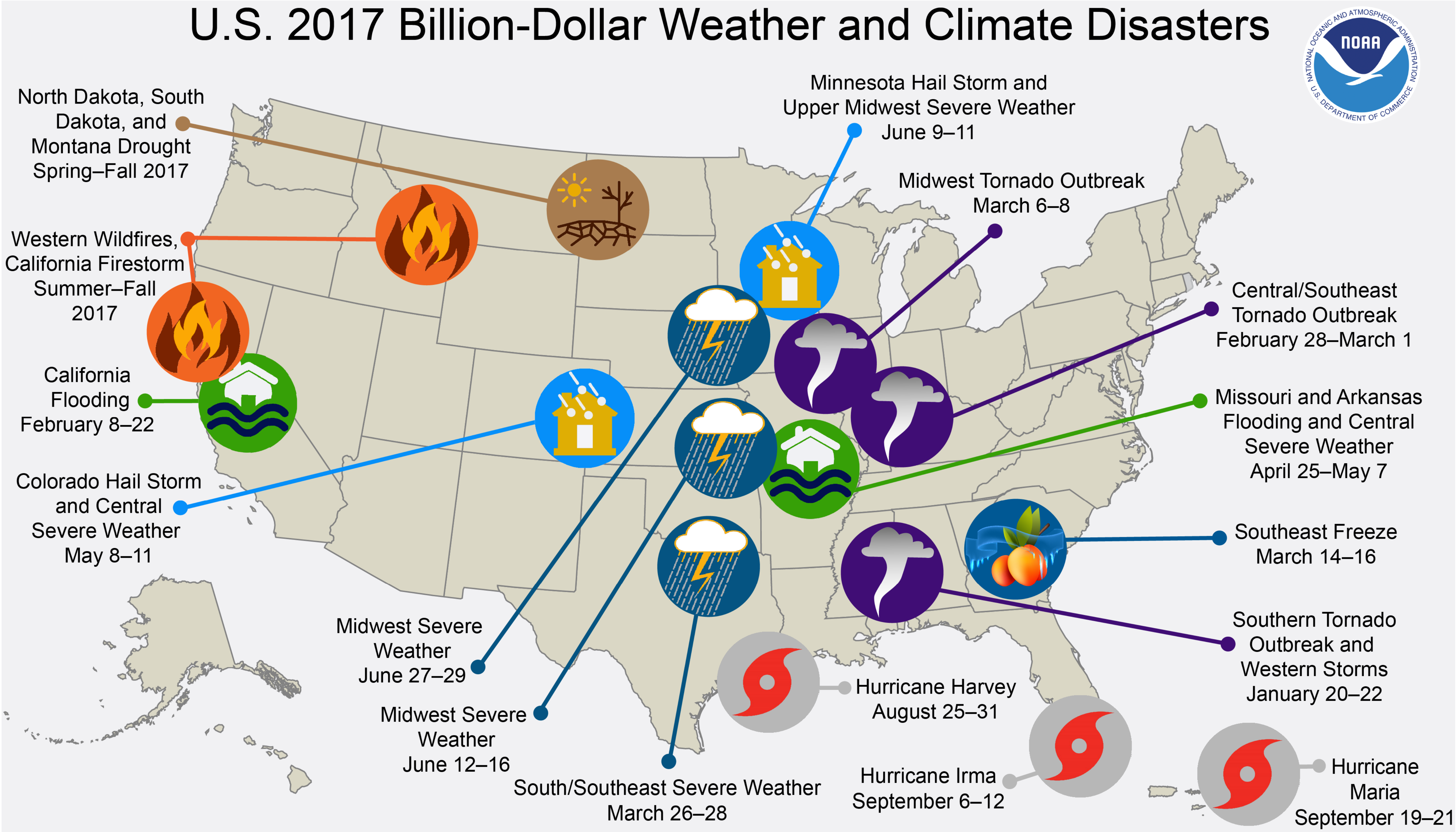
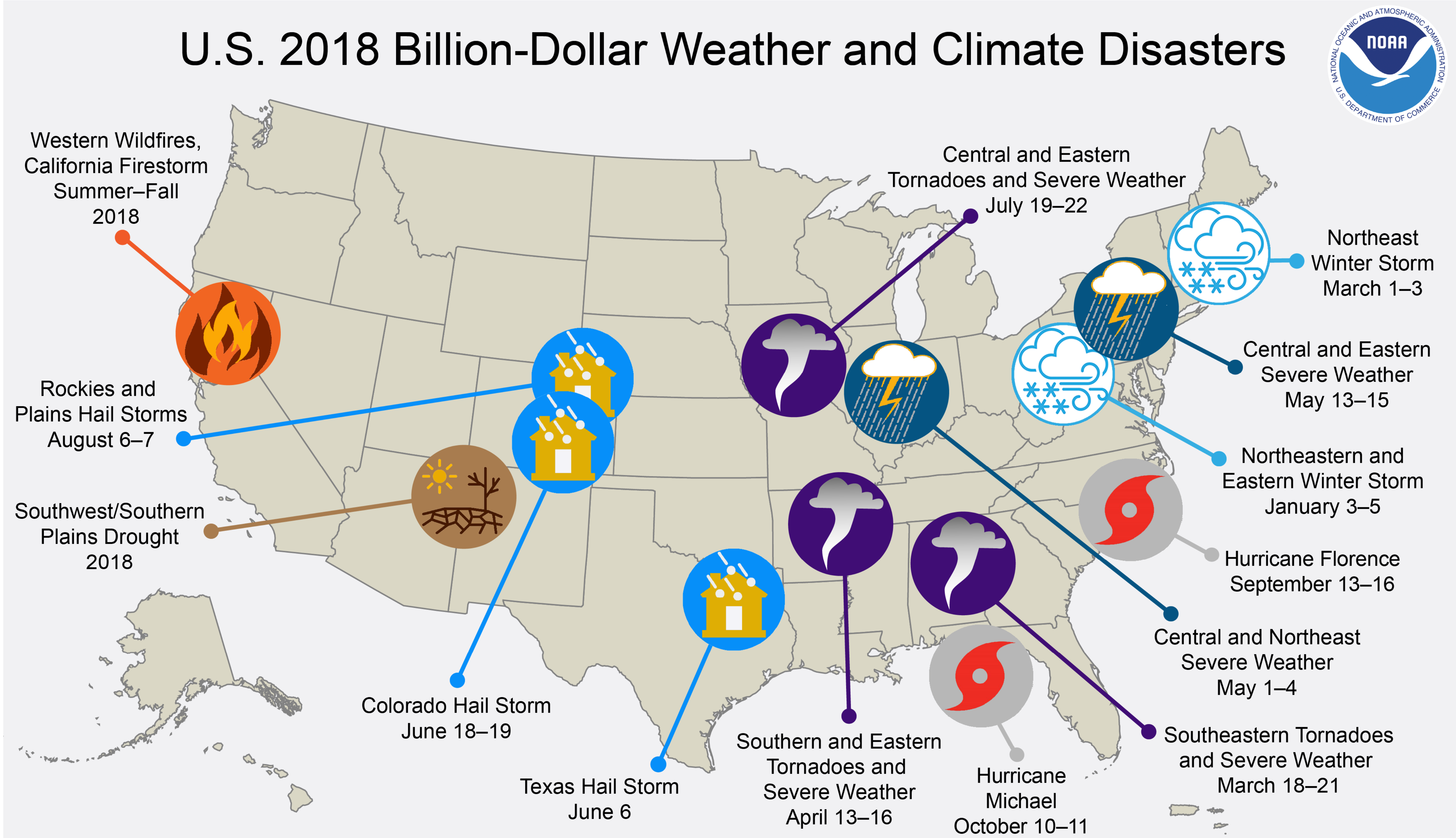
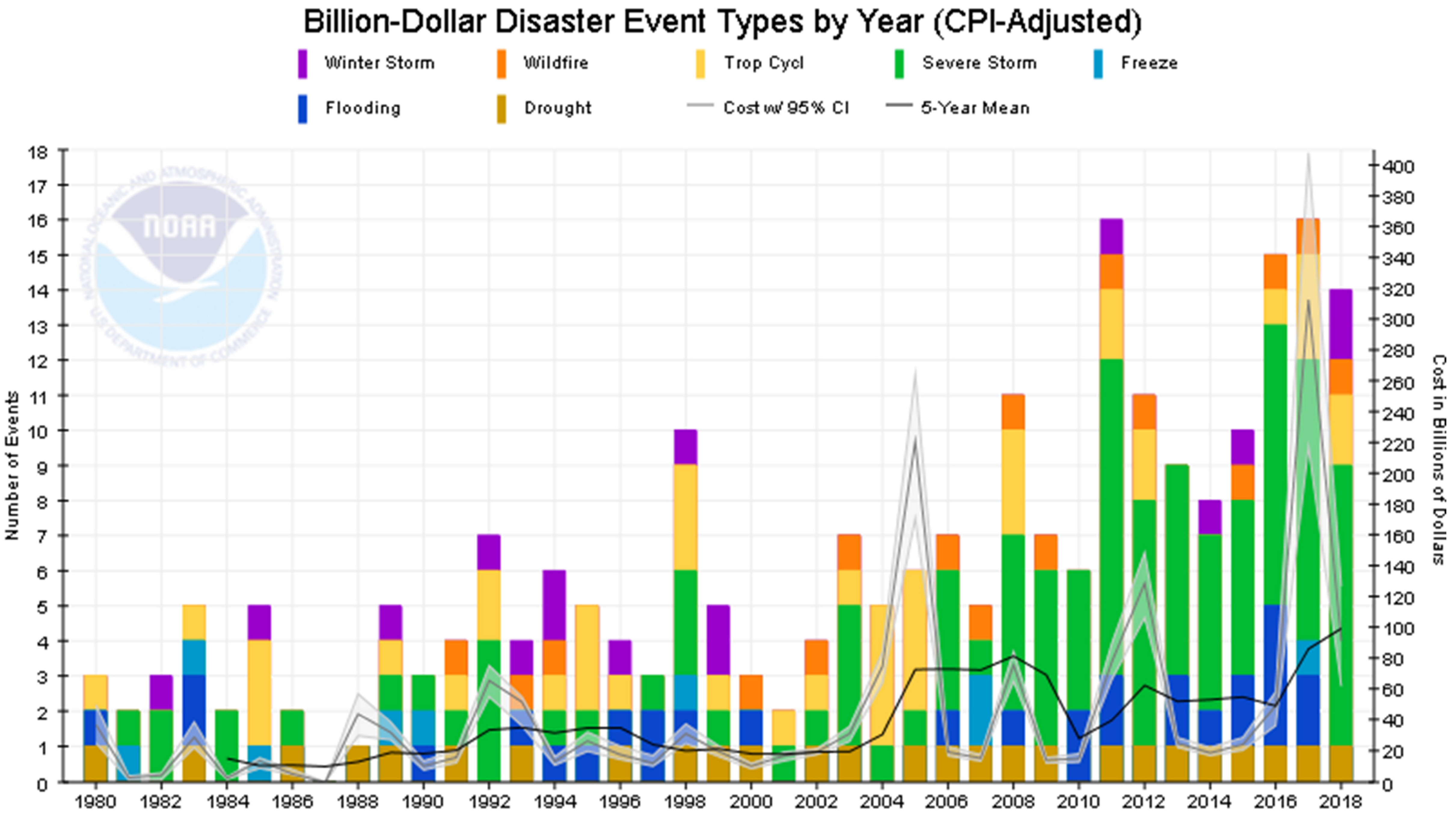


14 Events in 2018 with Cumulative Impact of $91B



Billion Dollar Disaster Event Types (1980 – 2018)



246 Events from 1980 to 2018 with Cumulative Impact of $1.6T
Adjusted by Consumer Price Index (Source: NOAA)

“Climate” Event Attribution

What aspects of such events can be attributed to a changing climate?

- The US wildfire season is three months longer than in 1940 and more intense
- Tropical storms of greater intensity (e.g., Hurricane Florence had > 50% more rain and was about 50 miles larger)
- More flooding events due to precipitation of greater intensity and coastal storm surge
- Increased droughts

Sources: U.S. Global Change Research Program, https://science2017.globalchange.gov/, Kip Evans / Alamy Stock Photo, NASA

A Few Implications of Climate Change

- The oceans are not just rising, they are warming and changing
  - Economic impact is occurring from nuisance (tidal) and storm-driven flooding
  - Coastal cities, ports, power plants and naval stations, etc. are at risk
  - There will be a negative effect on life in our oceans, which will impact the global food chain

Toms River, NJ, January 2017, Source: NJ Advance Media, NJ.com

Charleston, SC, Source: NOAA

Coastal airports are at risk

- About two dozen of the world's busiest airports are less than 33 feet above sea level -- half are less than 16 feet above sea level
- JFK, LGA and EWR were closed in the aftermath of Post Tropical Cyclone Sandy
- Kansai airport near Osaka was flooded in September due to Typhoon Jebi
- Destruction in October at Tyndall Air Force Base from Hurricane Michael

Source: AP

IBM Studies of the Impacts of Climate Change

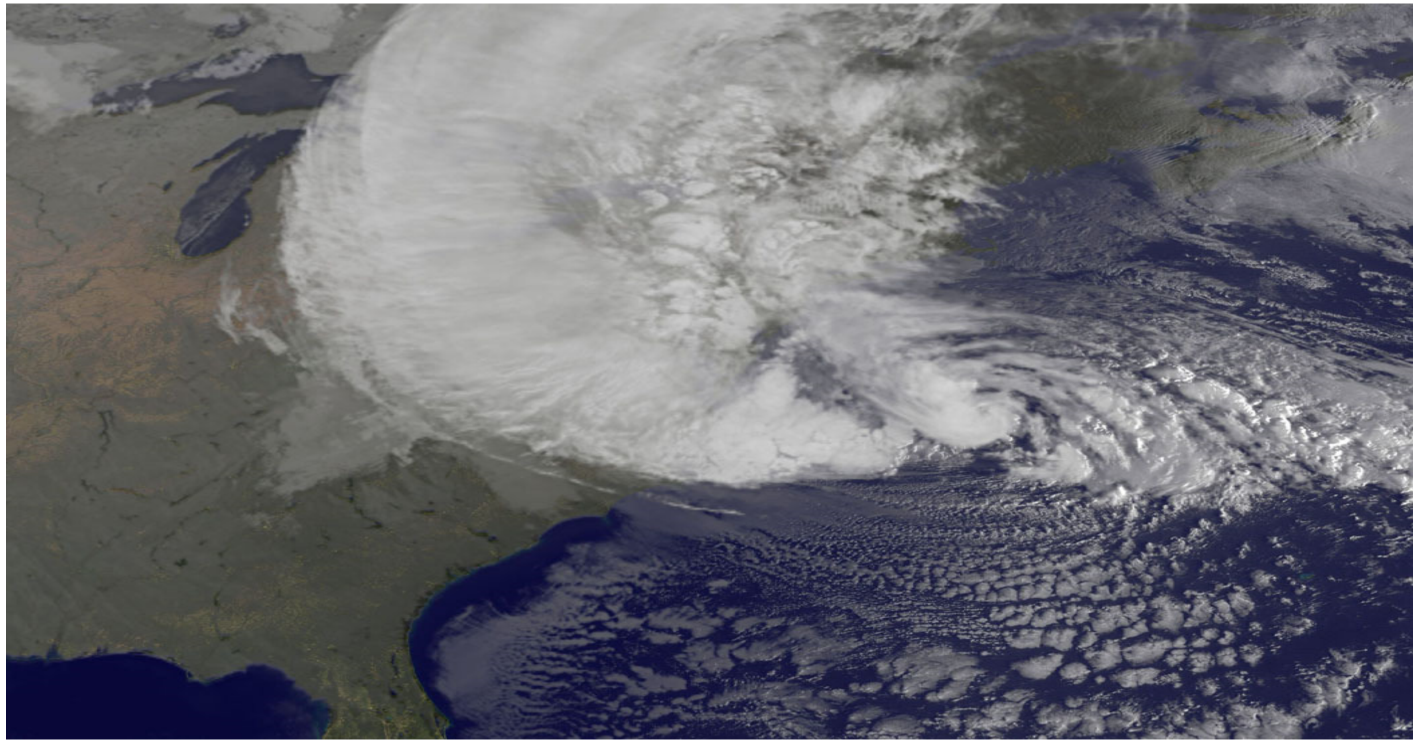
IBM Studies of the Impacts of Climate Change

- We are looking at localized impacts especially on businesses and long-term, strategic planning
- We are trying to understand the effectiveness of mitigation strategies

One example:

- How can hurricanes change in a future climate ?

Post-Tropical Cyclone Sandy (October 2012)



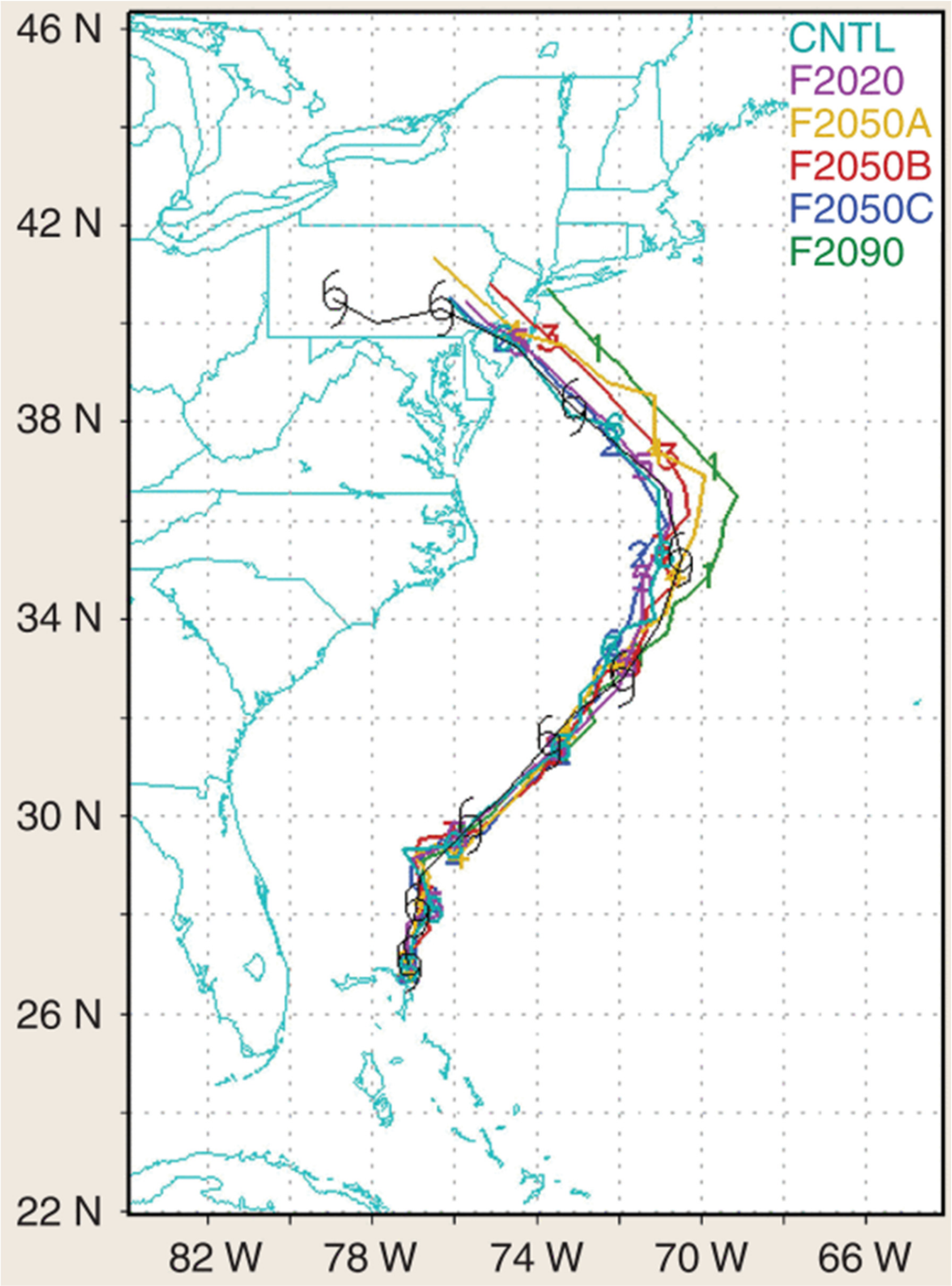
- **Over 100 deaths and about $80B in property damage**
- **Electricity service lost to about 8M residences and businesses**
- **Widespread disruption of all transportation systems**

Post-Tropical Cyclone Sandy (October 2012)

- Wind gusts of 60 to 90 mph with extensive coastal flooding
- Thousands left homeless
- Significant disruption of communications systems

How different would a Sandy-like storm be in the future?

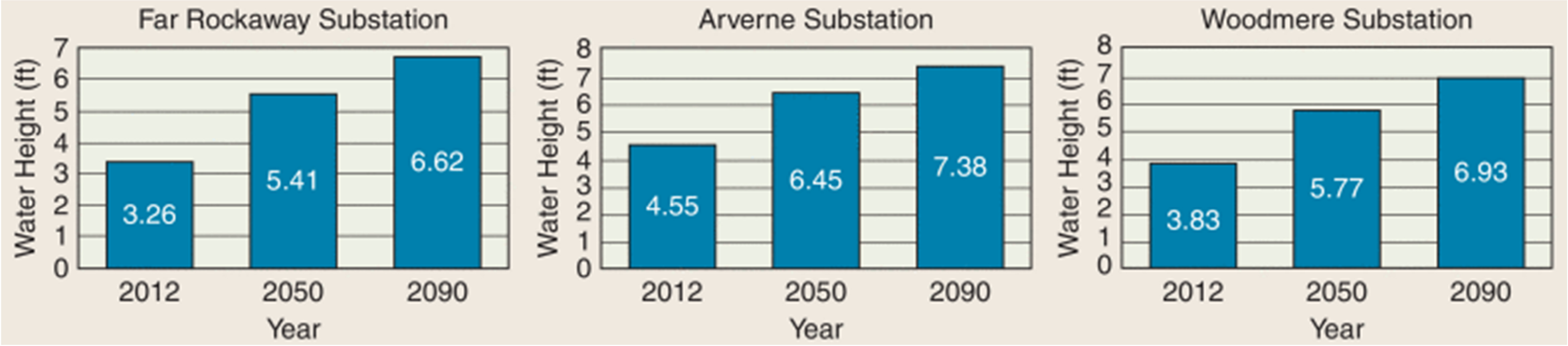
Comparing "Sandy" Tracks in a Future Climate



- **CNTL shows the actual track of Sandy**
- **Tracks marked "F" illustrate different climate scenarios at three times in the future**
  - **F2020 corresponds to 2020**
  - **F2050A, F2050B and F2050C are different scenarios for 2050**
  - **F2090 corresponds to 2090**
- **The numbers on the tracks indicate the delay in landfall in hours compared to actual**
- **A difference of up to about six hours in the landfall time and 100 miles closer to New York City in landfall**
- **In the 2090 simulation there is more widespread rainfall into western Long Island, up to 1.5 inches for the 24-hour period of the simulations (not shown)**

Comparing Flooding from a Future "Sandy"

- About twice as many electric substations in Nassau and Suffolk Counties would be flooded compared to what actually occurred in 2012
- 27 under the 2050B scenario vs. 30 in the 2090 scenario
- Three examples are shown below



Conclusions

- Weather risk mitigation is a reality because the lead time and skill of forecasts are sufficient to be actionable
- Weather forecast models are coupled to predictions of the impacts of weather
- Businesses can proactively allocate and deploy resources to minimize time for restoration of damage from severe events
- We are extending these concepts to a climate scale in order to evaluate the potential localized impacts of a warming planet and the effectiveness of strategies being used to mitigate such impacts

Questions ?