# The Past, Present, and Future of Weather Forecasting

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# Outline

- History of weather forecasting

- Modern weather forecasting
  - -Nowcasting
  - -Weather forecasting (up to approx. 7 days)
  - -Seasonal to subseasonal forecasting
  - -Climate forecasting

- Future of forecasting

*"…behind each [weather] prediction is one of* ***humankind's greatest accomplishments****—something that requires armies of people all over the globe collecting and sharing data, exquisite mathematical modeling, and staggering computer power. The weather doesn't respect political or geographic boundaries: we're all living under the same sky. And so* ***weather prediction has been a marvel not only of technology but also of international cooperation****. As we enter an era of more storms and greater uncertainty than we've ever experienced, let's hope it stays that way."*

*—Hannah Fry, The New Yorker, June 24, 2019*

# History of Weather Forecasting

# History of Weather Forecasting

## Vilhelm Bjerknes

*Father of Modern of Meteorology*

- Worked with *Heinrich Hertz* (*of the unit of frequency*) on the existence of electromagnetic waves and instruments that transmit/receive radio pulses
- 1895 – Professor at the University of Stockholm
  - Using a combination of fluid dynamics and thermodynamics, developed primitive equations to describe atmospheric motion (*still used today!!!!*)

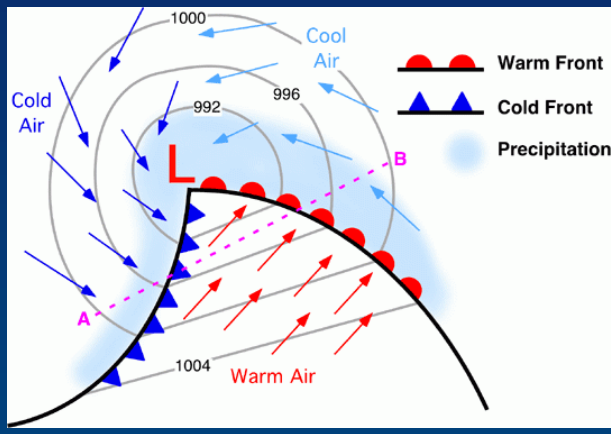
**Prof. Vilhelm Bjerknes**

- 1904 – Theorized that these **equations could be used to predict atmospheric motion**

  Given a set of initial conditions, use the equations to integrate forward in time to solve for a future state

  → Given the lack of computing technology of 1904, this was not possible!

- Developed the **cyclone model** after observing Norwegian coastal weather conditions during World War I




**Norwegian Cyclone Model**

# The forecast that changed the world…


Original invasion planned for **June 5**, but unusually strong late spring weather system was approaching!

With a **new storm** approaching over the North Atlantic, it was feared that the invasion would have to wait **two weeks** until the tidal conditions were ideal again.

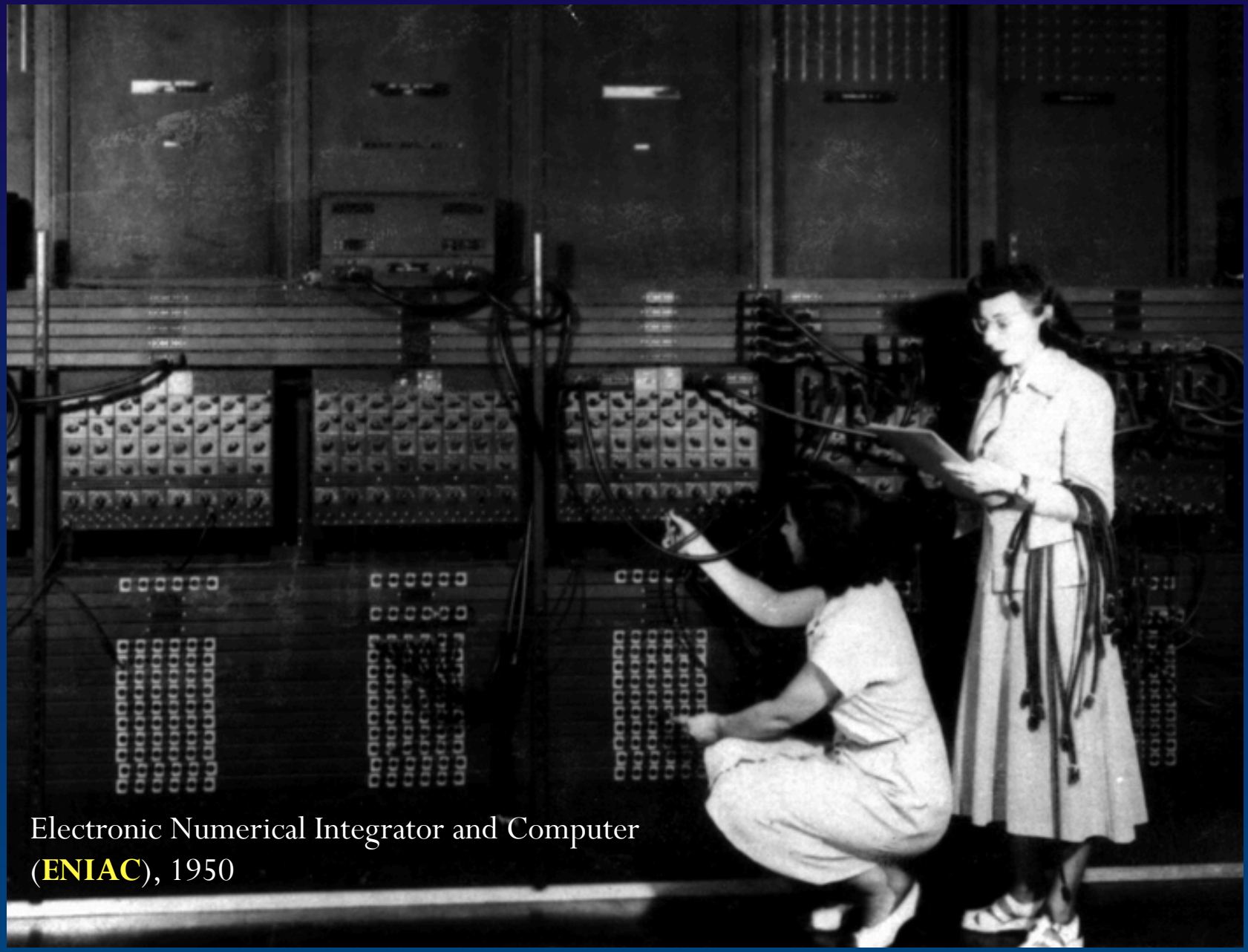
U.K. meteorologists Pettersen and Douglas asserted that the morning of **June 6** would provide a brief weakening of the winds between weather systems.

This narrow window of relatively tranquil weather allowed for the invasion, and any delay may have cost the allied forces the war.


*Steve Kahn / Thomas Valle (WGN-TV)*

# D-Day: June 6, 1944

# Using Bjerknes' equations now possible with …



Electronic Numerical Integrator and Computer (**ENIAC**), 1950

# Using Bjerknes' equations now possible with …

**National Centers for Environmental Prediction**
**Supercomputer 2016**

*10,000 times faster than a modern desktop computer!*


FAIR-
COOL
NEAR 40°
SUNNY-
MILD 65°
1949


H
L
H
60
H
78
80
1970s

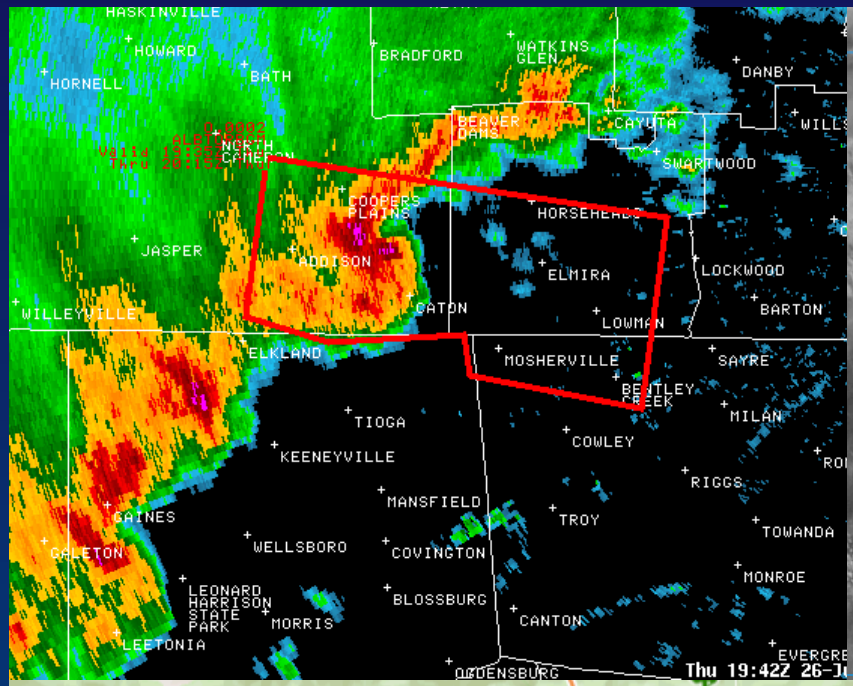

CURRENT
1990s

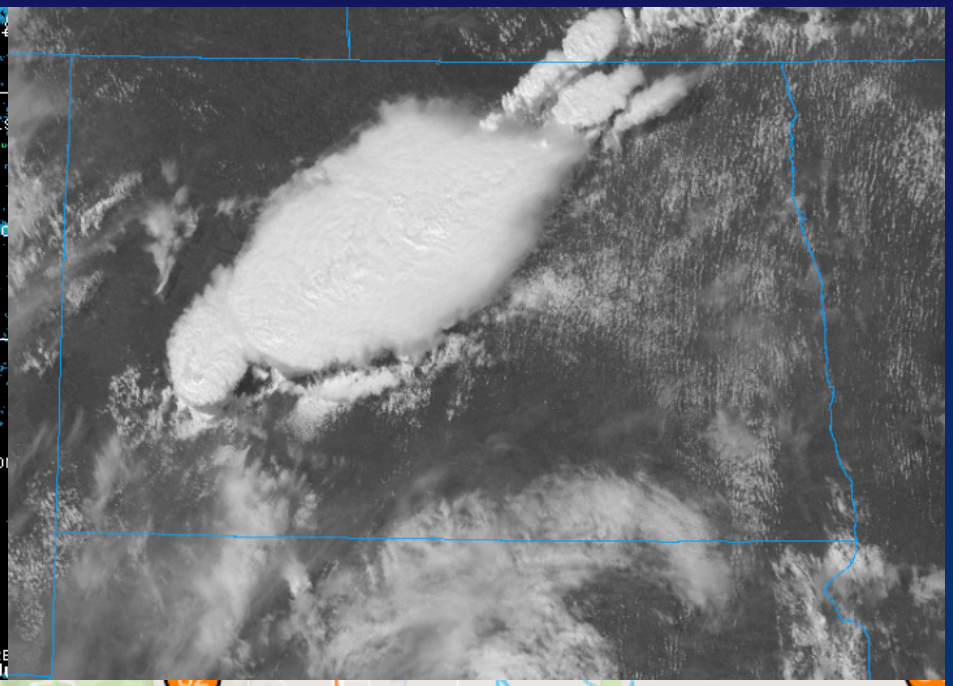

TROPICAL DOWNPOURS
THU 7/11
AREAS OF SPIN | EURO MODEL
Memphis
Dallas
Atlanta
Jacksonville
New Orleans
Corpus Christi
Miami
2019
The Weather Channel
A Tropical Depression could form by the end of the week
2:14 / 3:02

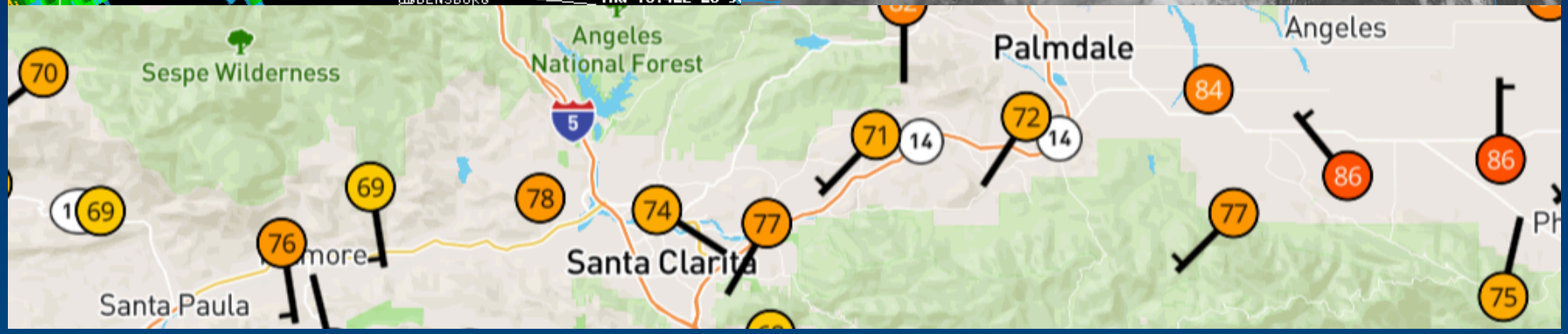
# Types of forecasts

**Nowcasting:**

Forecasts of up to six hours in advance

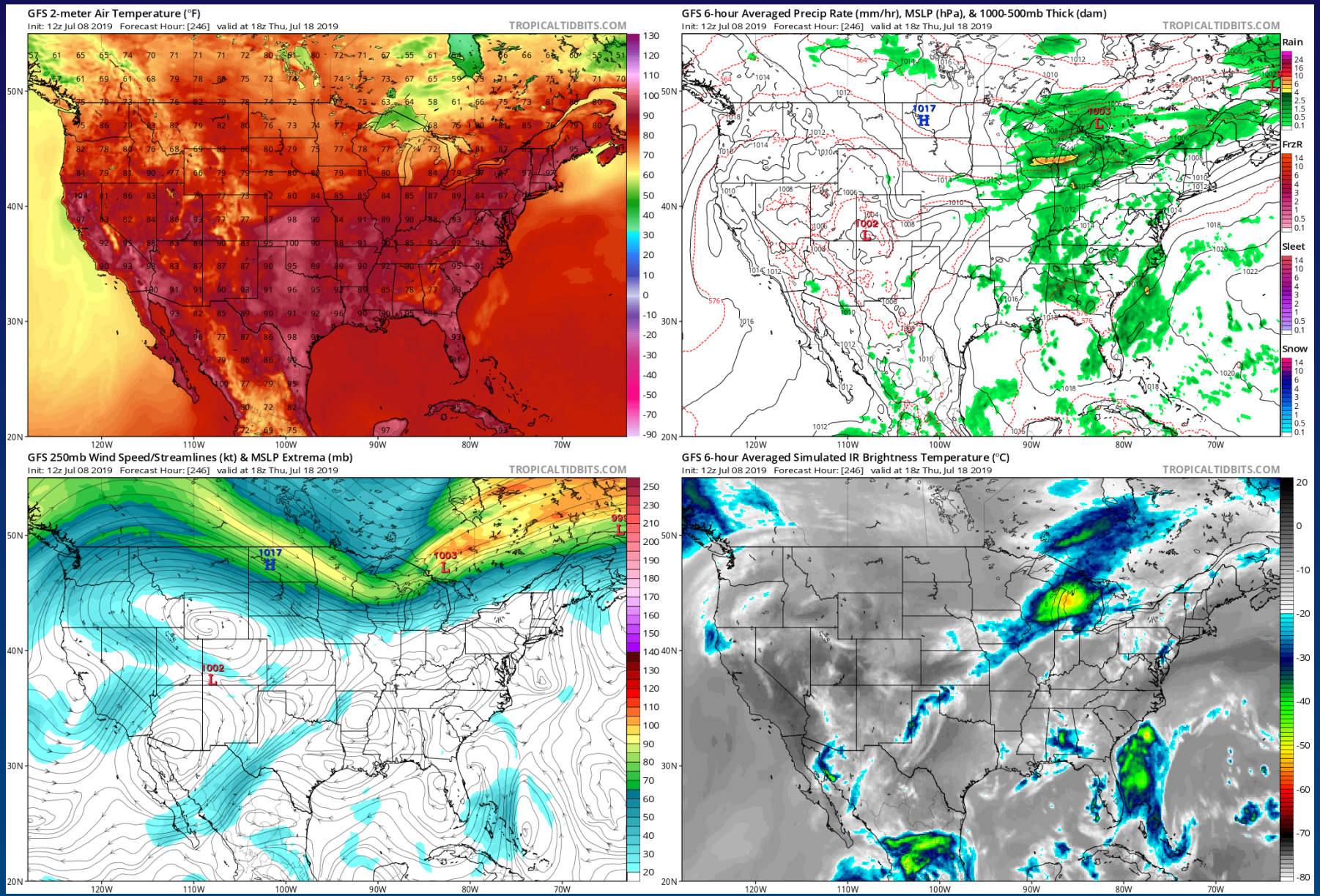




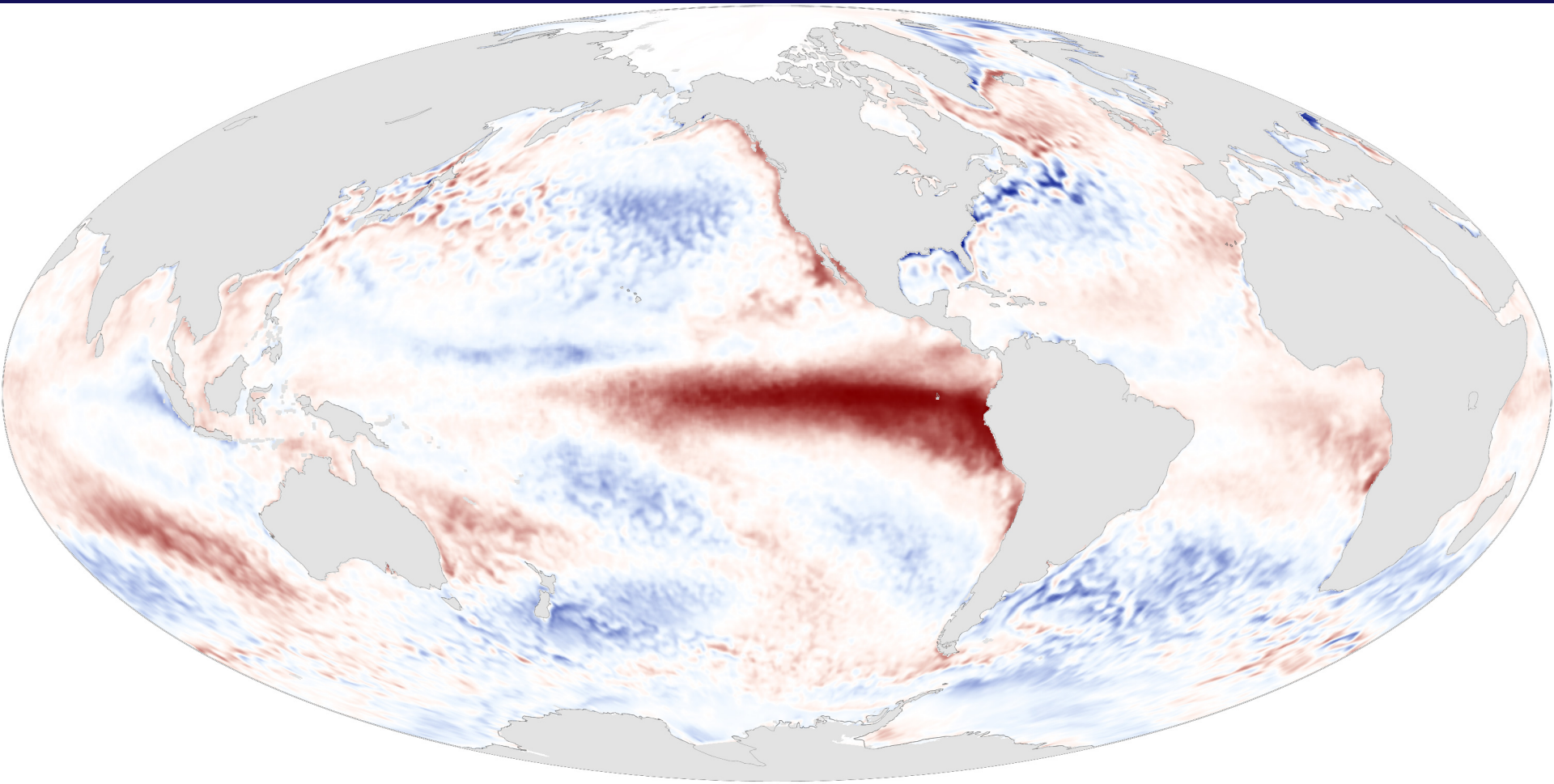
# Short-range weather forecasts:

Forecasts of up to 7-10 days in advance



# Seasonal to Subseasonal forecasting

What is the probability of a snowy winter? A hot summer?

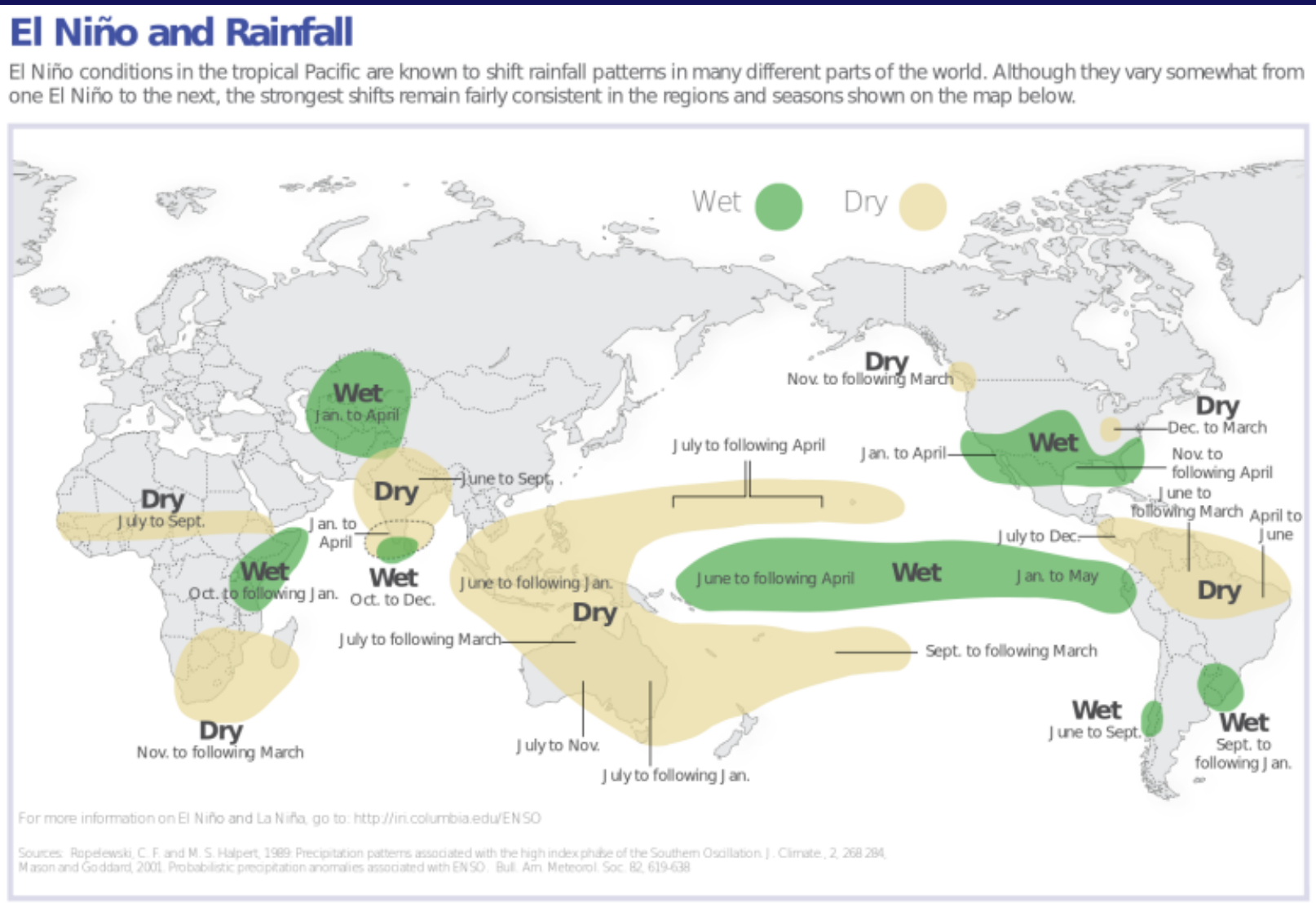



**Sea surface temperatures in December 1997 (El Niño)**

*Up to **10°F warmer than normal** over the Tropical Pacific!*

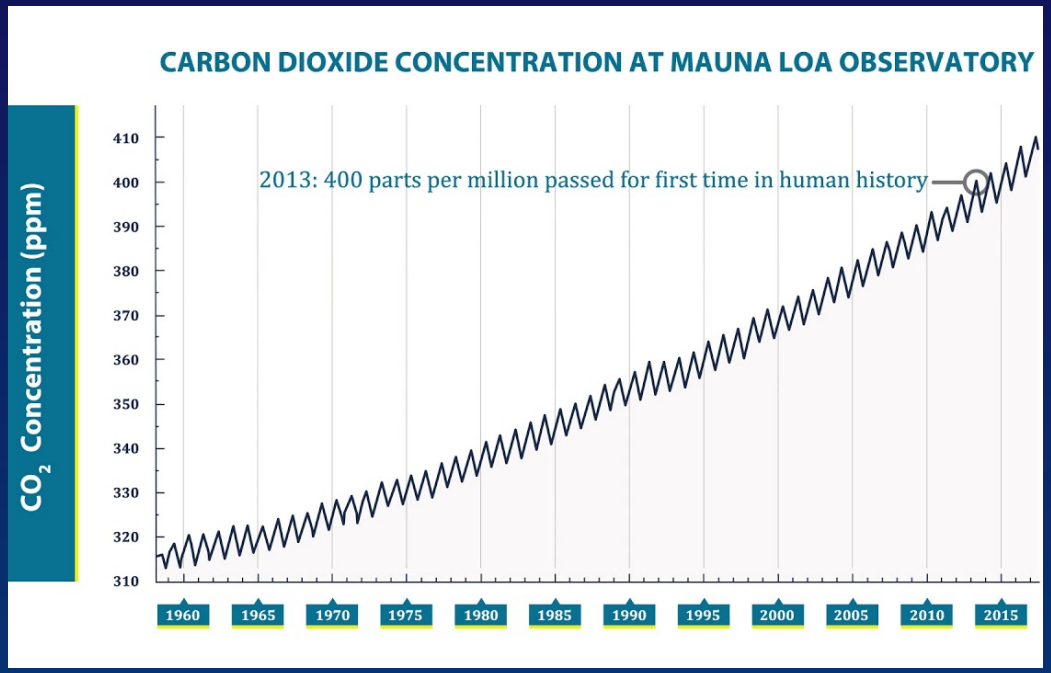
# Seasonal and Subseasonal forecasting

What is the probability of a snowy winter? A hot summer?



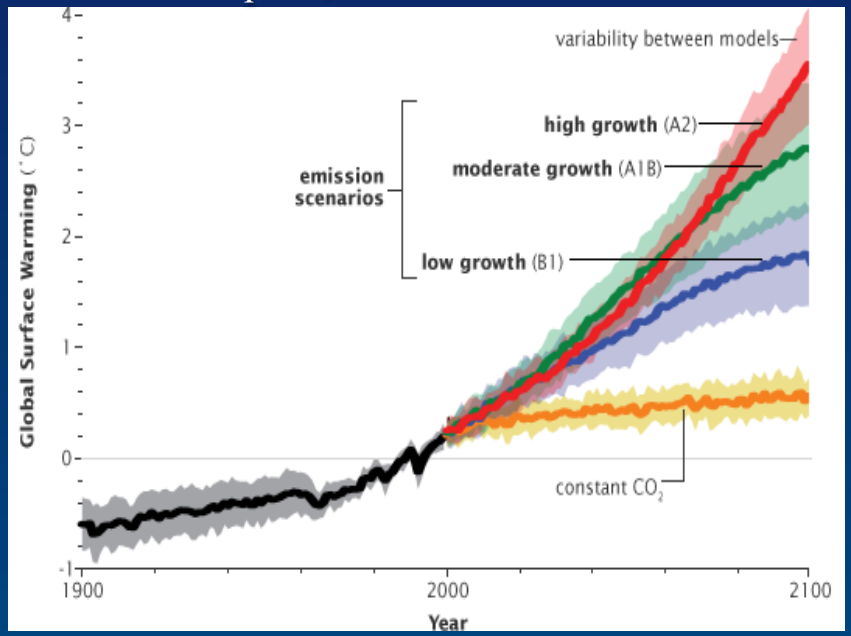
# Climate forecasting

How will natural and human-induced changes to our planet affect global temperatures and precipitation?

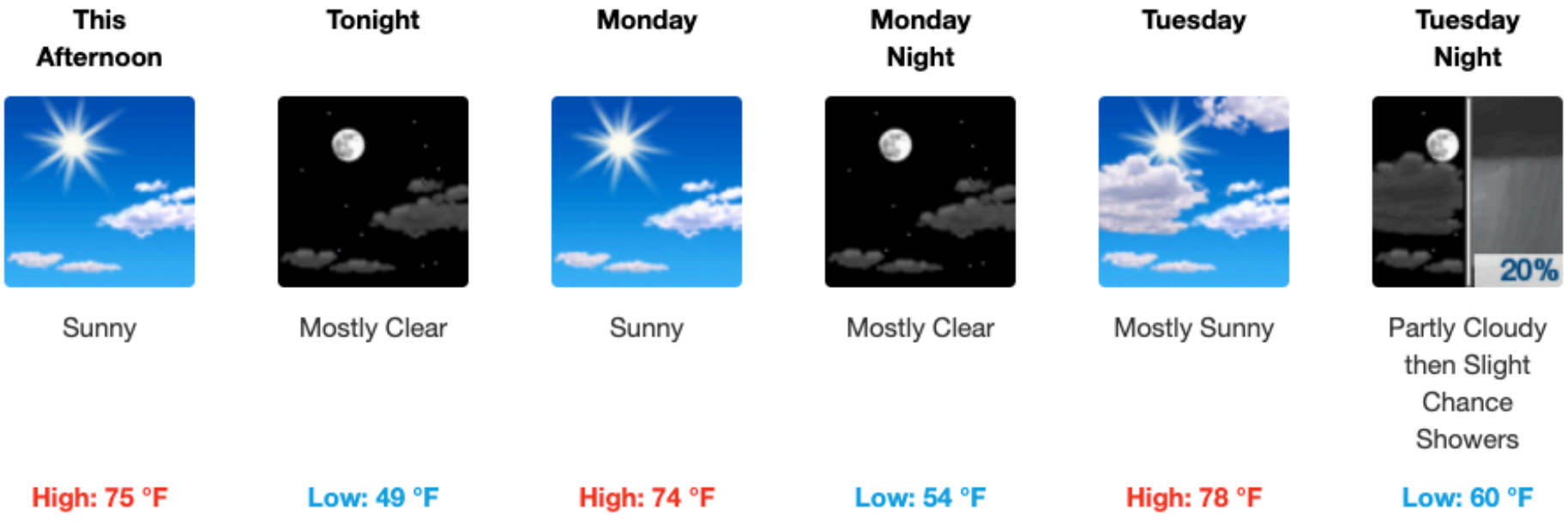



Scripps Institute for Oceanography

IPCC Report, 2007



# How do meteorologists *make* a weather forecast?



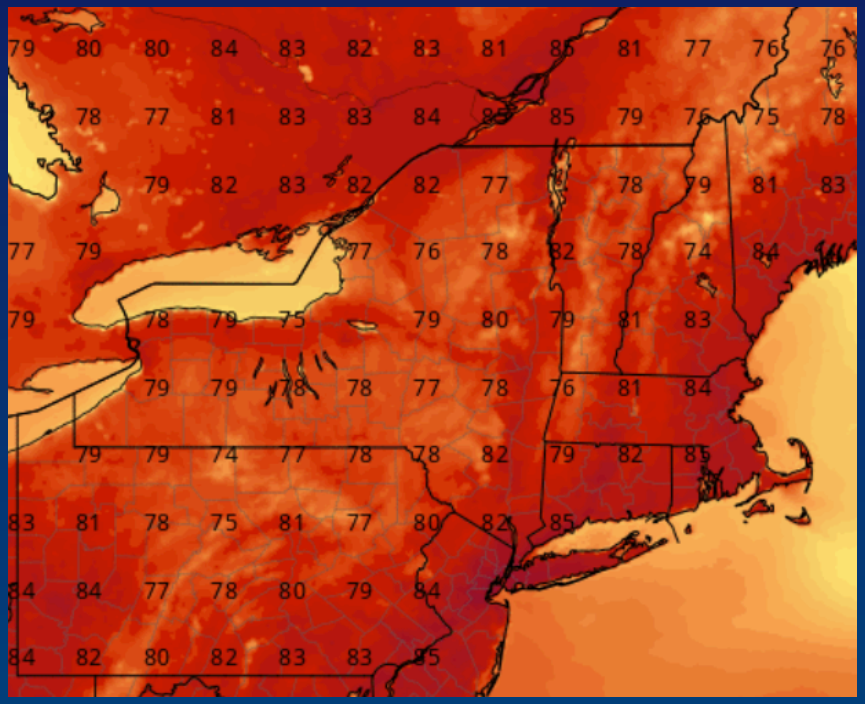

*National Weather Service forecast for Albany, N.Y. – August 25, 2019*

- Current weather
- Weather models
- Research
- Intuition (memory and understanding of past similar events)

*Part of why an unprecedented storm, like* ***Superstorm Sandy****, is a tough forecast!*

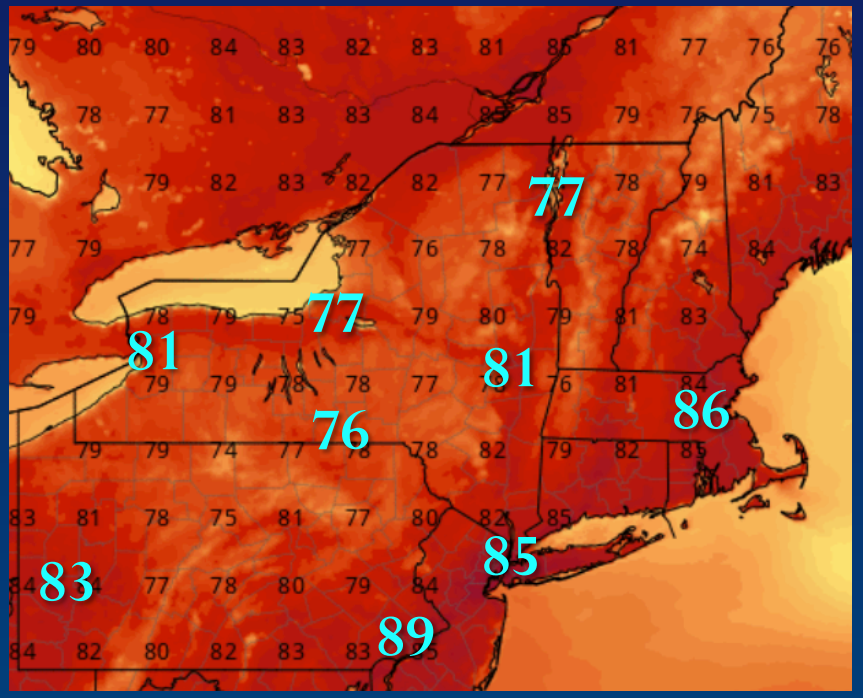
# What is a weather **model**?

- Models start with the **current weather conditions** (from observations at airports, planes, weather balloons, satellite imagery, etc.)
- Combine observations with a recent forecast to make a **best guess** of the current conditions on a grid within the domain of a model
- Take Bjerknes' equations and integrate forward in time!



Temperatures from a prior model run

+




Combine with current observations

# Integrate forward in time …

**Wind Forecast Equations**

1a. $$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - \omega\frac{\partial u}{\partial p} + fv - g\frac{\partial z}{\partial x} + F_x$$

1b. $$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - \omega\frac{\partial v}{\partial p} - fu - g\frac{\partial z}{\partial y} + F_y$$

**Continuity Equation**

2. $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial \omega}{\partial p} = 0$$

**Temperature Forecast Equation**

3. $$\frac{\partial T}{\partial t} = -u\frac{\partial T}{\partial x} - v\frac{\partial T}{\partial y} - \omega\left(\frac{\partial T}{\partial p} - \frac{RT}{c_p p}\right) + \frac{H}{c_p}$$

**Moisture Forecast Equation**

4. $$\frac{\partial q}{\partial t} = -u\frac{\partial q}{\partial x} - v\frac{\partial q}{\partial y} - \omega\frac{\partial q}{\partial p} + E - P$$

**Hydrostatic Equation**

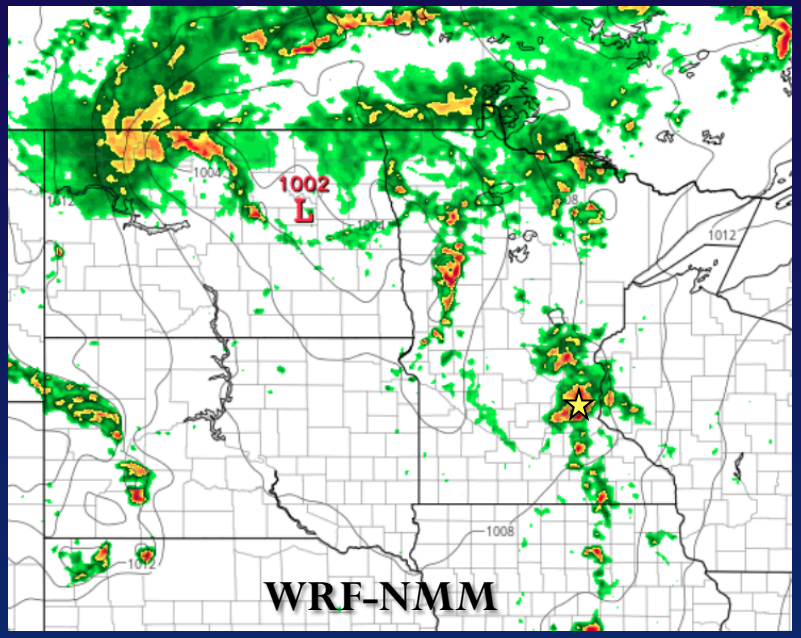
5. $$\frac{\partial z}{\partial p} = -\frac{RT}{pg}$$

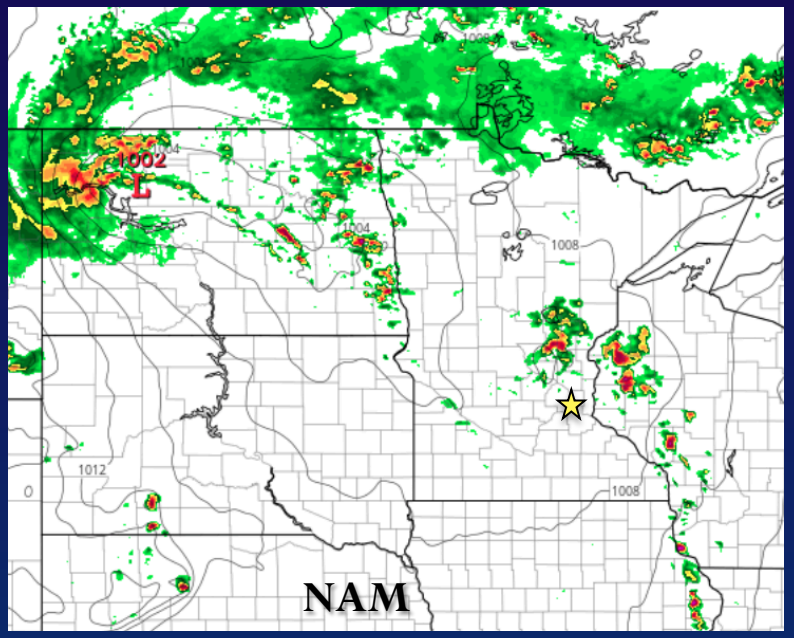
**From MetEd / UCAR**

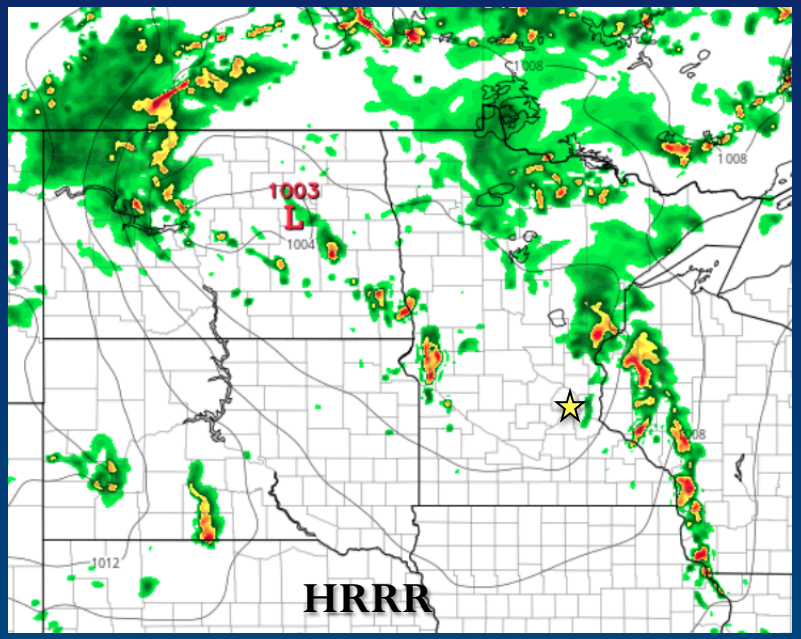
# How many models are there..?

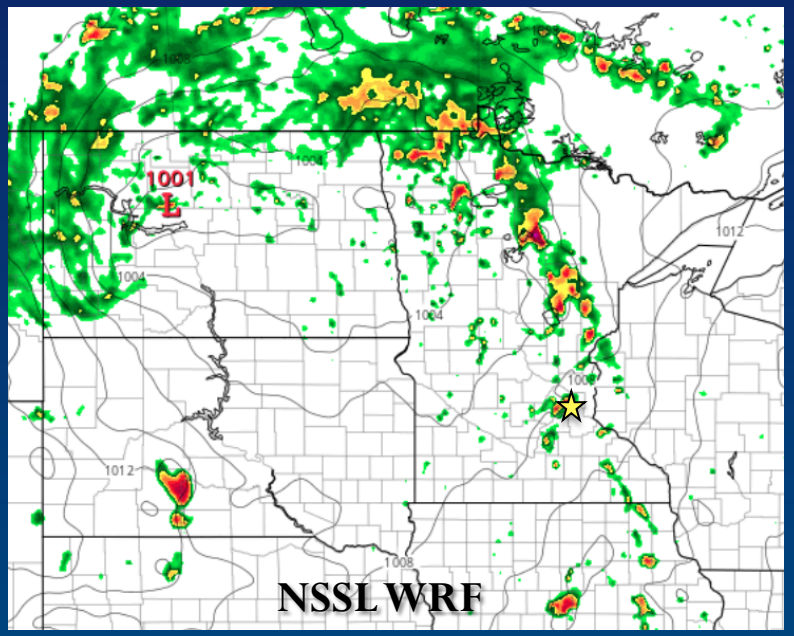
- High-resolution Rapid Refresh (HRRR) – 36 hours
- WRF-NMM – 48 hours
- WRF-ARW – 48 hours
- NSSL WRF – 48 hours
- NAM – 84 hours
- GFS – 16 days
- ECMWF (Euro) – 10 days
- UKMET – 10 days
- CMC (Canadian) – 10 days
- RGEM – 48 hours
- HRDPS – 48 hours
- NAVGEM (U.S. Navy) – 144 hours
- JMA (Japanese)
- ….and more…

# Four different model runs of **12-hour** forecasts



# Probabilistic forecasting

Because models inherently develop errors over time and offer a wide range of solutions, meteorologists refrain from using wording like:

*There will be a thunderstorm at 3:00 PM tomorrow*

*The rain will change to snow at midnight on Friday*

*It will not rain this weekend*

These are "deterministic" forecasts. Instead, meteorologists turn to **probabilistic forecasts:**

*There is increased likelihood of a thunderstorm tomorrow afternoon*

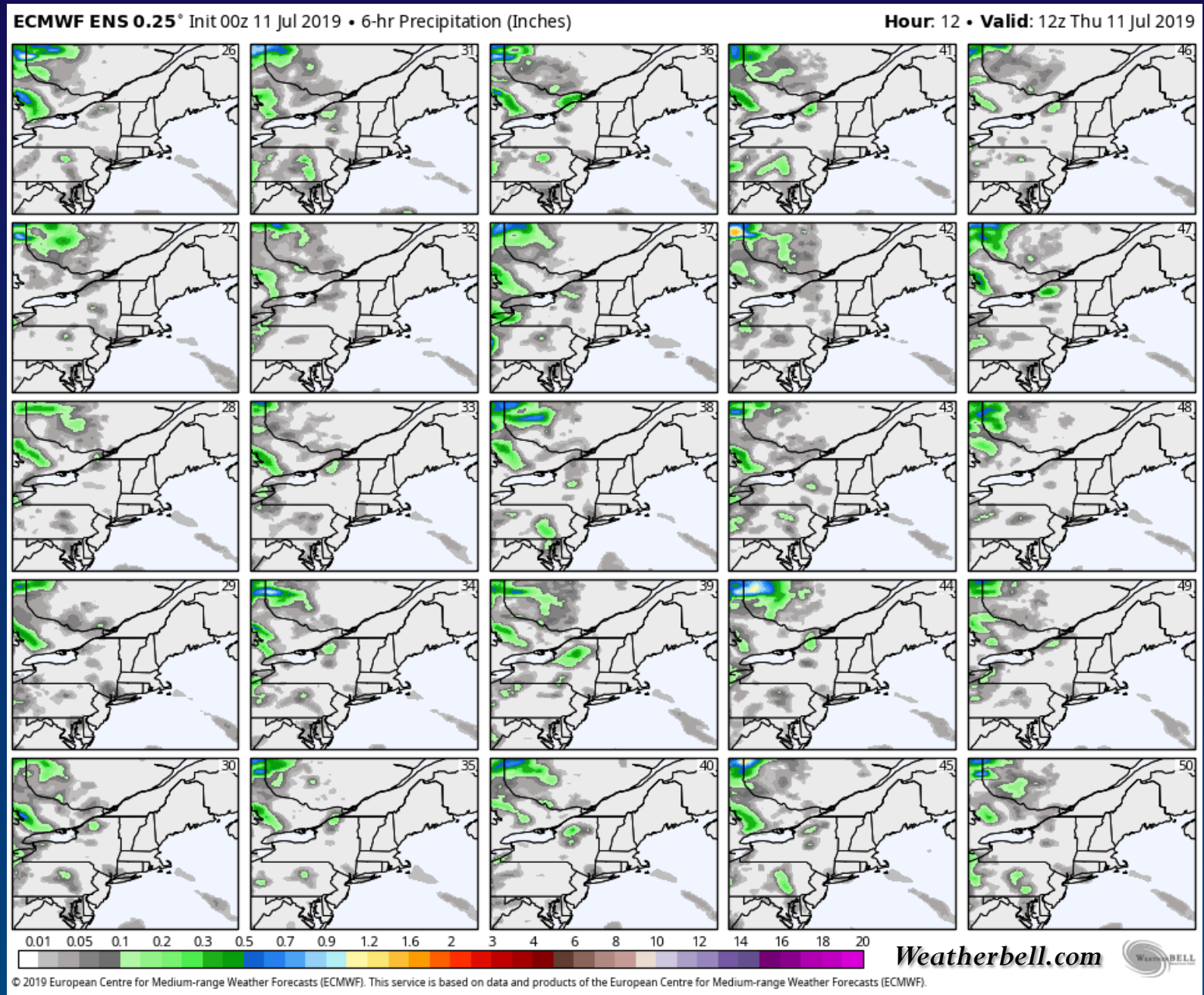
*Most models indicate the rain changing to snow around midnight on Friday*

*At this point, models indicate a dry weekend ahead*

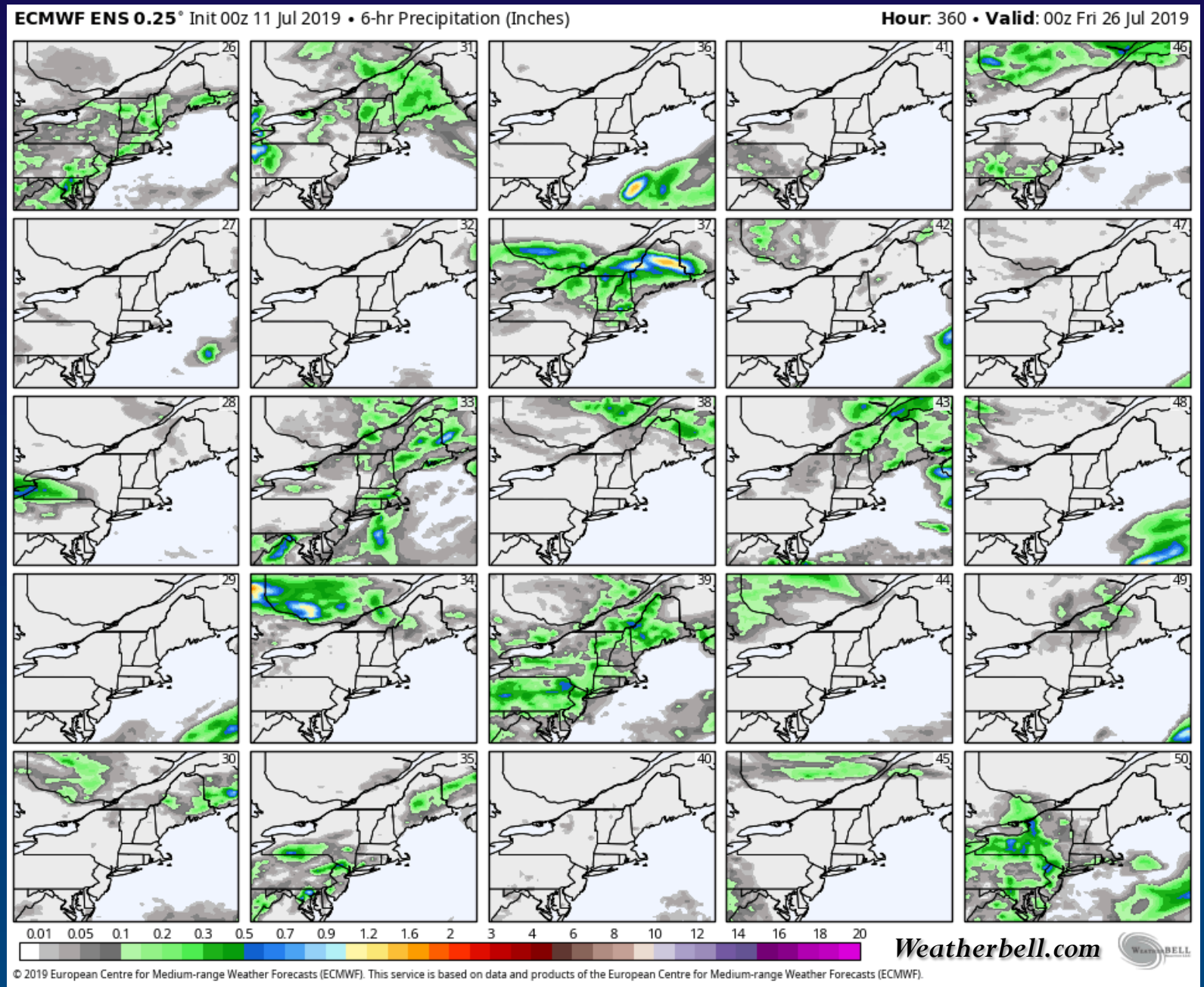
Probabilistic forecasting requires using a **model ensemble.**

- Take a model (GFS)
- Make tiny changes to the initial state of the atmosphere 20+ times
- 20+ model solutions that show a range of possible outcomes

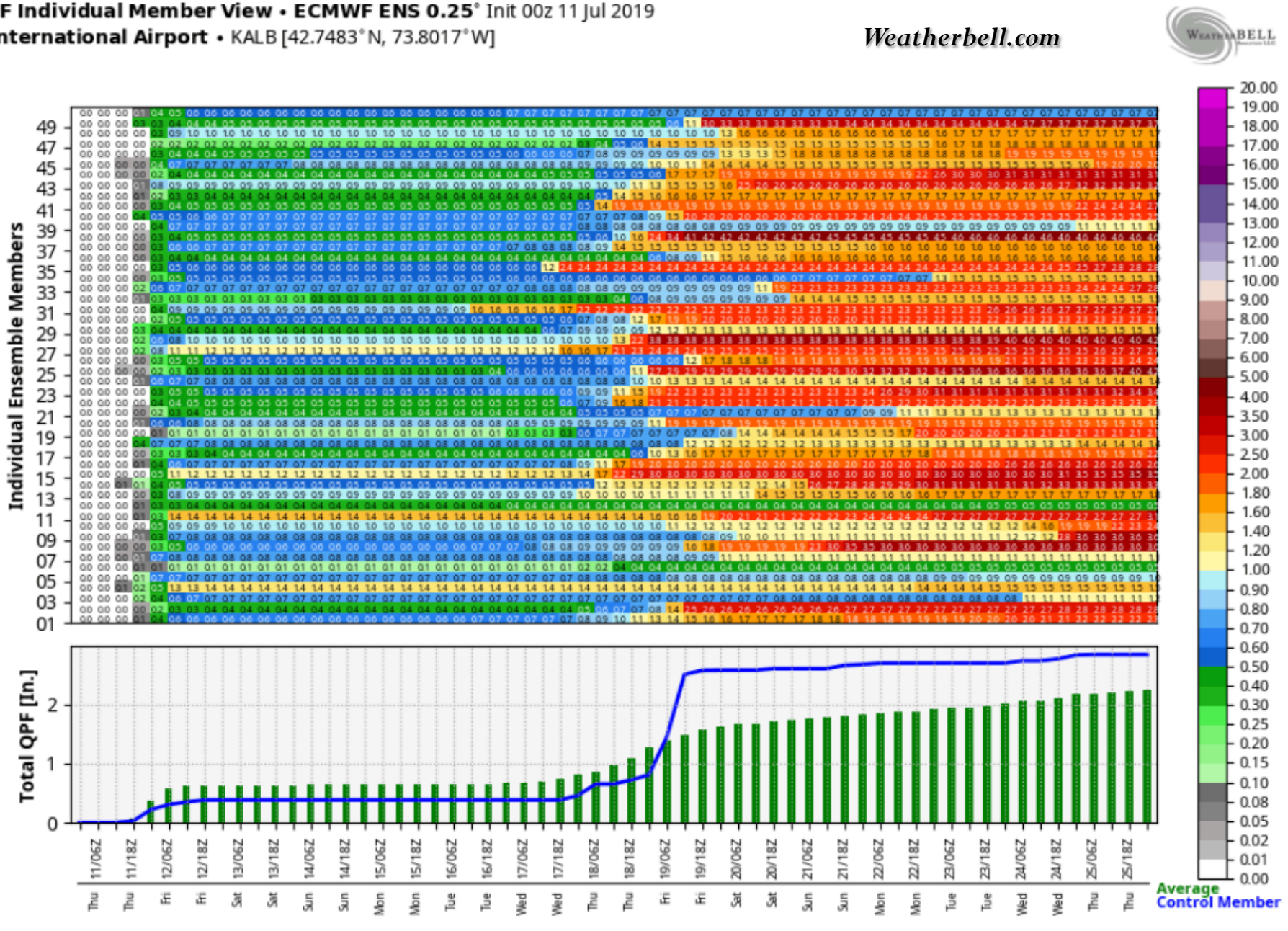
# Ensemble forecasting: 12-hour forecast



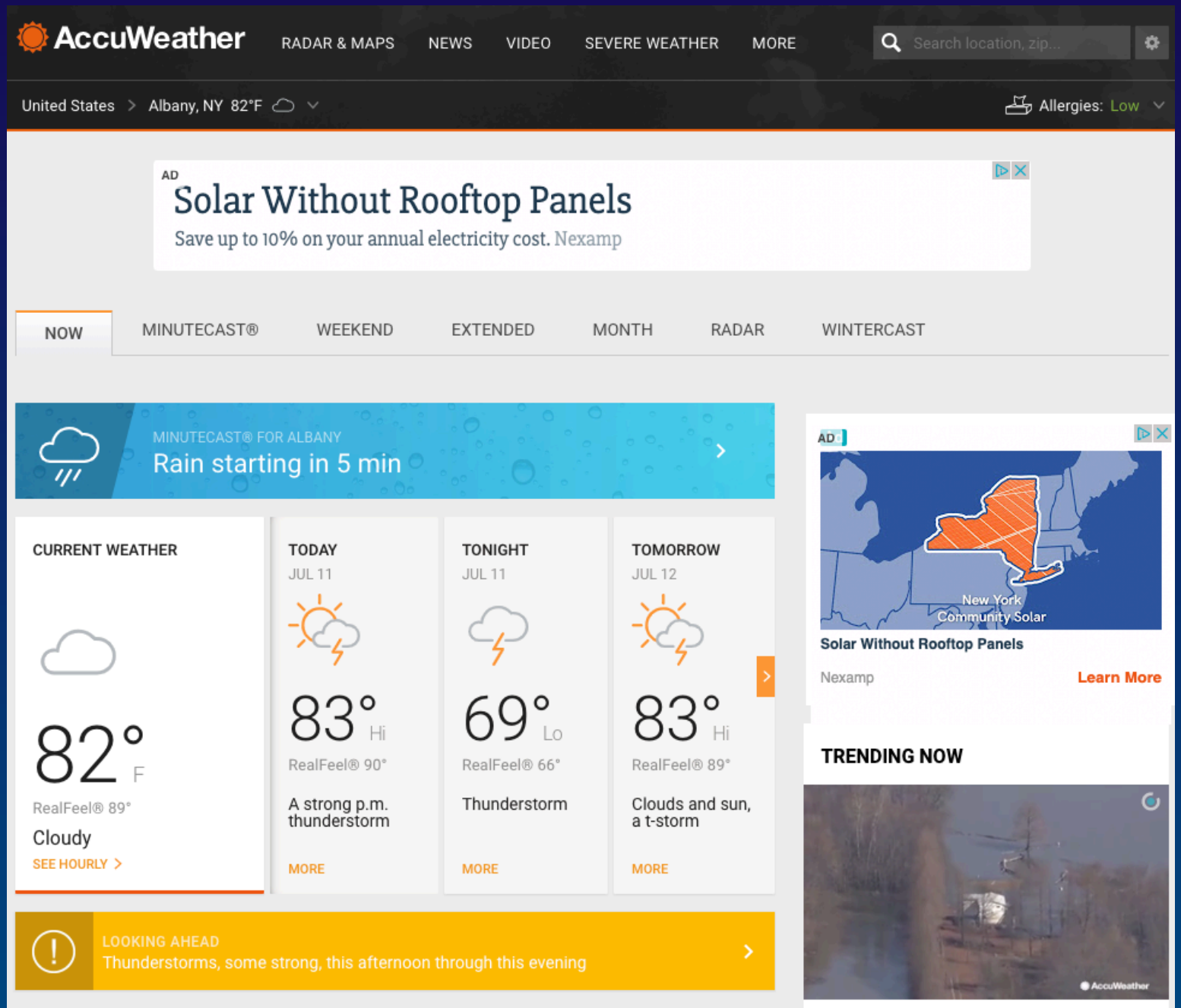
# Ensemble forecasting: 360-hour (15-day) forecast



# Ensemble forecasting



# So, if there is such low predictability past two weeks, then why….



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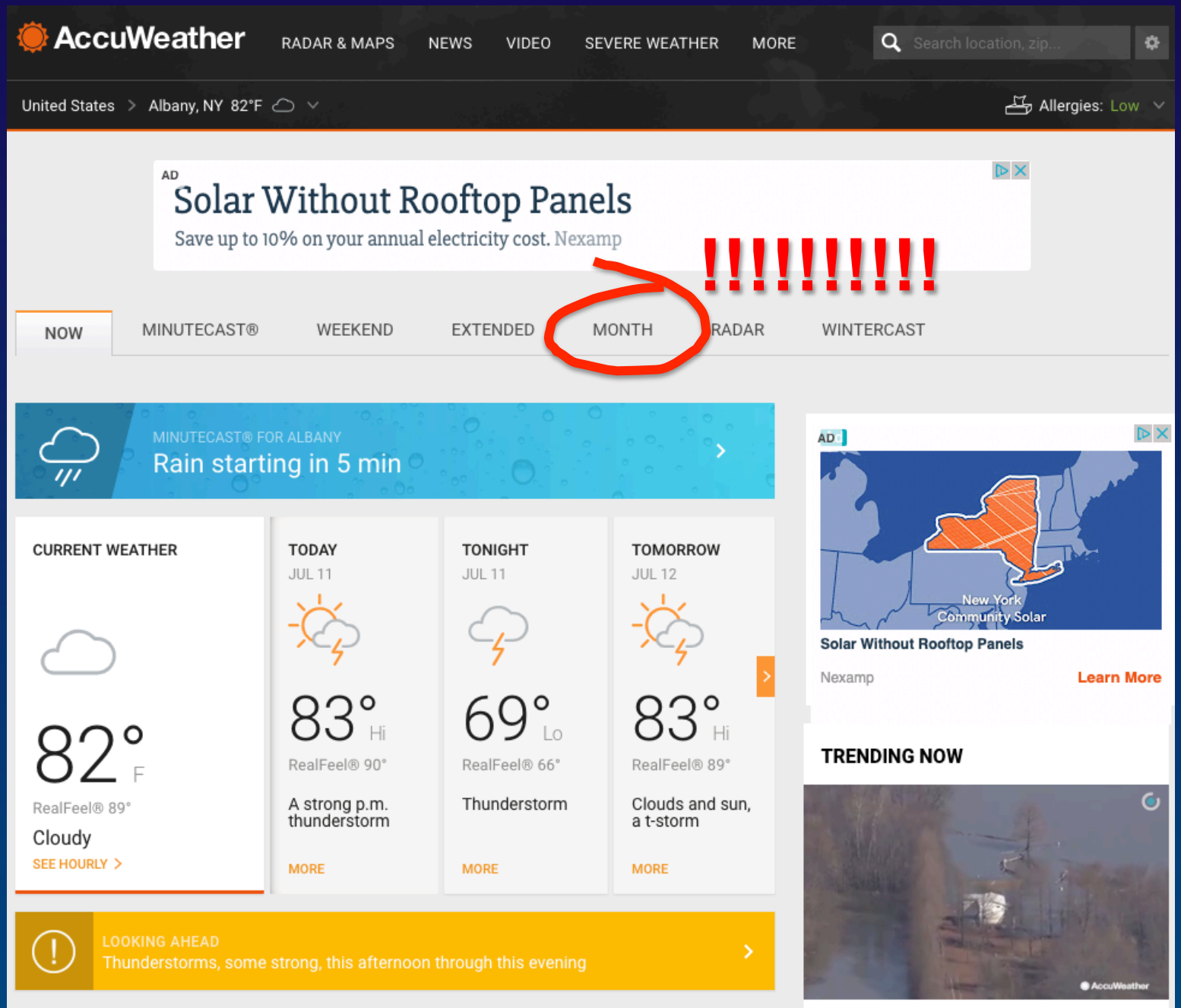

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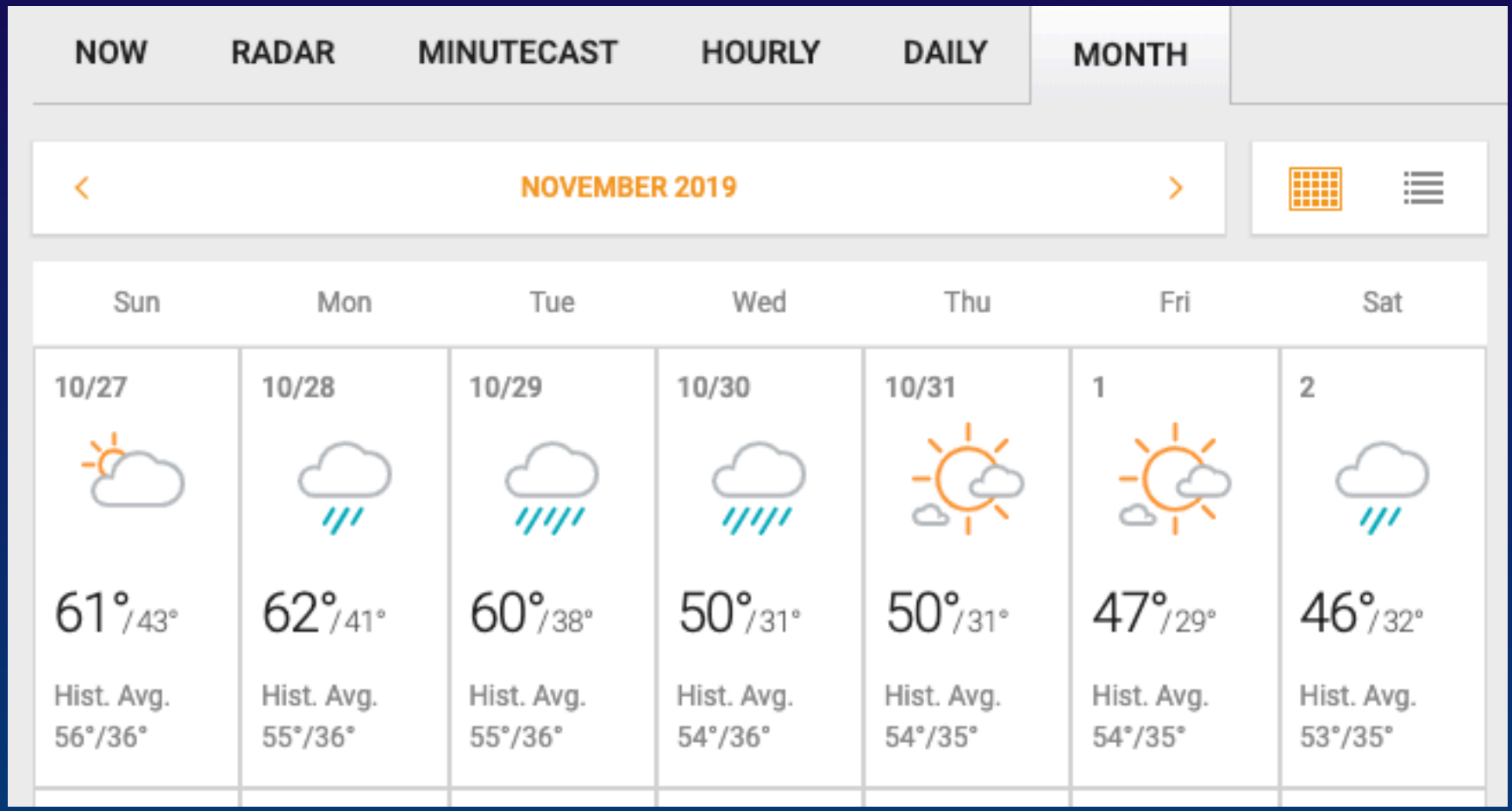


*This forecast is garbage!*

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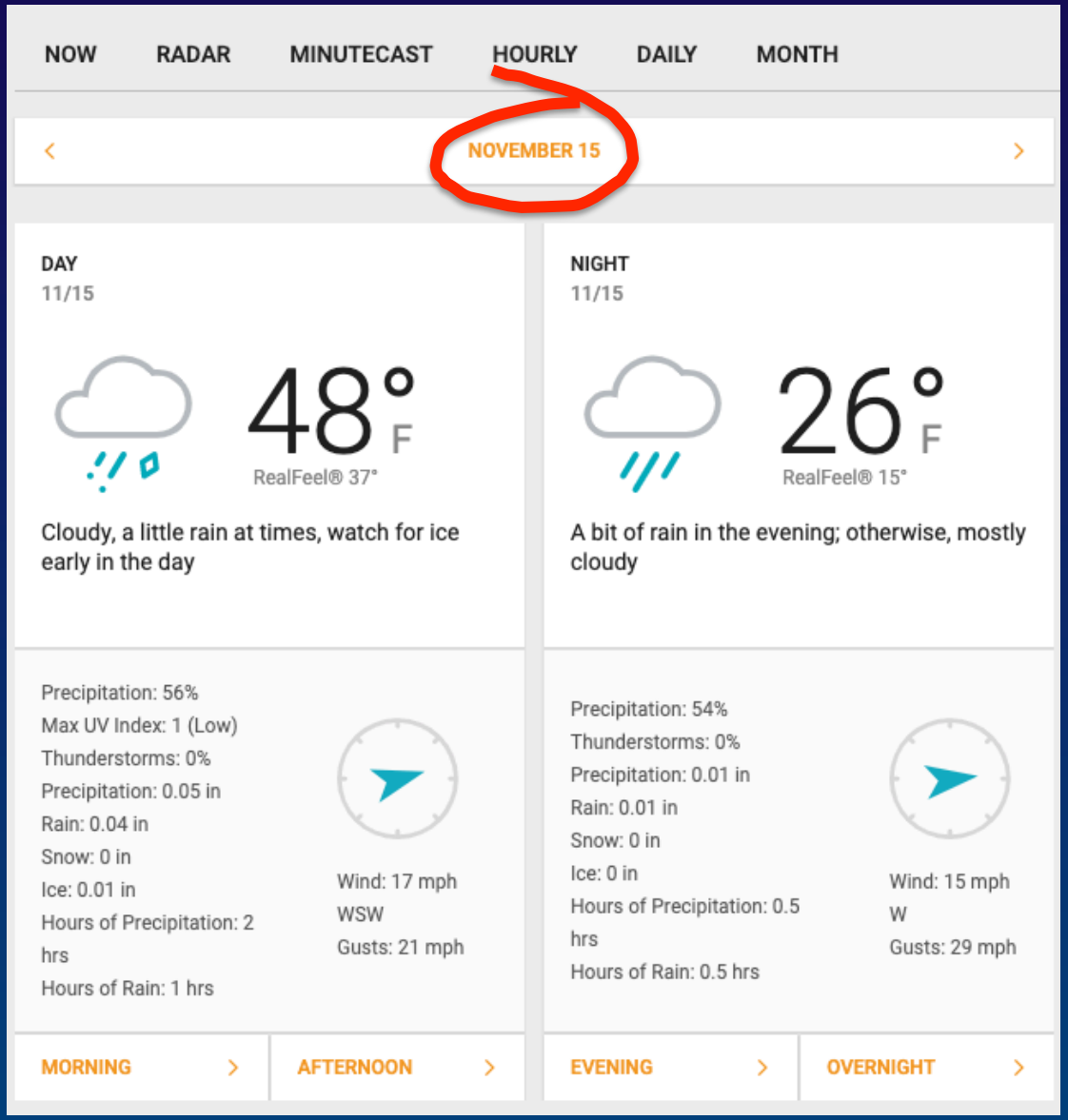
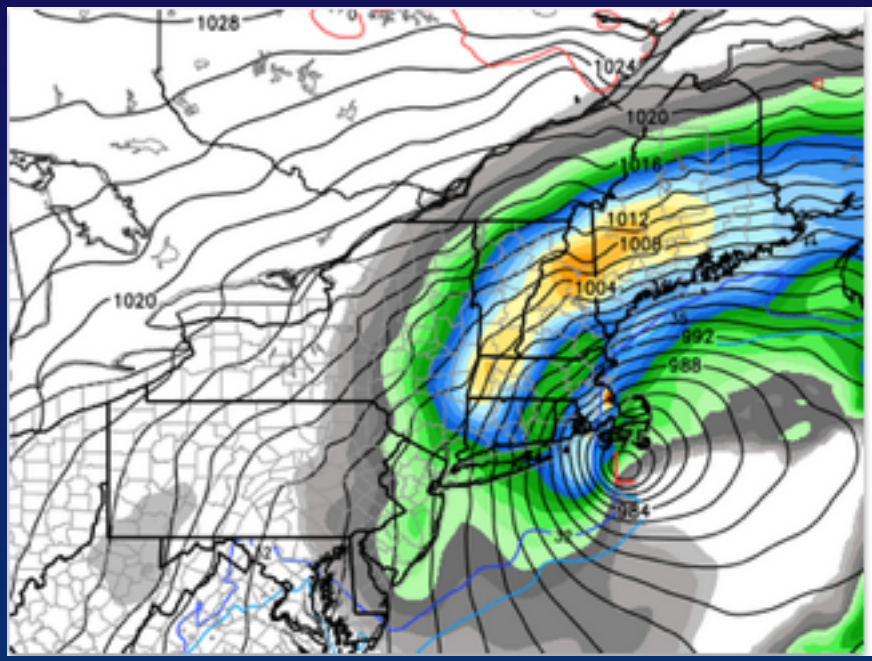
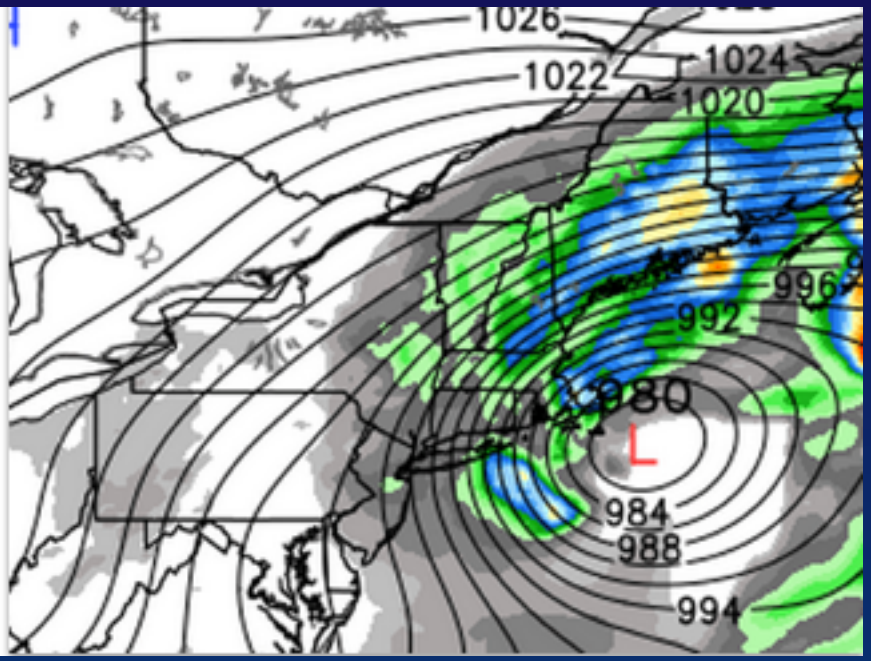



*This forecast is garbage!*

# Forecast model failure … January 27, 2015



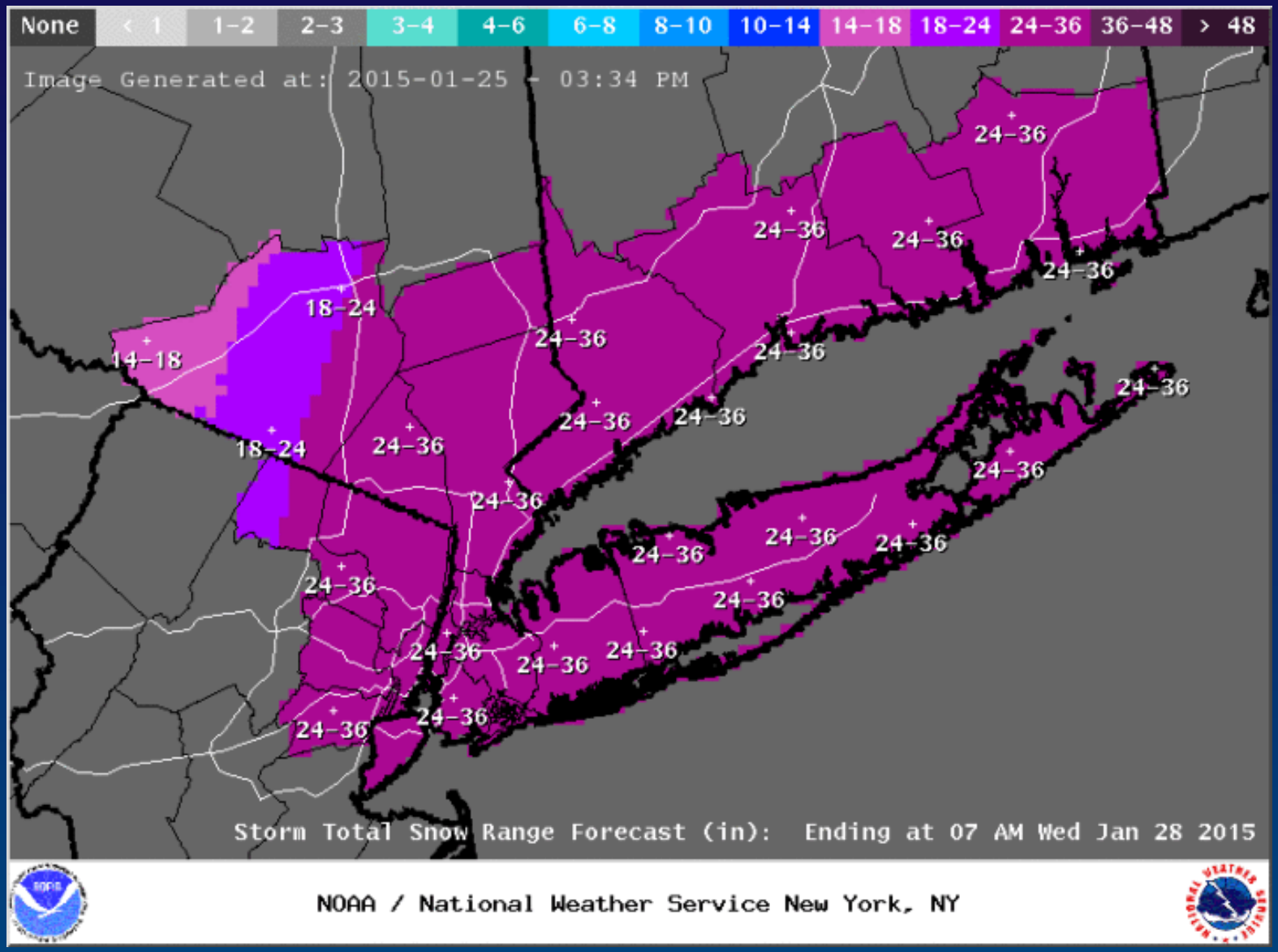

ECMWF 12Z 26 Jan 2015




GFS 12Z 26 Jan 2015

**Forecast precipitation for 00Z to 06Z 27 Jan 2015**

# Forecast model failure … January 27, 2015



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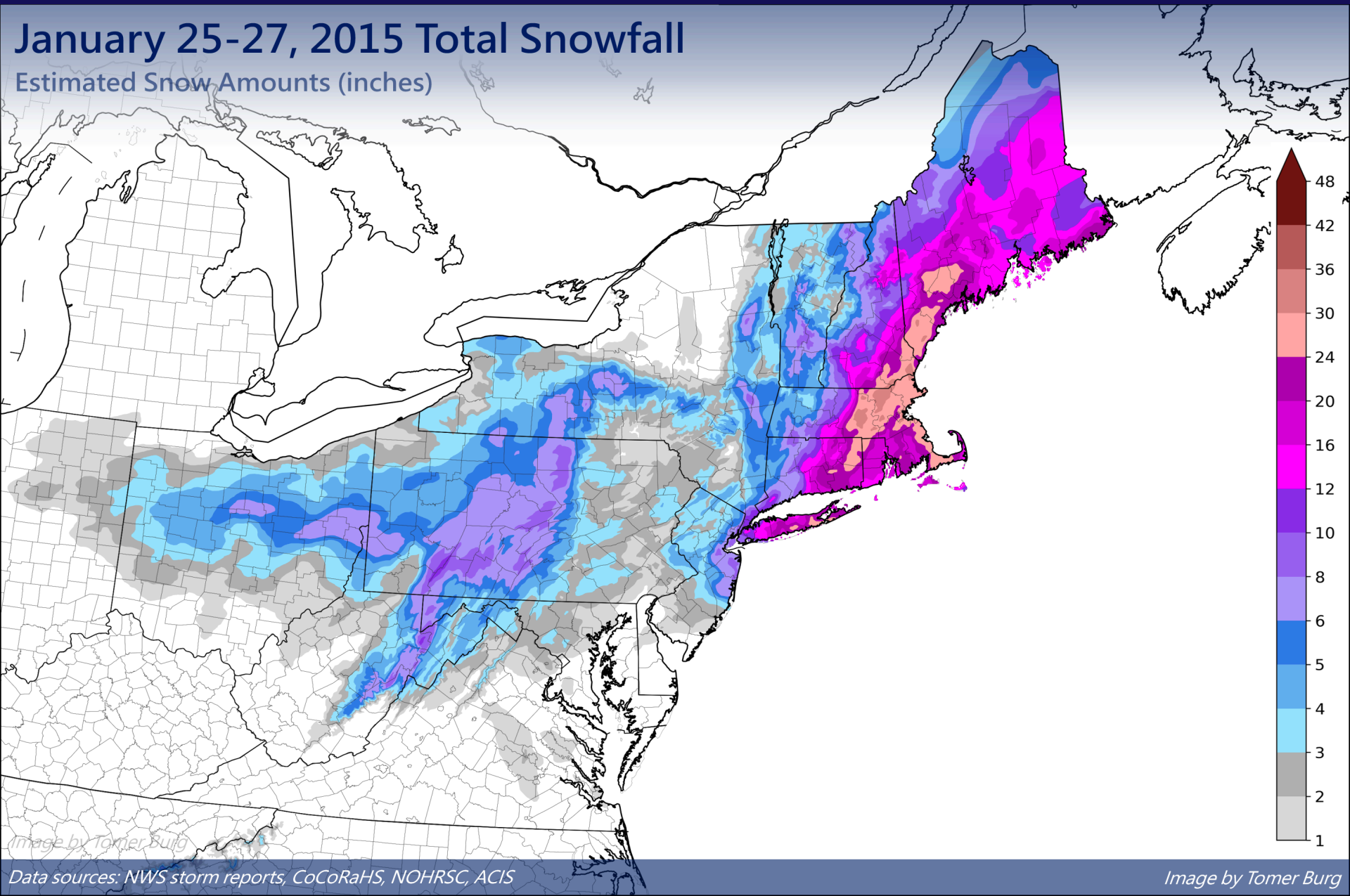


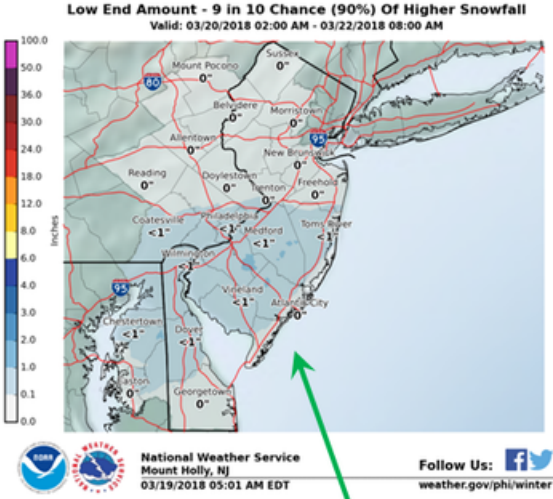
*Recent change:*

# National Weather Service now makes probabilistic snowfall forecasts!

## Snowfall Potential for Late Tonight – Wednesday (March 20-21)

### Low End Potential

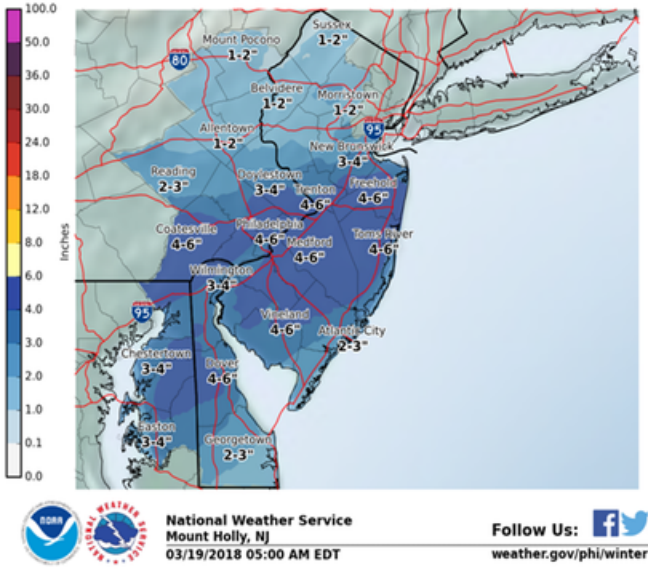
***9 in 10 (90%) Chance of Higher Snowfall***




*(Potential for lower amounts if the coastal storm tracks farther south & offshore)*

### Expected Snowfall

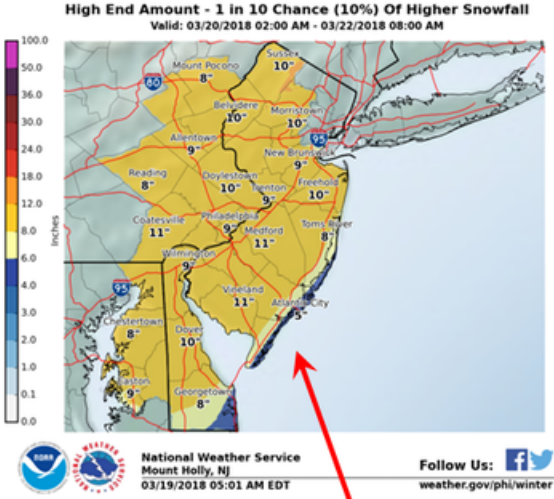
***Official NWS Forecast***




*National Weather Service*
*Mount Holly, N.J.*

### High End Potential

***1 in 10 (10%) Chance of Higher Snowfall***




*(Potential for higher amounts mainly on Wednesday if the second coastal storm tracks farther north & closer to the coast)*

# Forecast communication failure … November 15, 2018

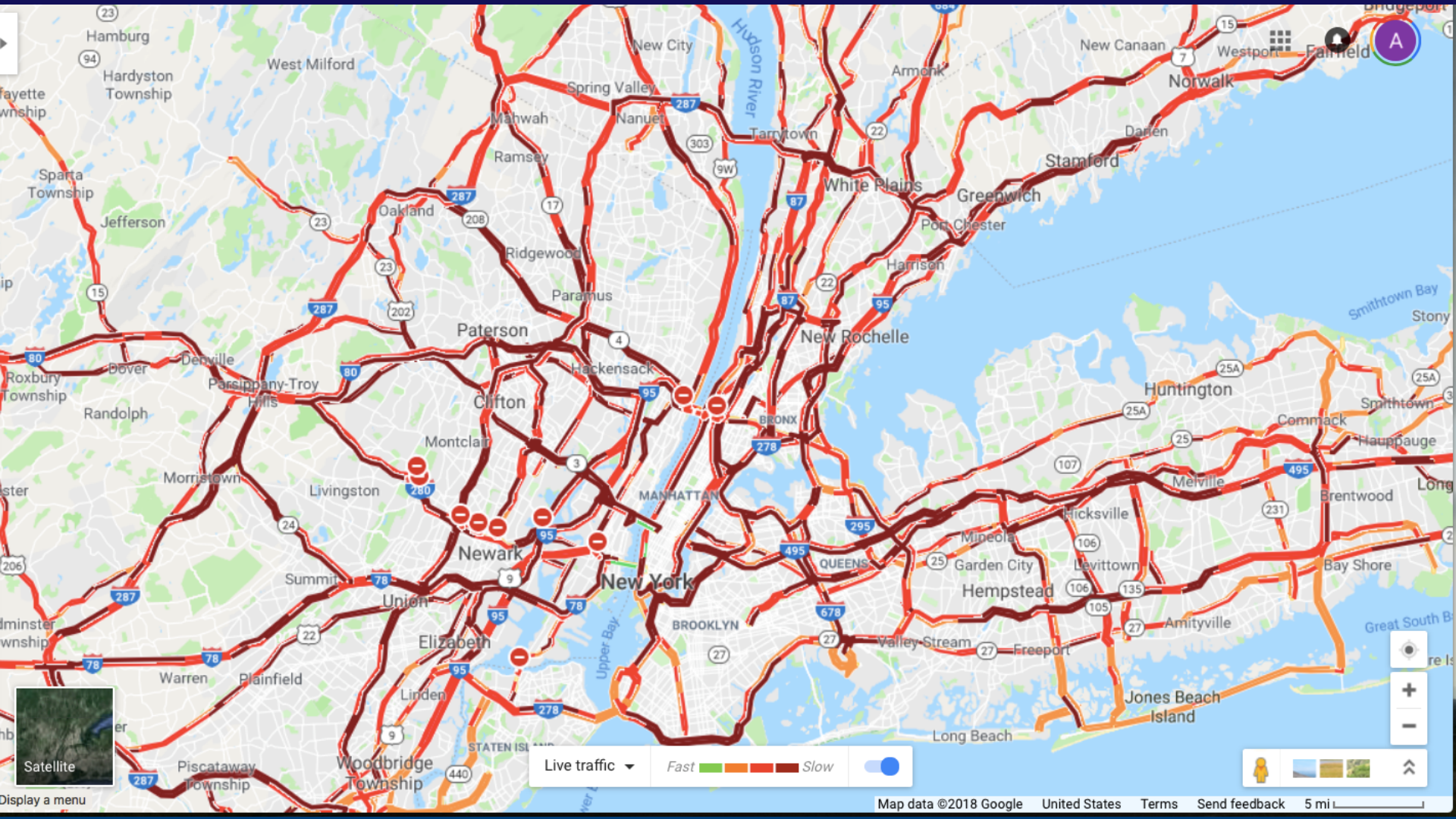
*CBS News*

- Heavy snow during afternoon and evening in NYC
- Poor forecasts despite fairly good and consistent model simulations


*New Jersey Globe*


*NY Post*

# Forecast communication failure … November 15, 2018



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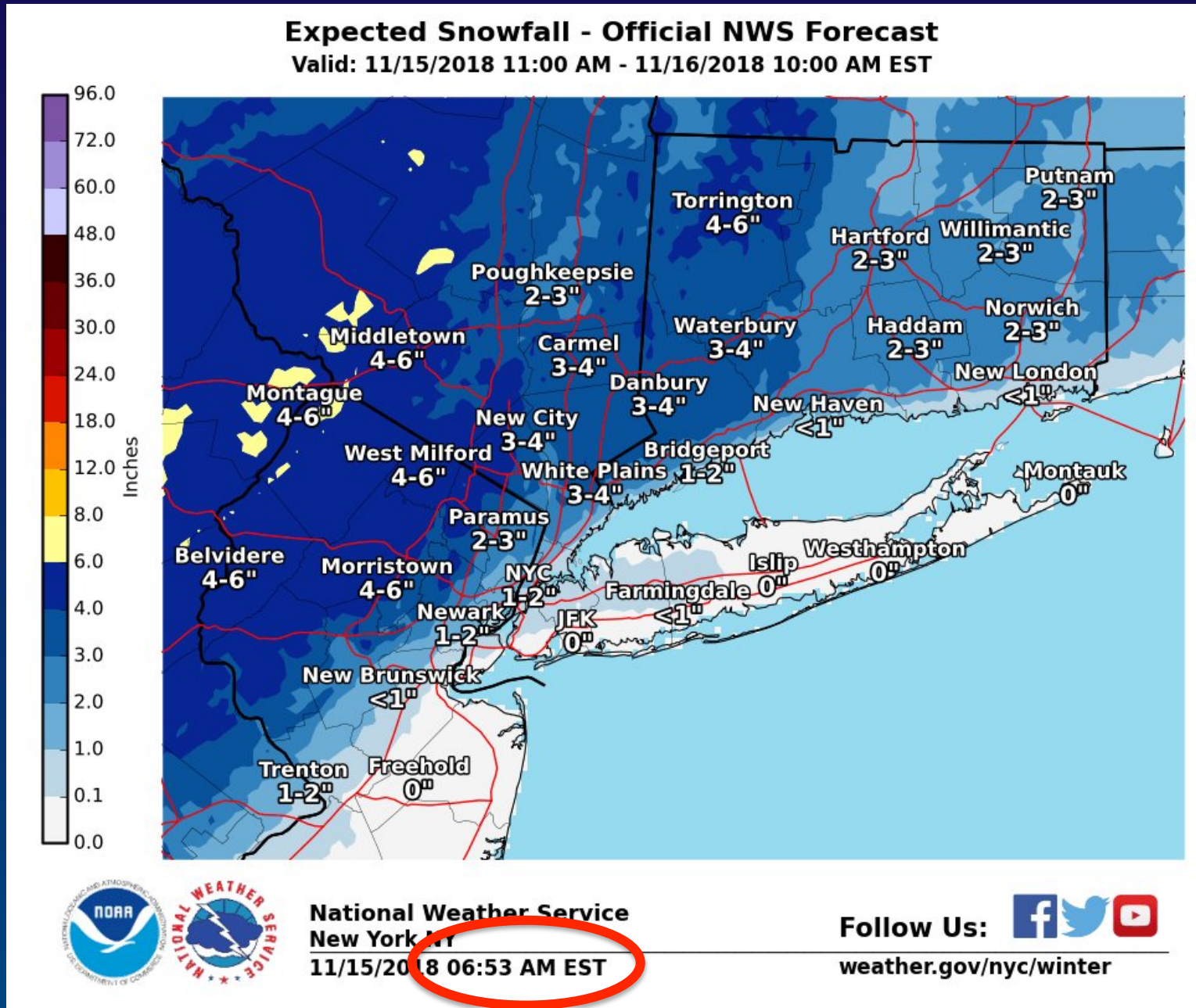

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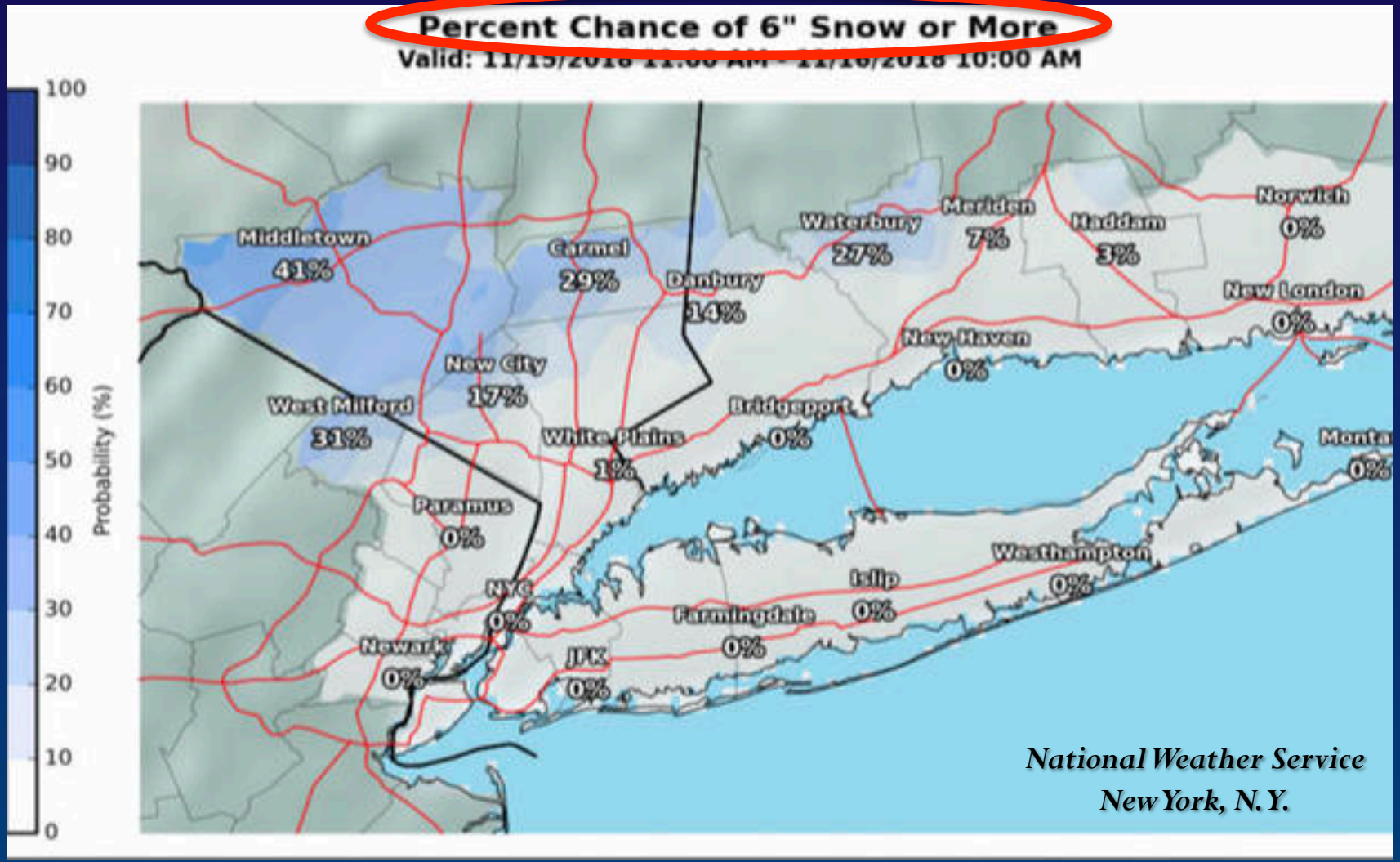
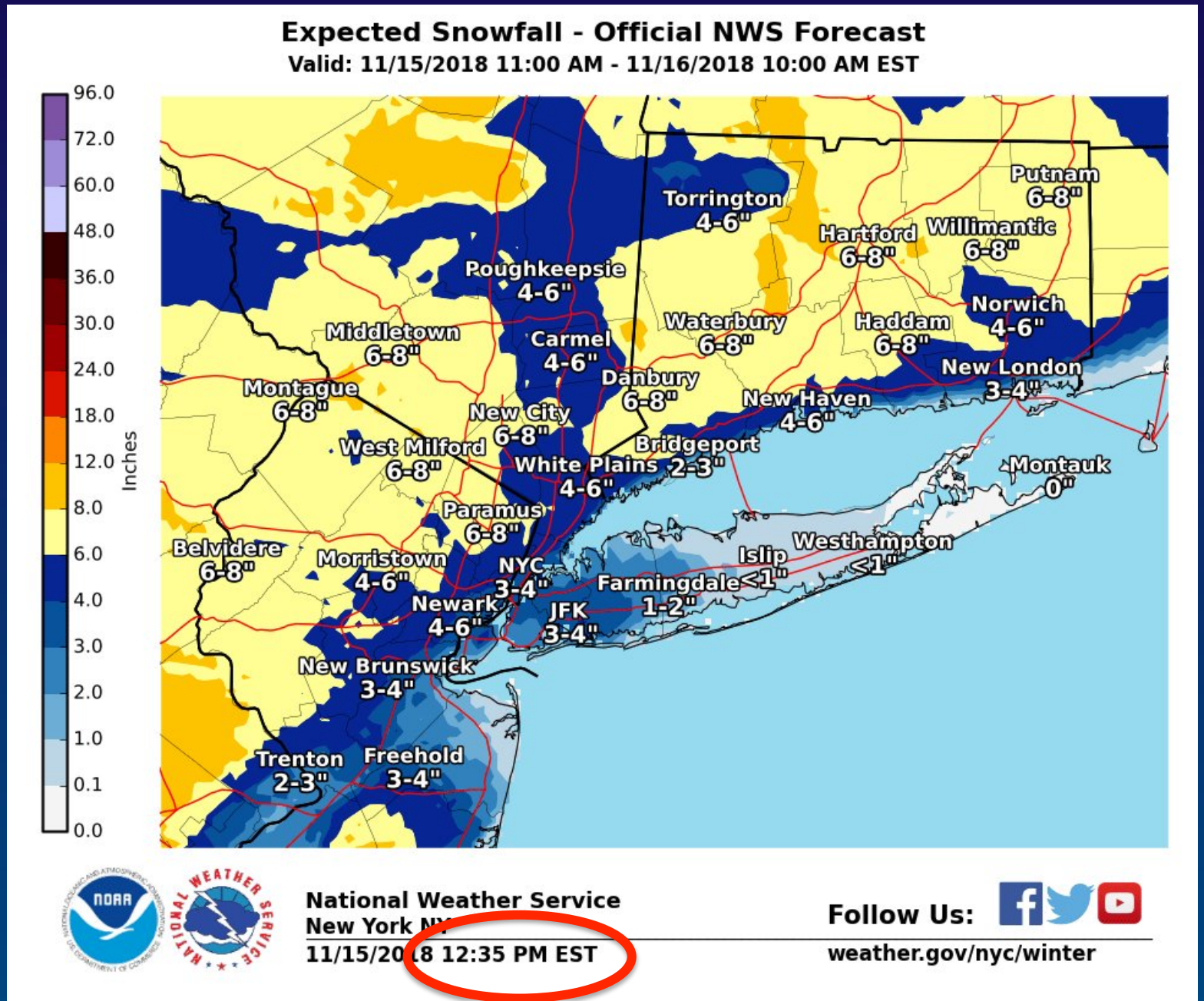



*Officially 6.4" at Central Park*

# Forecast communication failure … November 15, 2018



# Forecast communication failure … November 15, 2018

**What went wrong?**

- Time of year

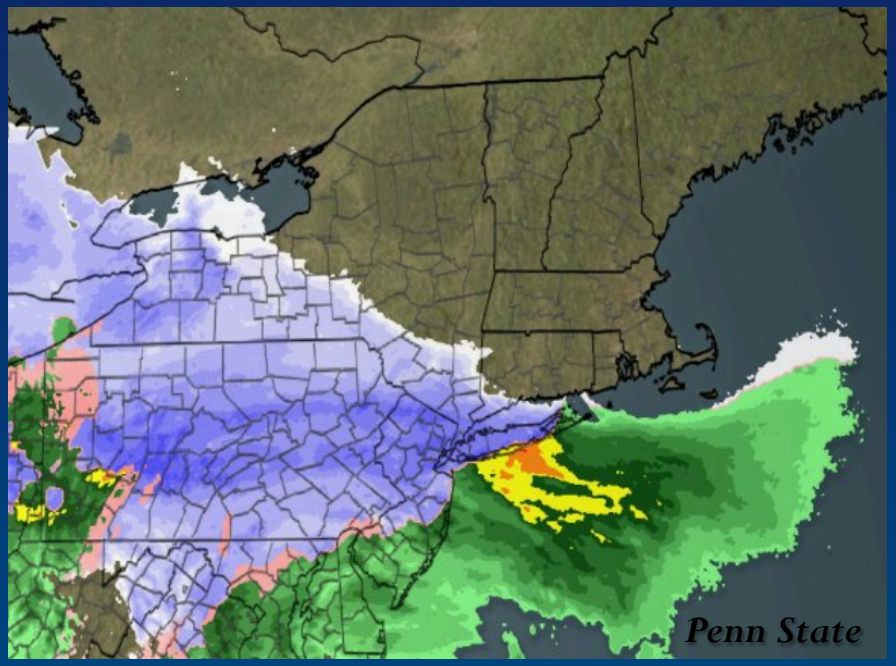
  *Unusual to have a major snowstorm in the Mid-Atlantic to NewYork City in mid-November, especially with relatively warm ocean waters*

- While some models were very consistent, others were less so, and meteorologists were hesitant at going "all in"

- Air was unusually dry

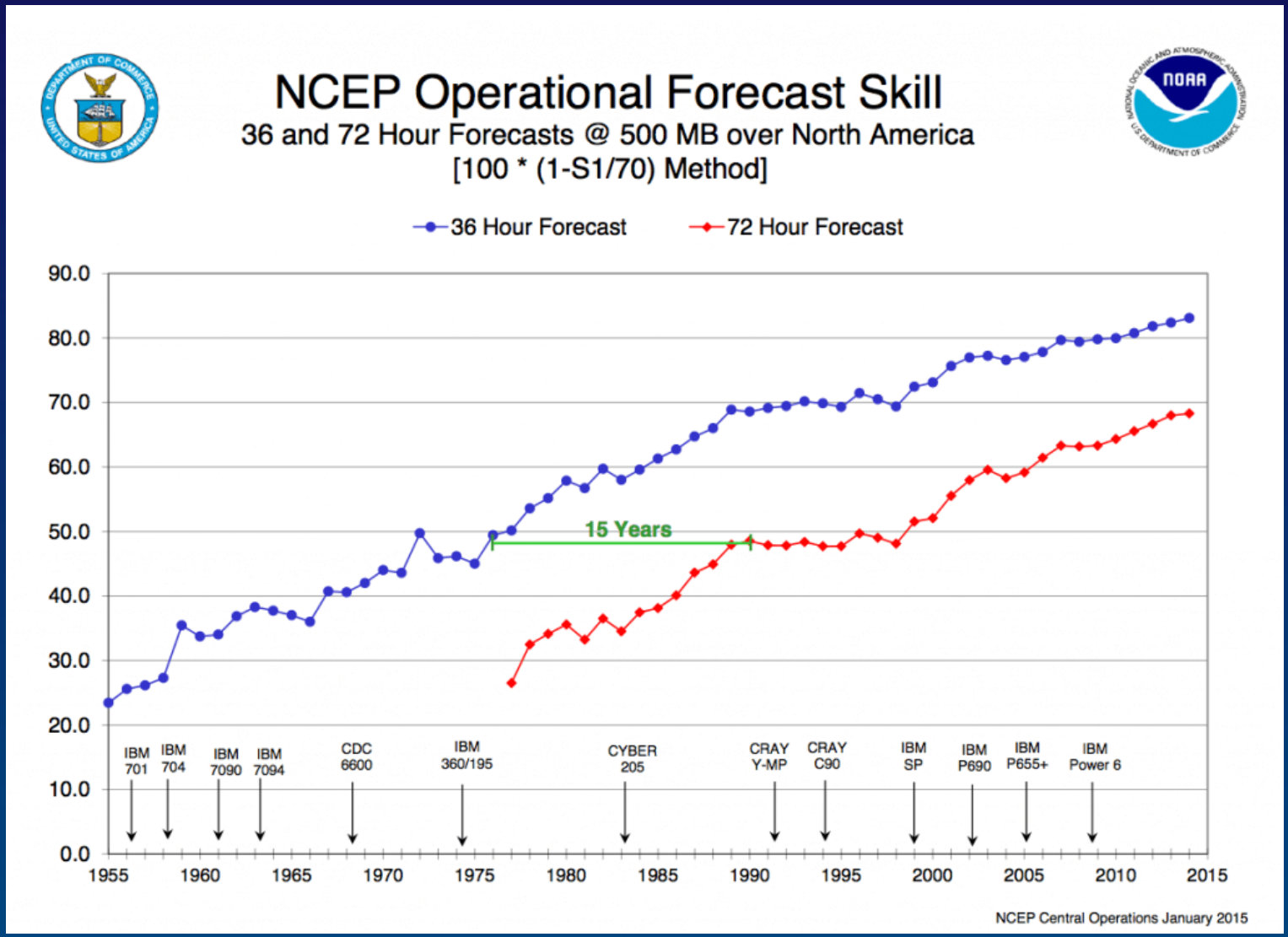
  *With surface winds coming from Canada, the air was drier than models indicated.*

  *Result: More evaporation, and more cooling (longer duration snow!)*

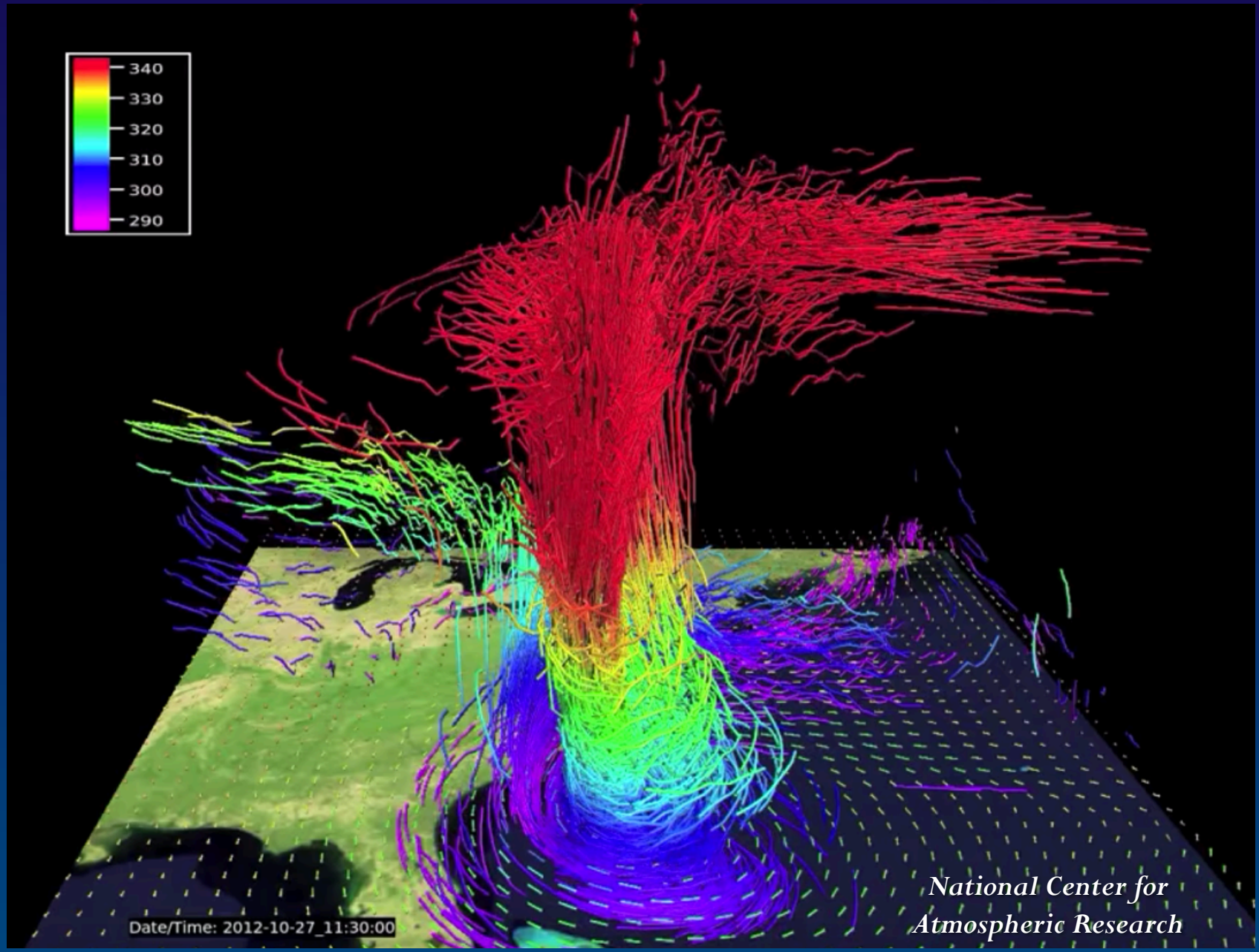


# We learn from storms like these …

# … and models and forecasters are improving every year!



# Future of weather forecasting



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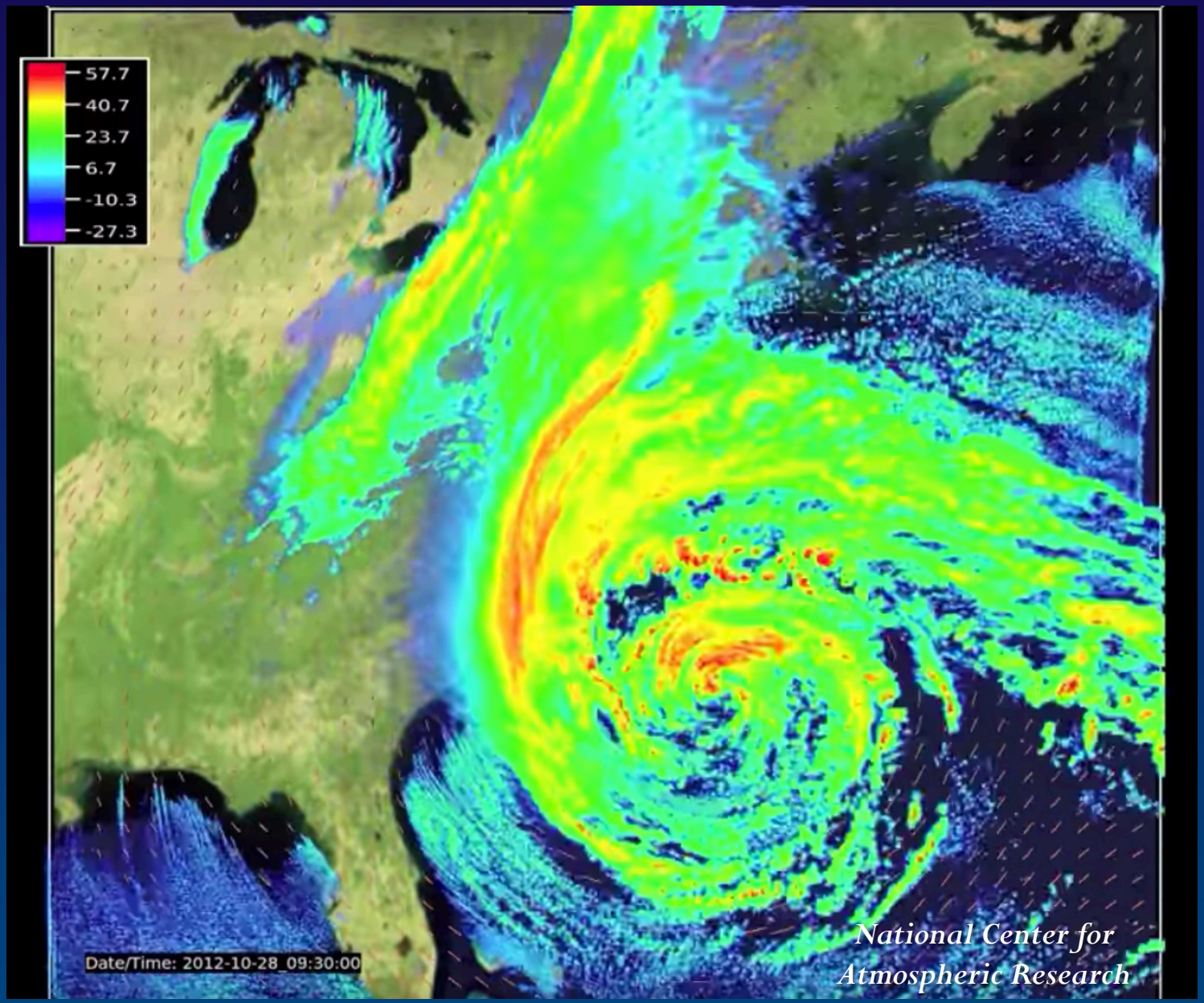

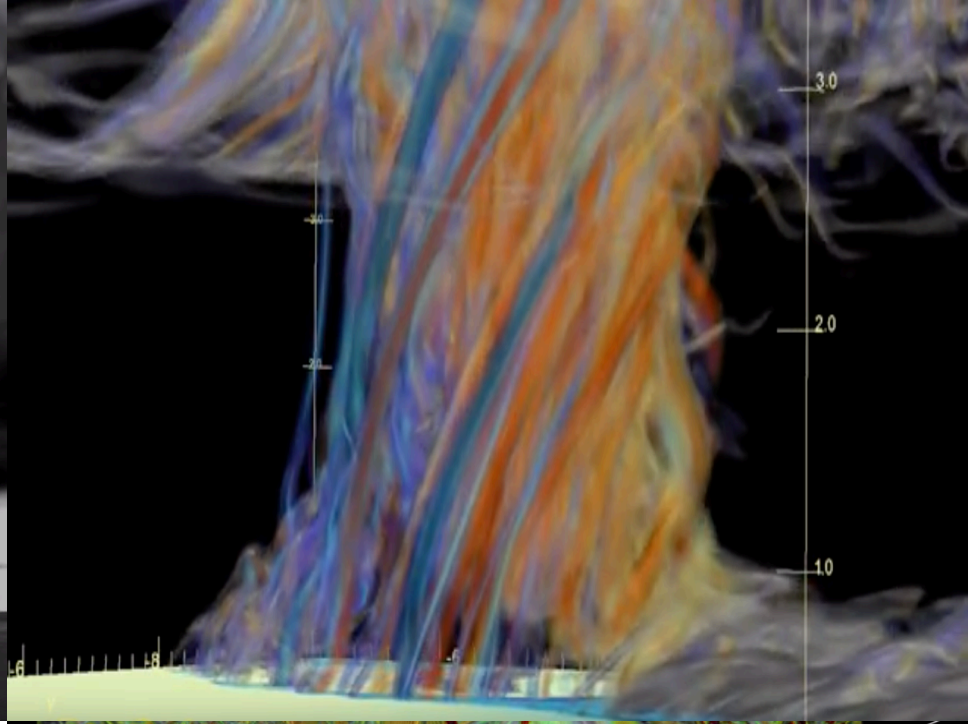
3.0
2.0
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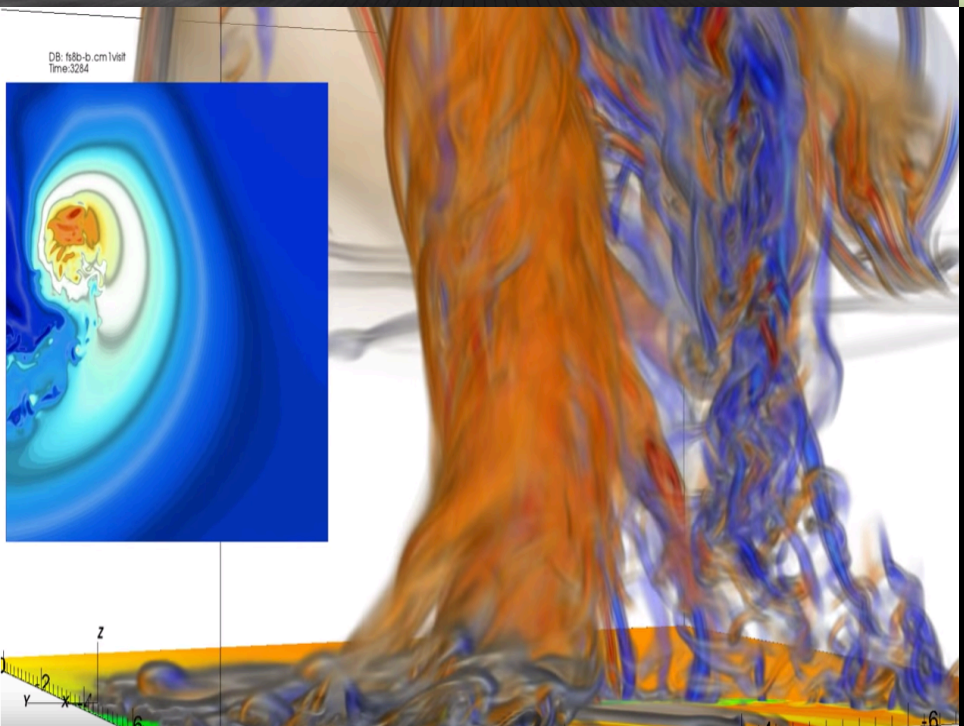
DB: fs8b-b.cm1visit
Time:3284
z
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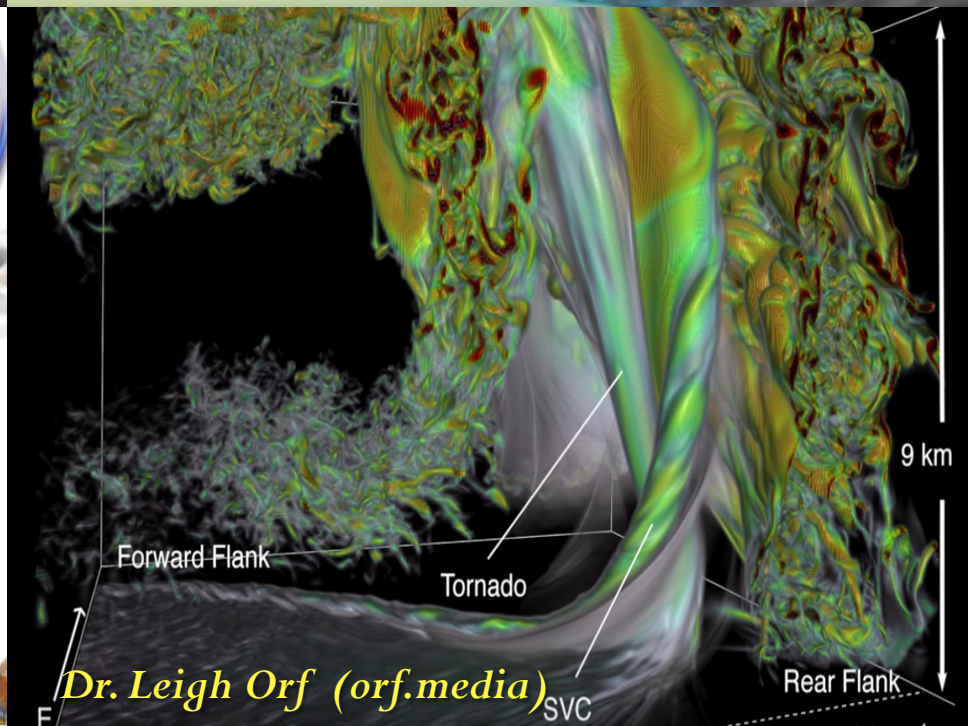

9 km
Forward Flank
Tornado
Rear Flank
SVC
Dr. Leigh Orf (orf.media)

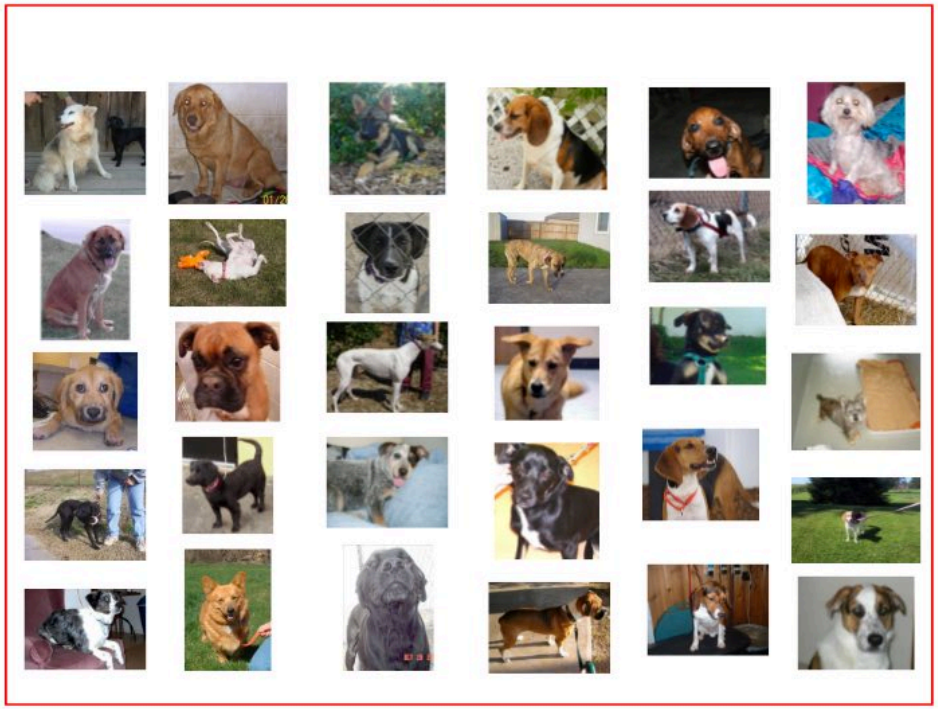
# Artificial intelligence and weather forecasting

**Rather than use a model to forecast the weather, we can use pattern recognition**

*Train a **machine learning algorithm** to learn what certain objects look like:*

Cats

Dogs

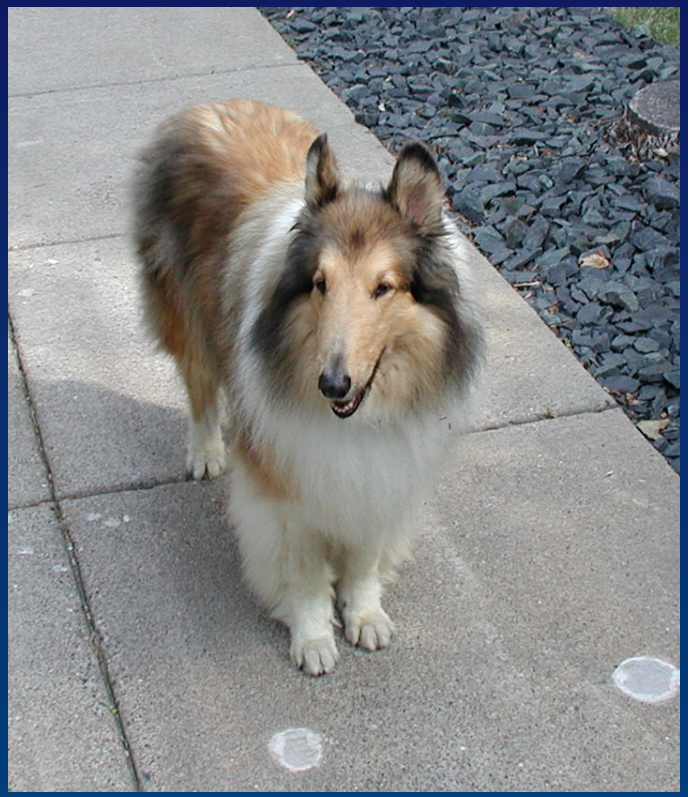


*Sample cats and dogs from entire training dataset (from Adil Moujahid)*

# Artificial intelligence and weather forecasting

**Rather than use a model to forecast the weather, we can try pattern recognition**

*Train a **machine learning algorithm** to learn what certain objects look like:*



**Dog (Quint)**

**Cat (Maya)**

# Artificial intelligence and weather forecasting


**Can a machine learning algorithm tell the difference between:**

***A chihuahua and a blueberry muffin?***


chocolate cookie


fawn smooth Chihuahua


baked blueberry muffin


white chihuahua


fawn smooth Chihuahua


blueberry muffin


fawn smooth Chihuahua


muffin


[unknown]


brown coated Chihuahua


baked muffin


beige short coated puppy


tan smooth Chihuahua puppy


blueberry cupcakes


three smooth Chihuahua puppies

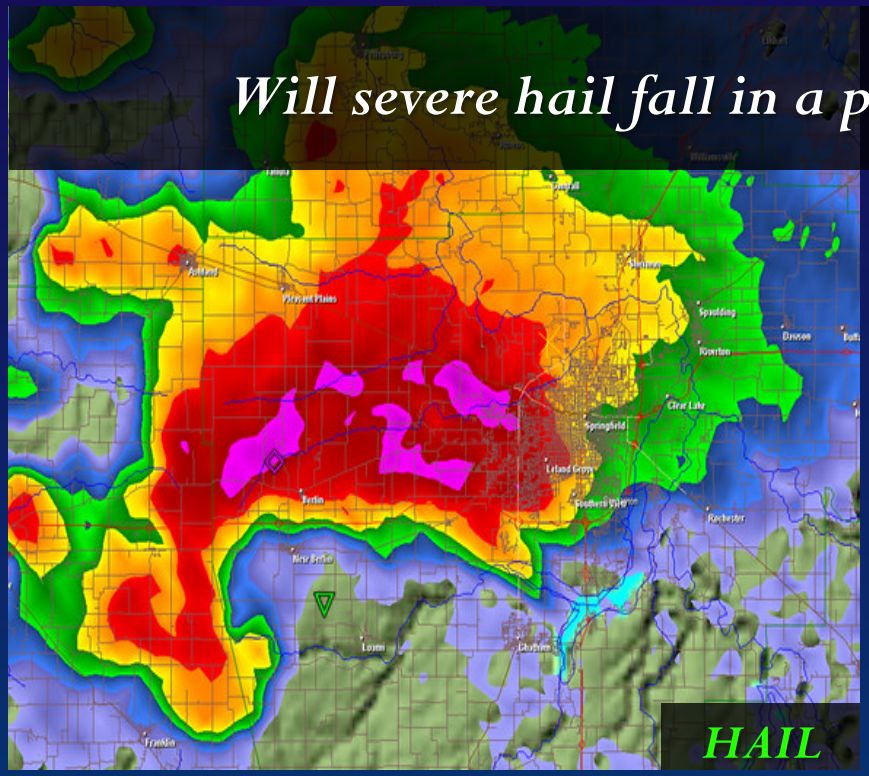

white and black muffin

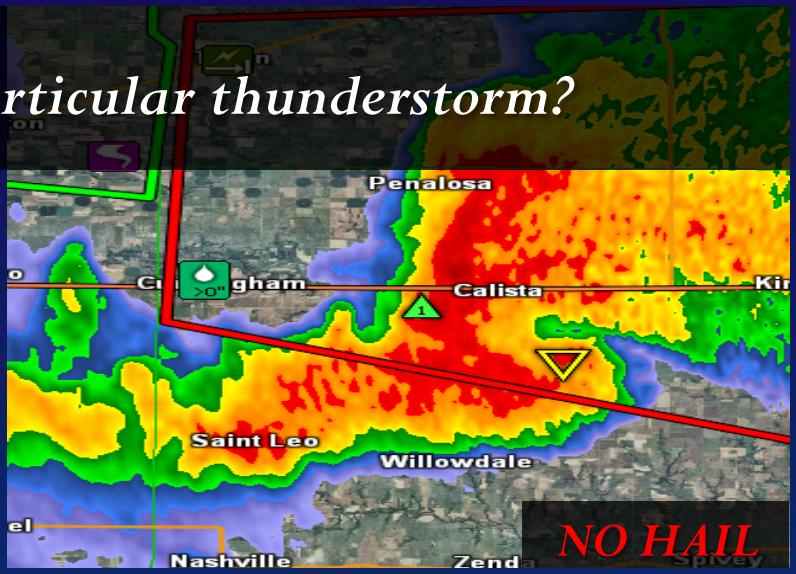
CloudSight™

**Mostly yes … but what does this have to do with weather?!**

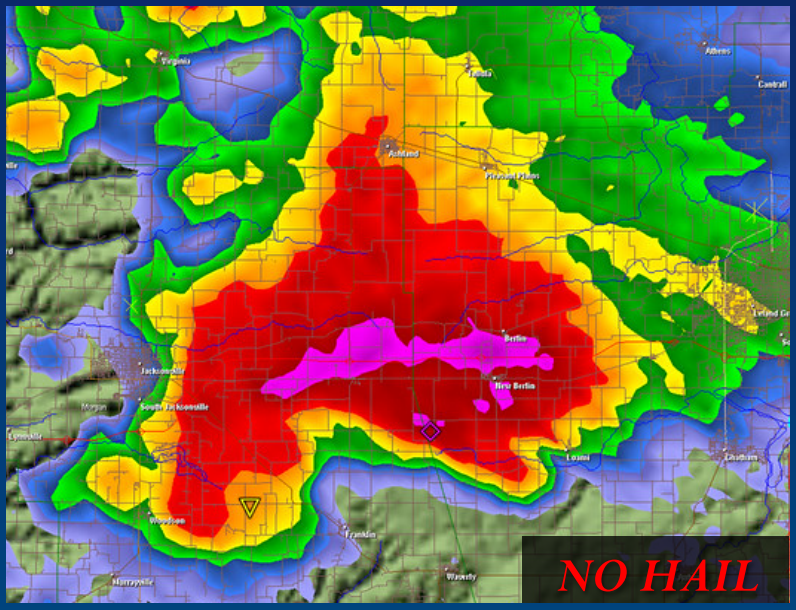
# Artificial intelligence and weather forecasting

*Will severe hail fall in a particular thunderstorm?*



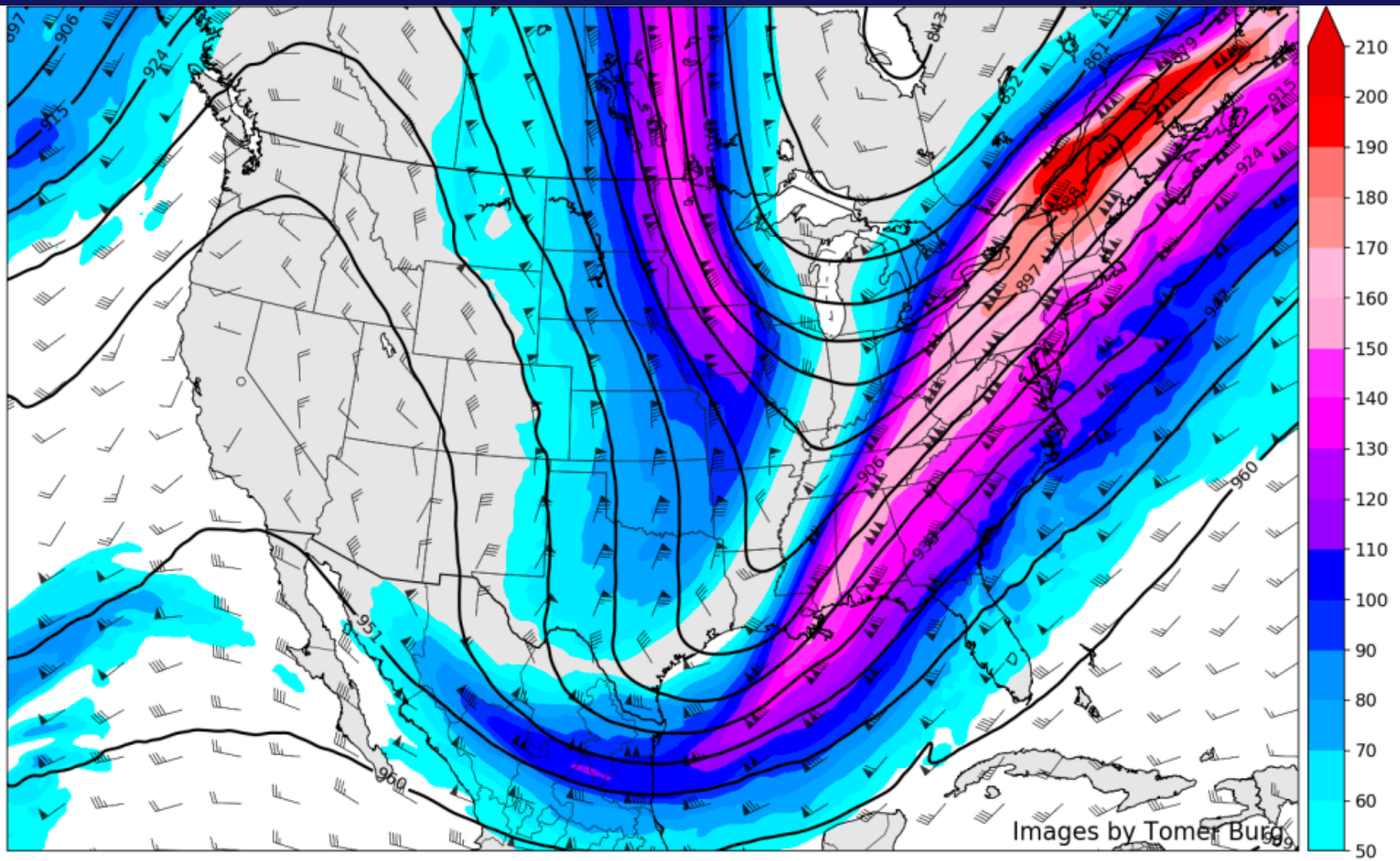







# Artificial intelligence and weather forecasting

***Will a particular jet stream result in a major nor'easter?***



# In summary …

**Past:** With the 20th century advent of advanced computing, we were able to make use of early equations theorized to predict the weather.

**Present:** We are presented with **many models**, and **model ensembles**!

-Must come up with better ways to disseminate **probabilistic forecasts**

-New methods of seasonal and subseasonal forecasting

-Climate models

**Future:**

-Higher resolution models

-**Artificial intelligence** as a new, non-dynamical forecasting method

*Thank you!*

**Questions?**


# Trivia for a $100 gift card to the UAlbany Bookstore!

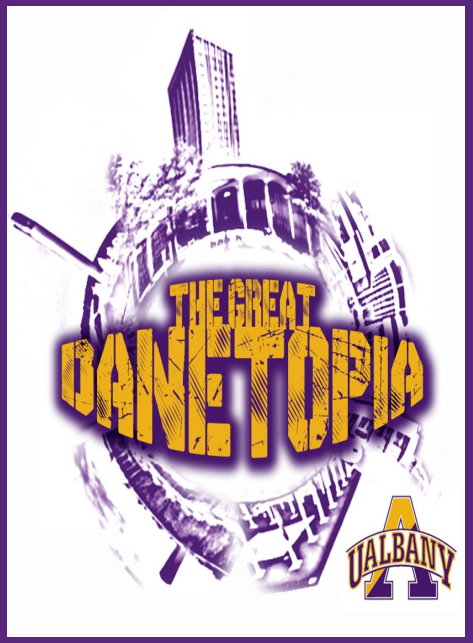
SEFCU

Check out their mobile app and branch in the Campus Center.

Special thanks to SEFCU for supporting Explore UAlbany!


# Next Steps to Success…

**NOW:** Learn about support offices




**9/24:** Meet faculty and advisors from all majors and minors


**ANYTIME:** Get to know a professor or advisor over lunch