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

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
  - Developed primitive equations to describe atmospheric motion (*still used today!!!!*)

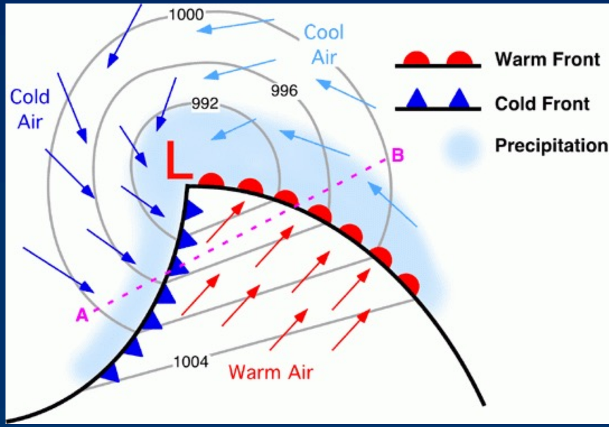
Prof. Vilhelm Bjerknes

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

  Given the initial state of the atmosphere, 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.

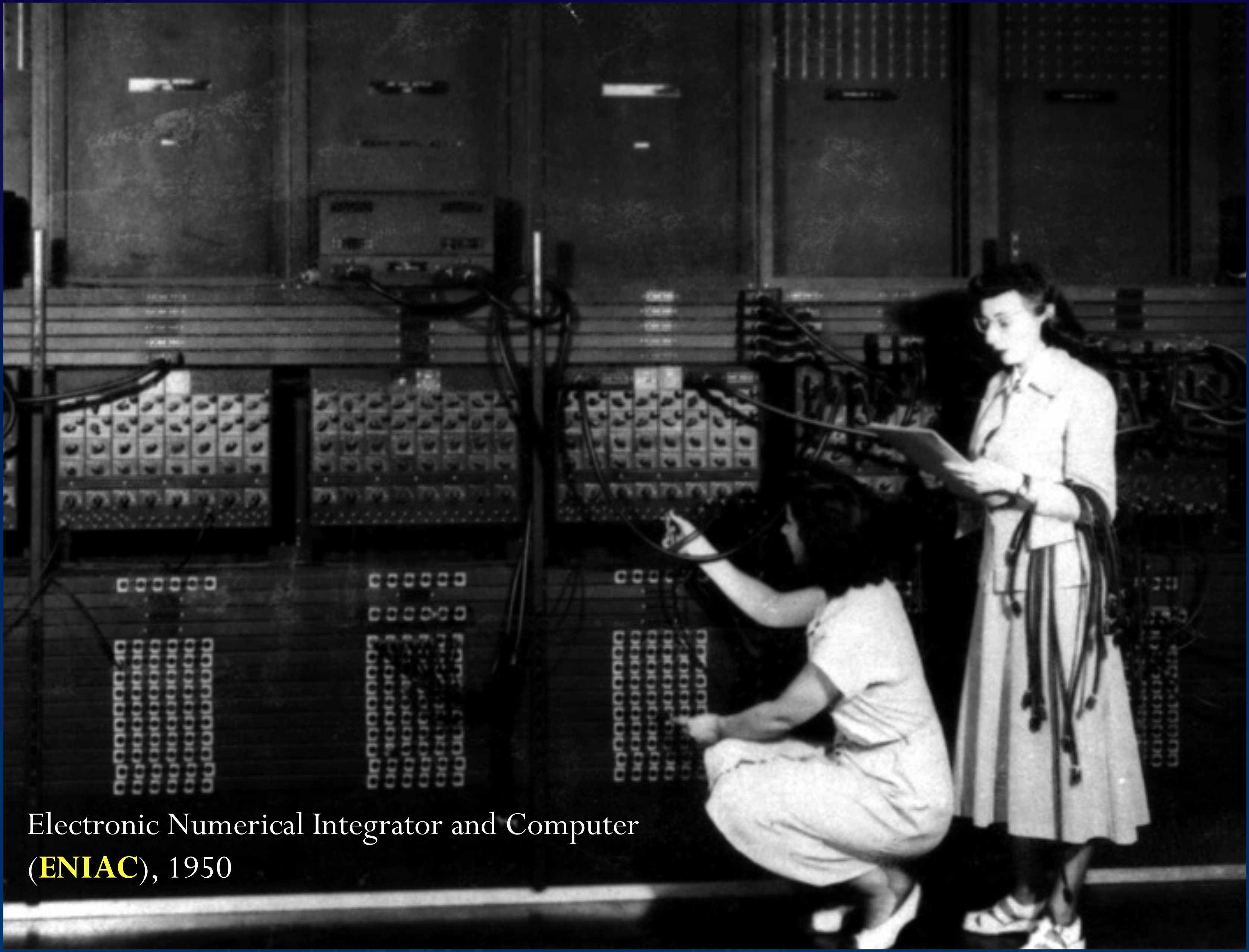
U.K. meteorologists Pettersen and Douglas asserted that the morning of **June 6** would provide a brief weakening of the winds between weather systems.

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!


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


H
L
H
60
H
78
L
80
1970s

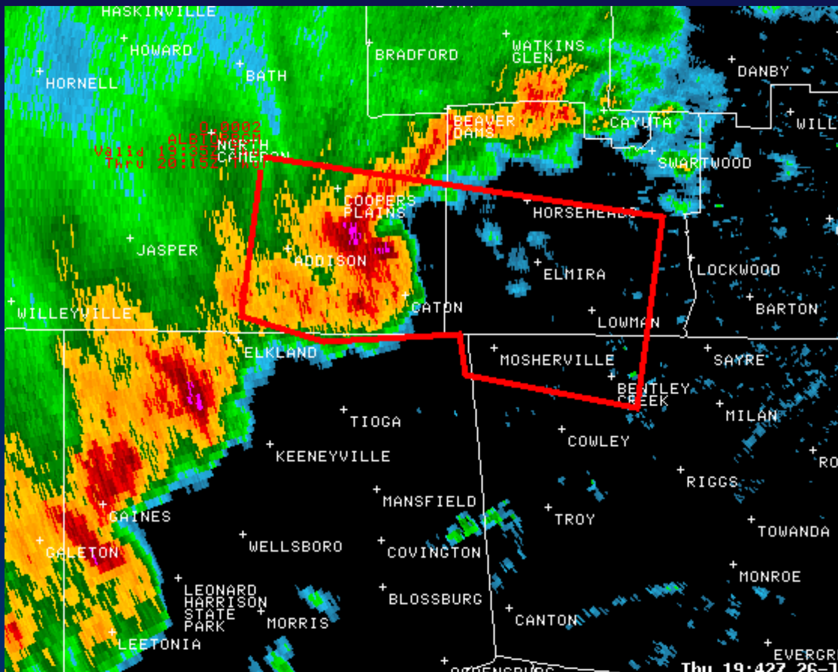

CURRENT
H
H
H
H
L
1990s

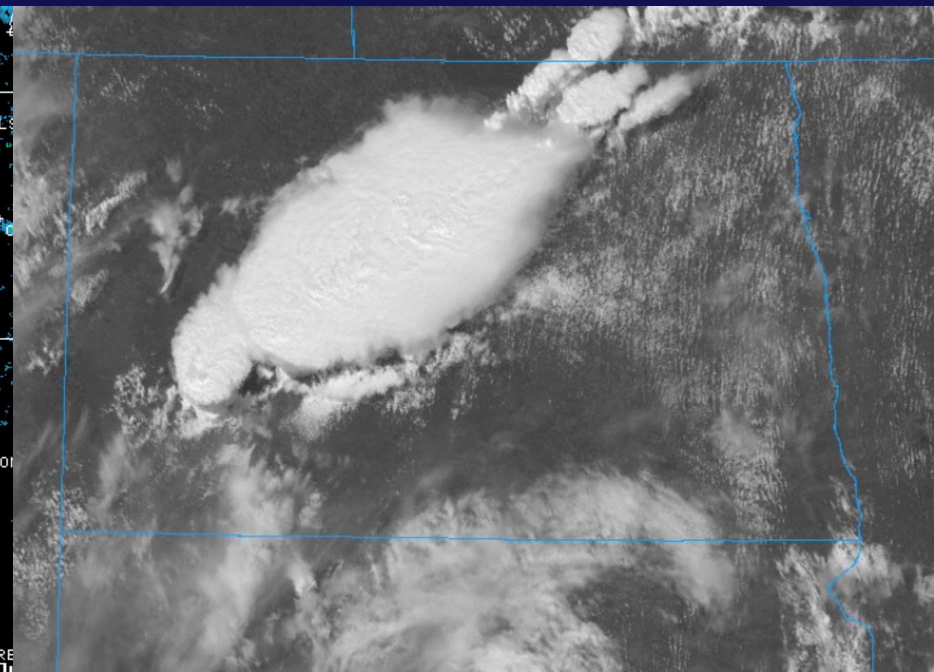

TROPICAL DOWNPOURS
THU 7/11
AREAS OF SPIN | EURO MODEL
Memphis
Dallas
Atlanta
New Orleans
Corpus Christi
Miami
2019
CLOSELY WATCHING THE GULF OF MEXICO
The Weather Channel
2:14 / 3:02
A Tropical Depression could form by the end of the week

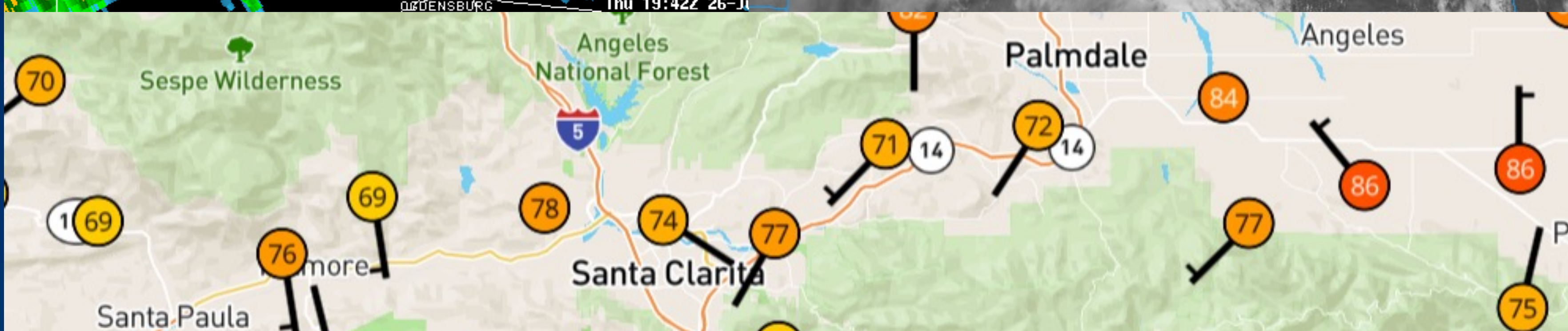
Types of forecasts

Nowcasting:

Forecasts of up to six hours in advance

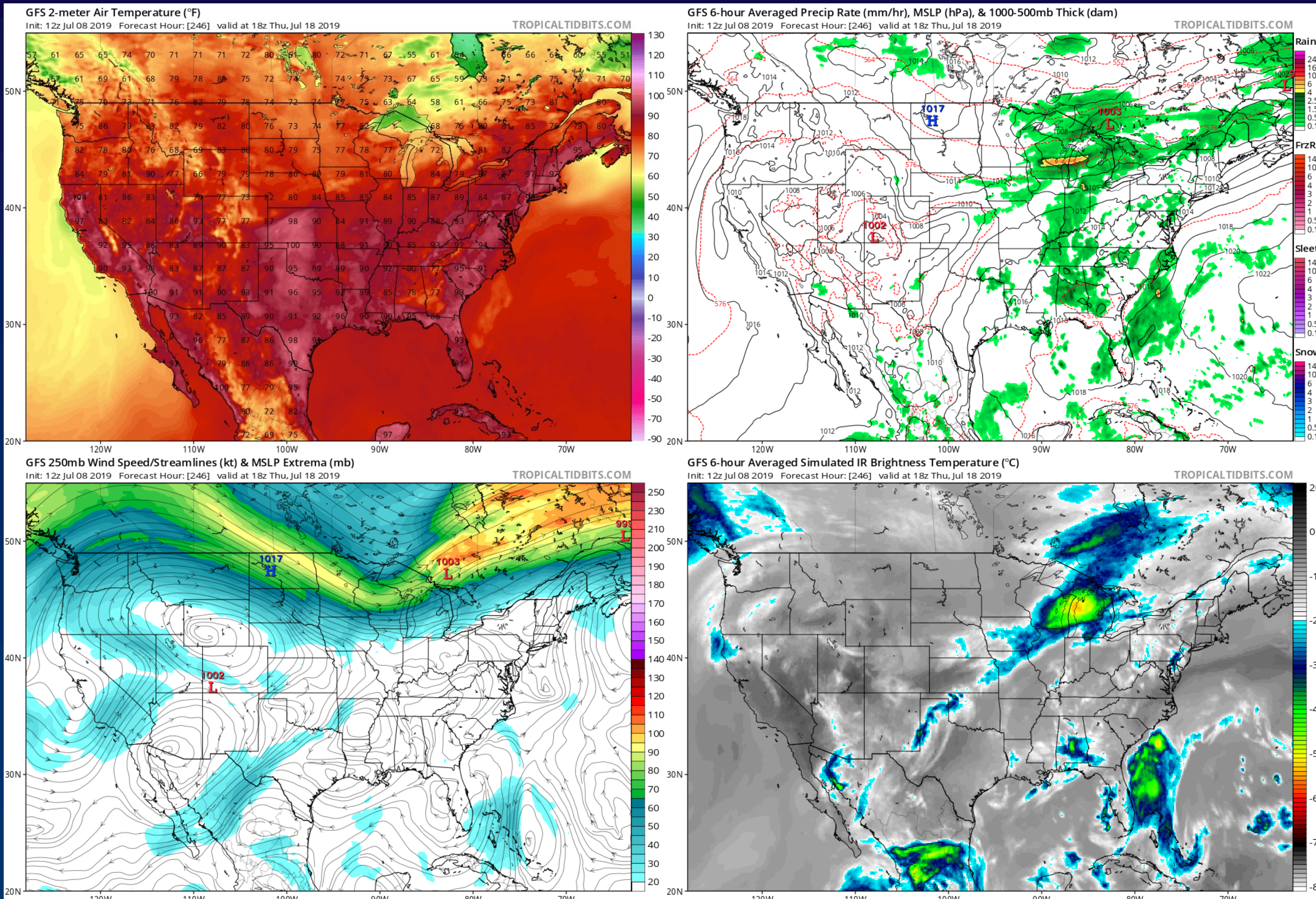






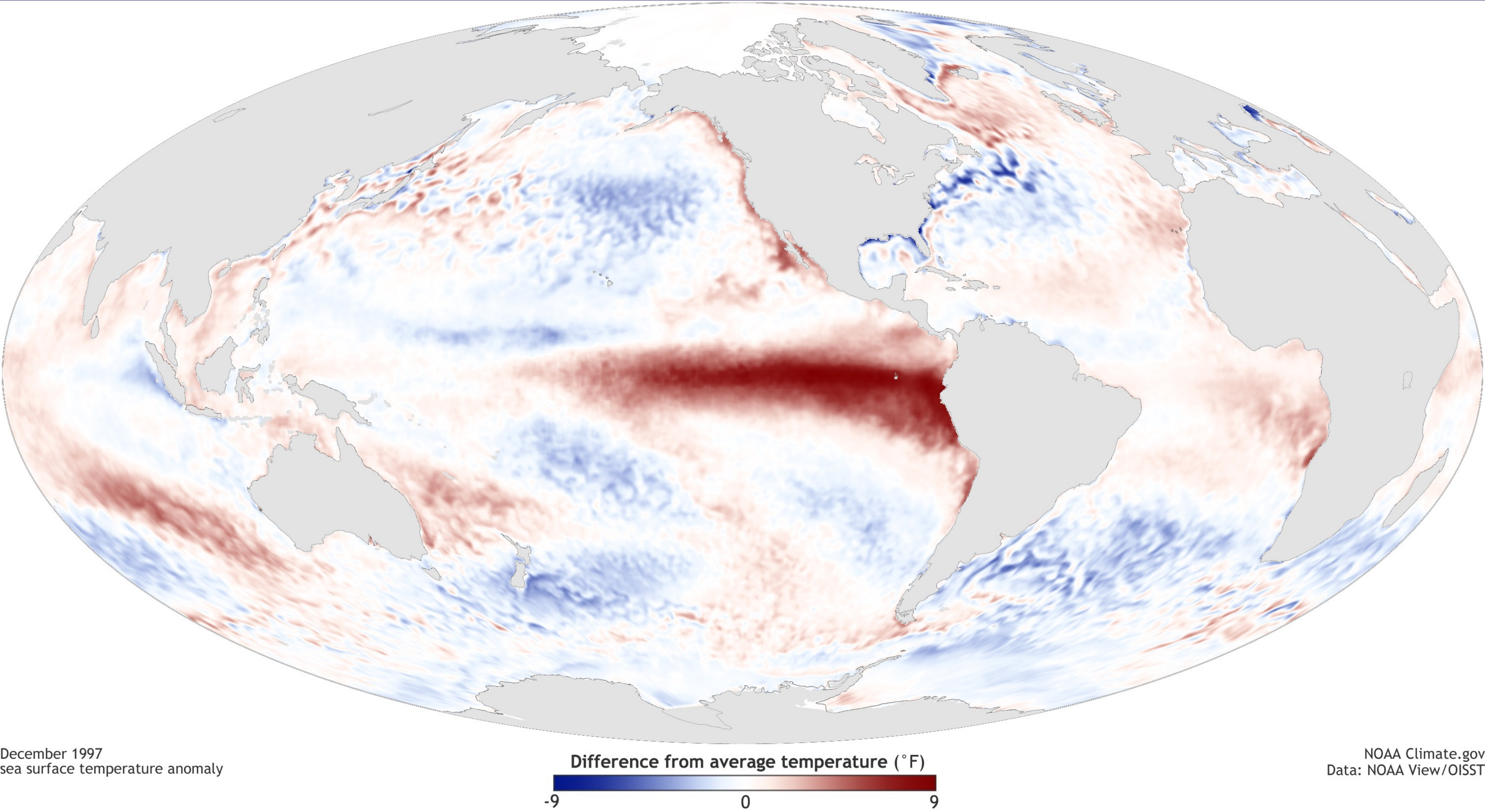
Short-range weather forecasts:

Forecasts of up to 7-10 days in advance



Seasonal to Subseasonal forecasting

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

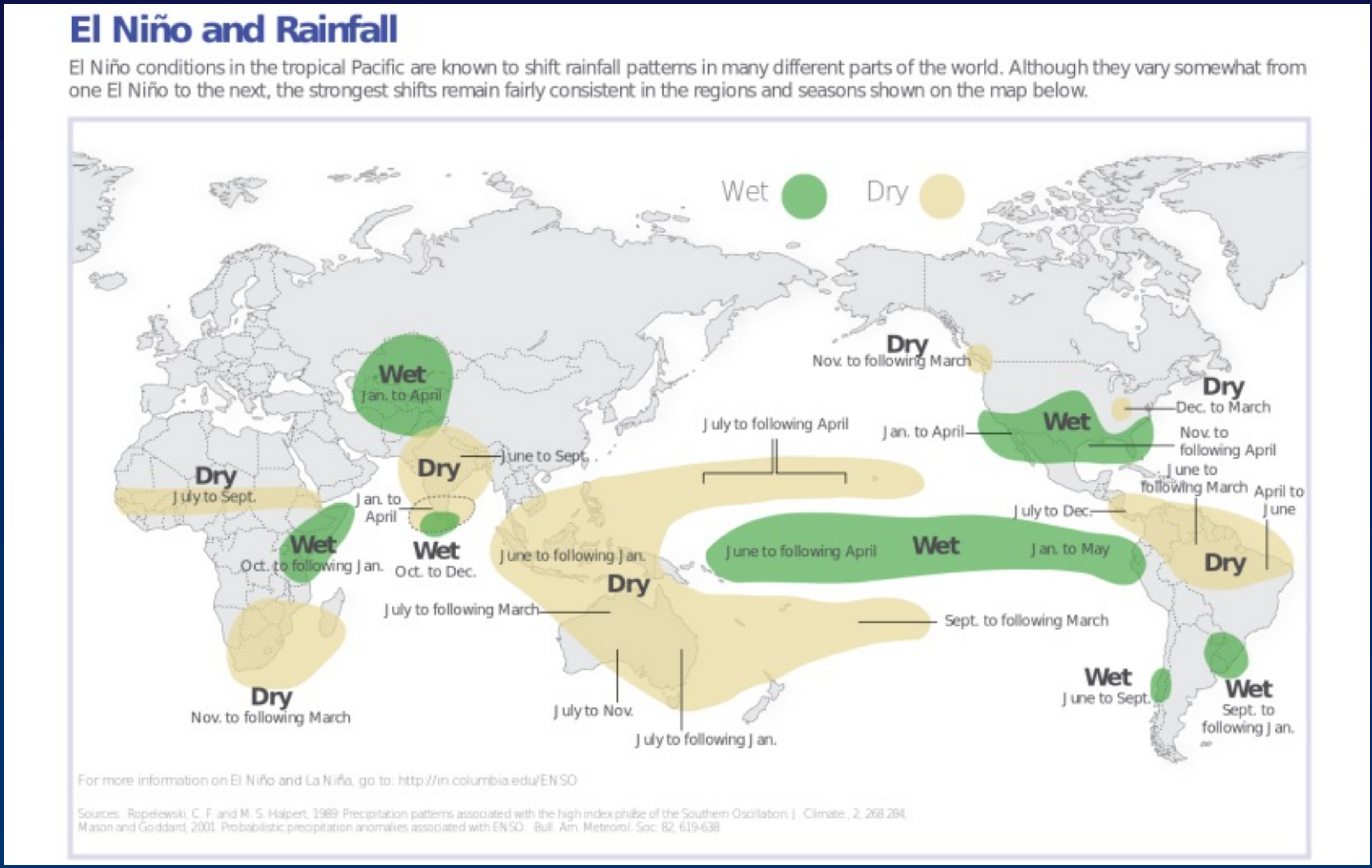


Sea surface temperatures in December 1997 (El Niño)

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

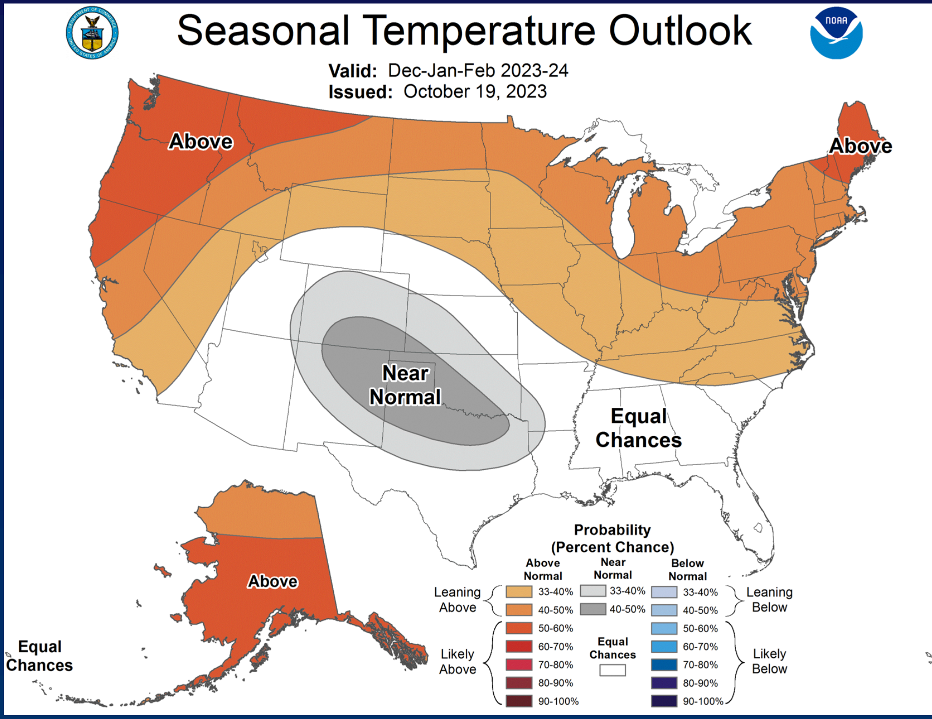
Seasonal and Subseasonal forecasting

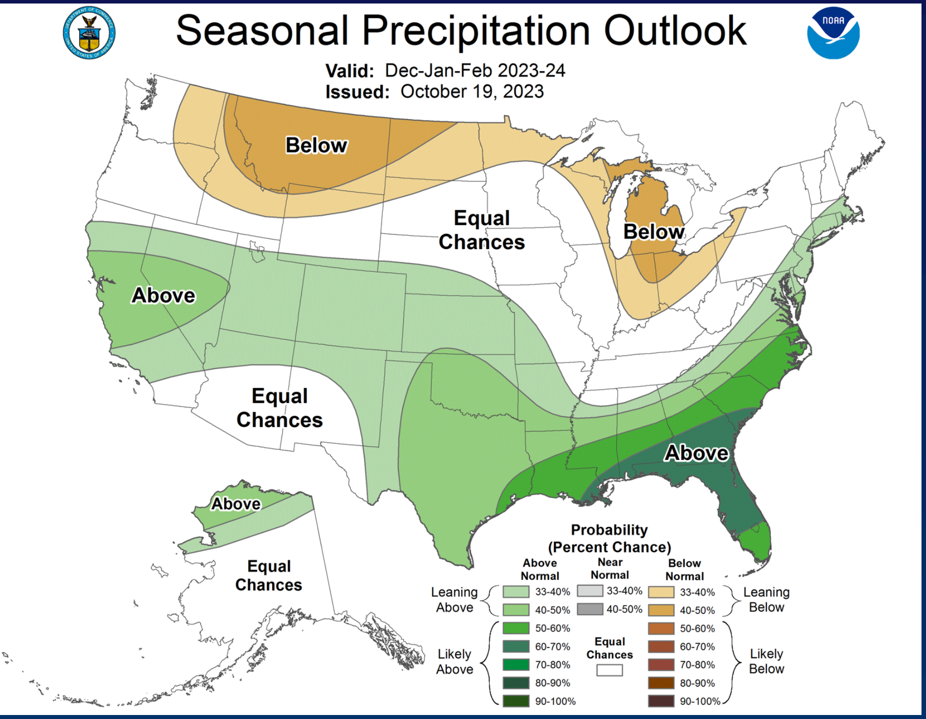
What is the probability of a snowy winter? A hot summer?



Seasonal and Subseasonal forecasting

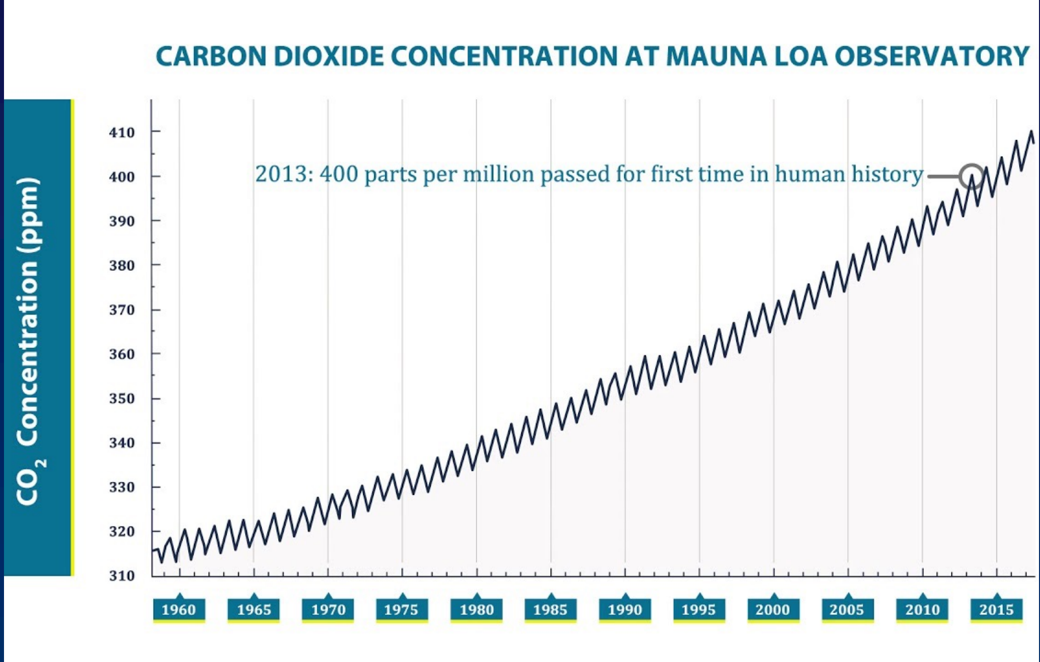
Let's take a look at the official ***Climate Prediction Center*** forecast for this winter!





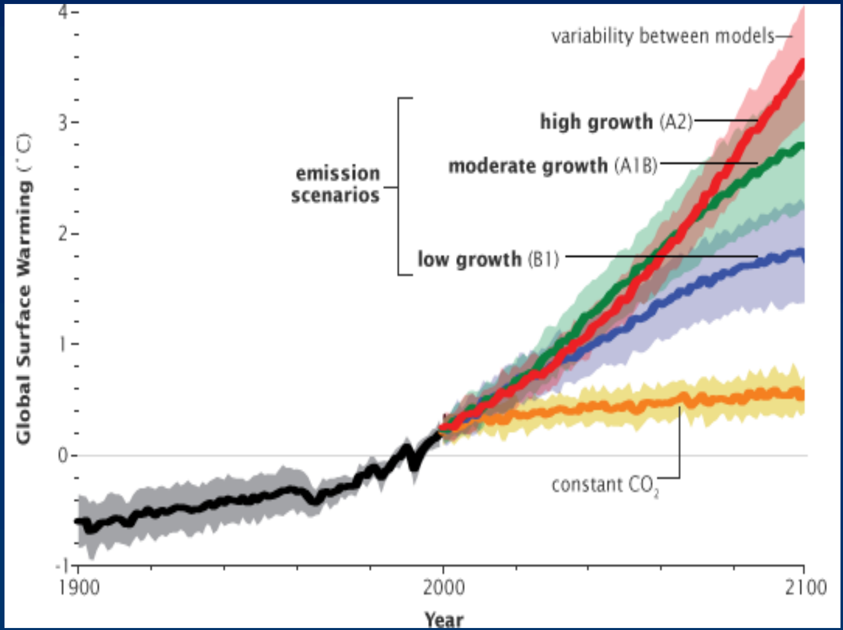
Climate forecasting

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

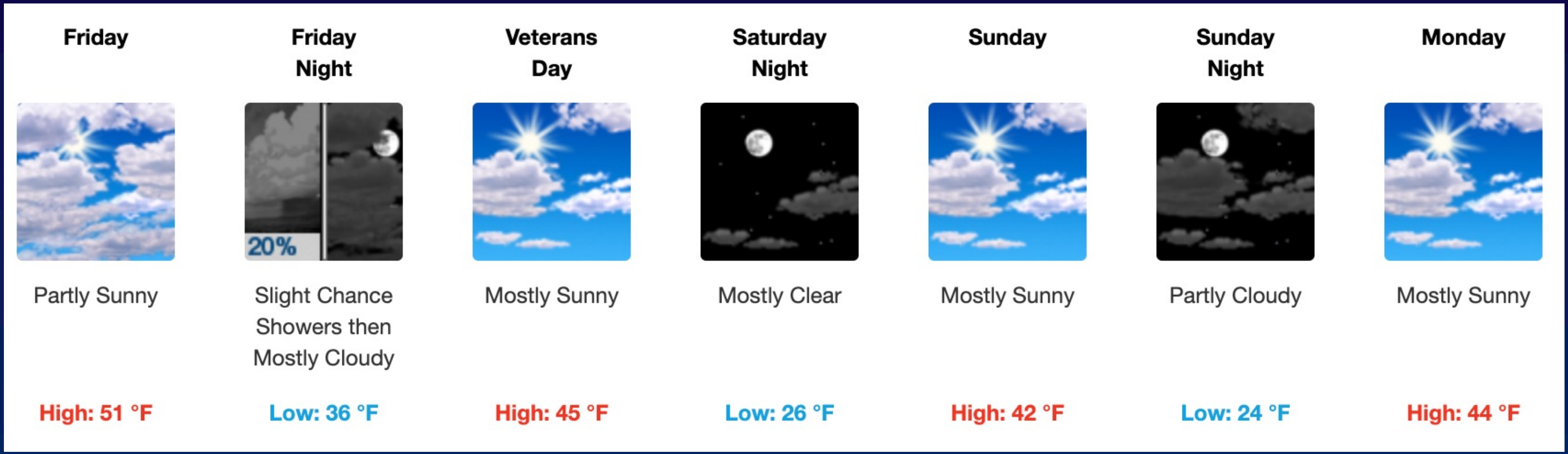


Scripps Institute for Oceanography

IPCC Report, 2007



How do meteorologists *make* a weather forecast?



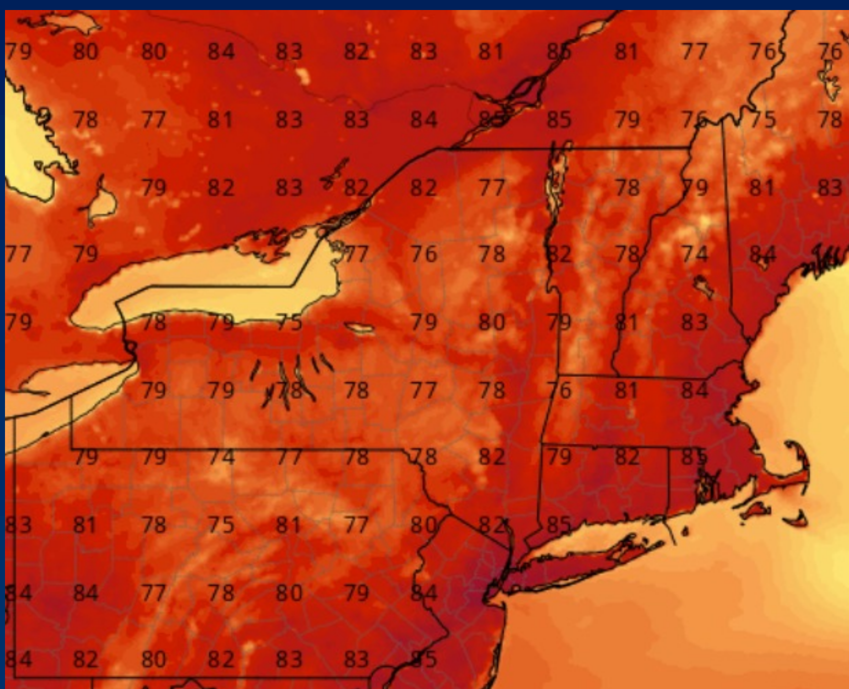
National Weather Service forecast for Albany, N.Y. – November 10, 2023

- 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!*

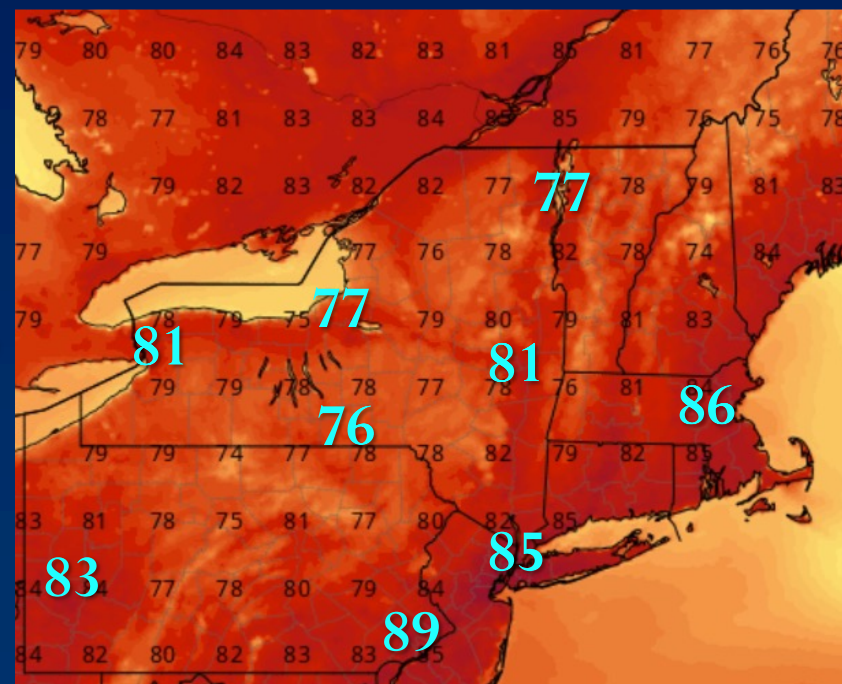
What is a weather **model**?

- 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

+

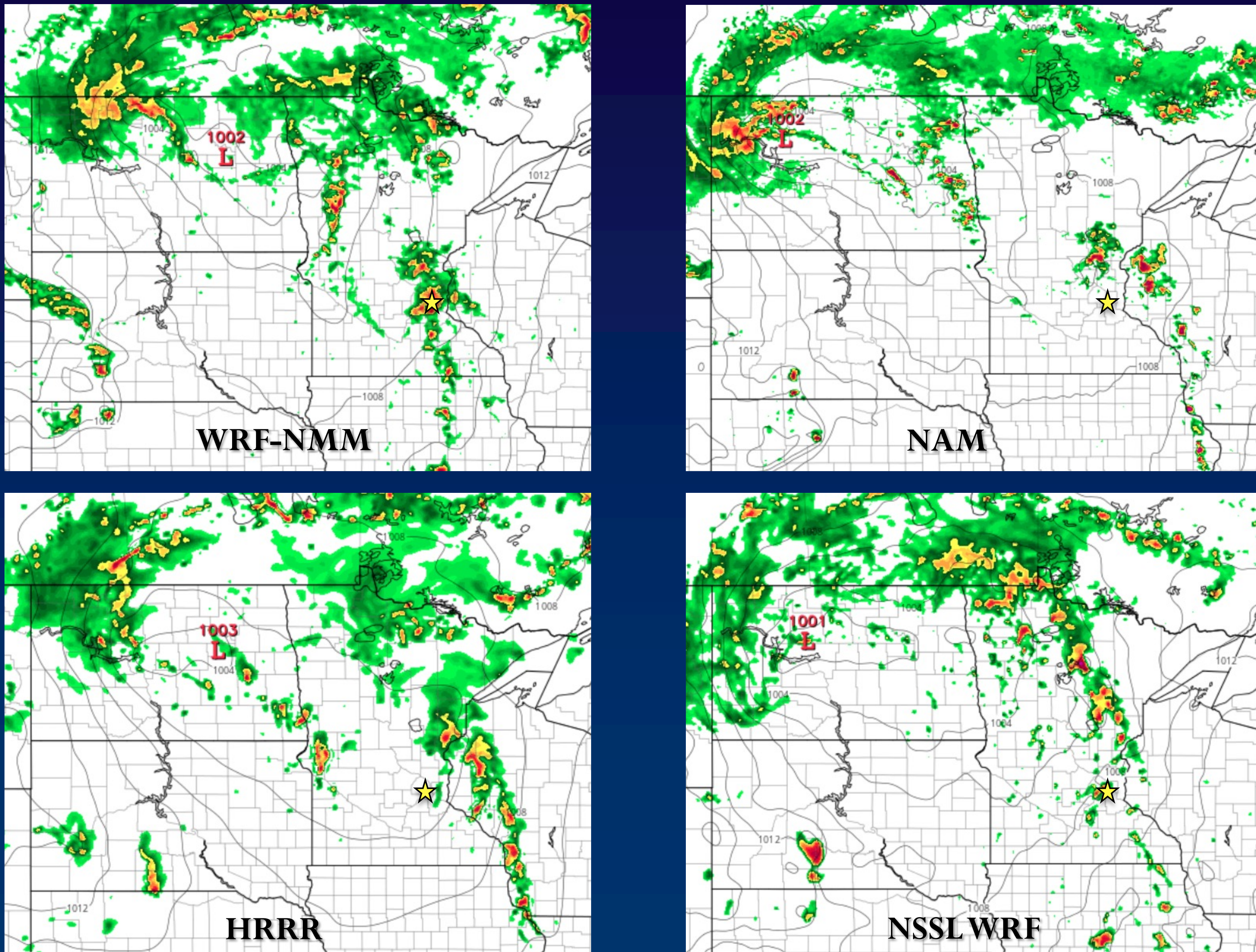


Combine with current observations

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

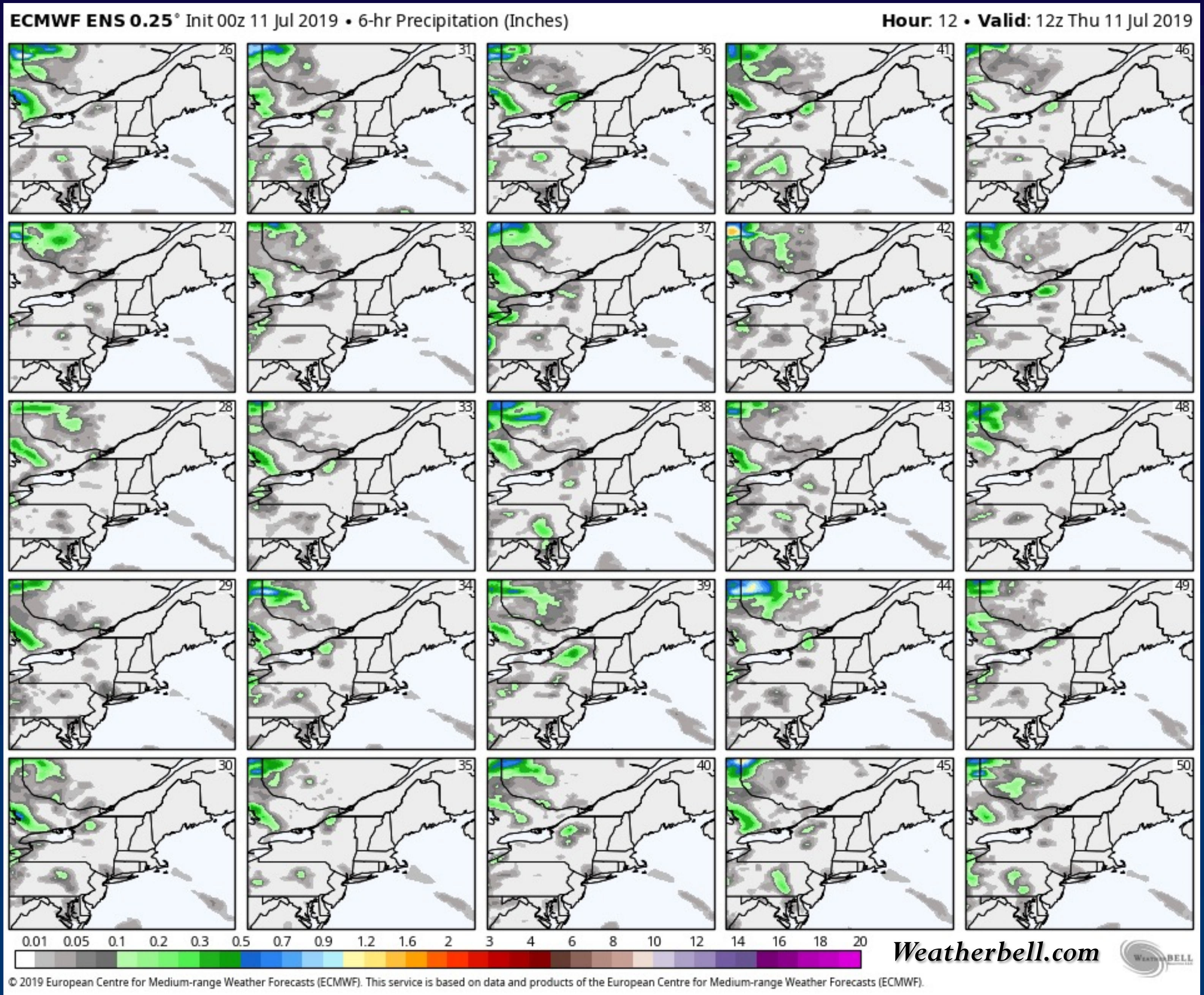
Most models indicate the rain changing to snow around midnight on Friday

At this point, models indicate a dry weekend ahead

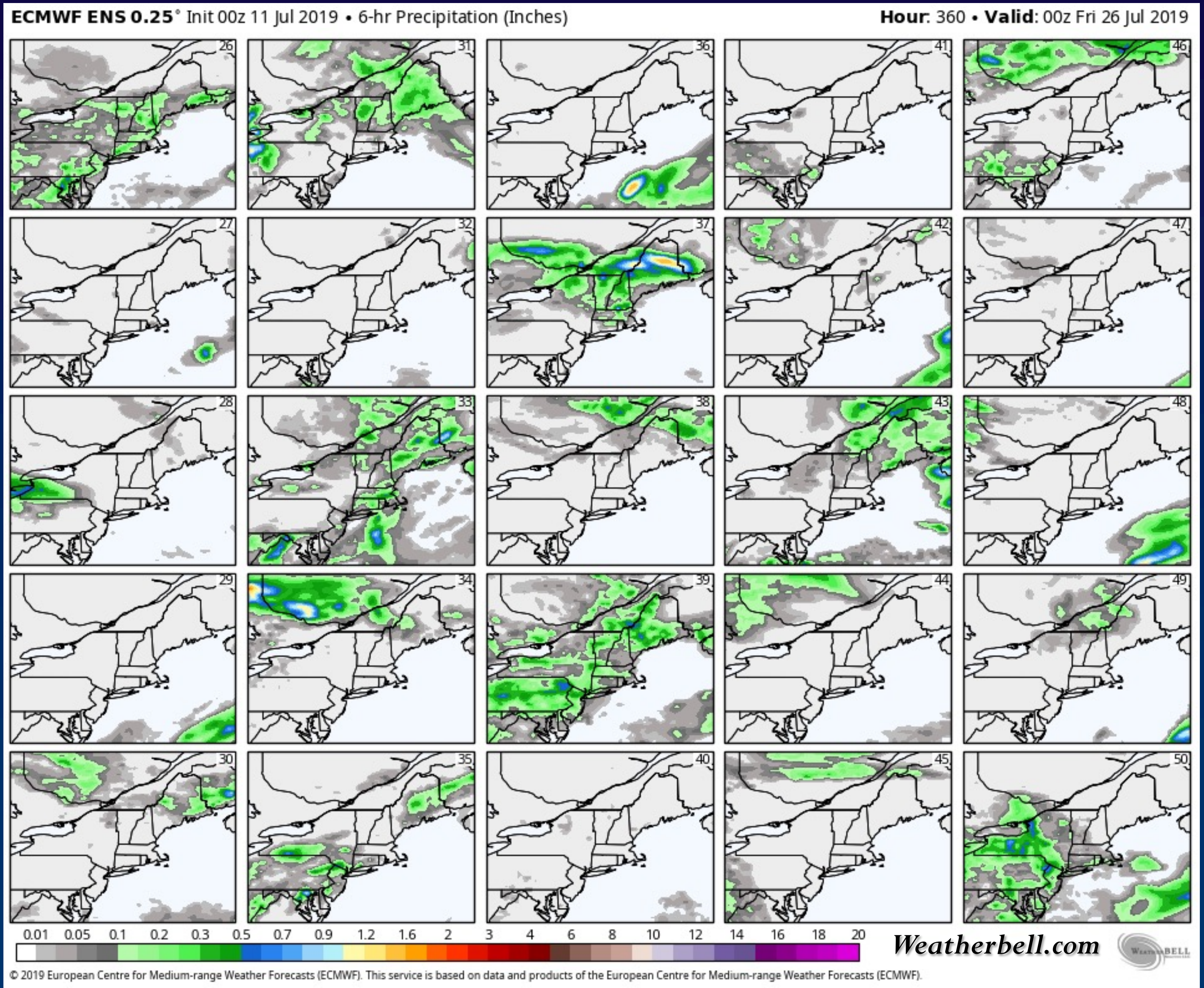
Probabilistic forecasting requires using a **model ensemble.**

- 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

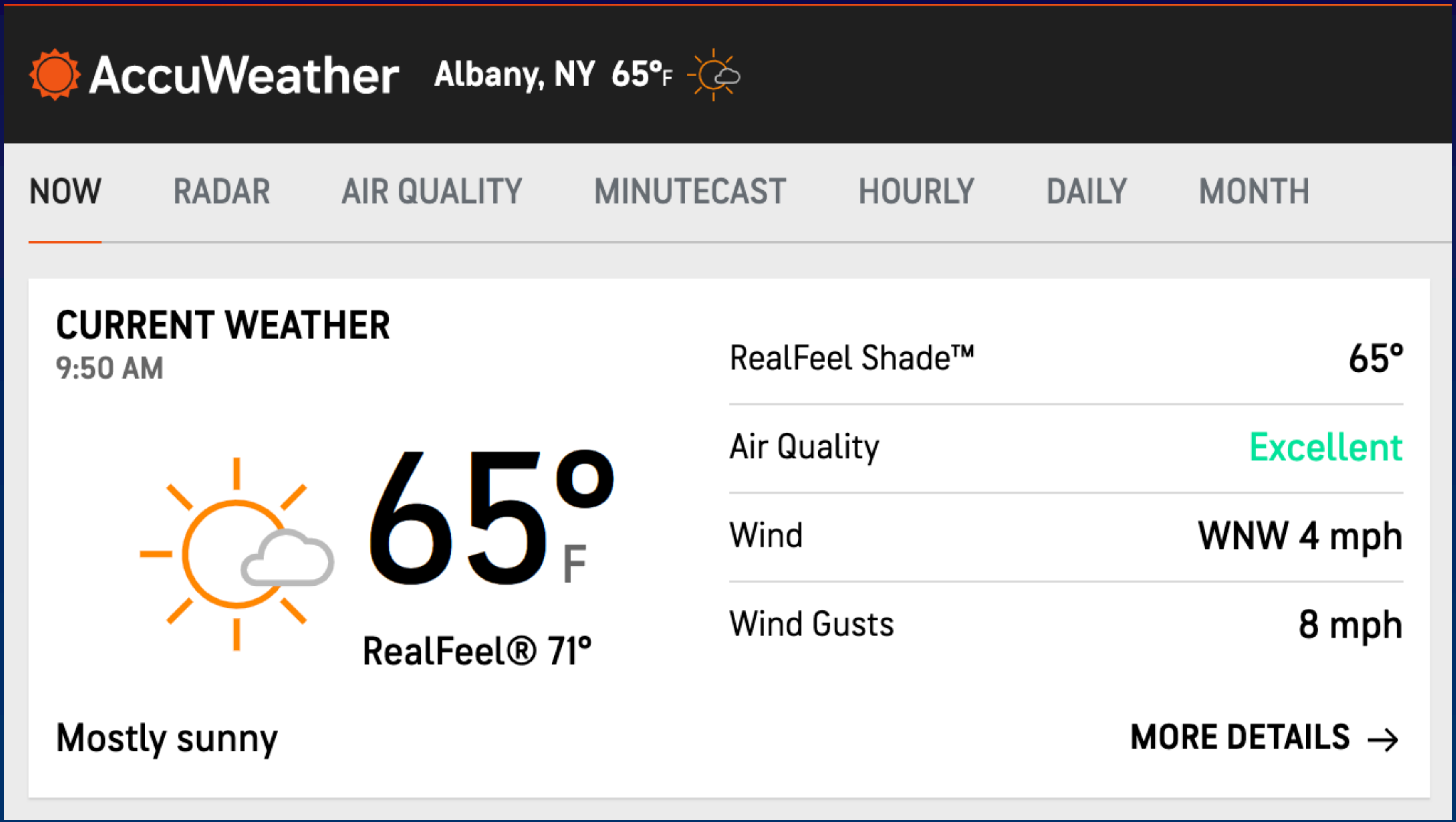
Ensemble forecasting: 12-hour forecast



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



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



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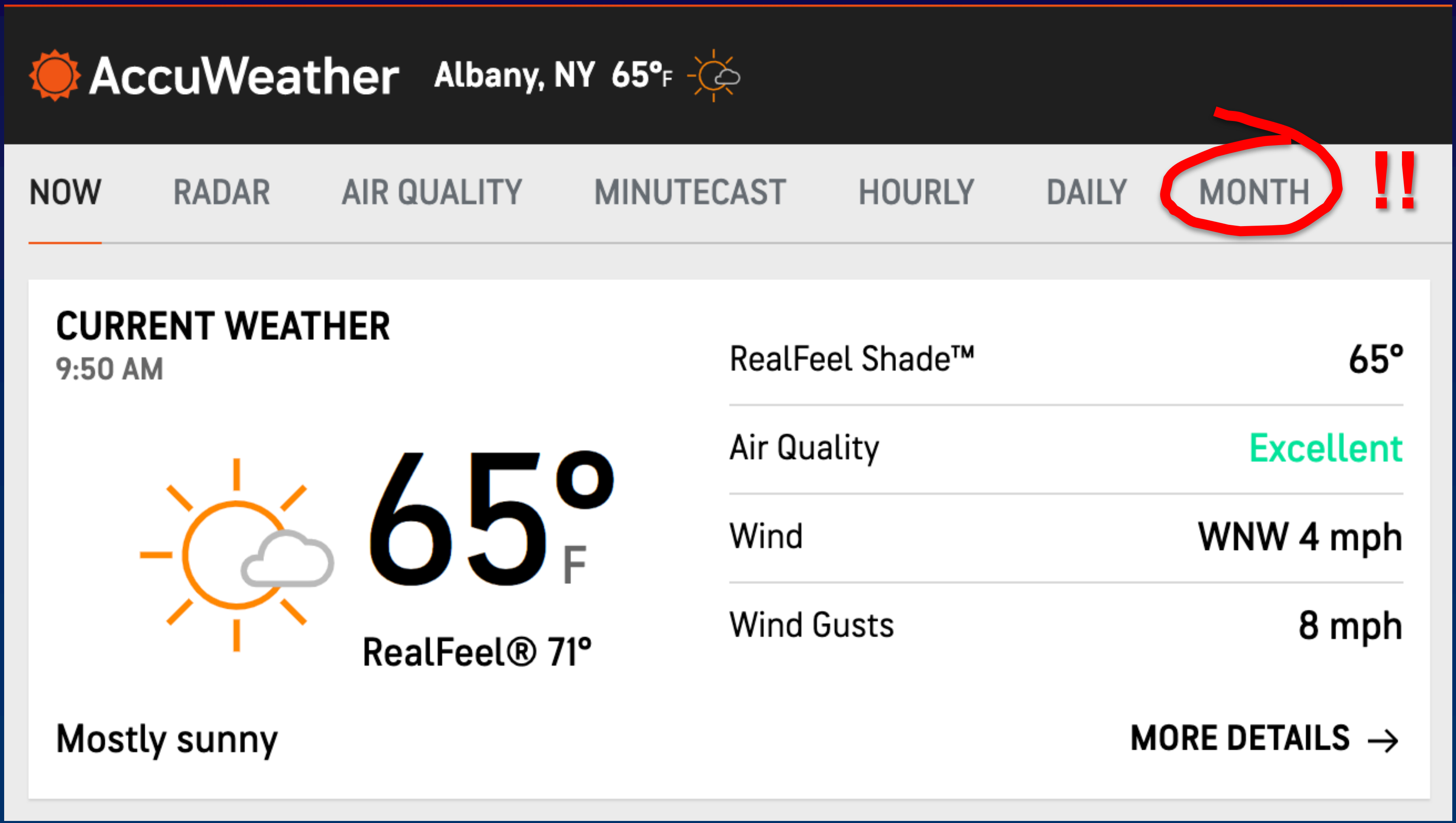


So, if there is such low predictability past two weeks, then why….

January 2024 DAILY →

S	M	T	W	T	F	S
31	1	2	3	4	5	6
35° 19°	37° 17°	33° 21°	34° 22°	36° 24°	36° 22°	39° 17°
7	8	9	10	11	12	13
34° 15°	30° 17°	34° 11°	29° 16°	28° 20°	34° 19°	36° 22°
14	15	16	17	18	19	20
39° 23°	39° 21°	37° 22°	39° 24°	39° 25°	42° 20°	42° 9°

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

TUESDAY, FEBRUARY 6

Day 2/6

40° Hi

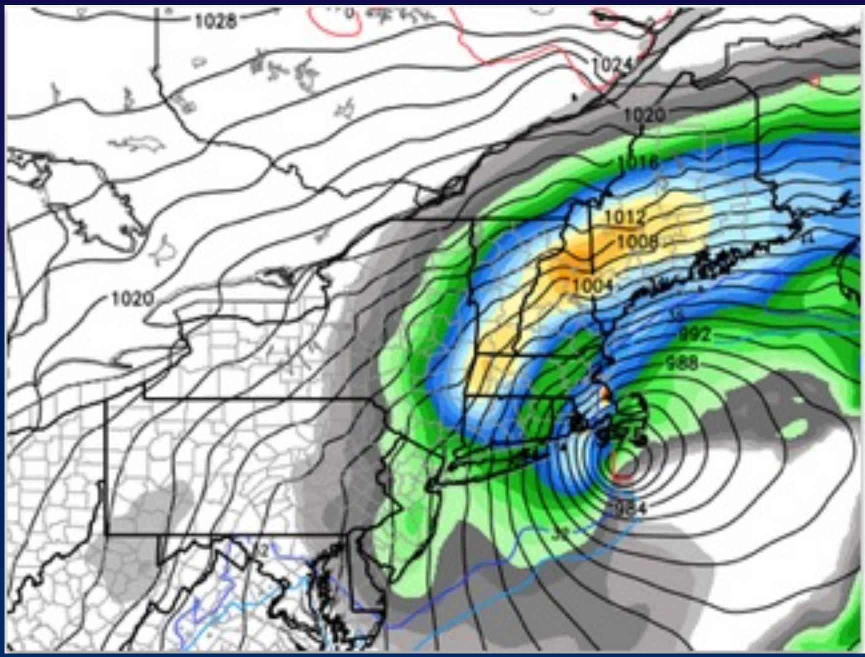
RealFeel® 37°

RealFeel Shade™ 37°

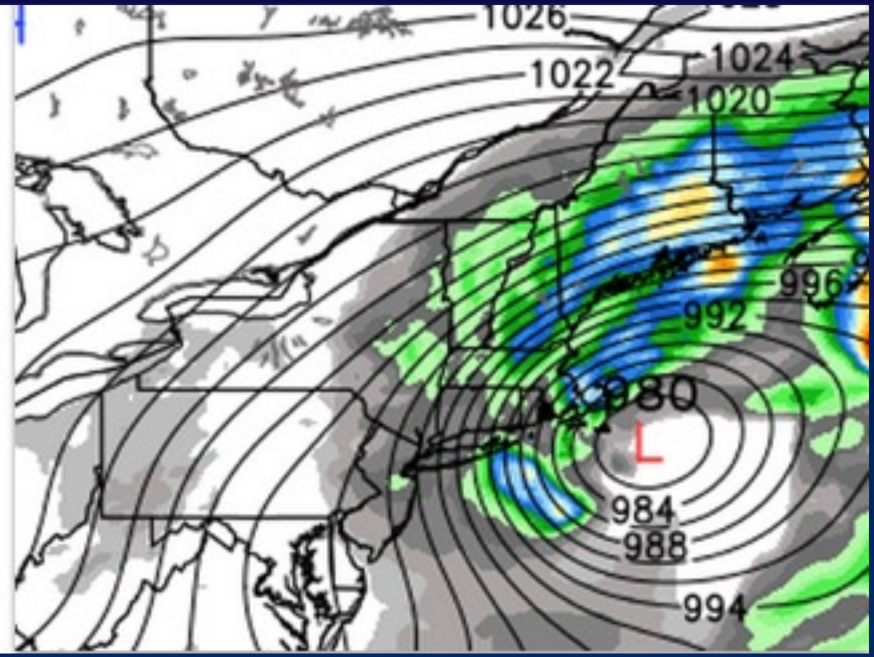
A bit of rain, some freezing in the morning; otherwise, cloudy

Max UV Index	1 Low	Precipitation	0.02 in
Wind	WNW 7 mph	Rain	0.02 in
Wind Gusts	9 mph	Hours of Precipitation	2.5
Probability of Precipitation	56%	Hours of Rain	0.5
Probability of Thunderstorms	0%	Cloud Cover	94%

Forecast model failure … **January 27, 2015**



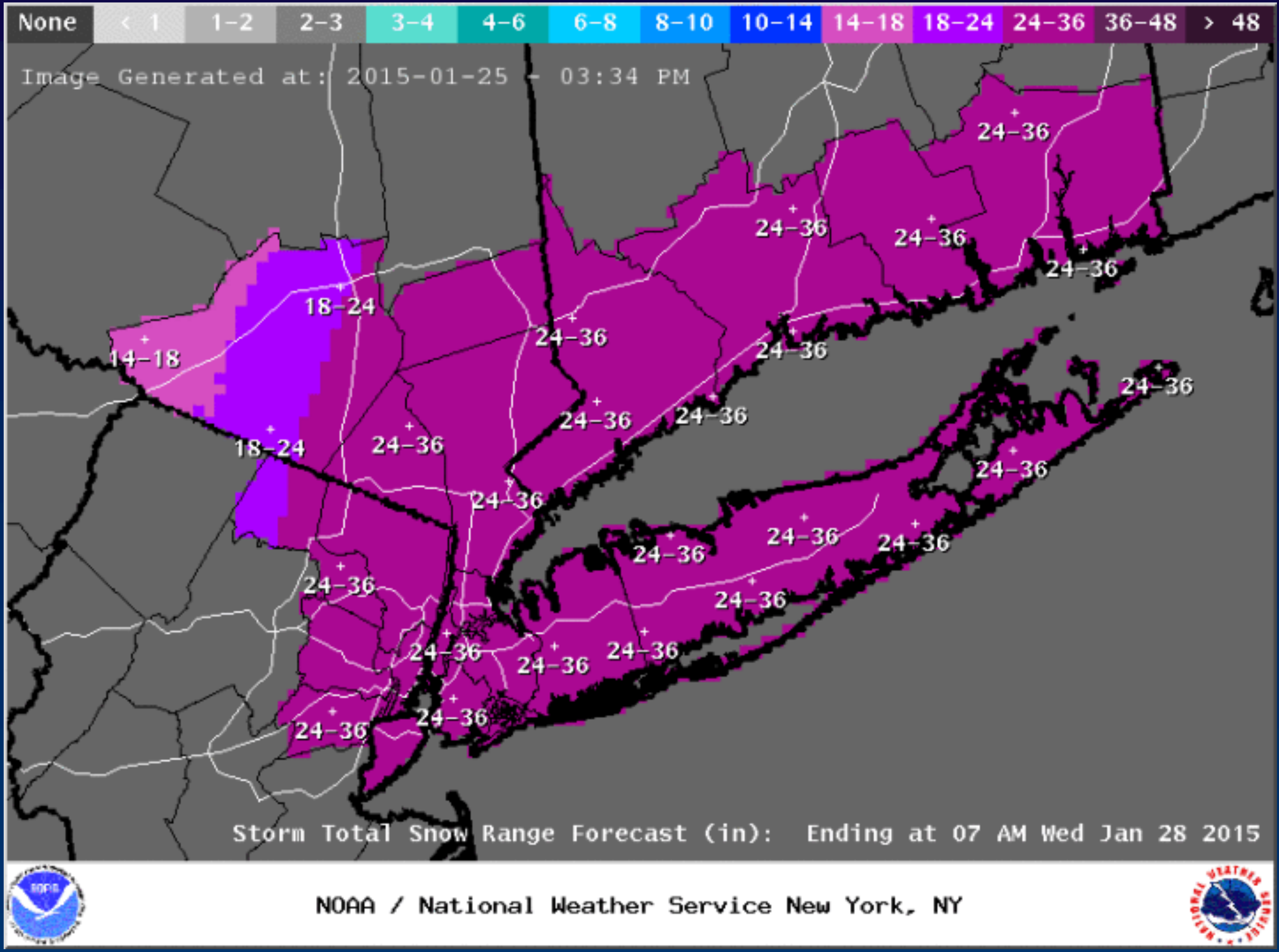
ECMWF 12Z 26 Jan 2015



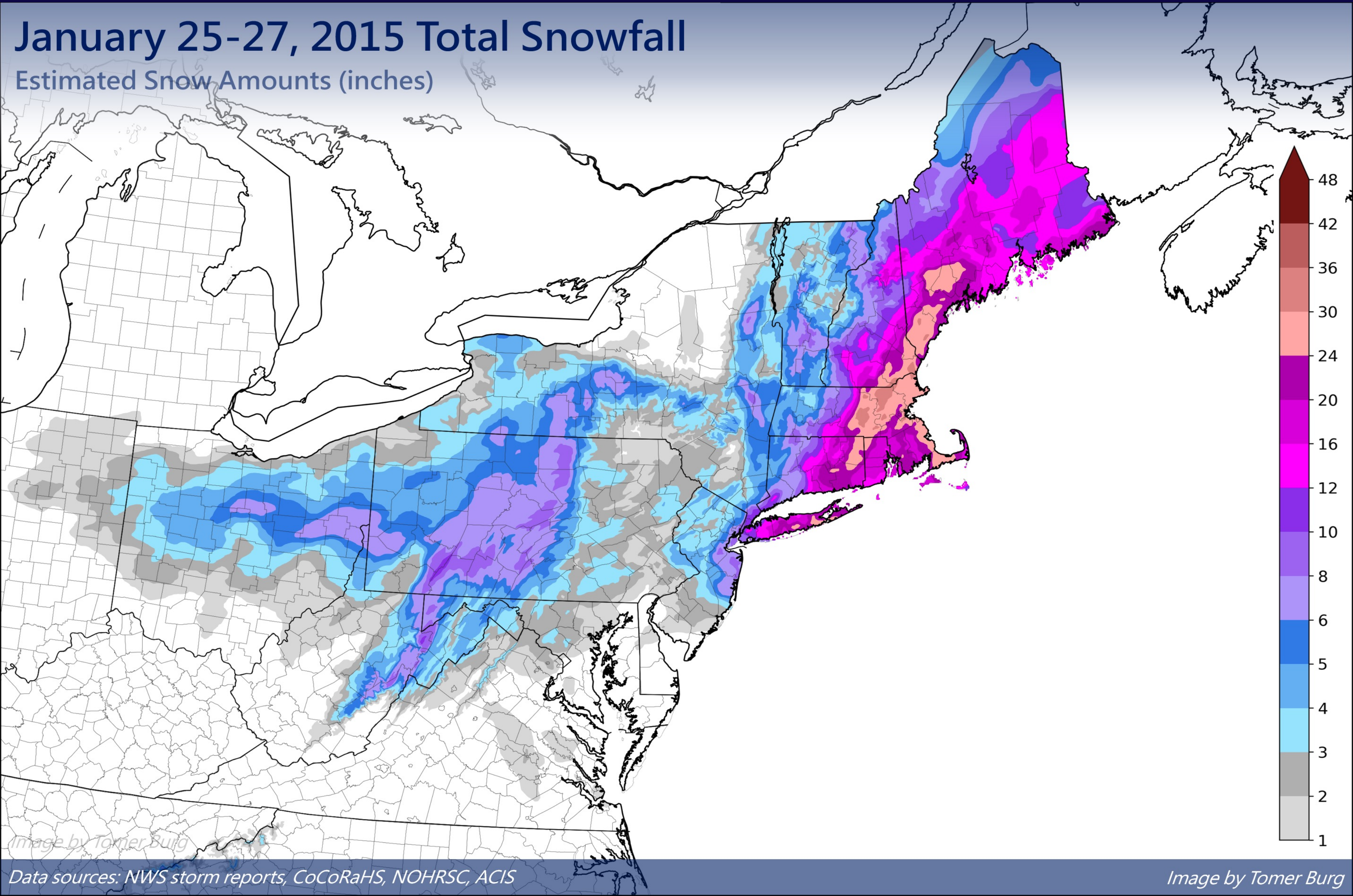
GFS 12Z 26 Jan 2015

Forecast precipitation for 00Z to 06Z 27 Jan 2015

Forecast model failure … January 27, 2015



Forecast model failure … January 27, 2015



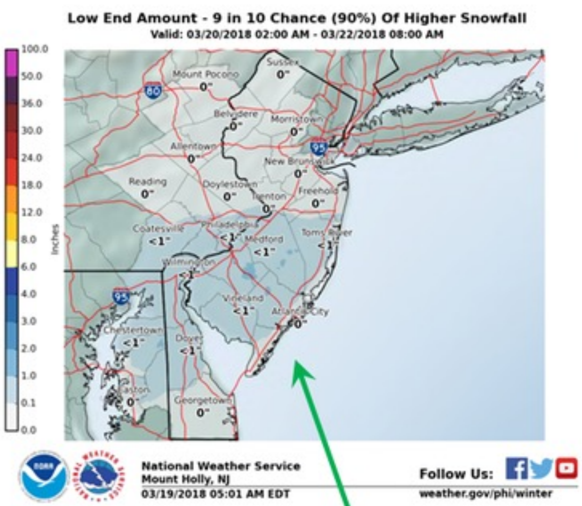
Recent change:

National Weather Service now makes probabilistic snowfall forecasts!

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

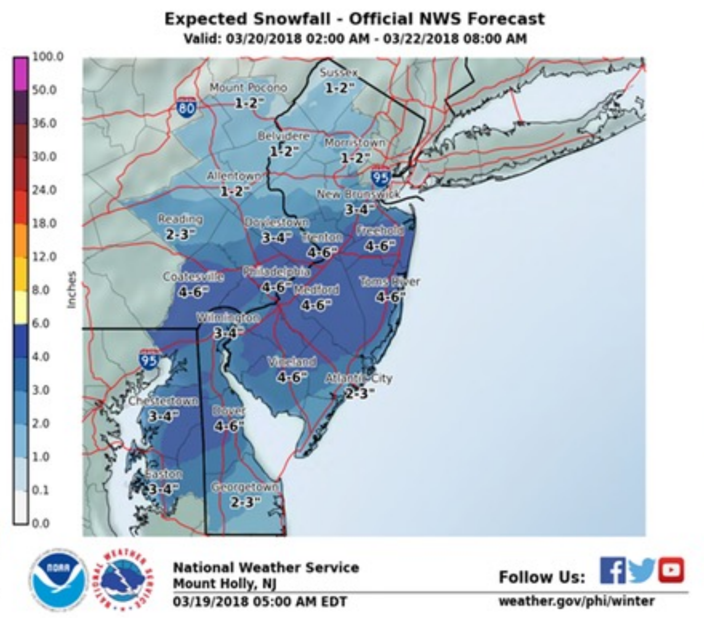
Low End Potential

9 in 10 (90%) Chance of Higher Snowfall



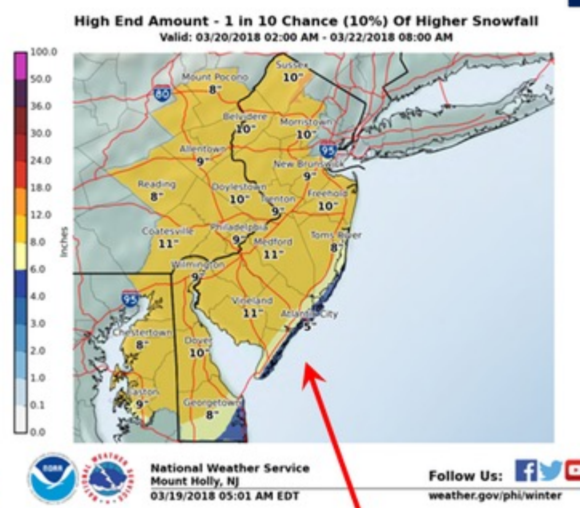
Expected Snowfall

Official NWS Forecast



High End Potential

1 in 10 (10%) Chance of Higher Snowfall



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

National Weather Service
Mount Holly, N.J.

(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

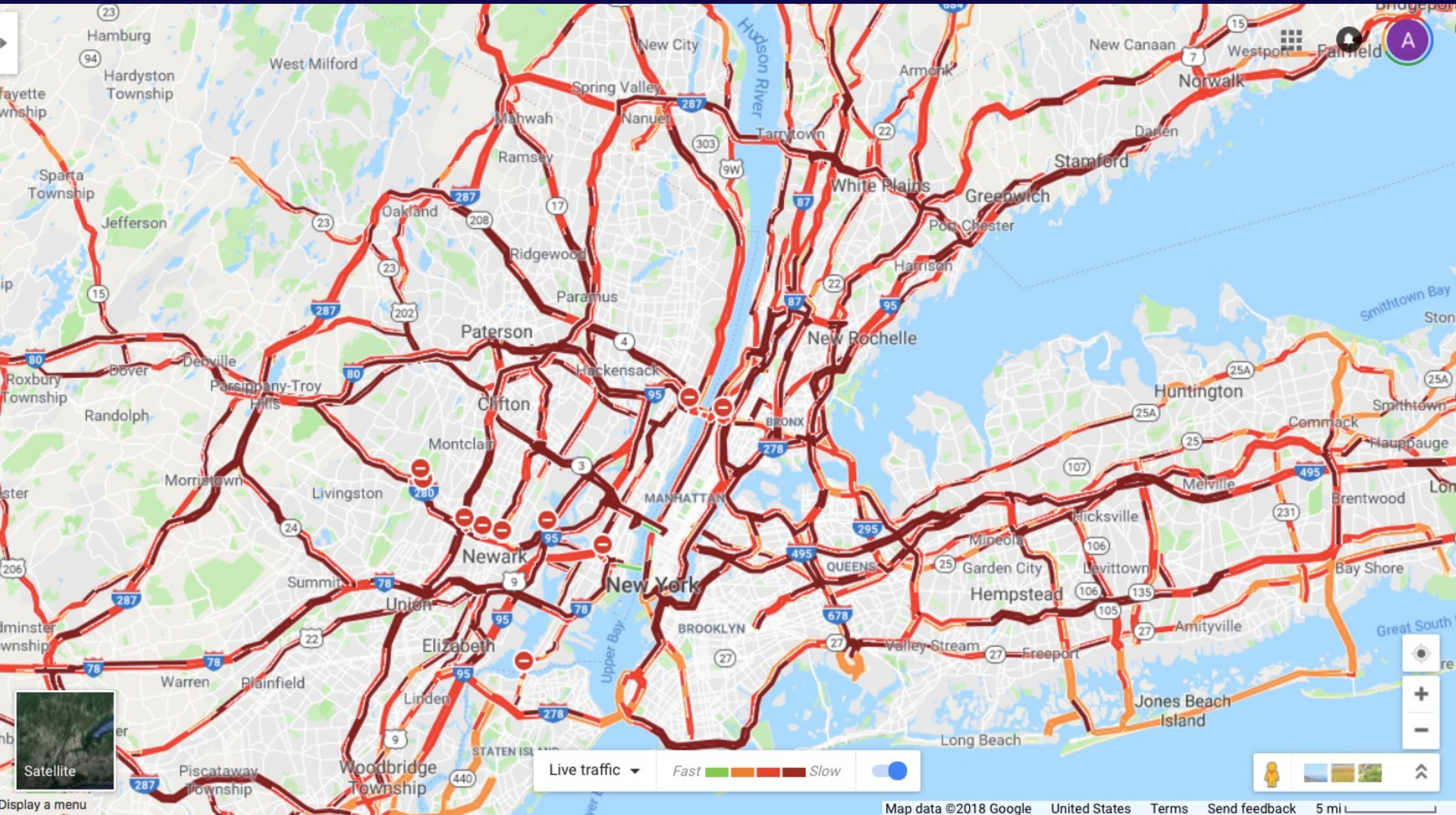
CBS News

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

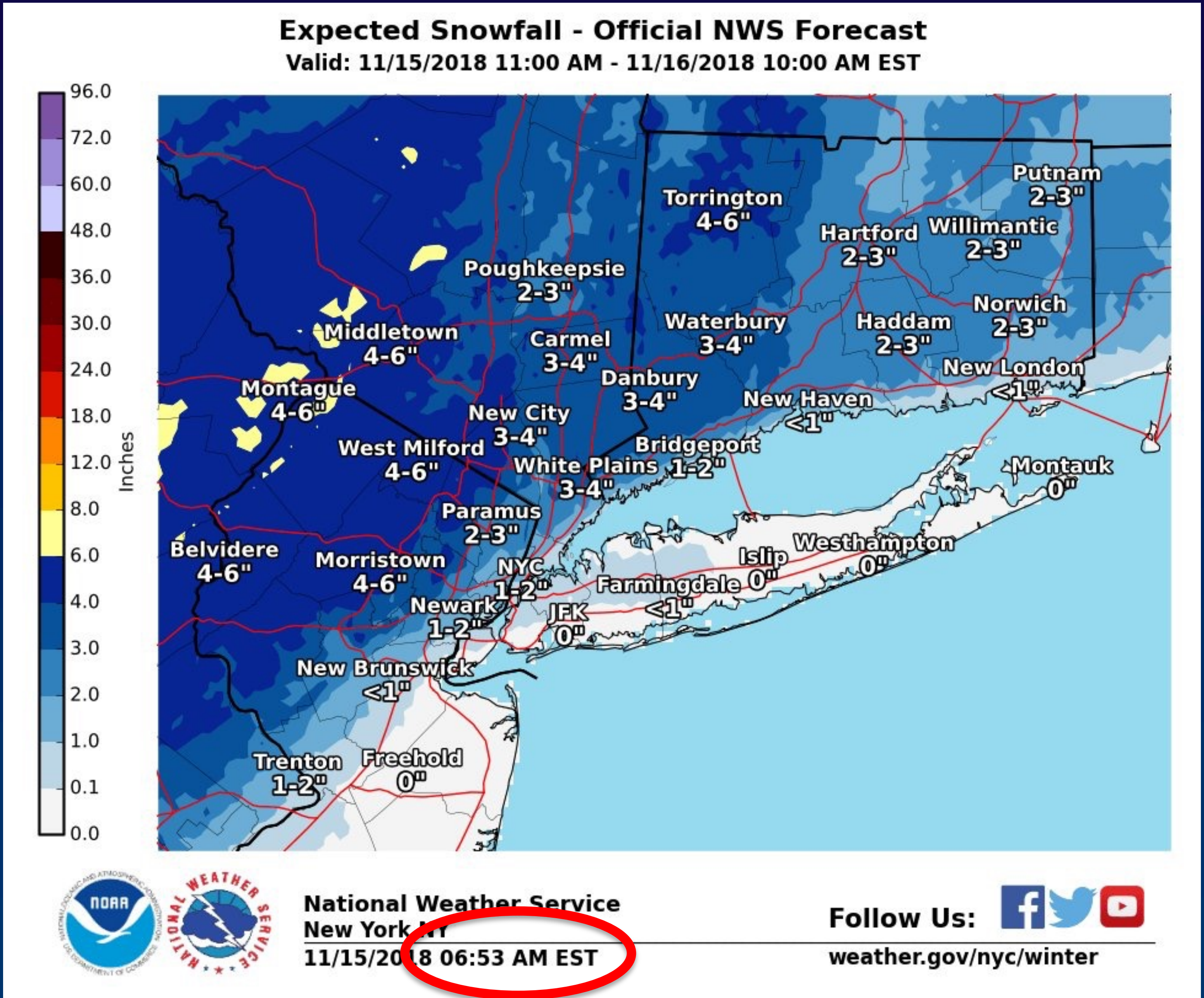
New Jersey Globe

NY Post

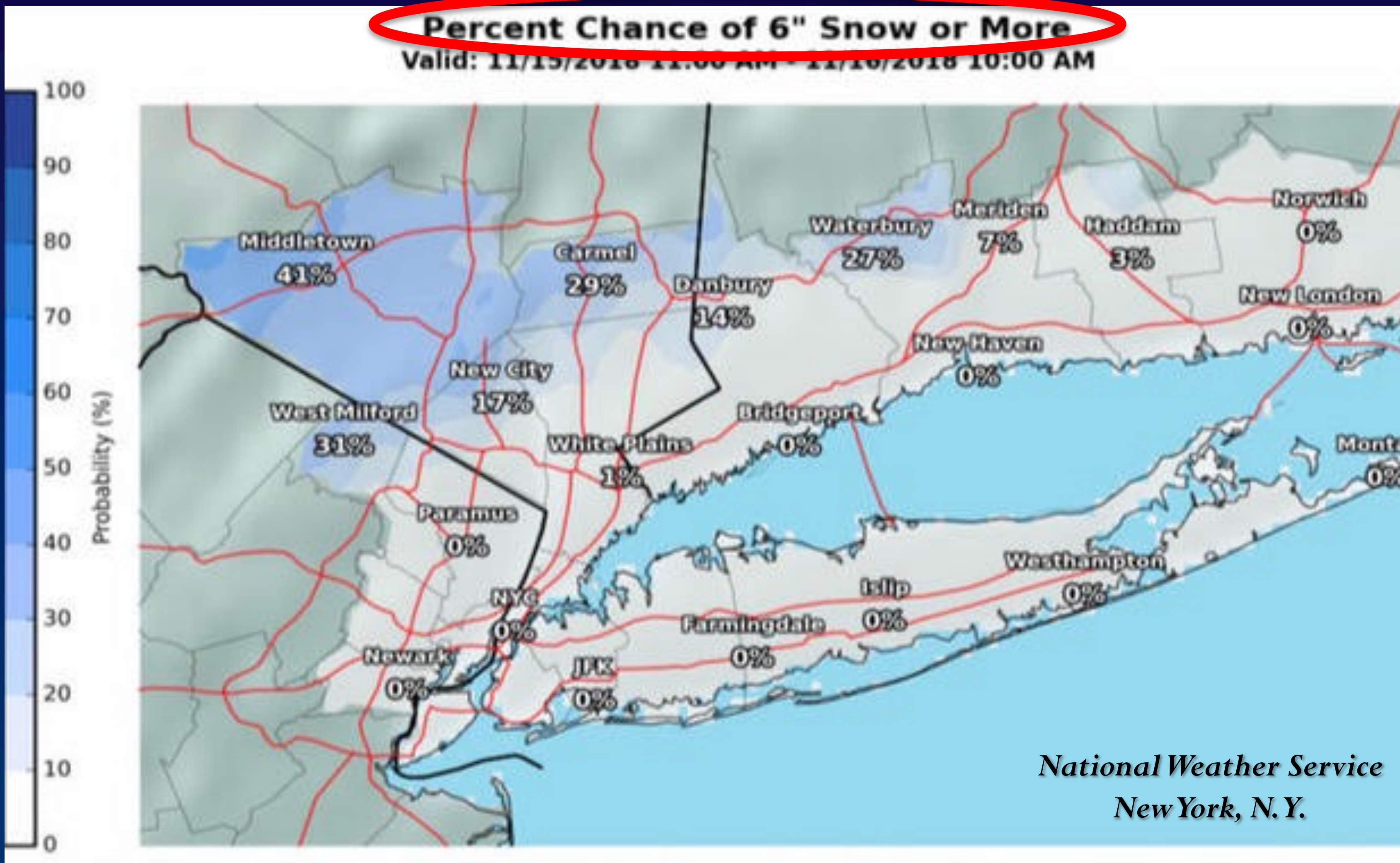
Forecast communication failure … November 15, 2018



Forecast communication failure … November 15, 2018

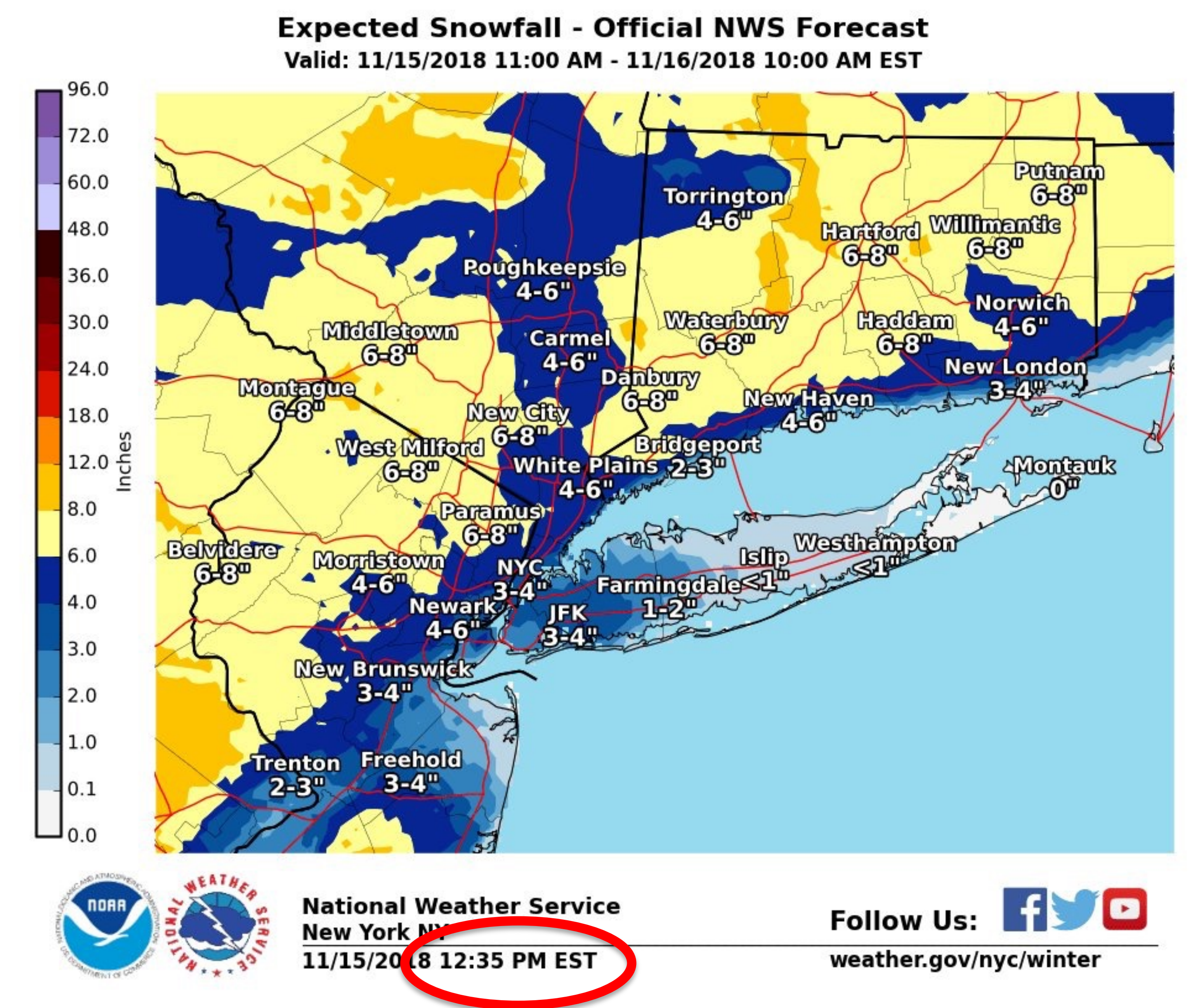


Forecast communication failure … **November 15, 2018**



Officially 6.4" at Central Park

Forecast communication failure … November 15, 2018



Forecast communication failure … **November 15, 2018**

What went wrong?

• Time of year

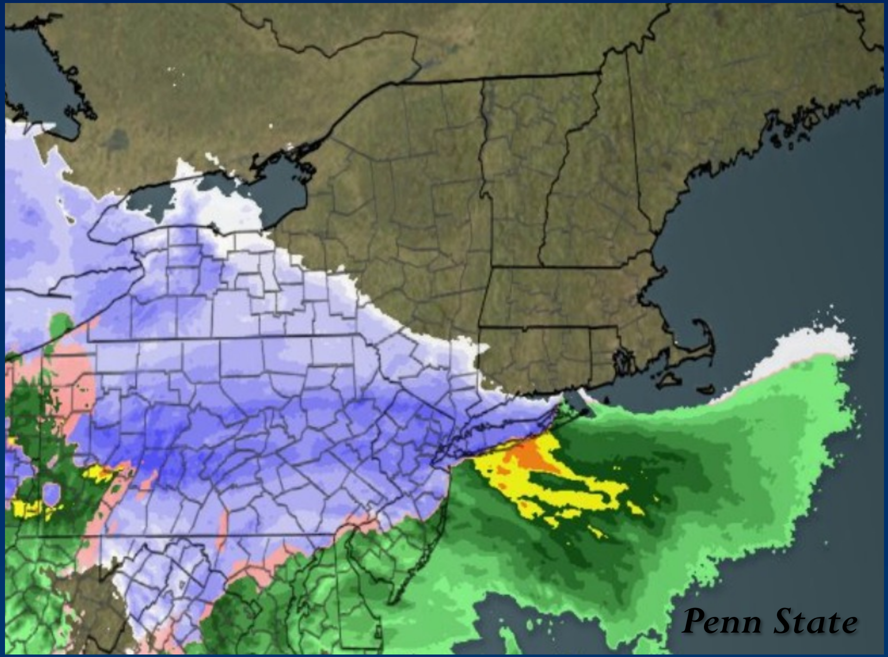
Unusual to have a major snowstorm in the Mid-Atlantic to New York City in mid-November, especially with relatively warm ocean waters

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

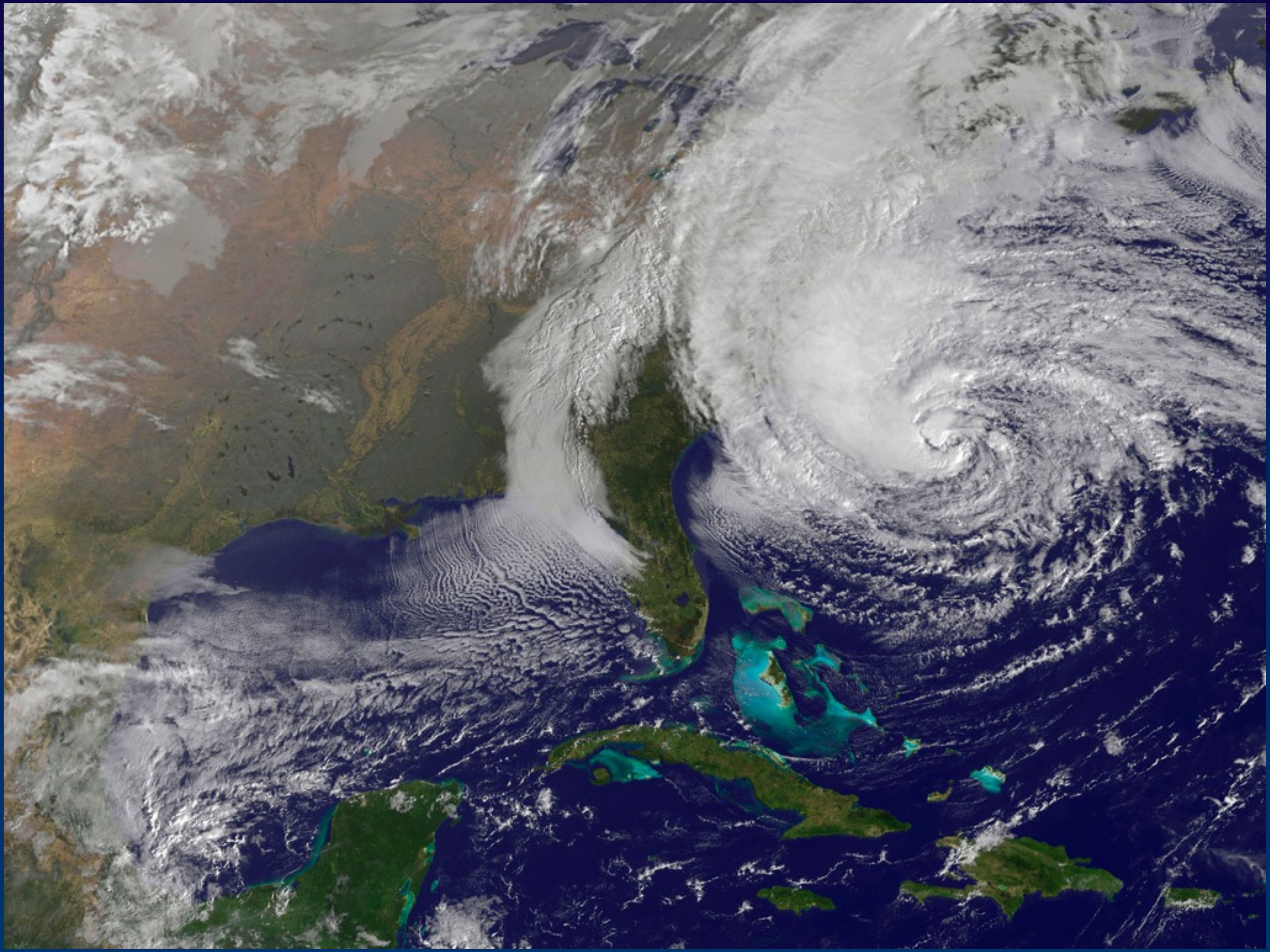
• Air was unusually dry

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

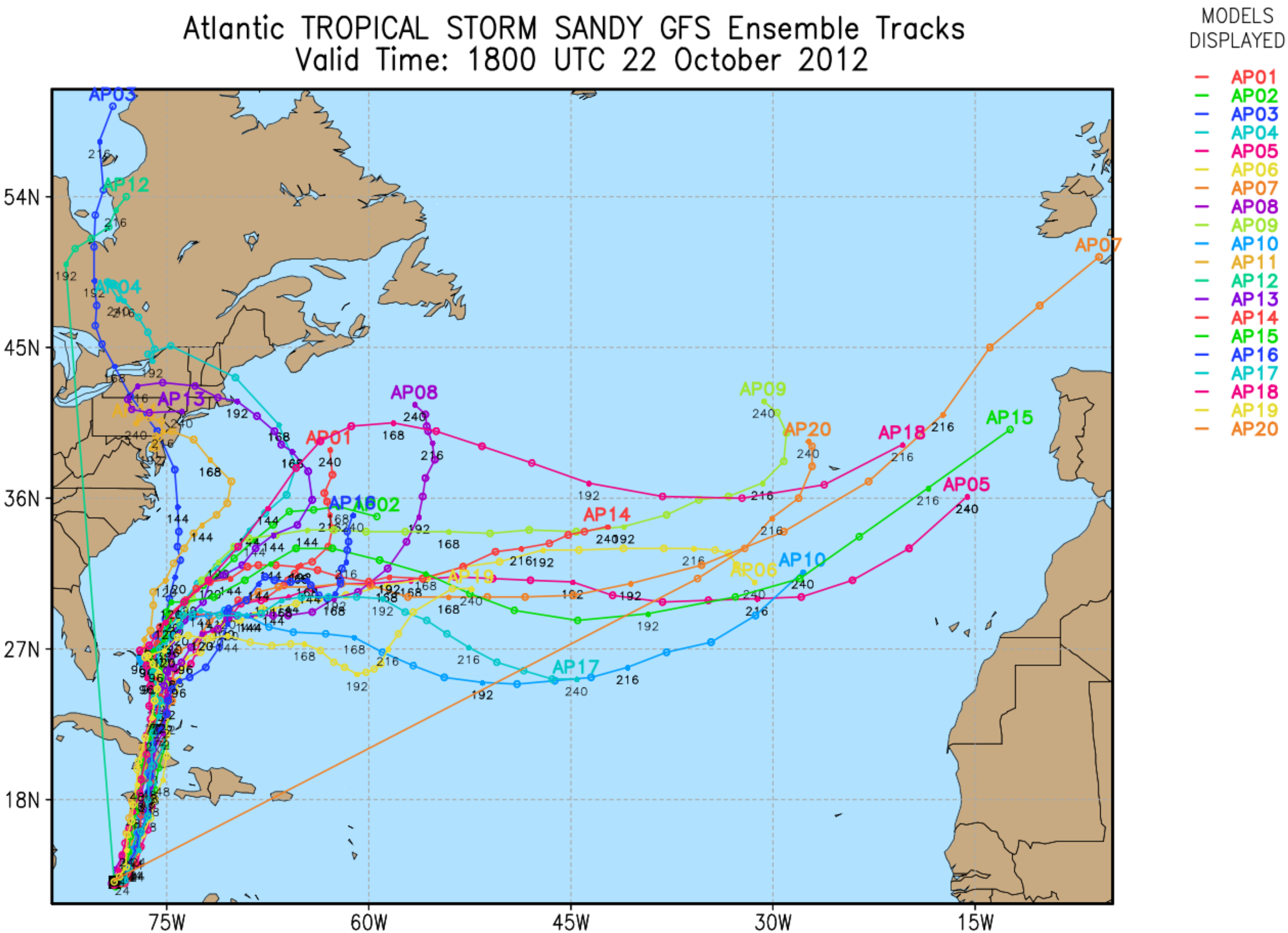
Result: More evaporation, and more cooling (longer duration snow!)



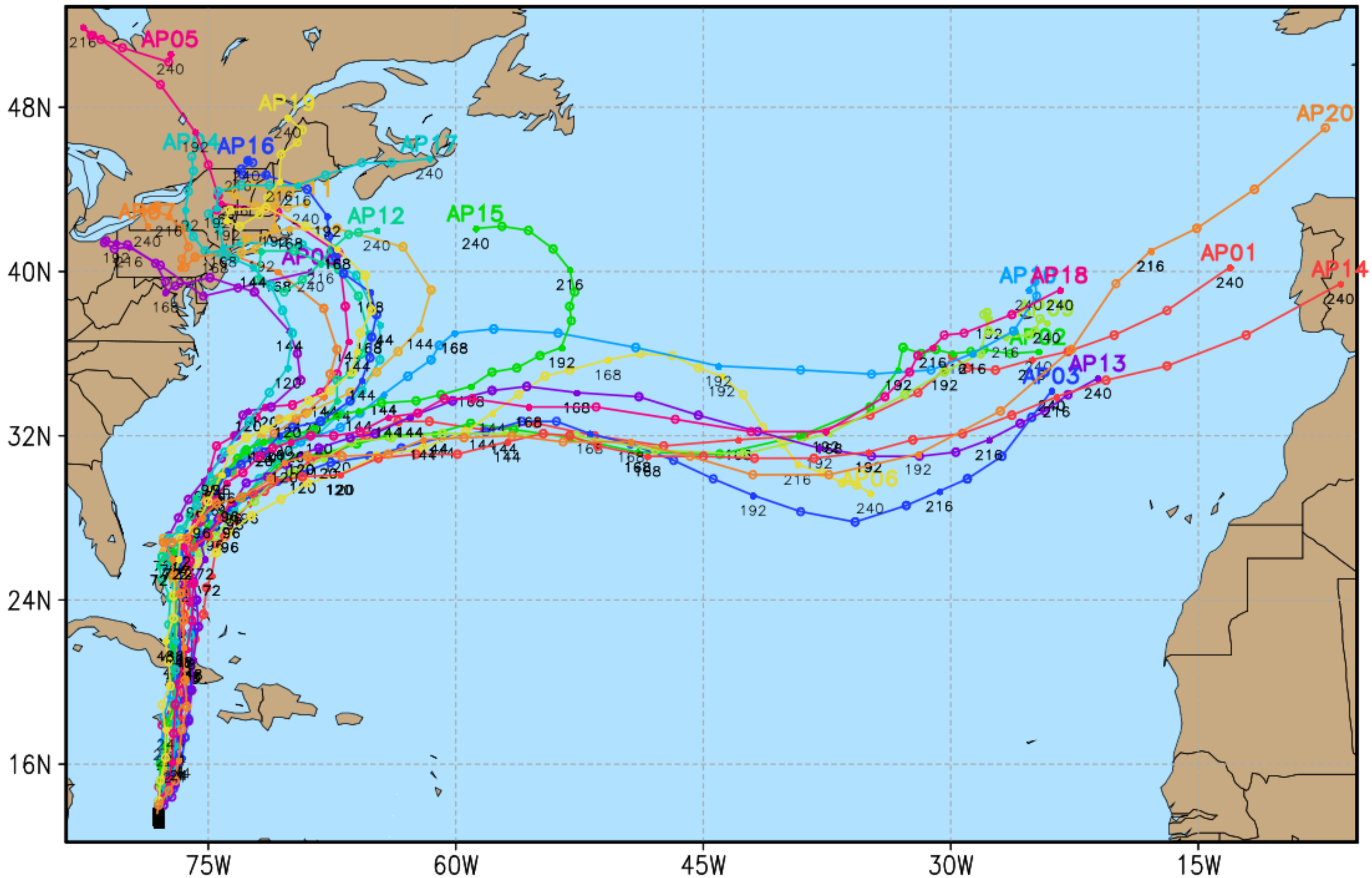
Hurricane Sandy, October 2012



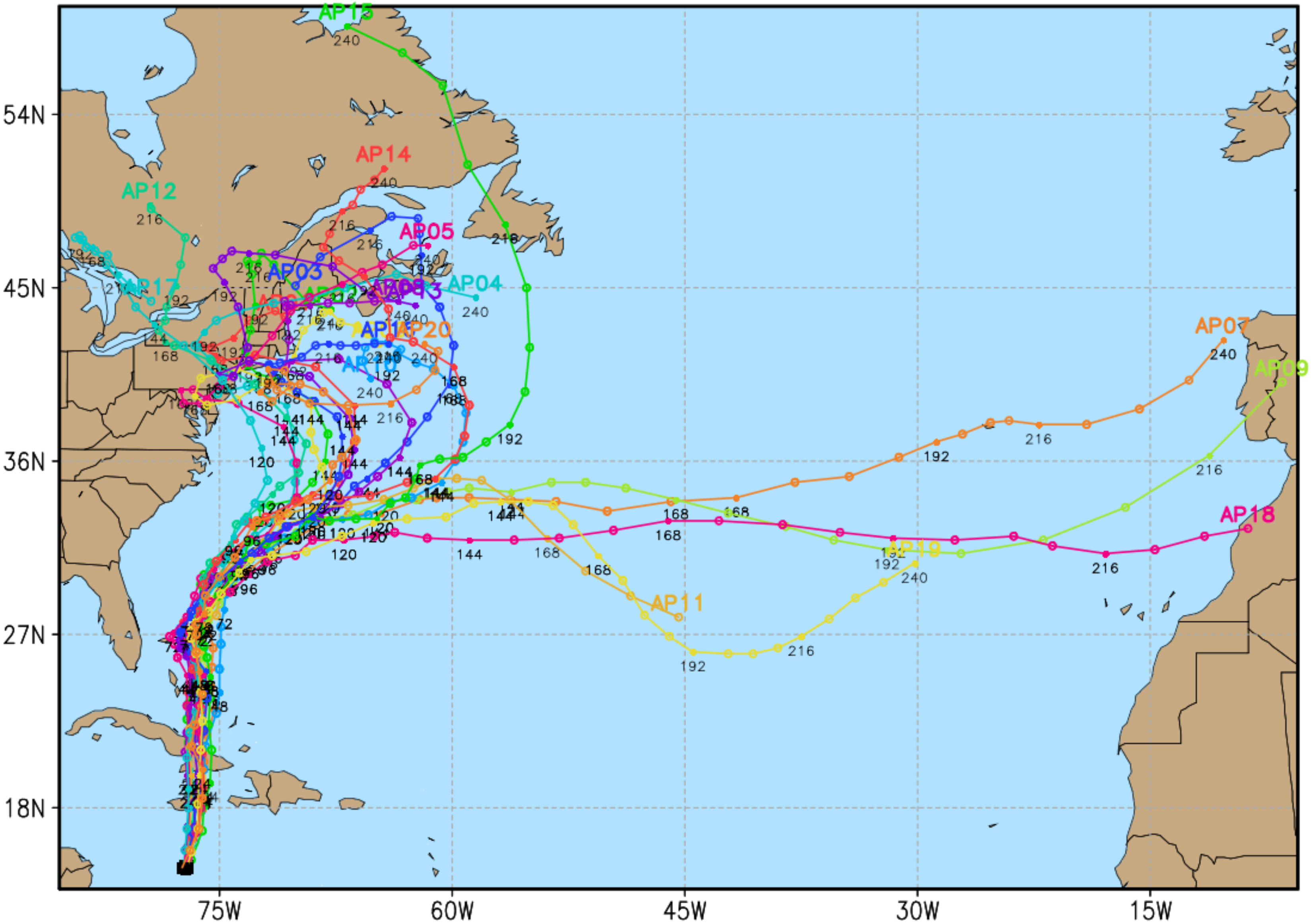
Atlantic TROPICAL STORM SANDY GFS Ensemble Tracks
Valid Time: 1800 UTC 22 October 2012



Atlantic TROPICAL STORM SANDY GFS Ensemble Tracks
Valid Time: 1200 UTC 23 October 2012



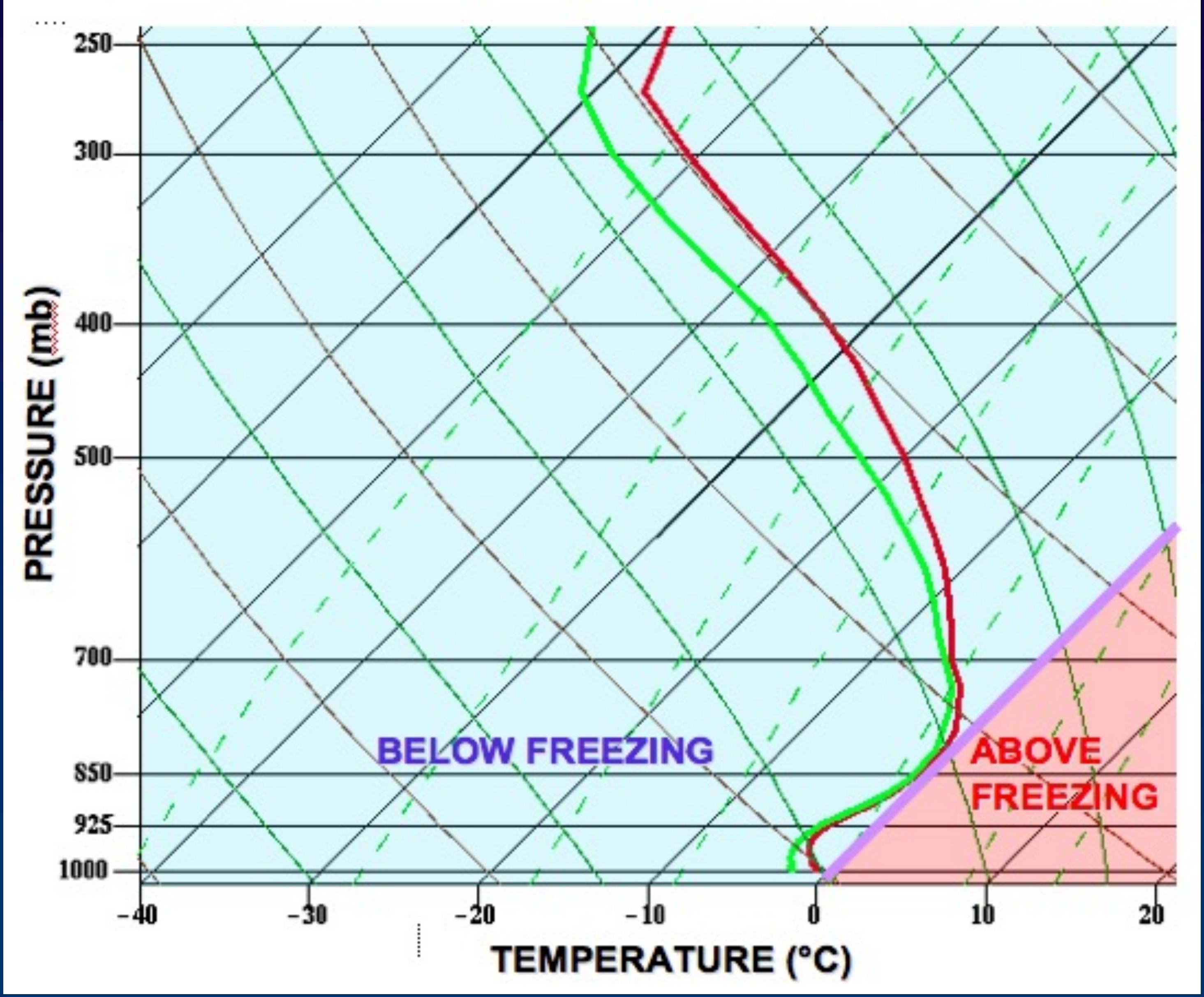
Atlantic TROPICAL STORM SANDY GFS Ensemble Tracks
Valid Time: 0000 UTC 24 October 2012



MODELS DISPLAYED

- AP01
- AP02
- AP03
- AP04
- AP05
- AP06
- AP07
- AP08
- AP09
- AP10
- AP11
- AP12
- AP13
- AP14
- AP15
- AP16
- AP17
- AP18
- AP19
- AP20

Other forecast challenges: Precipitation type!



Forecast temperature profile for March 19, 2013 winter storm

Other forecast challenges: Precipitation type!

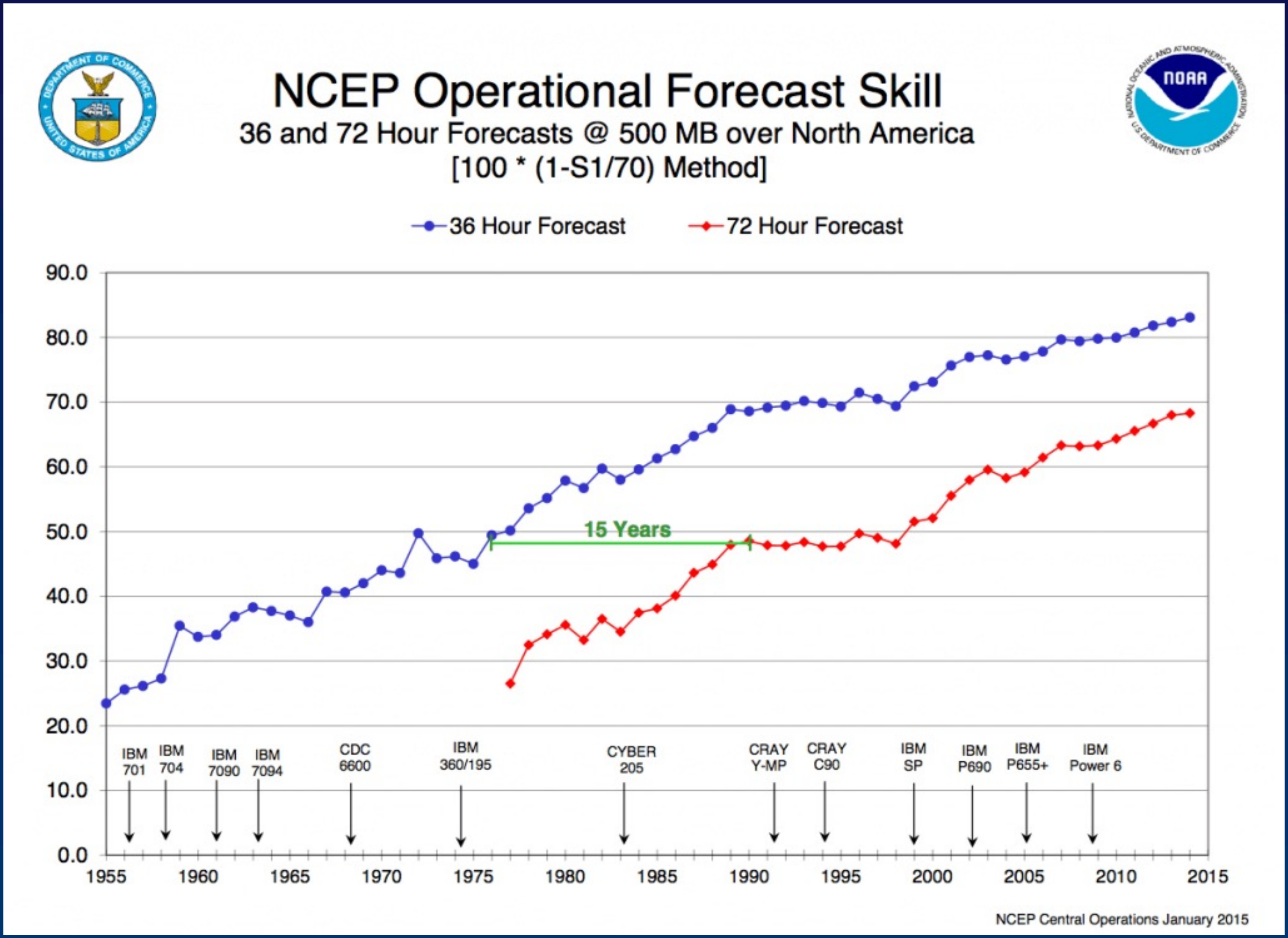
72518 ALB Albany Observations at 12Z 19 Mar 2013

PRES hPa	HGHT m	TEMP C	DWPT C	RELH %	MIXR g/kg	DRCT deg	SKNT knot	THTA K	THTE K	THTV K
1000.0	96	-0.3	-3.3	80	3.01	185	3	272.9	281.2	273.4
974.3	305	-1.8	-6.3	71	2.46	150	16	273.4	280.3	273.8
969.0	349	-2.1	-6.9	70	2.36	146	17	273.5	280.2	273.9
937.6	610	-4.1	-6.8	81	2.45	125	21	274.1	281.0	274.5
925.0	718	-4.9	-6.8	87	2.49	125	24	274.3	281.3	274.7
902.2	914	-5.9	-7.1	91	2.50	130	34	275.2	282.3	275.7
888.0	1038	-6.5	-7.3	94	2.50	134	38	275.9	283.0	276.3
867.7	1219	-6.5	-7.1	95	2.60	140	43	277.7	285.1	278.1
867.0	1225	-6.5	-7.1	96	2.60	141	43	277.8	285.2	278.2
855.0	1335	-3.7	-4.1	97	3.32	154	44	281.8	291.3	282.4
850.0	1381	-3.3	-3.7	97	3.44	160	45	282.7	292.6	283.3
834.9	1524	-1.6	-2.0	97	3.96	160	45	285.9	297.4	286.6
822.0	1648	-0.1	-0.6	96	4.48	176	40	288.8	301.8	289.6
803.6	1829	-0.1	-0.5	97	4.61	200	33	290.6	304.2	291.5
781.0	2058	-0.1	-0.4	98	4.78	219	28	293.0	307.2	293.9
773.6	2134	-0.4	-0.6	98	4.75	225	26	293.5	307.6	294.4
749.0	2392	-1.3	-1.4	99	4.63	225	24	295.2	309.1	296.1
744.7	2438	-1.6	-1.7	99	4.56	225	24	295.4	309.1	296.3
716.6	2743	-3.4	-3.7	98	4.08	235	29	296.7	309.1	297.4
700.0	2929	-4.5	-4.9	97	3.81	240	30	297.5	309.1	298.2
689.5	3048	-4.9	-5.3	97	3.74	235	42	298.3	309.7	298.9
681.0	3146	-5.3	-5.7	97	3.69	234	42	298.9	310.3	299.6

ACTUAL temperature profile for March 19, 2013 winter storm…
Close call for a heavy sleet storm!

We learn from storms like these …

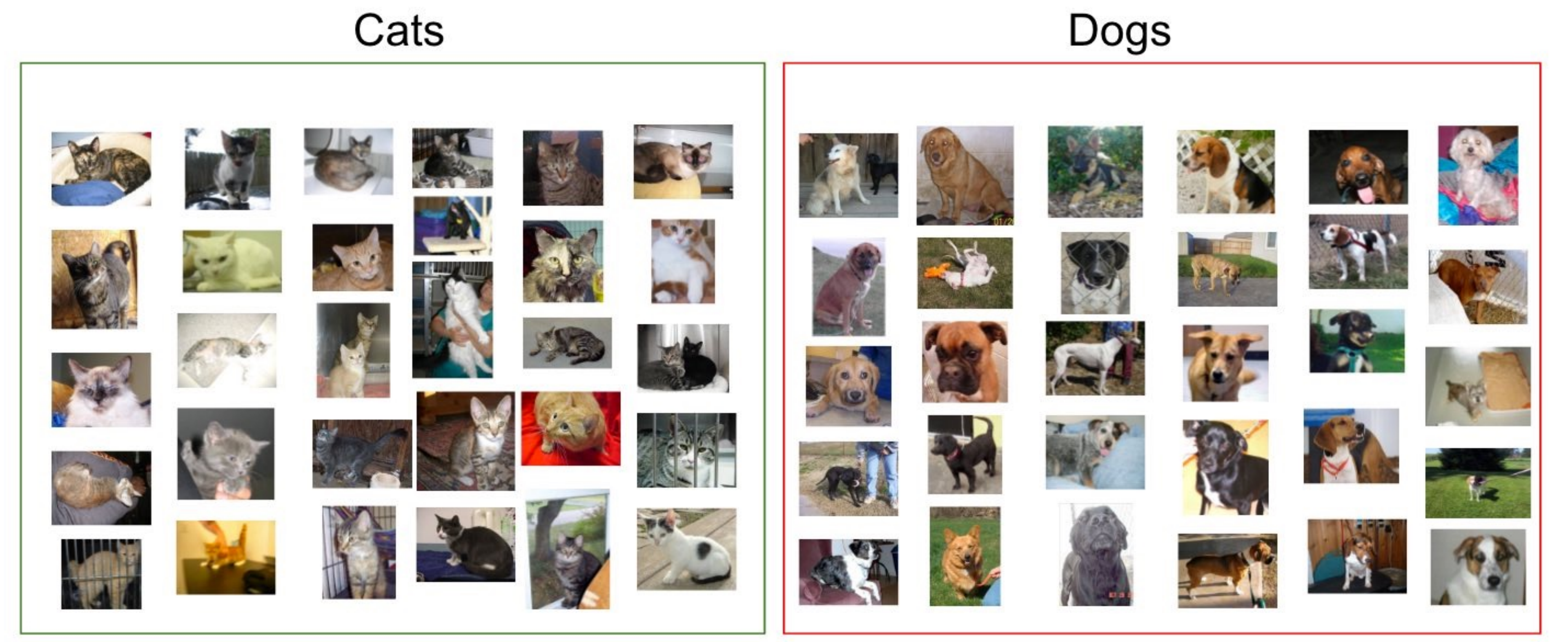
… and models and forecasters are improving every year!



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:*



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

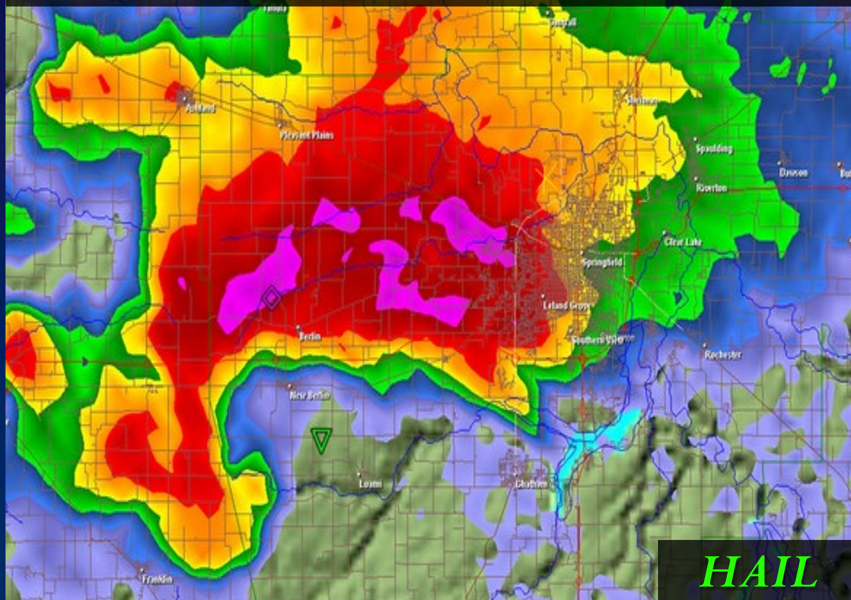
Can a machine learning algorithm tell the difference between:

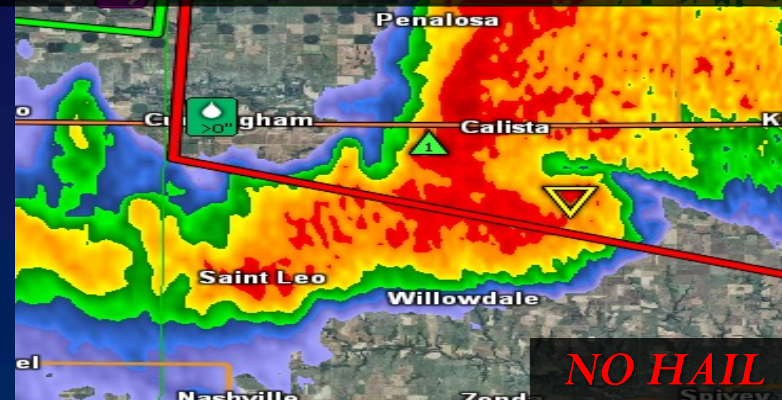
A chihuahua and a blueberry muffin?

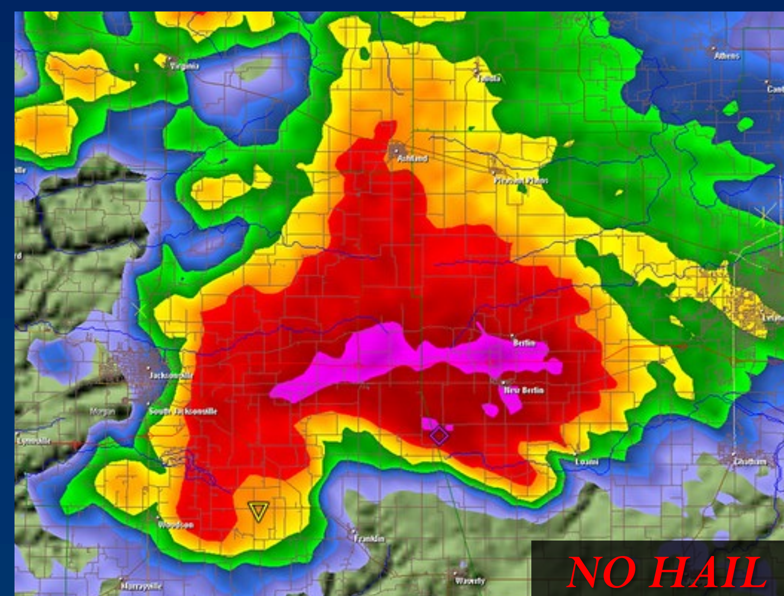
Mostly yes … but what does this have to do with weather?!

Artificial intelligence and weather forecasting

Will severe hail fall in a particular thunderstorm?

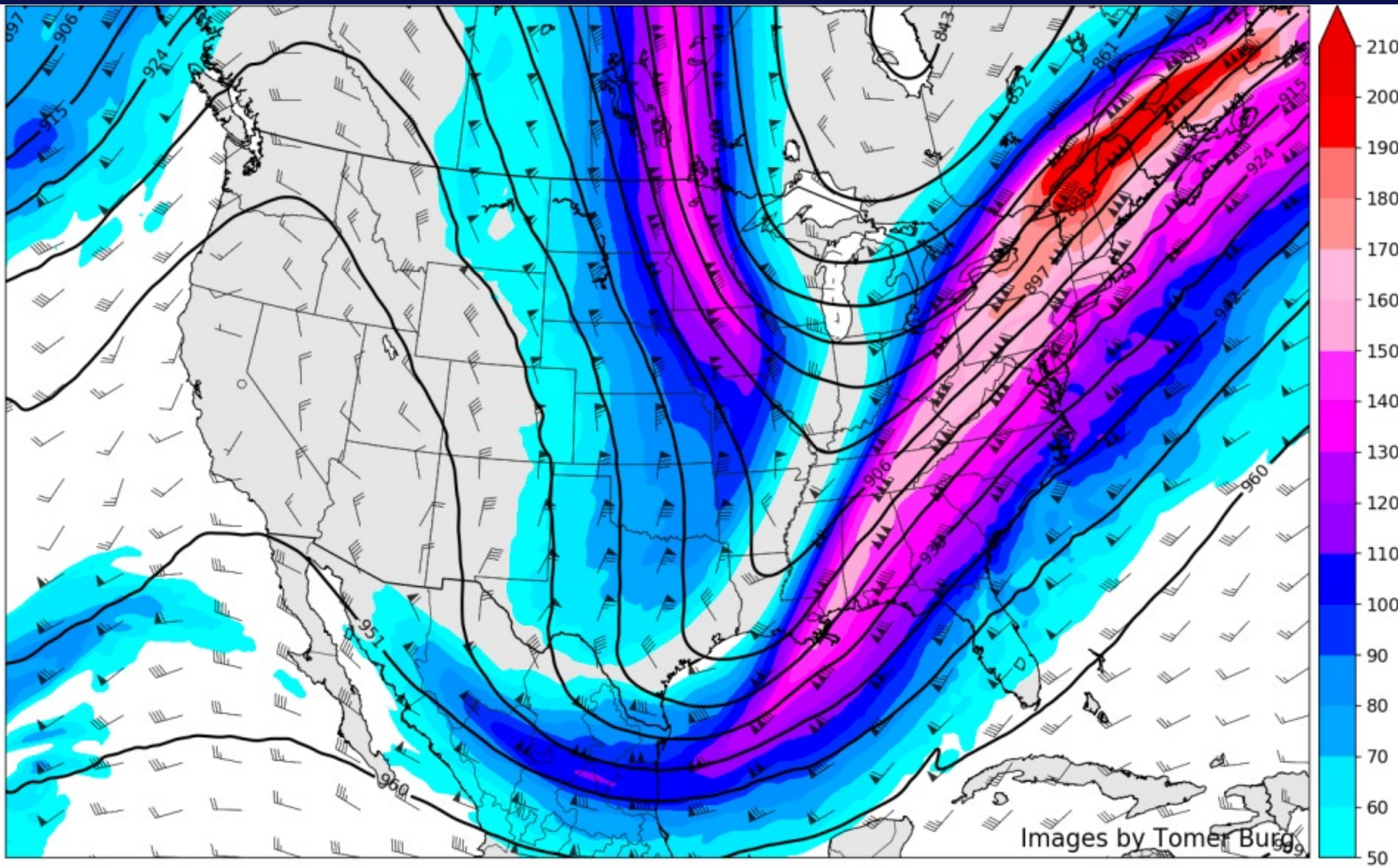






Artificial intelligence and weather forecasting

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**

Future:

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

Questions?