

A satellite image of Earth's surface, showing cloud patterns and landmasses. A semi-transparent weather map is overlaid on the image, with lines indicating pressure systems and fronts. The map covers a large portion of the Northern Hemisphere, including North America, Europe, and parts of Asia and Africa.

The Past, Present, and Future of Weather Forecasting

Ross A. Lazear

Department of Atmospheric and
Environmental Sciences

August 25, 2019

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

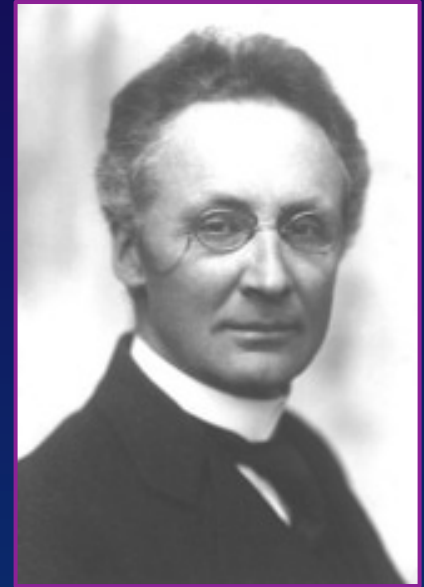
Vilhelm Bjerknes

Father of Modern of Meteorology

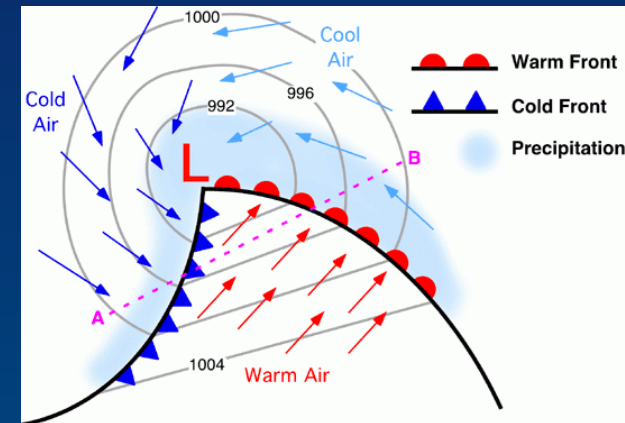
- Worked with *Heinrich Hertz* (of the unit of frequency) on the existence of electromagnetic waves and instruments that transmit/receive radio pulses
- 1895 – Professor at the University of Stockholm
 - Using a combination of fluid dynamics and thermodynamics, developed primitive equations to describe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



Prof. Vilhelm Bjerknes



Norwegian Cyclone Model

The forecast that changed the world...

How the weather evolved

June 4, 1944: High winds and rain lash the English Channel. With a new storm approaching, the invasion was aborted.



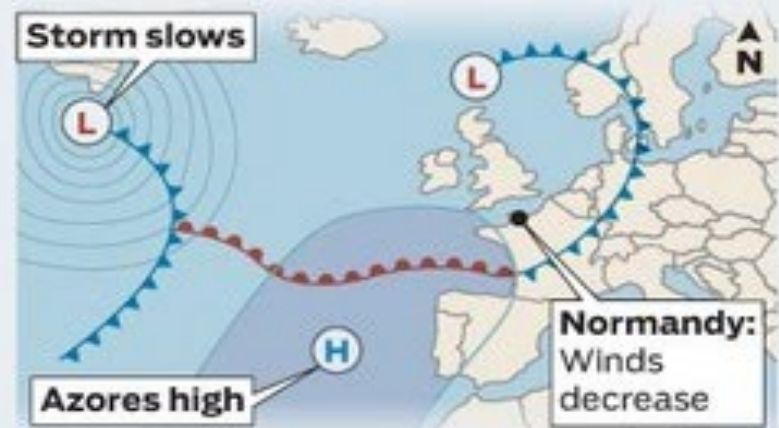
Original invasion planned for **June 5**, but unusually strong late spring weather system was approaching!

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.

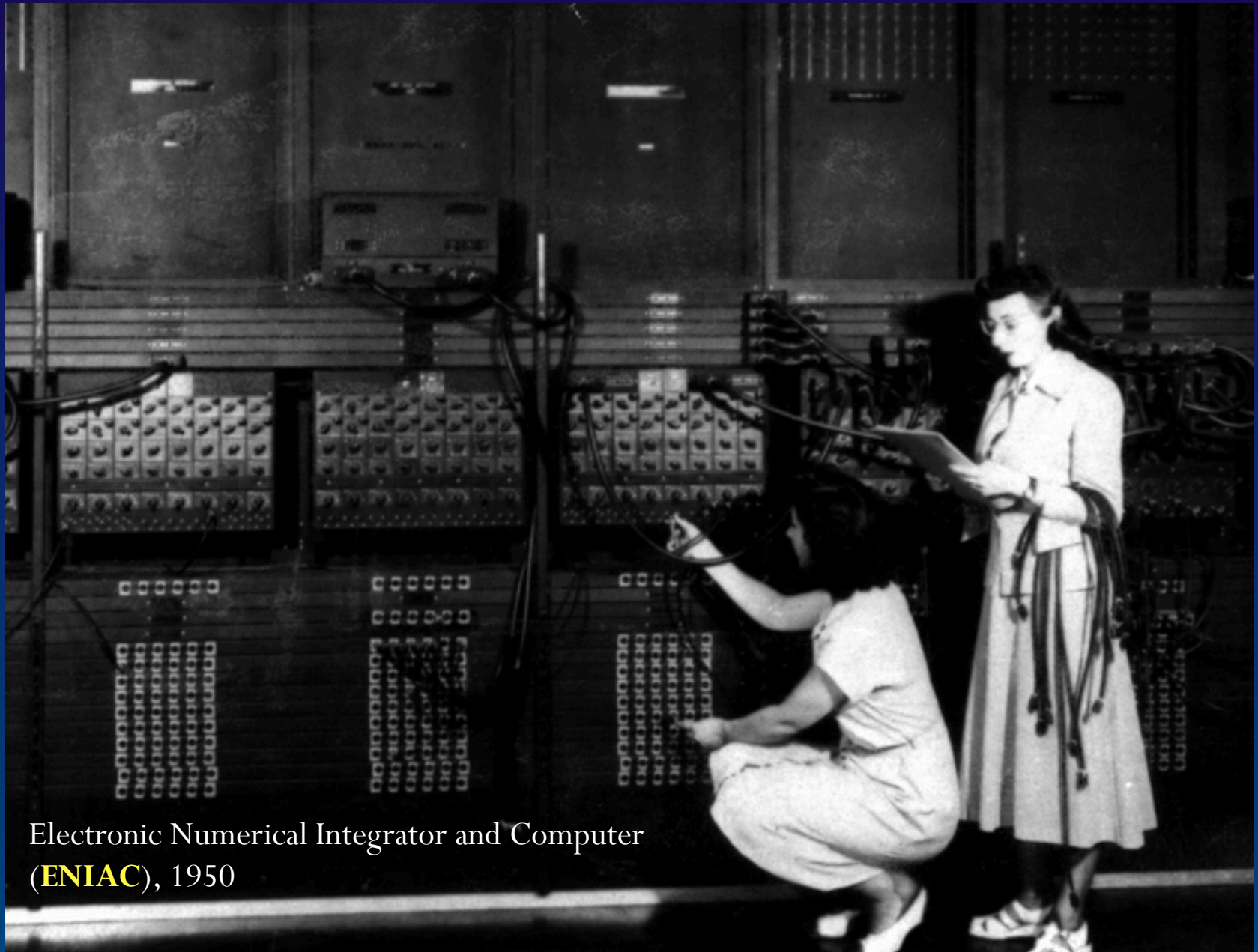
June 6, 1944: Although the new storm intensifies, it slows down as an Azores high builds into Europe. The invasion begins.



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!



1949



1970s



1990s



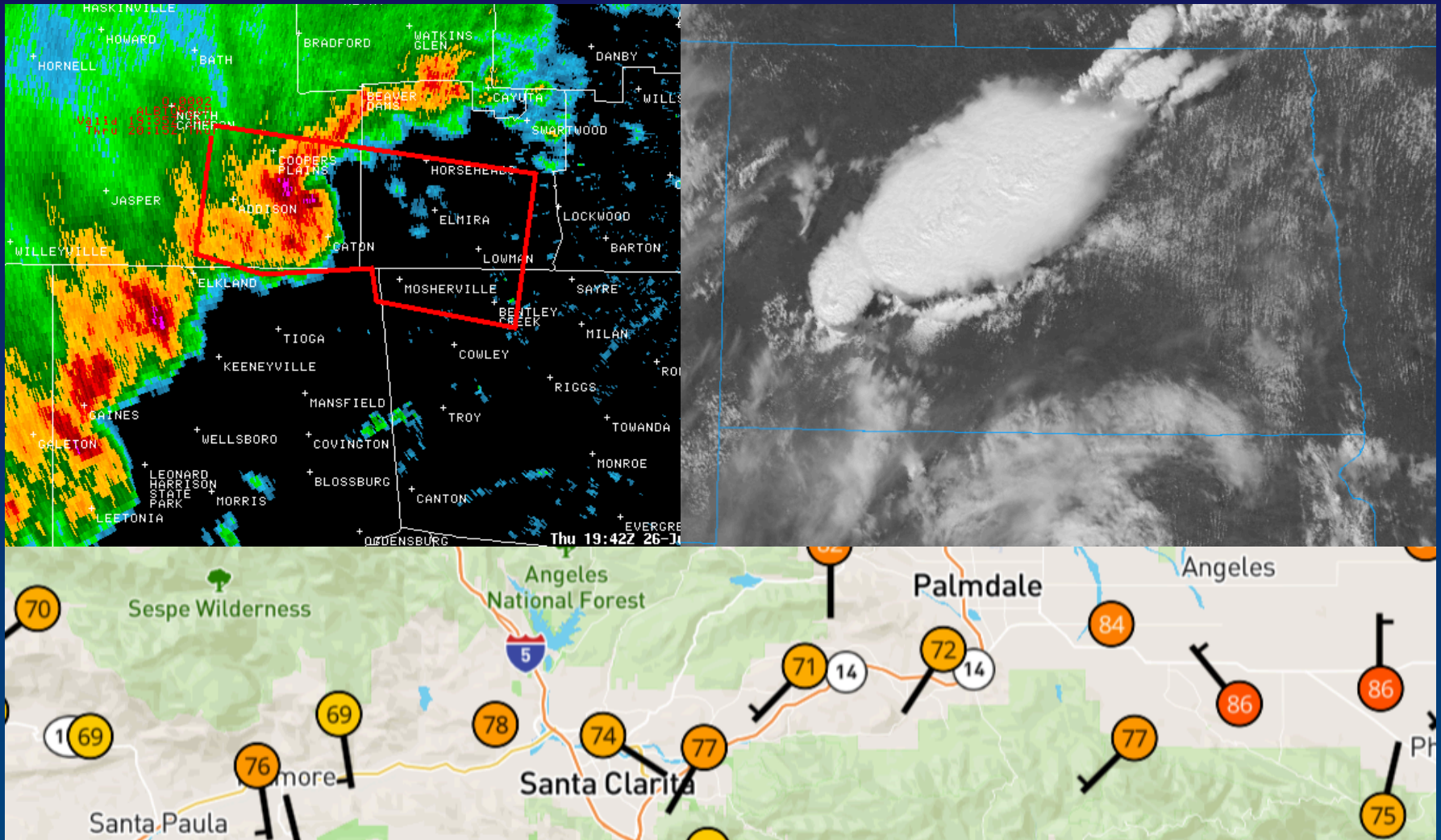
2019

The WEATHER Channel
CLOSELY WATCHING THE GULF OF MEXICO
A Tropical Depression could form by the end of the week

Types of forecasts

Nowcasting:

Forecasts of up to six hours in advance



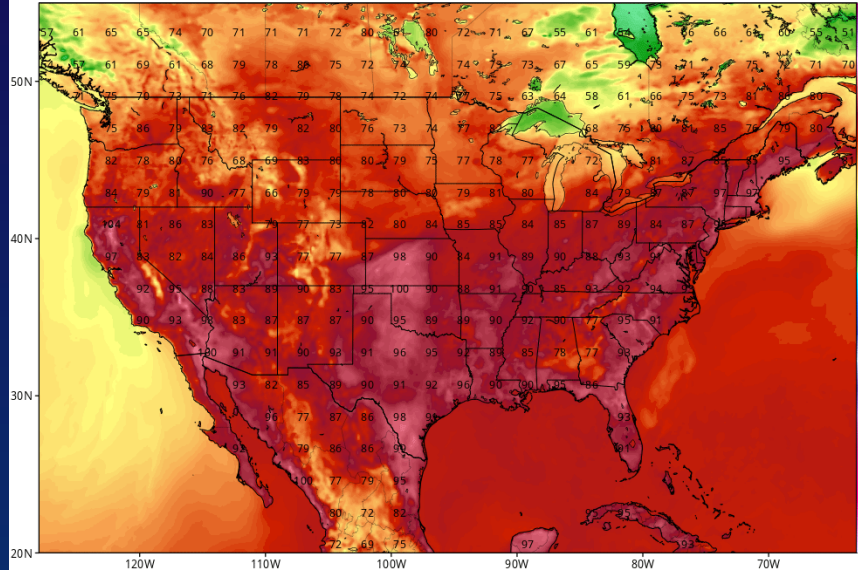
Short-range weather forecasts:

Forecasts of up to 7-10 days in advance

GFS 2-meter Air Temperature (°F)

Init: 12z Jul 08 2019 Forecast Hour: [246] valid at 18z Thu, Jul 18 2019

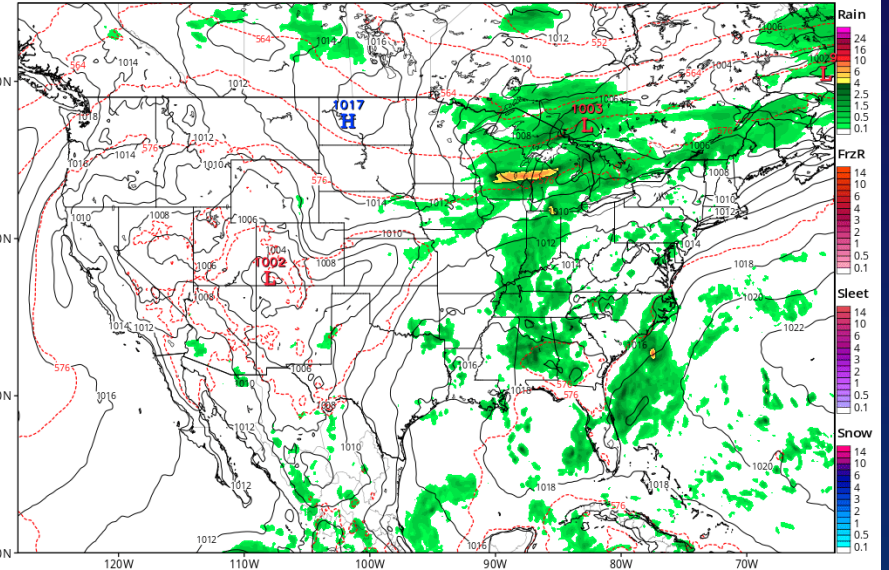
TROPICALTIDBITS.COM



GFS 6-hour Averaged Precip Rate (mm/hr), MSLP (hPa), & 1000-500mb Thick (dam)

Init: 12z Jul 08 2019 Forecast Hour: [246] valid at 18z Thu, Jul 18 2019

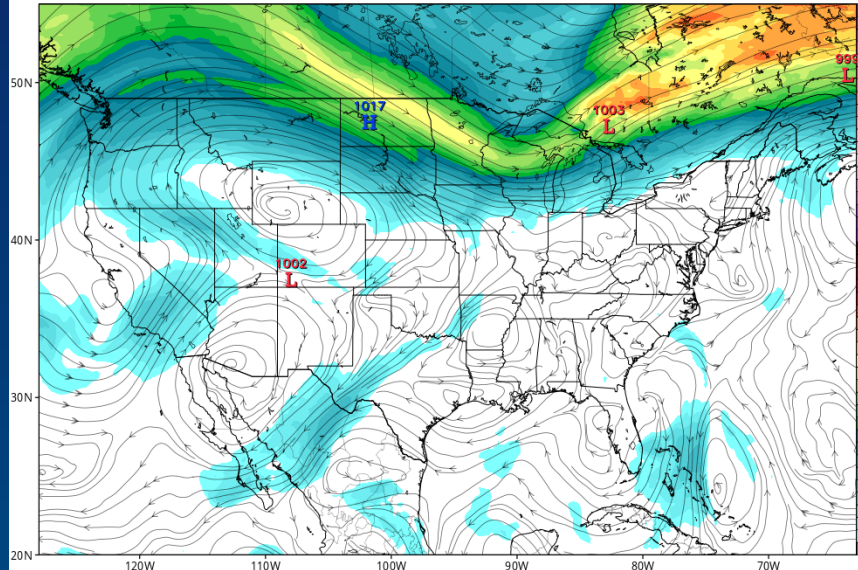
TROPICALTIDBITS.COM



GFS 250mb Wind Speed/Streamlines (kt) & MSLP Extrema (mb)

Init: 12z Jul 08 2019 Forecast Hour: [246] valid at 18z Thu, Jul 18 2019

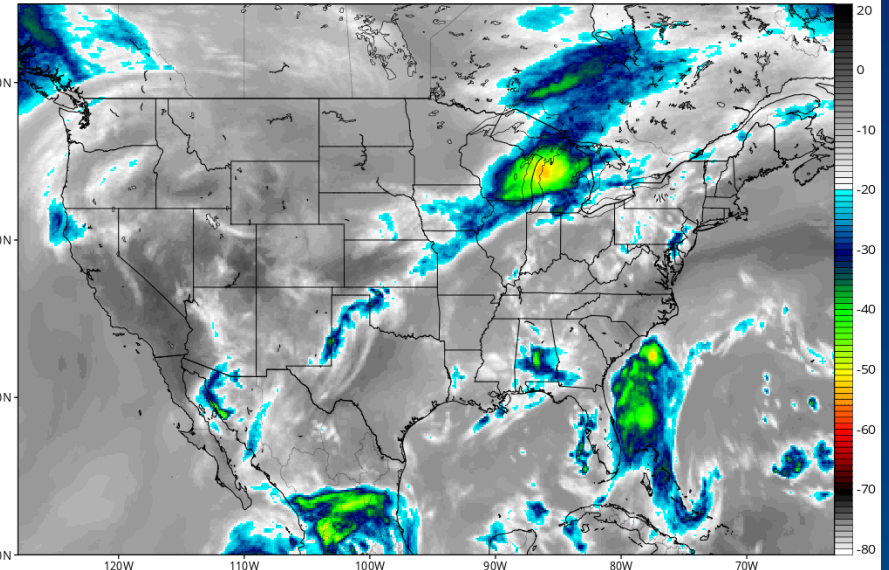
TROPICALTIDBITS.COM



GFS 6-hour Averaged Simulated IR Brightness Temperature (°C)

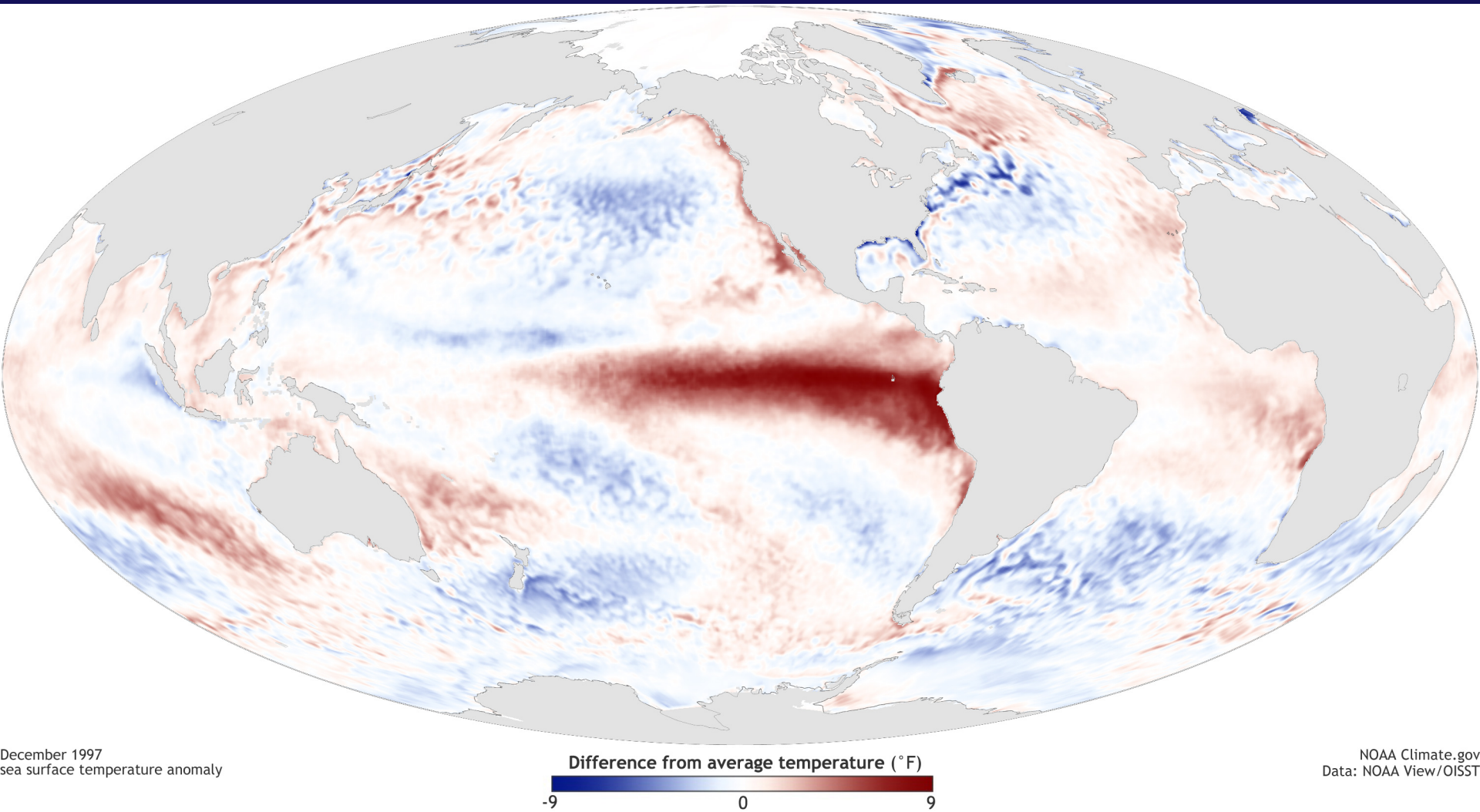
Init: 12z Jul 08 2019 Forecast Hour: [246] valid at 18z Thu, Jul 18 2019

TROPICALTIDBITS.COM



Seasonal to Subseasonal forecasting

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



Sea surface temperatures in December 1997 (El Niño)

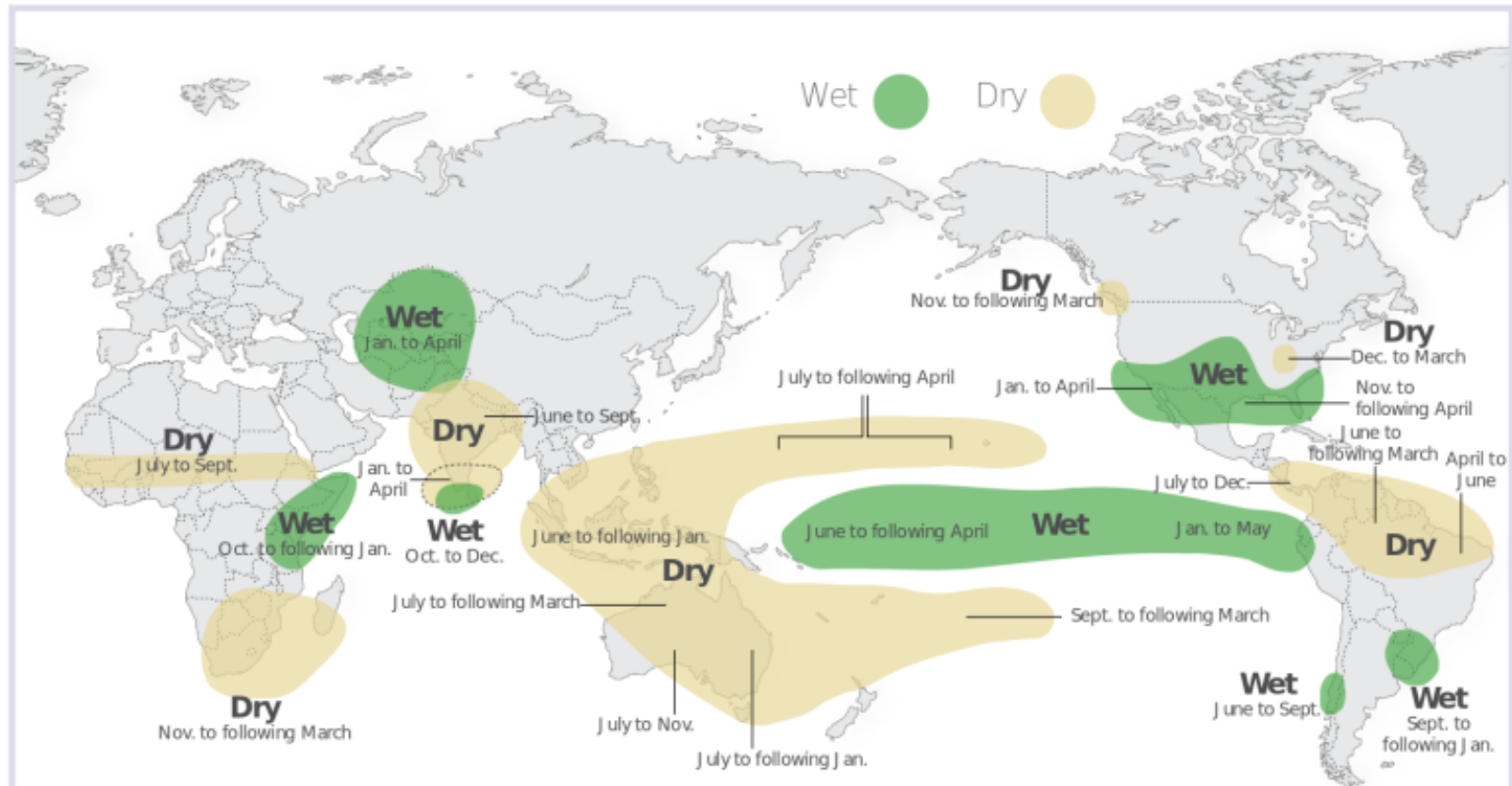
*Up to **10°F warmer than normal** over the Tropical Pacific!*

Seasonal and Subseasonal forecasting

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

El Niño and Rainfall

El Niño conditions in the tropical Pacific are known to shift rainfall patterns in many different parts of the world. Although they vary somewhat from one El Niño to the next, the strongest shifts remain fairly consistent in the regions and seasons shown on the map below.



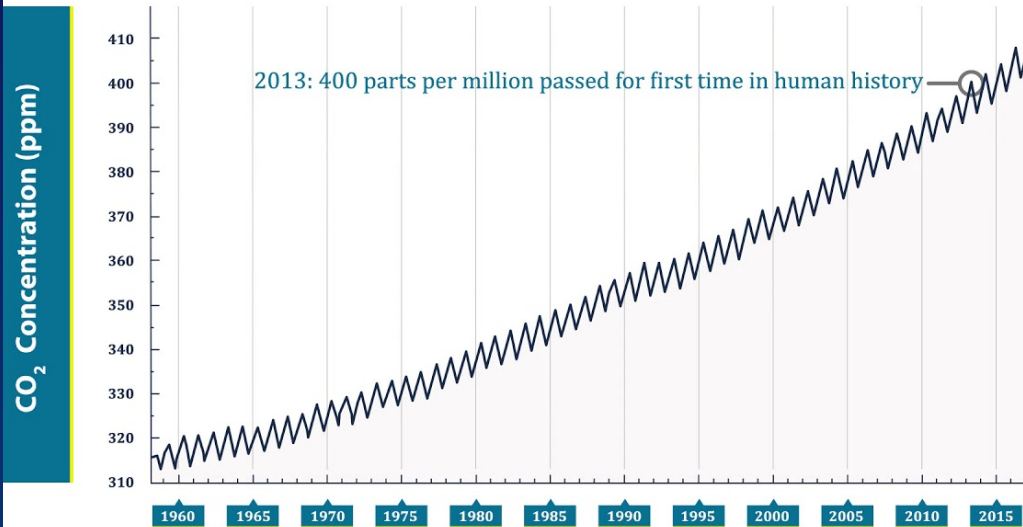
For more information on El Niño and La Niña, go to: <http://iri.columbia.edu/ENSO>

Sources: Ropelewski, C. F. and M. S. Halpert, 1989: Precipitation patterns associated with the high index phase of the Southern Oscillation. *J. Climate*, 2, 268-284.
Mason and Goddard, 2001: Probabilistic precipitation anomalies associated with ENSO. *Bull. Am. Meteorol. Soc.* 82, 619-638

Climate forecasting

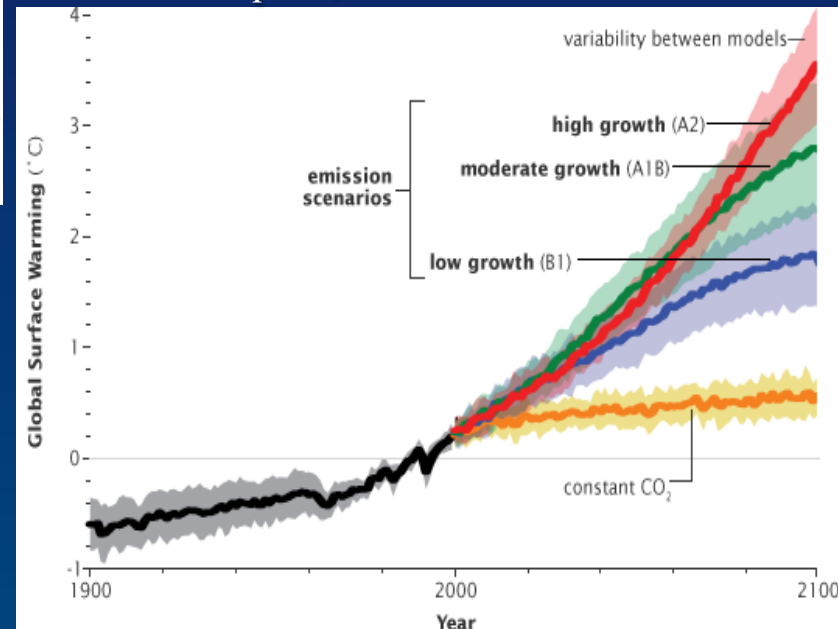
How will natural and human-induced changes to our planet affect global temperatures and precipitation?

CARBON DIOXIDE CONCENTRATION AT MAUNA LOA OBSERVATORY

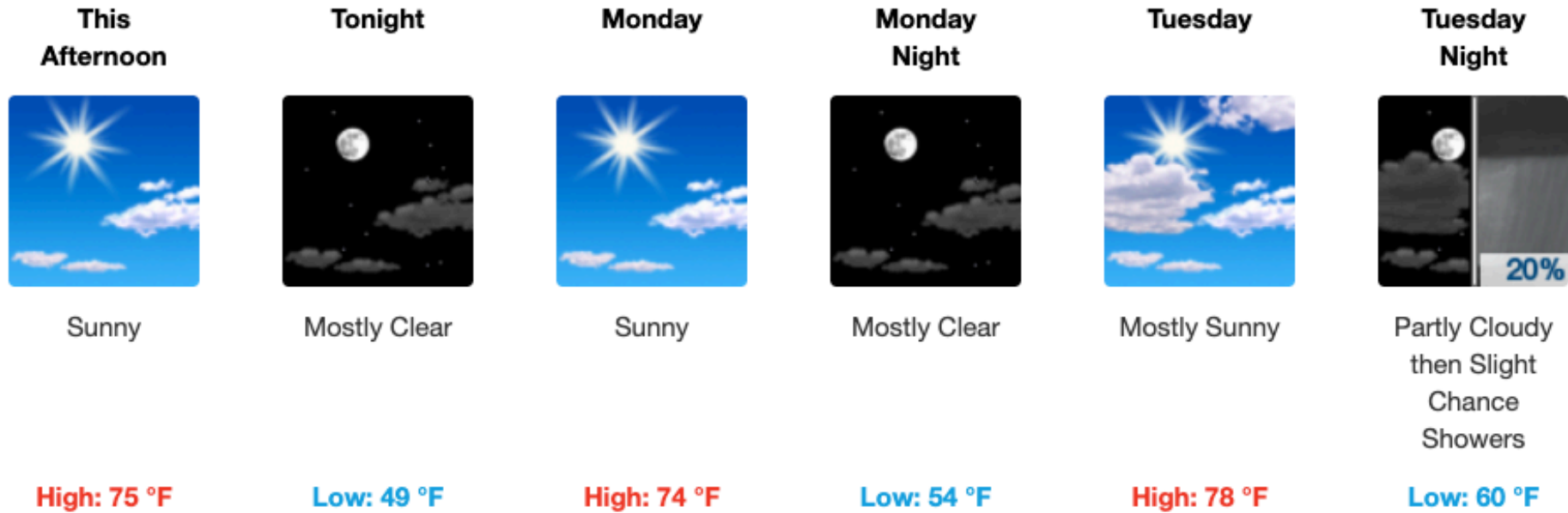


Scripps Institute for Oceanography

IPCC Report, 2007



How do meteorologists *make* a weather forecast?



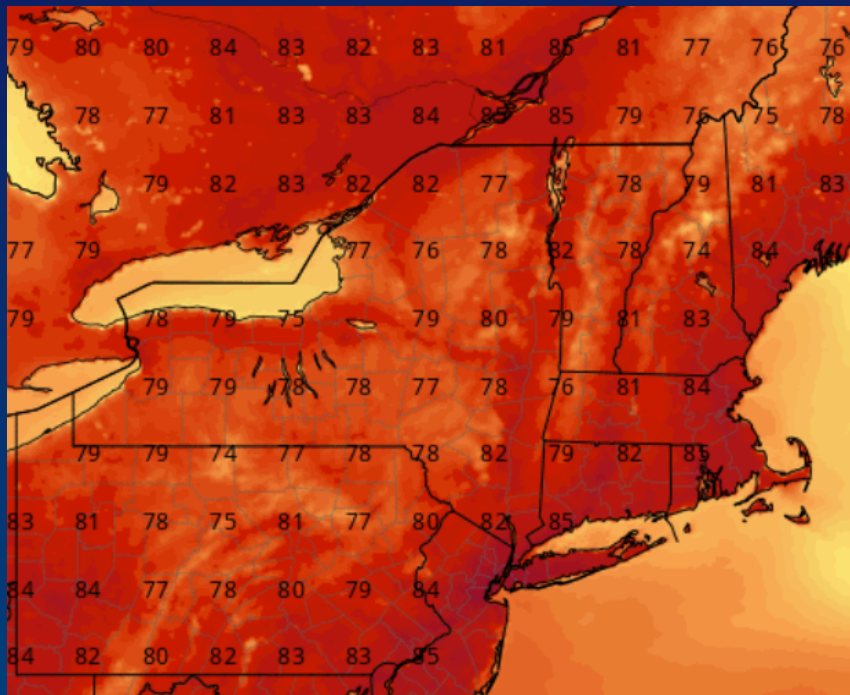
National Weather Service forecast for Albany, N.Y. — August 25, 2019

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

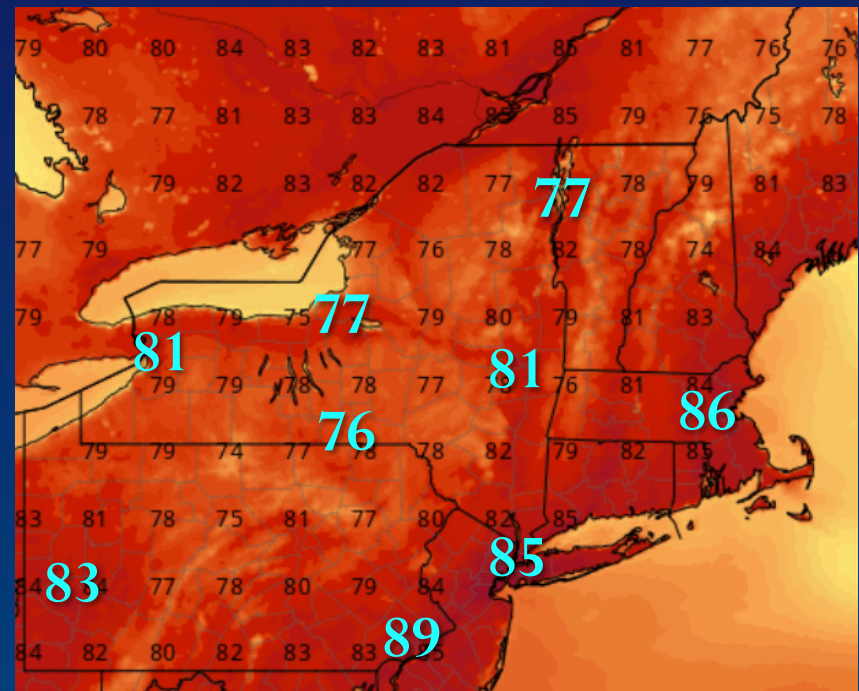
*Part of why an unprecedented storm, like **Superstorm Sandy**, is a tough forecast!*

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

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

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

Continuity Equation

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

Temperature Forecast Equation

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

Moisture Forecast Equation

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

Hydrostatic Equation

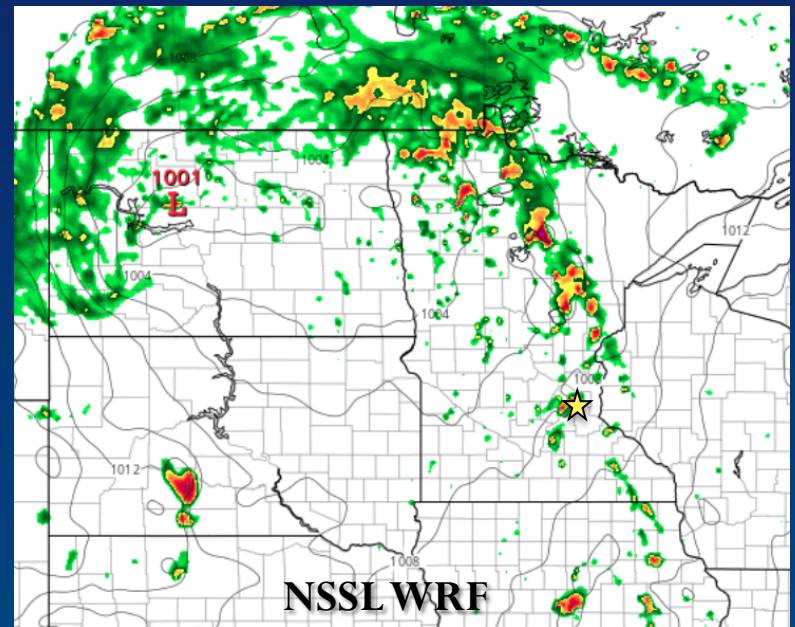
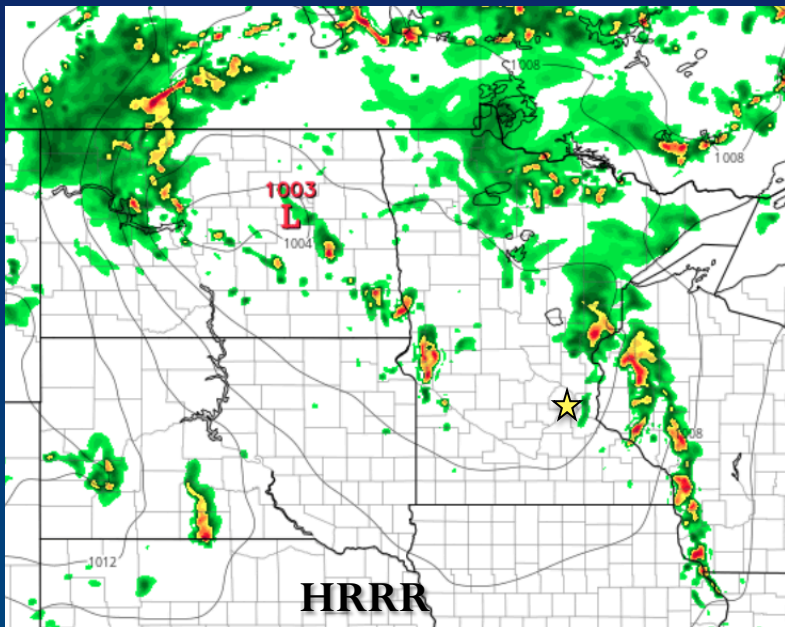
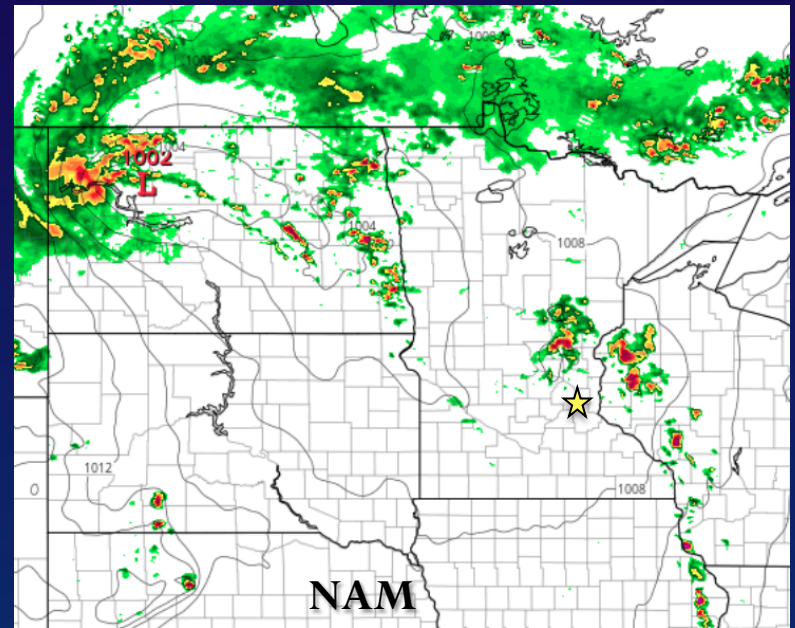
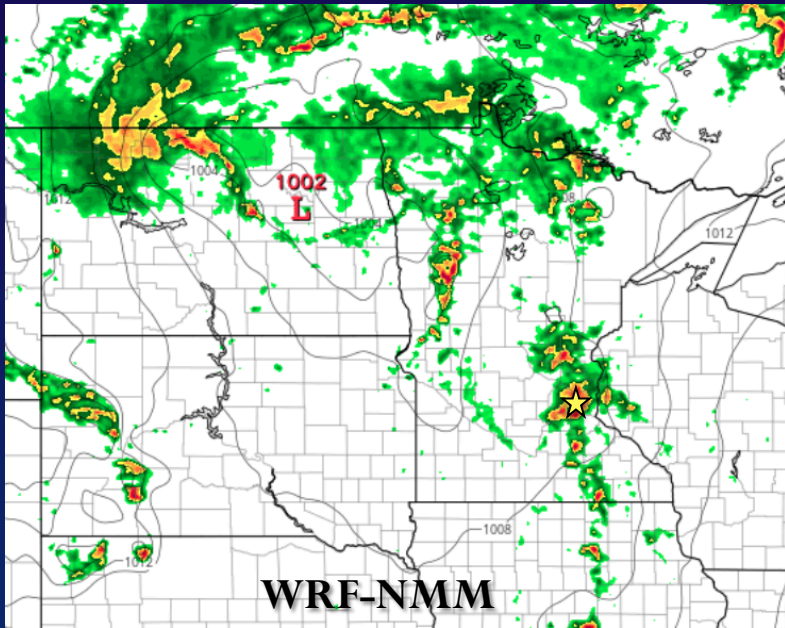
$$5. \quad \frac{\partial z}{\partial p} = - \frac{RT}{pg}$$

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

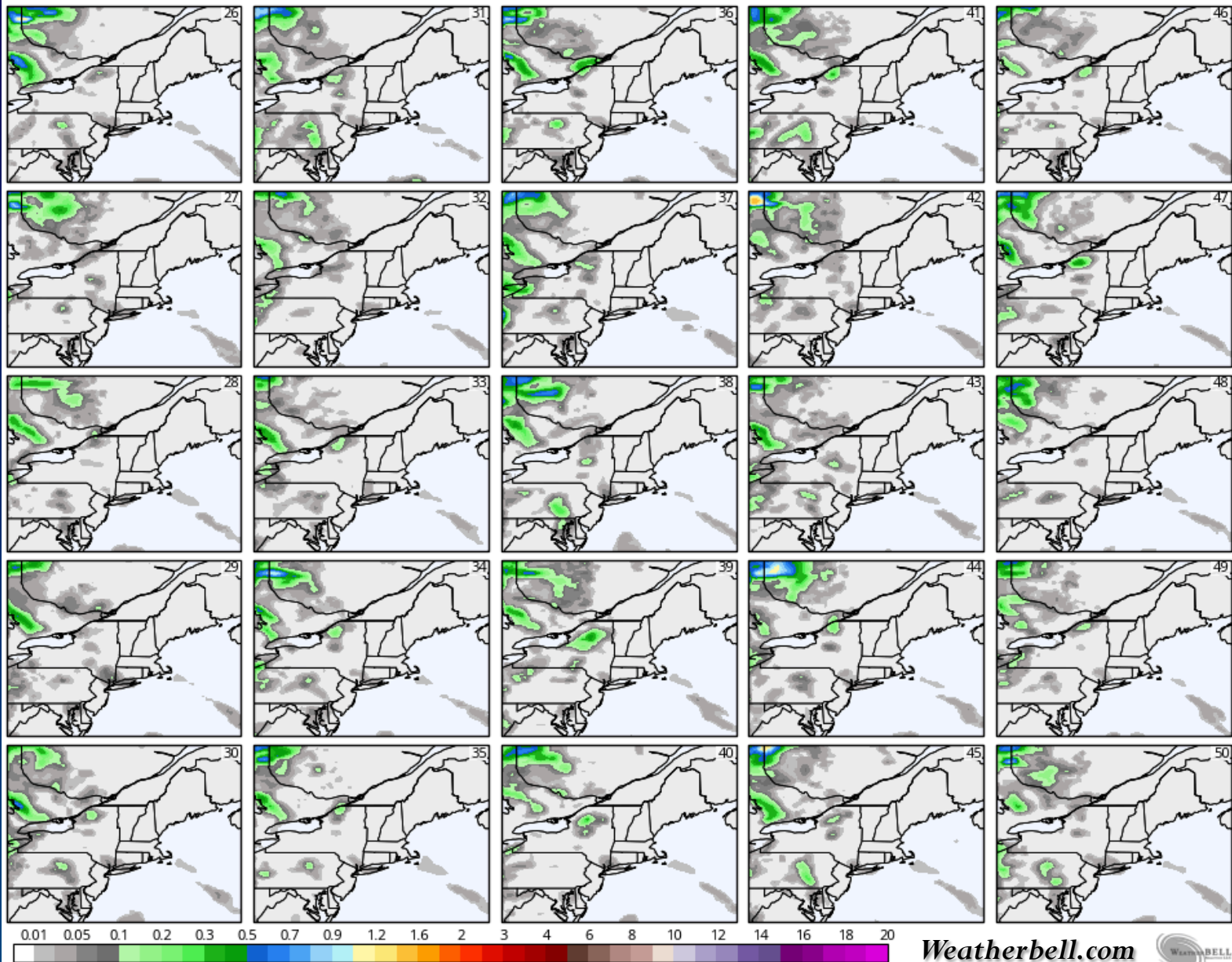
Probabilistic forecasting requires using a **model ensemble**.

- 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

ECMWF ENS 0.25° Init 00z 11 Jul 2019 • 6-hr Precipitation (Inches)

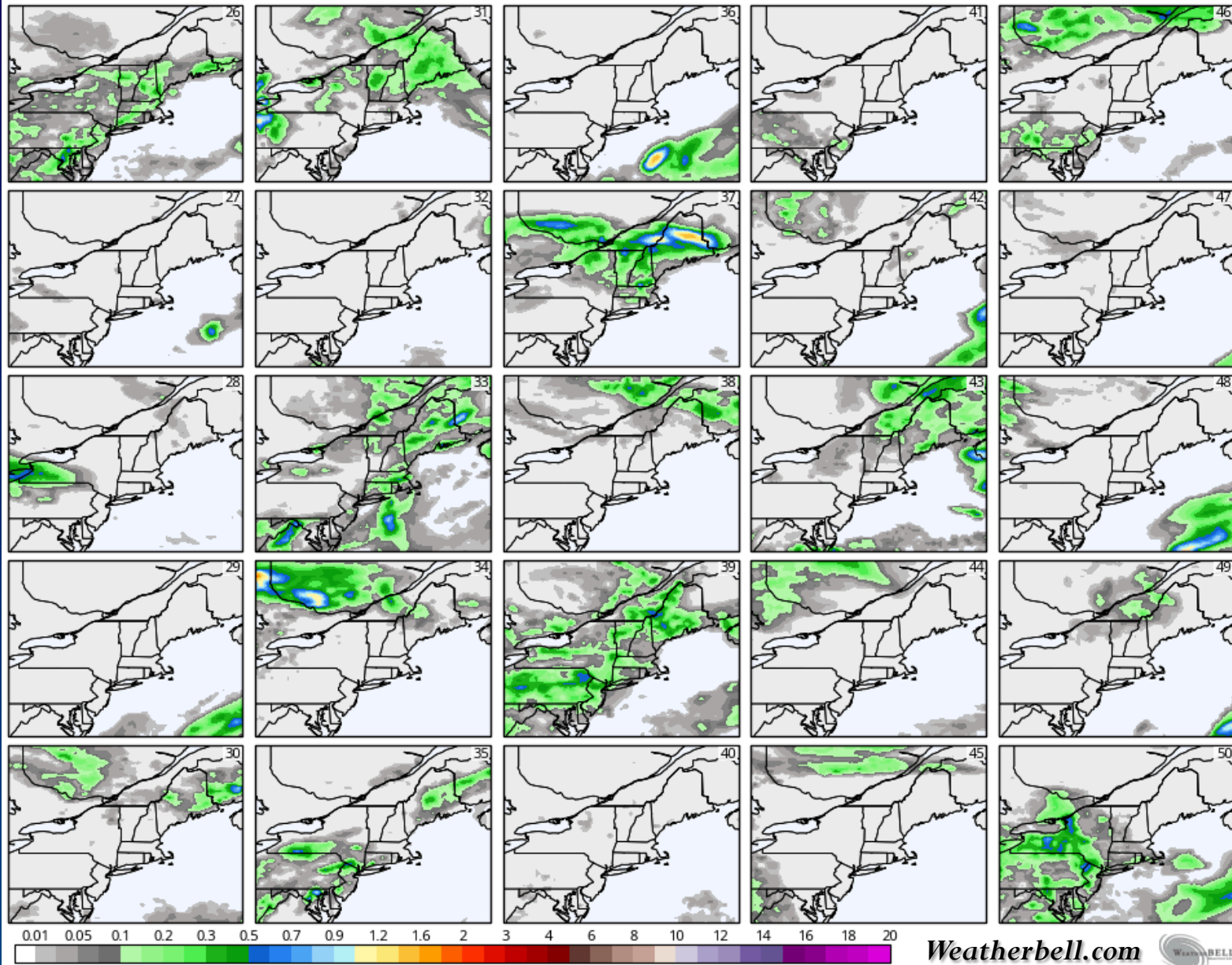
Hour: 12 • Valid: 12z Thu 11 Jul 2019



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

ECMWF ENS 0.25° Init 00z 11 Jul 2019 • 6-hr Precipitation (Inches)

Hour: 360 • Valid: 00z Fri 26 Jul 2019

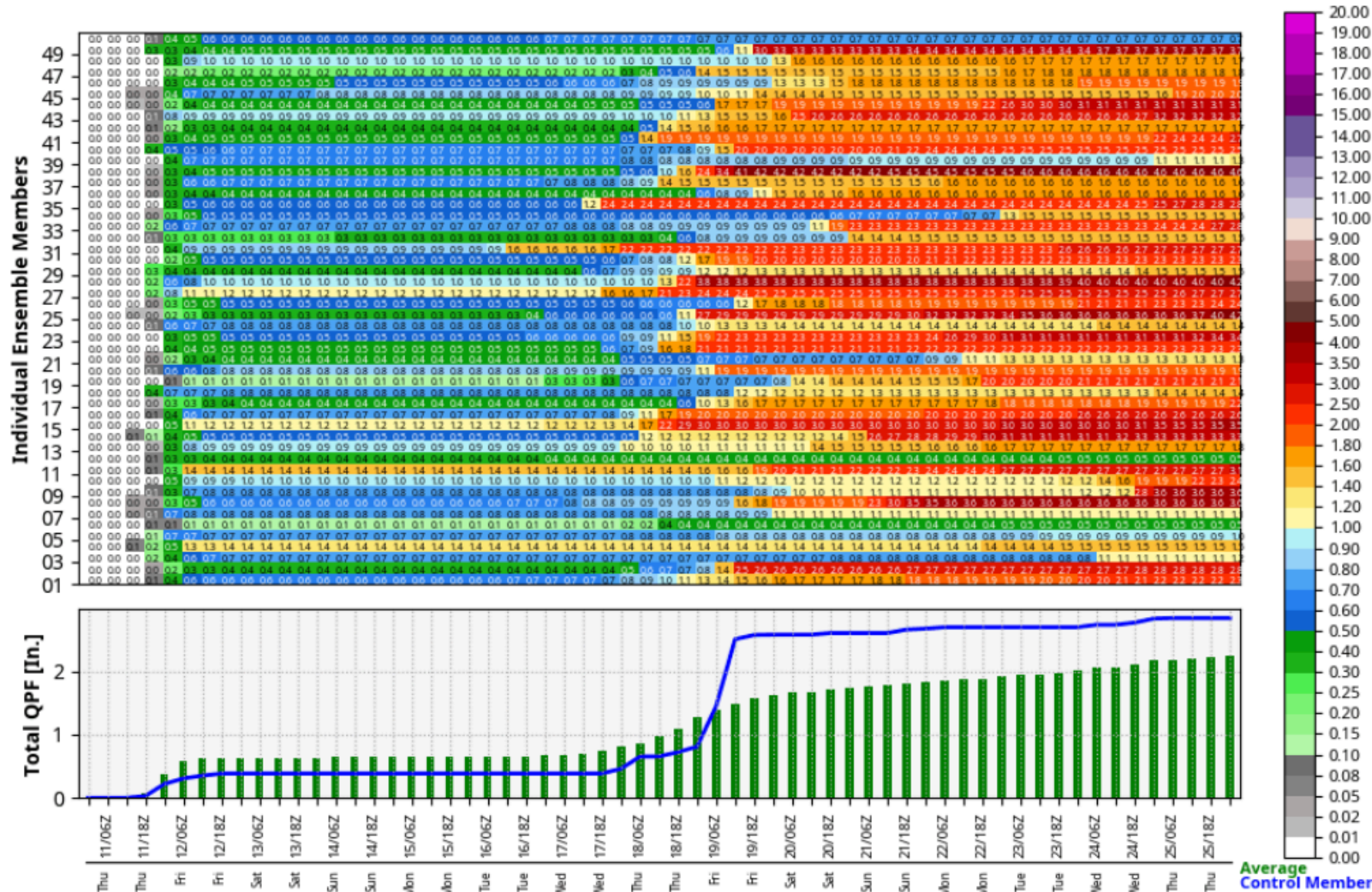


Ensemble forecasting


Total QPF Individual Member View • ECMWF ENS 0.25° Init 00z 11 Jul 2019



Albany International Airport • KALB [42.7483°N, 73.8017°W]


Weatherbell.com




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

RADAR & MAPSNEWSVIDEOSEVERE WEATHERMORE

 Search location, zip...


United States > Albany, NY 82°F 

Allergies: Low 

AD

Solar Without Rooftop Panels

Save up to 10% on your annual electricity cost. Nexamp



NOW

MINUTECAST®


WEEKEND

EXTENDED


MONTH

RADAR


WINTERCAST



MINUTECAST® FOR ALBANY
Rain starting in 5 min



CURRENT WEATHER




82°_F

RealFeel® 89°

Cloudy

SEE HOURLY >

TODAY
JUL 11




83°_{Hi}

RealFeel® 90°

A strong p.m. thunderstorm

MORE

TONIGHT
JUL 11



69°_{Lo}

RealFeel® 66°

Thunderstorm

MORE

TOMORROW
JUL 12




83°_{Hi}

RealFeel® 89°

Clouds and sun, a t-storm

MORE

AD



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Learn More


TRENDING NOW



AccuWeather



LOOKING AHEAD
Thunderstorms, some strong, this afternoon through this evening



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

AccuWeather RADAR & MAPS NEWS VIDEO SEVERE WEATHER MORE

United States > Albany, NY 82°F ☁️

Allergies: Low

AD Solar Without Rooftop Panels
Save up to 10% on your annual electricity cost. Nexamp

!!!

NOW MINUTECAST® WEEKEND EXTENDED **MONTH** RADAR WINTERCAST

MINUTECAST® FOR ALBANY
Rain starting in 5 min

CURRENT WEATHER

☁️

82° F
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[SEE HOURLY >](#)

TODAY JUL 11

☀️⚡️

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A strong p.m. thunderstorm
[MORE](#)

TONIGHT JUL 11

☁️⚡️

69° Lo
RealFeel® 66°
Thunderstorm
[MORE](#)

TOMORROW JUL 12

☀️⚡️










83° Hi
RealFeel® 89°
Clouds and sun, a t-storm
[MORE](#)

AD New York Community Solar
Solar Without Rooftop Panels
Nexamp [Learn More](#)

TRENDING NOW

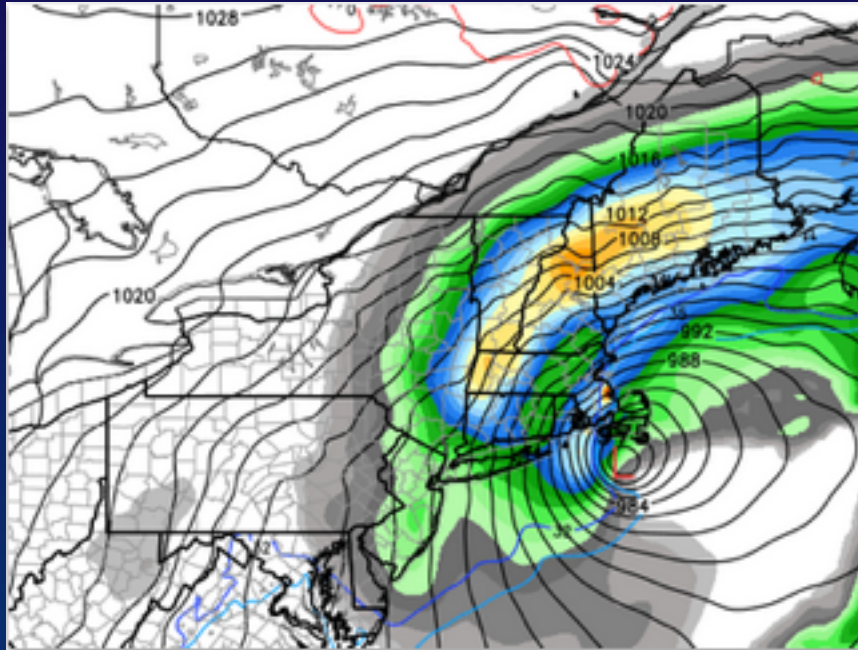
! **LOOKING AHEAD**
Thunderstorms, some strong, this afternoon through this evening

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

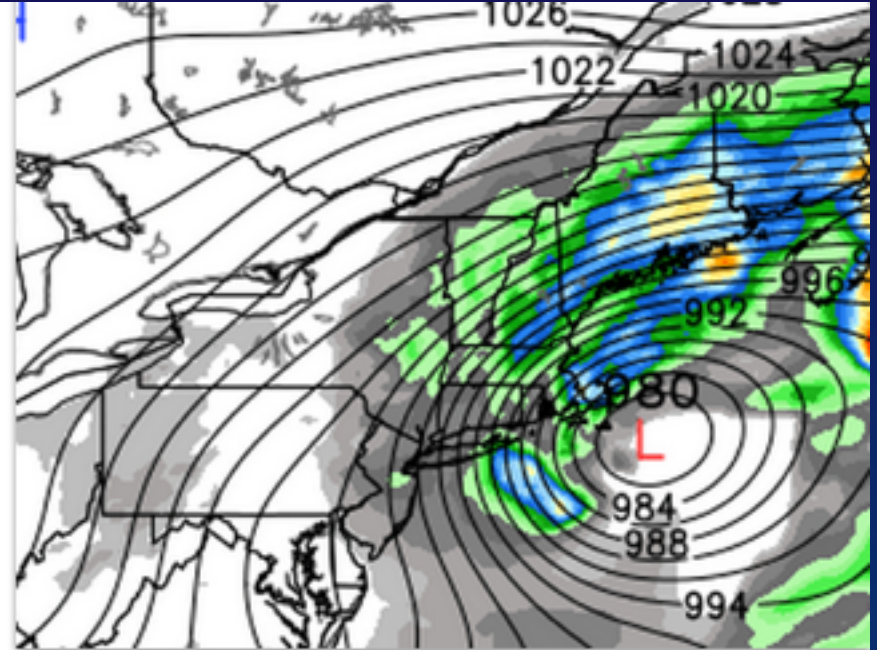
NOW	RADAR	MINUTECAST	HOURLY	DAILY	MONTH		
					< NOVEMBER 2019 >		 
Sun	Mon	Tue	Wed	Thu	Fri	Sat	
10/27  61°/43° Hist. Avg. 56°/36°	10/28  62°/41° Hist. Avg. 55°/36°	10/29  60°/38° Hist. Avg. 55°/36°	10/30  50°/31° Hist. Avg. 54°/36°	10/31  50°/31° Hist. Avg. 54°/35°	1  47°/29° Hist. Avg. 54°/35°	2  46°/32° Hist. Avg. 53°/35°	

This forecast is garbage!

Forecast model failure ... January 27, 2015



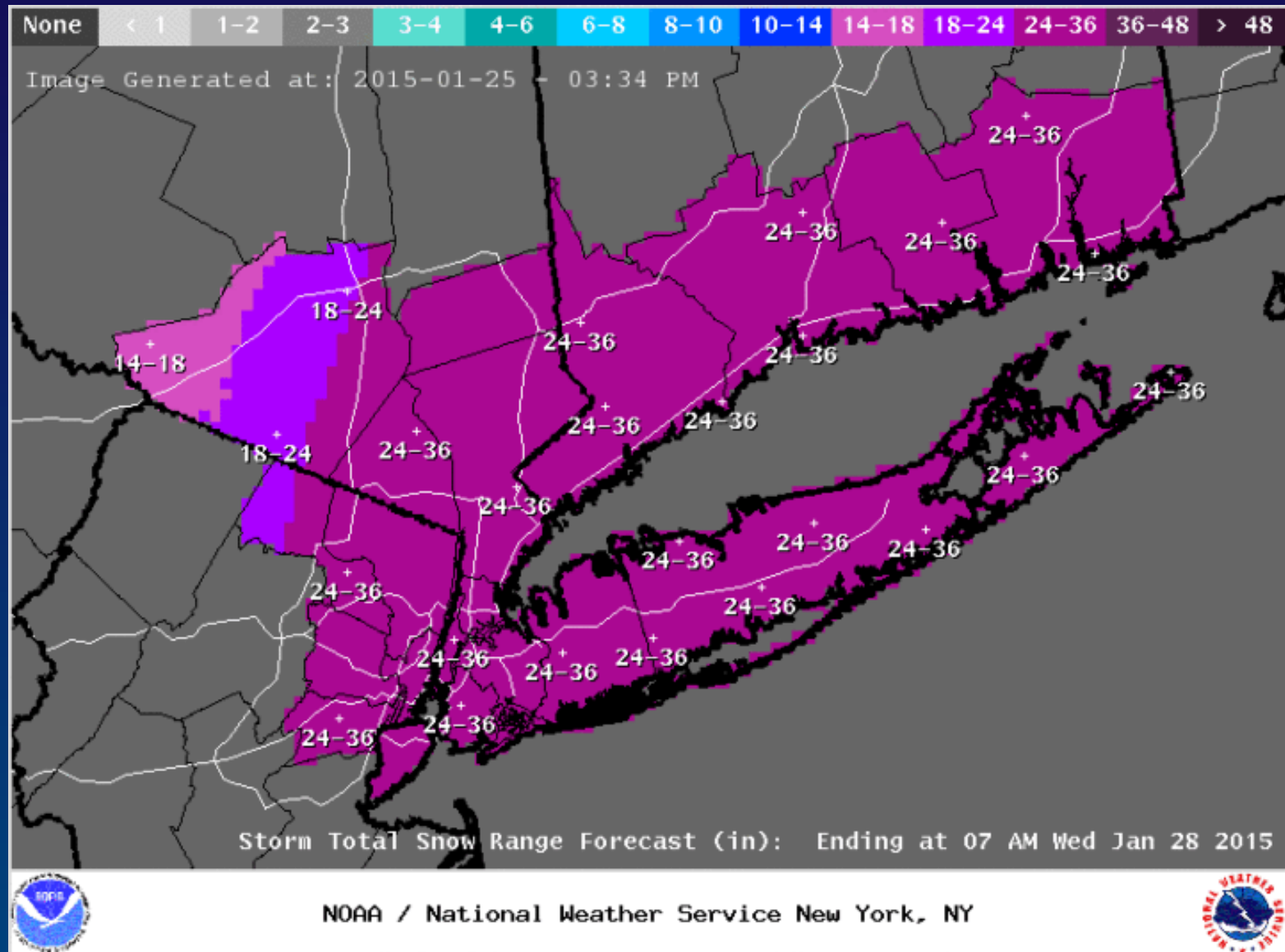
ECMWF 12Z 26 Jan 2015



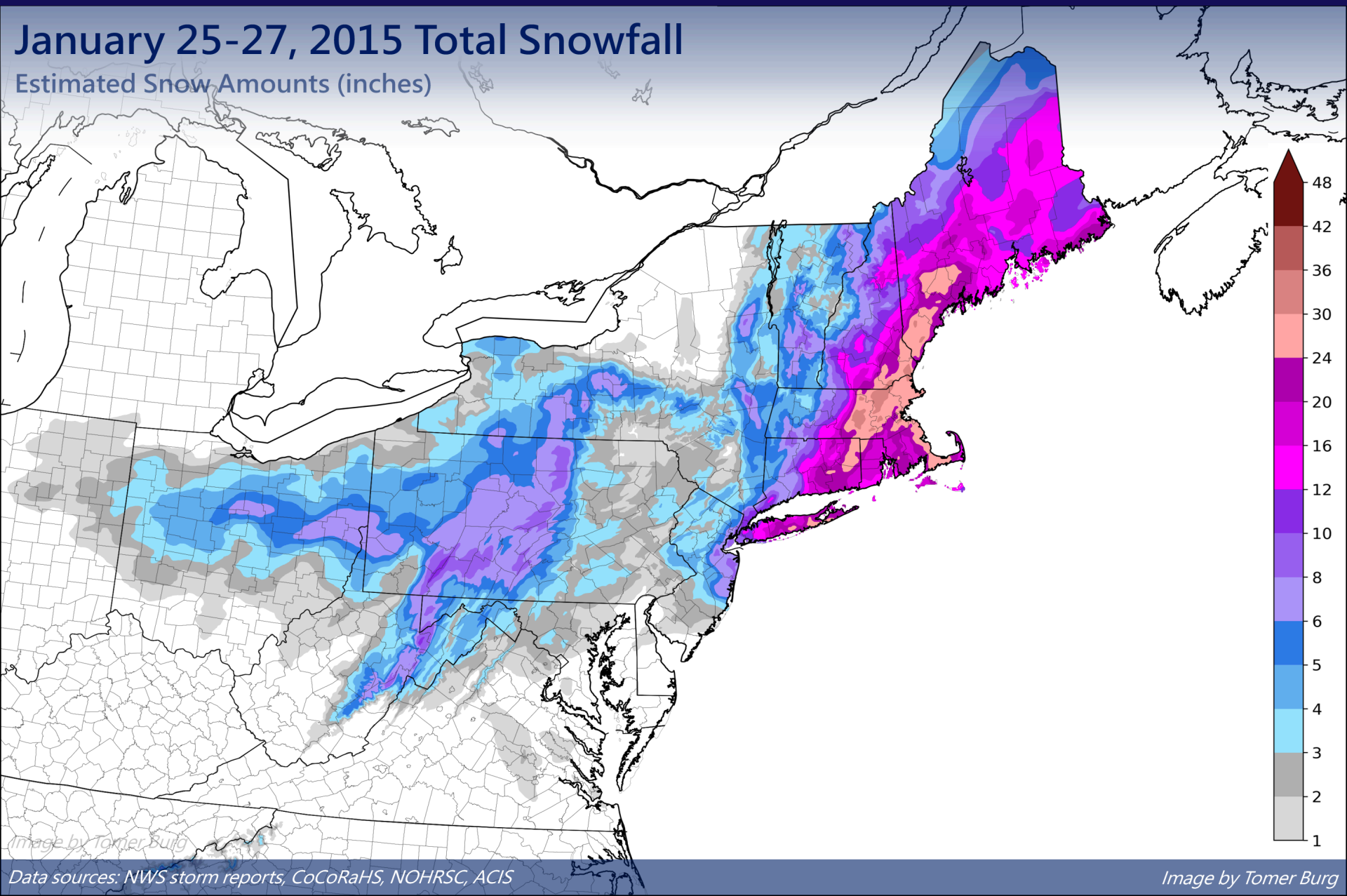
GFS 12Z 26 Jan 2015

Forecast precipitation for 00Z to 06Z 27 Jan 2015

Forecast model failure ... January 27, 2015



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**

Low End Amount - 9 in 10 Chance (90%) Of Higher Snowfall
Valid: 03/20/2018 02:00 AM - 03/22/2018 08:00 AM



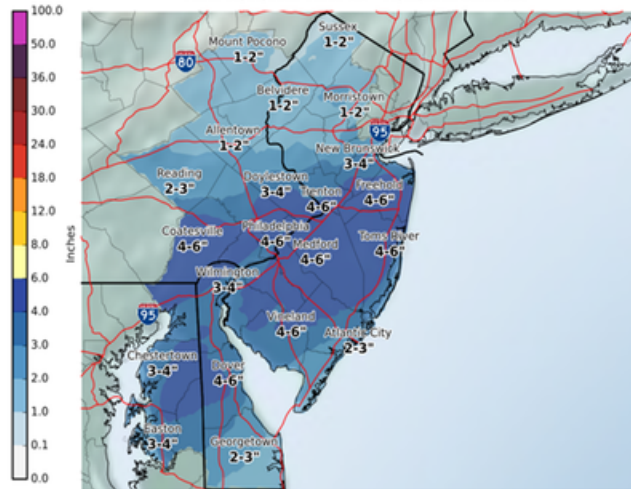
National Weather Service
Mount Holly, NJ
03/19/2018 05:01 AM EDT

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weather.gov/phi/winter

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

Expected Snowfall
Official NWS Forecast

Expected Snowfall - Official NWS Forecast
Valid: 03/20/2018 02:00 AM - 03/22/2018 08:00 AM



National Weather Service
Mount Holly, NJ
03/19/2018 05:00 AM EDT

Follow Us: [f](#) [t](#) [v](#)
weather.gov/phi/winter

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

High End Potential
**1 in 10 (10%) Chance of
Higher Snowfall**

High End Amount - 1 in 10 Chance (10%) Of Higher Snowfall
Valid: 03/20/2018 02:00 AM - 03/22/2018 08:00 AM



National Weather Service
Mount Holly, NJ
03/19/2018 05:01 AM EDT

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weather.gov/phi/winter

*(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

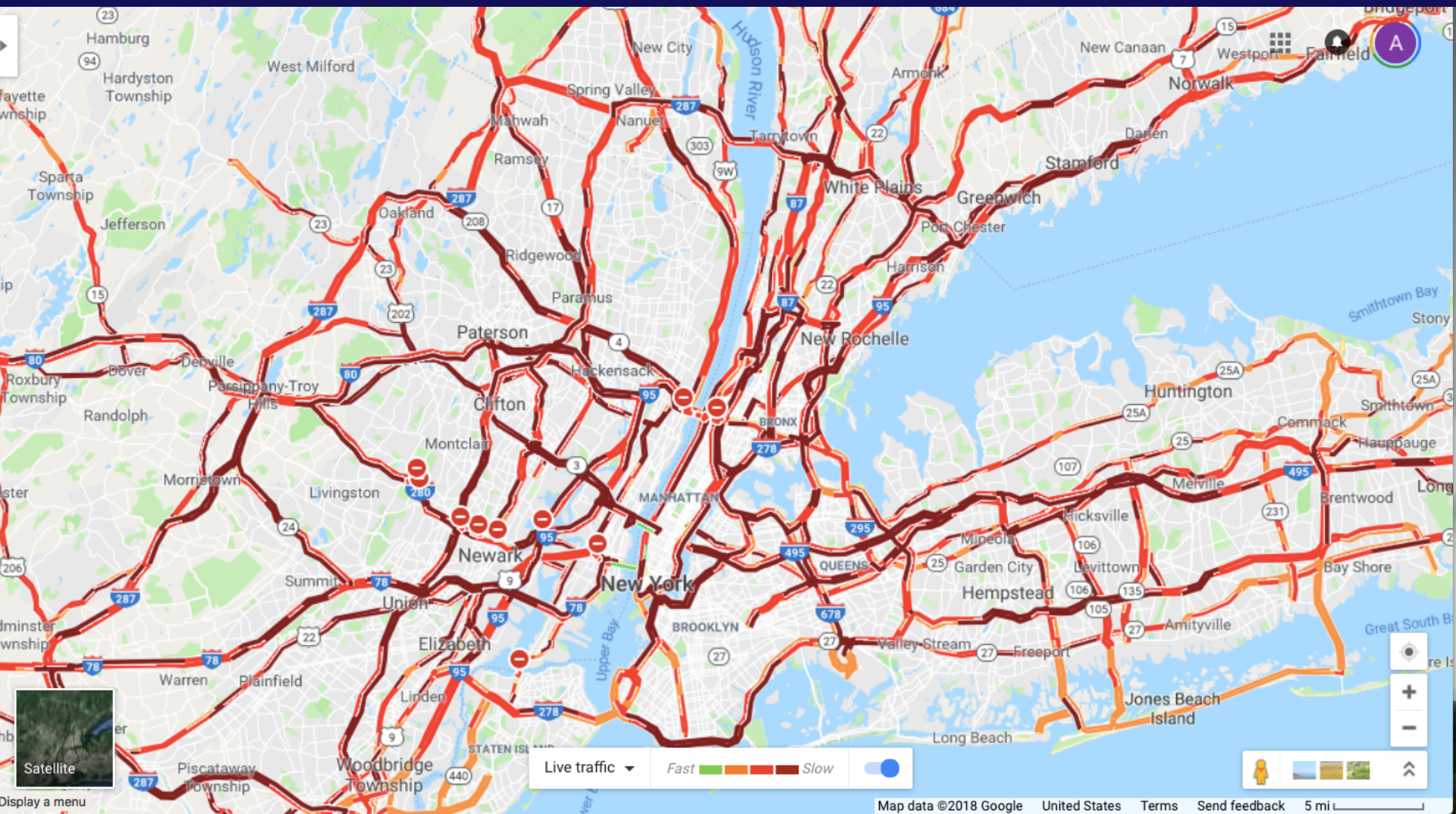


New Jersey Globe



NY Post

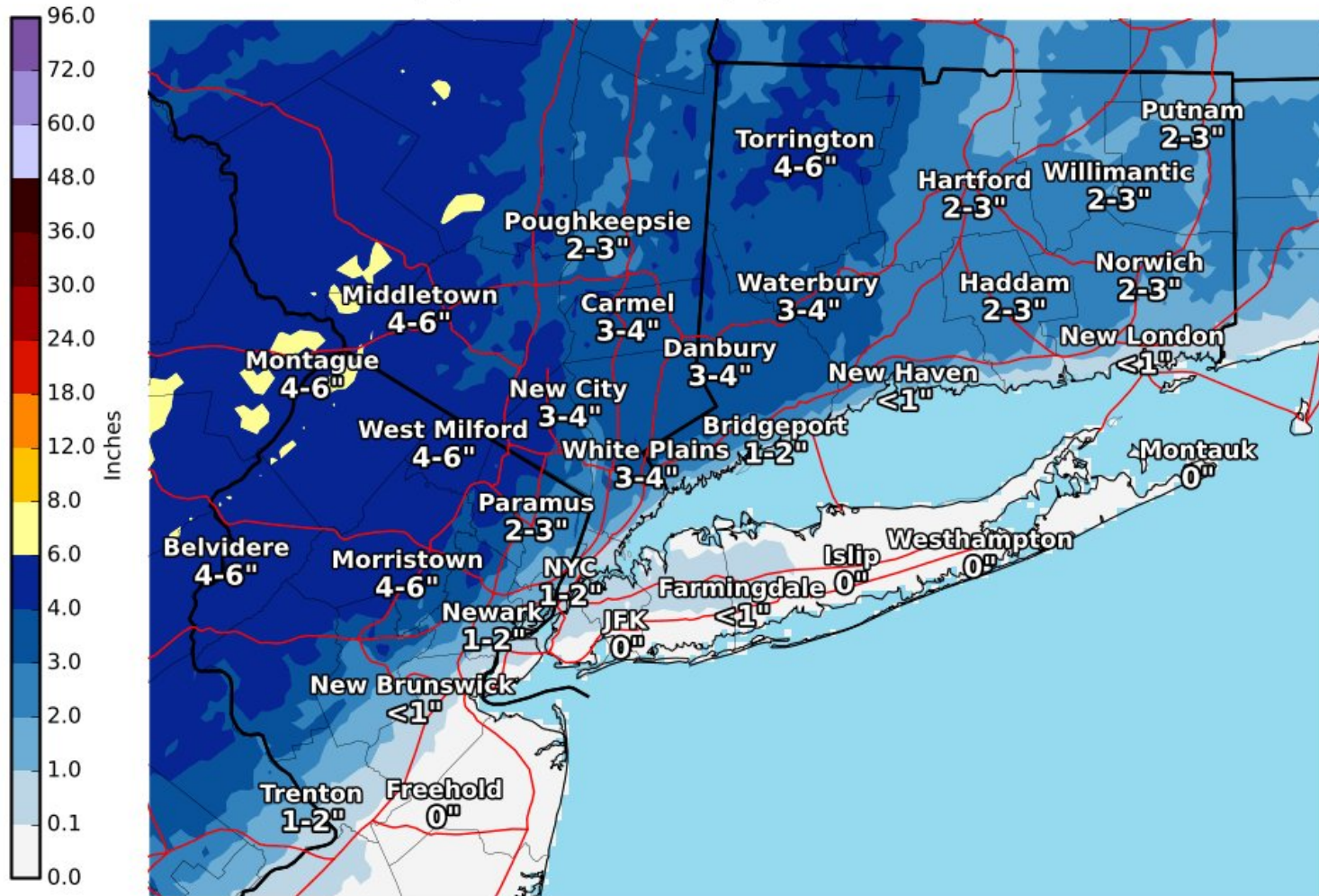
Forecast communication failure ... November 15, 2018



Forecast communication failure ... November 15, 2018

Expected Snowfall - Official NWS Forecast

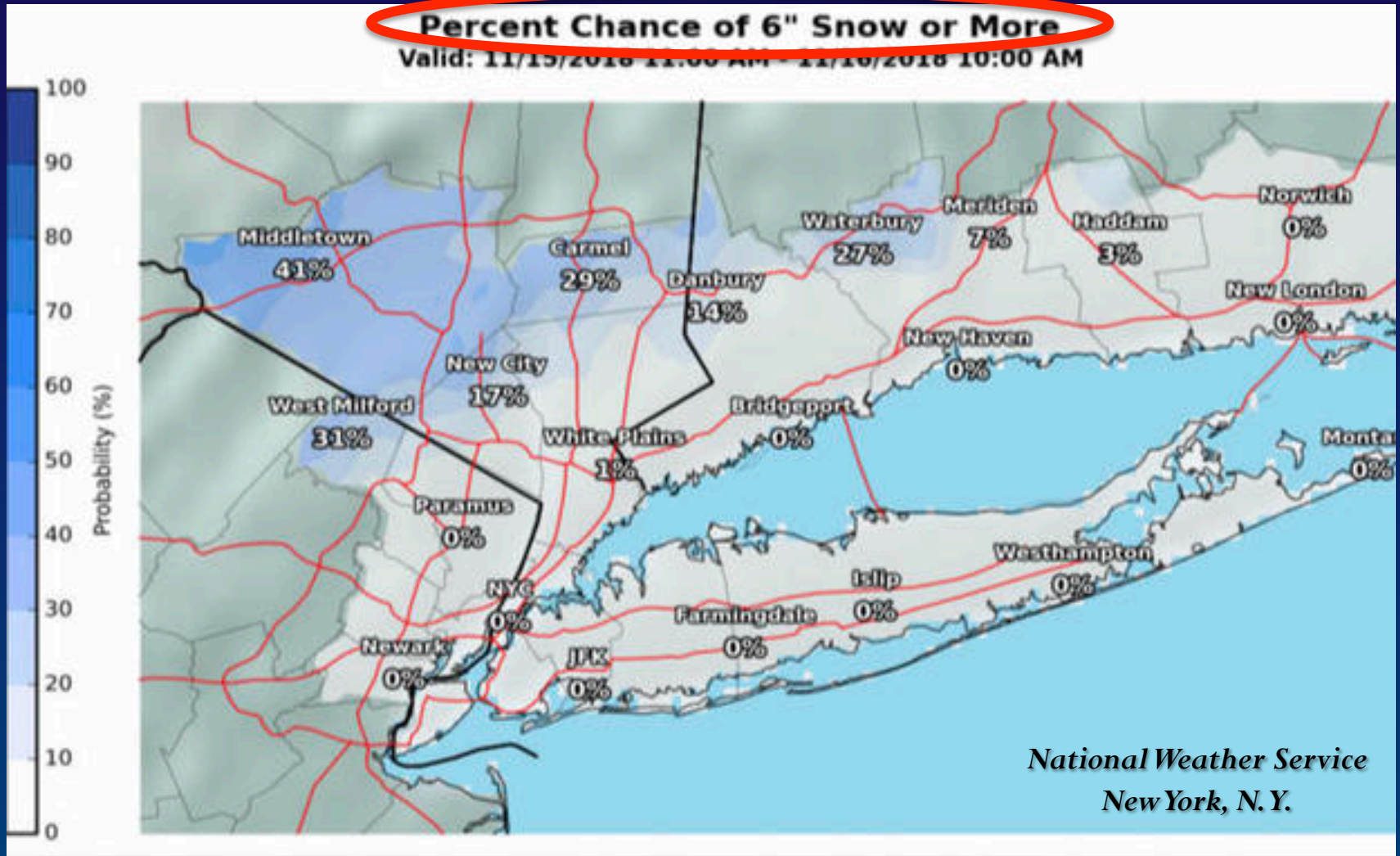
Valid: 11/15/2018 11:00 AM - 11/16/2018 10:00 AM EST



National Weather Service
New York, NY
11/15/2018 06:53 AM EST

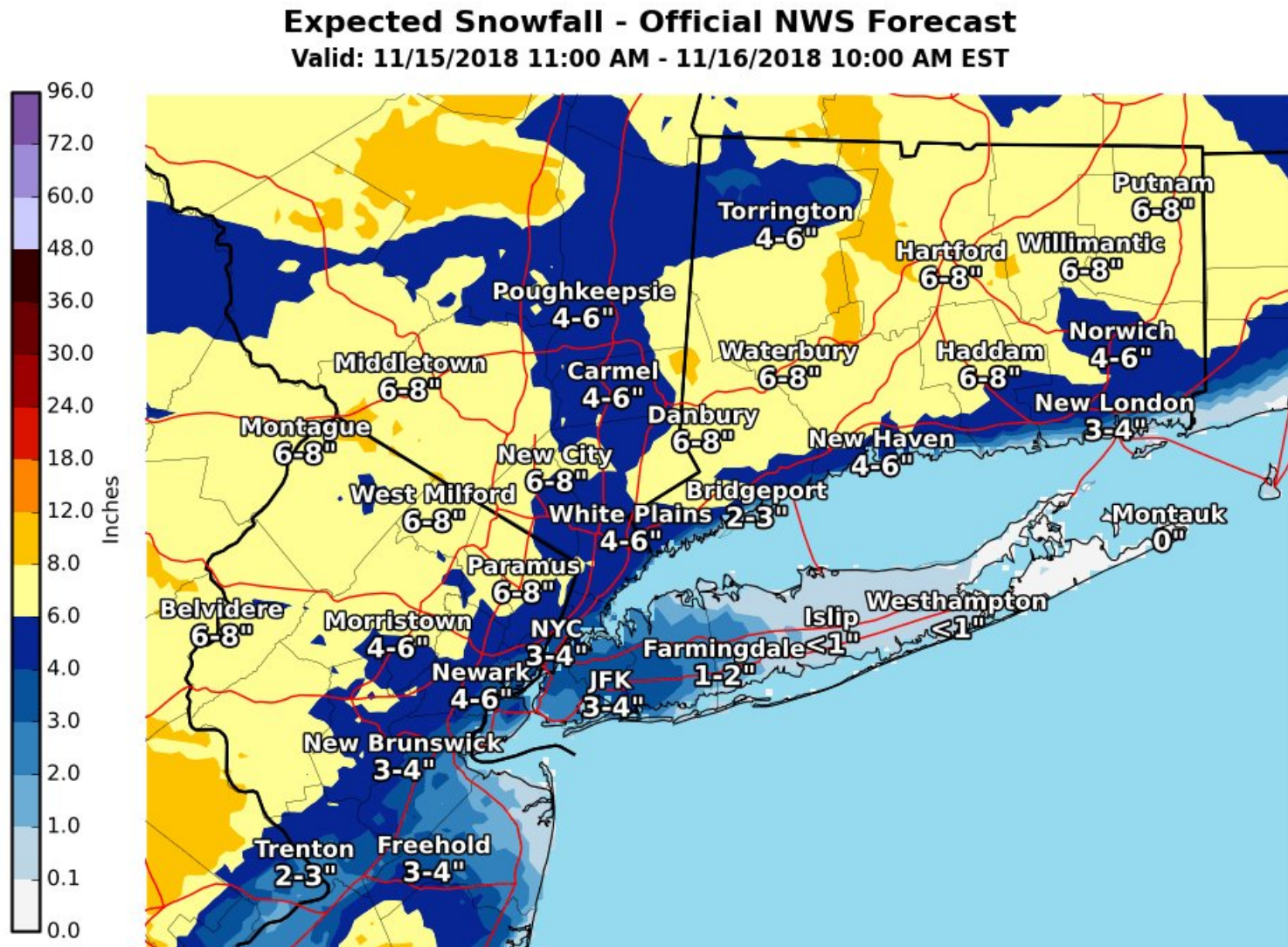
Follow Us:   
weather.gov/nyc/winter

Forecast communication failure ... November 15, 2018



Officially 6.4" at Central Park

Forecast communication failure ... November 15, 2018



National Weather Service
New York NY
11/15/2018 12:35 PM EST

Follow Us:   
weather.gov/nyc/winter

Forecast communication failure ... November 15, 2018

What went wrong?

- Time of year

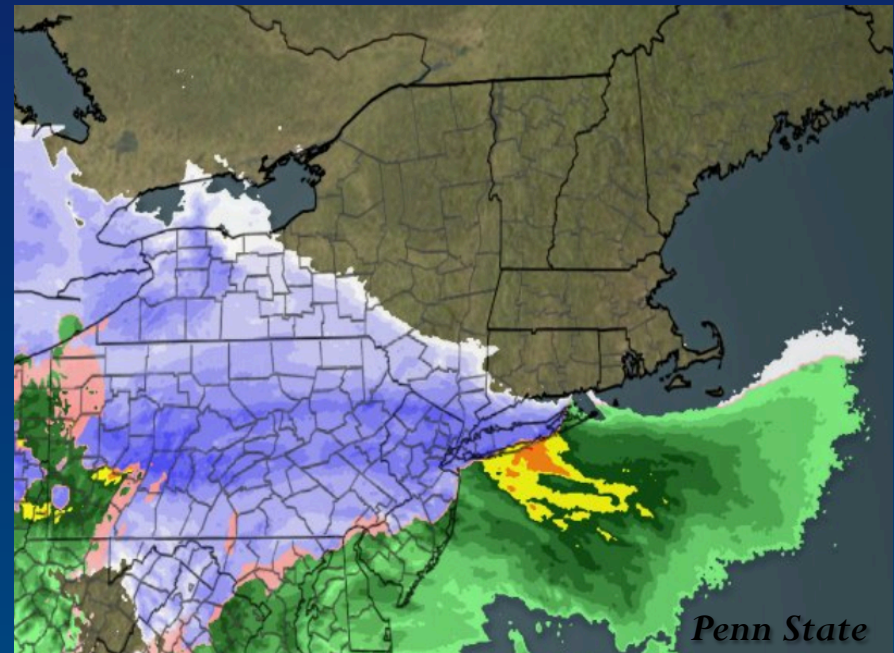
Unusual to have a major snowstorm in the Mid-Atlantic to New York City in mid-November, especially with relatively warm ocean waters

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

- Air was unusually dry

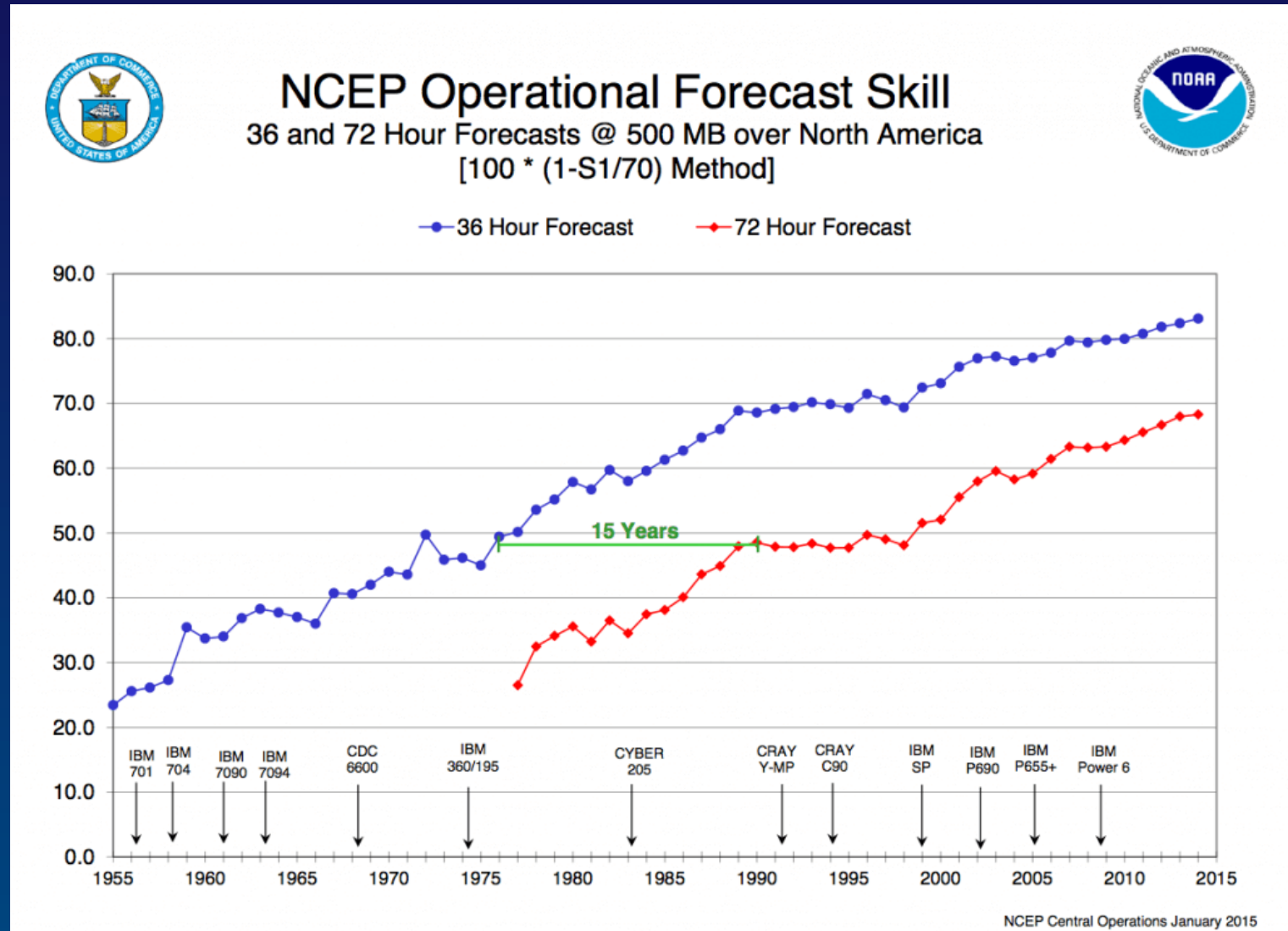
With surface winds coming from Canada, the air was drier than models indicated.

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

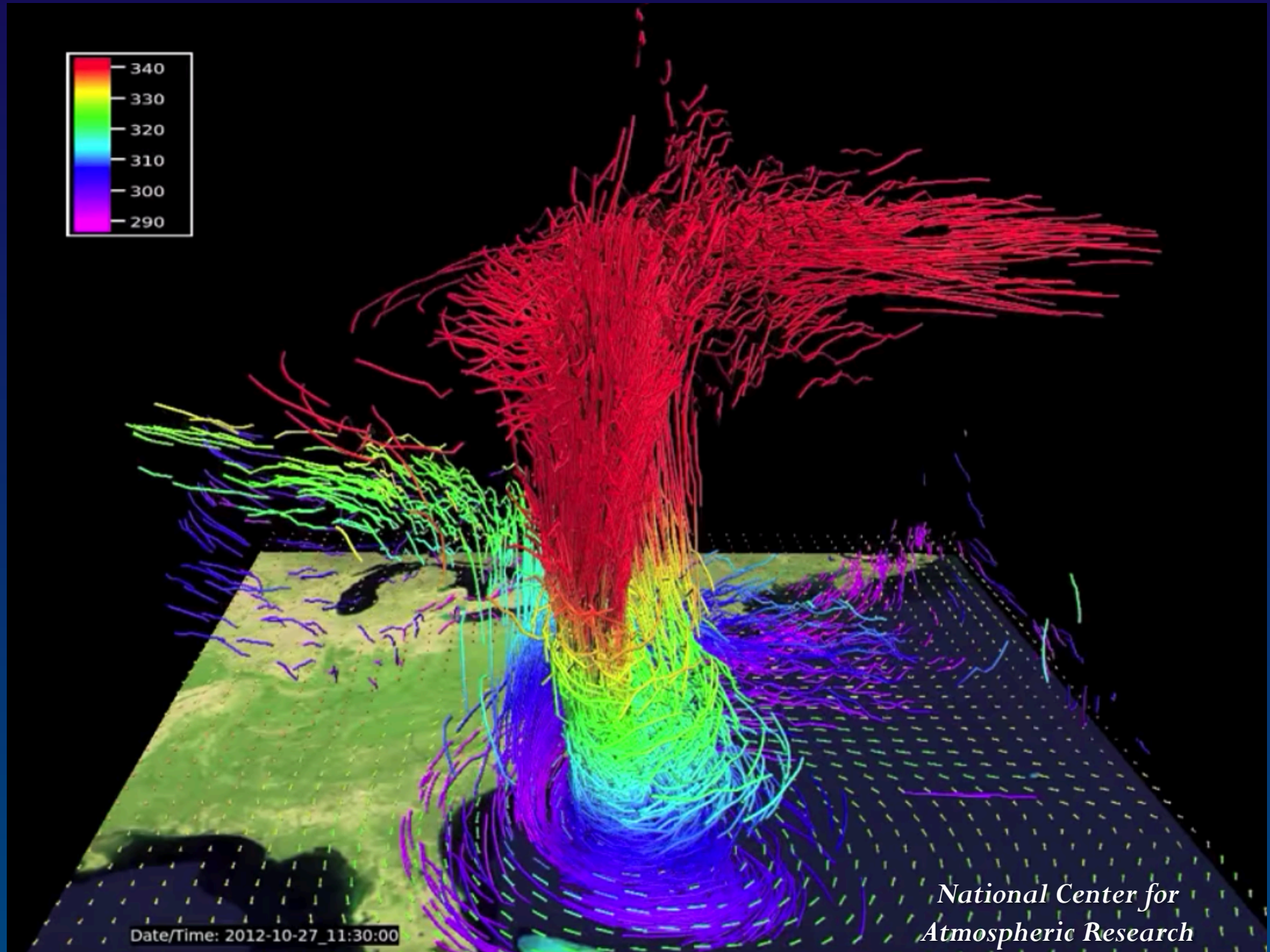


We learn from storms like these ...

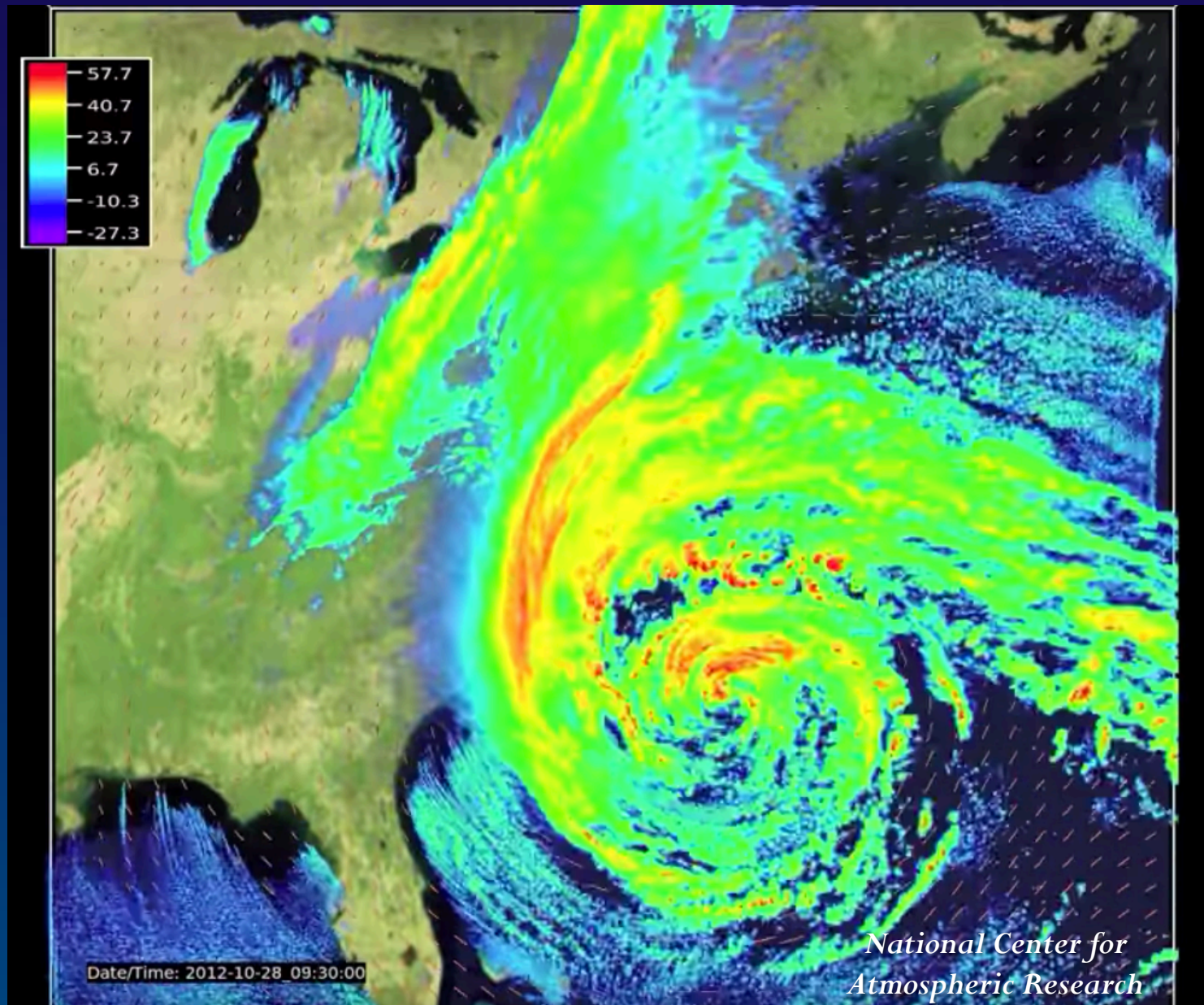
... and models and forecasters are improving every year!

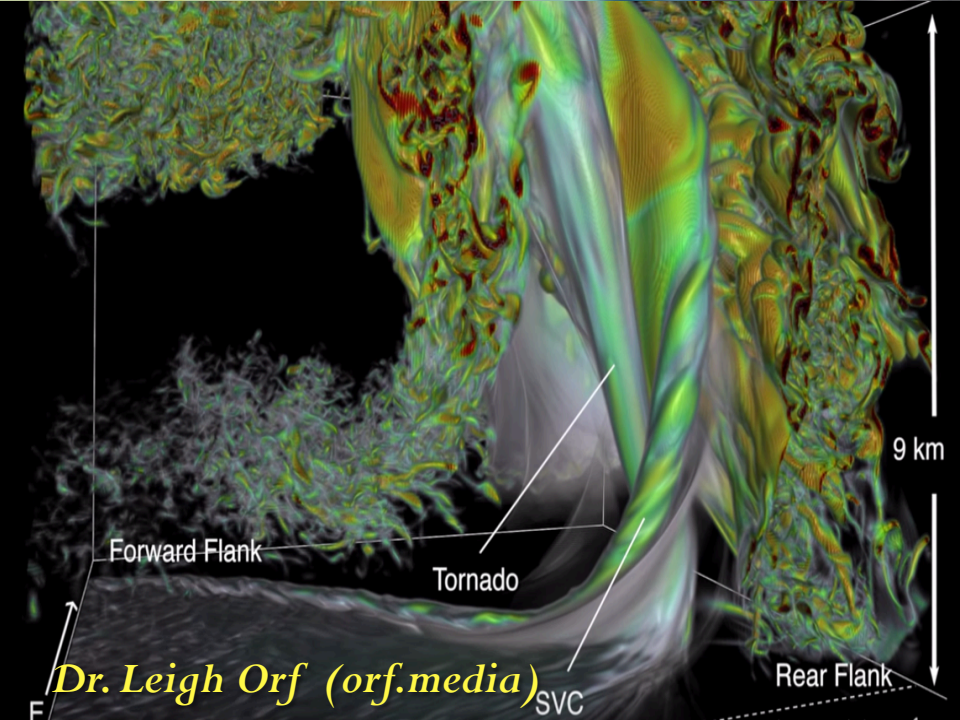
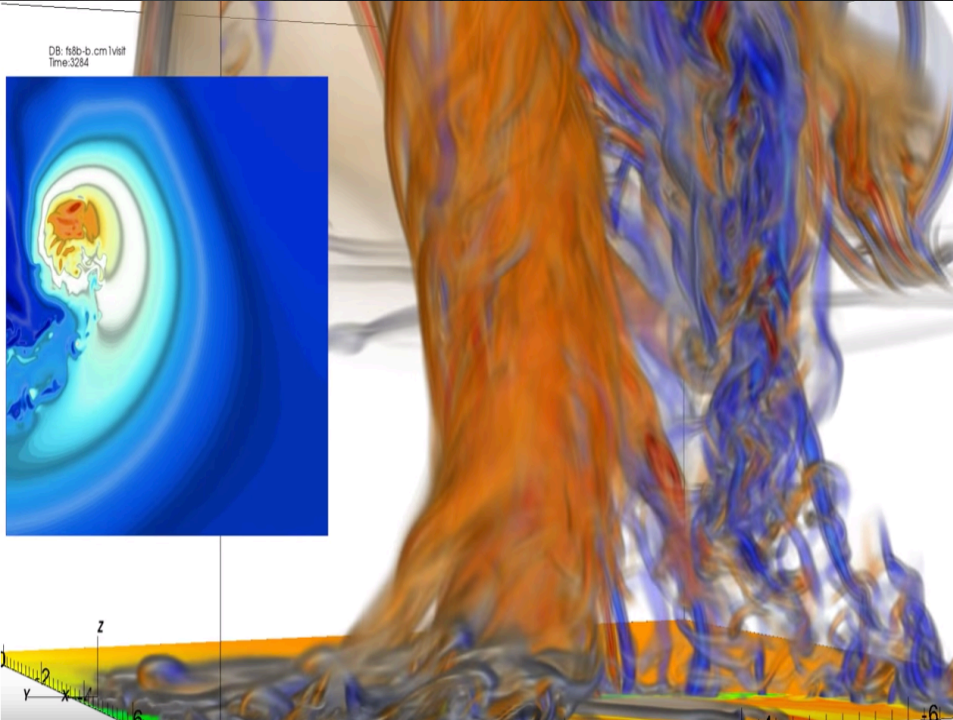
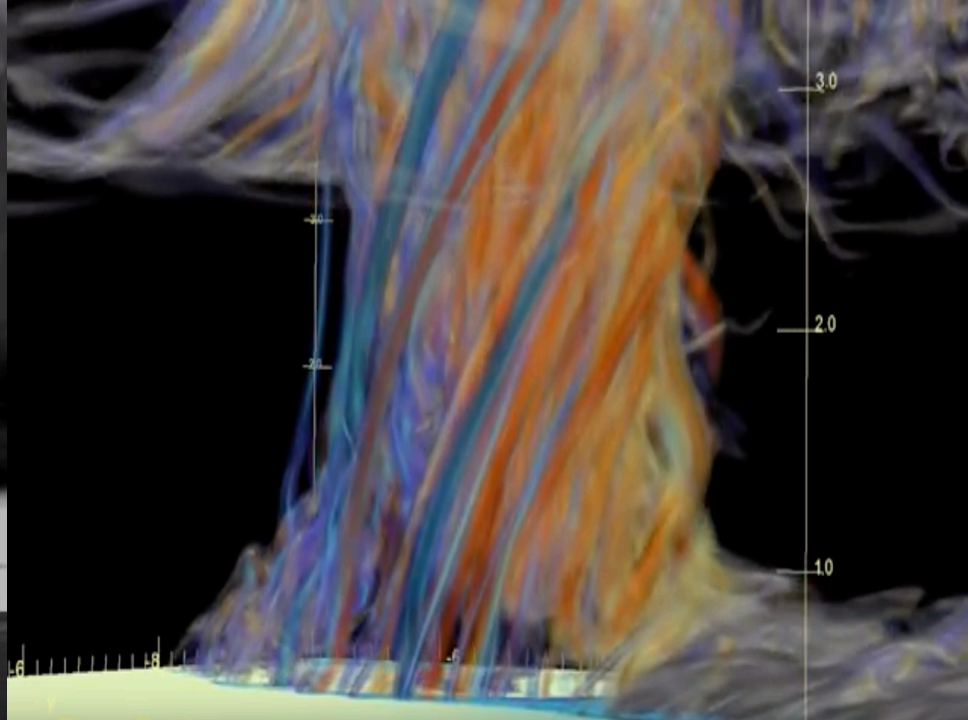


Future of weather forecasting



Future of weather forecasting





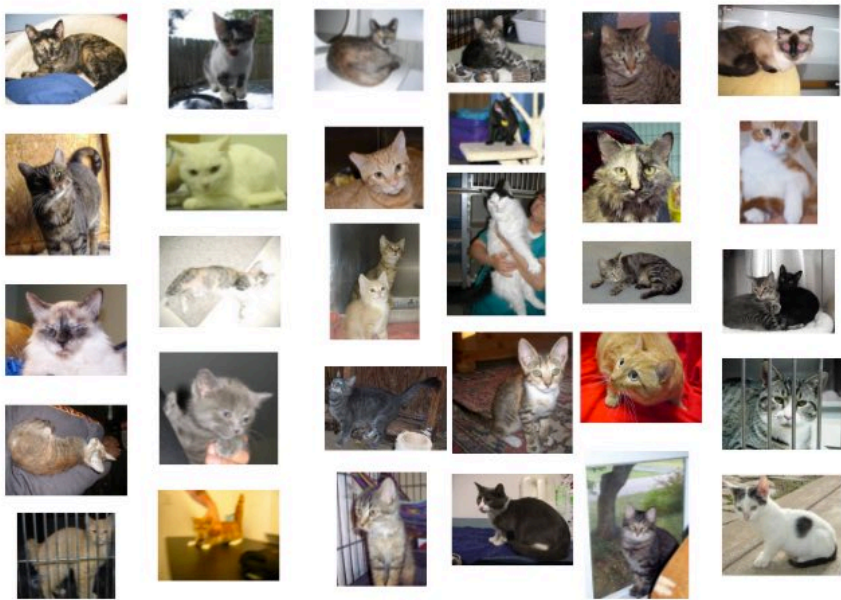
Dr. Leigh Orf (orf.media)

Artificial intelligence and weather forecasting

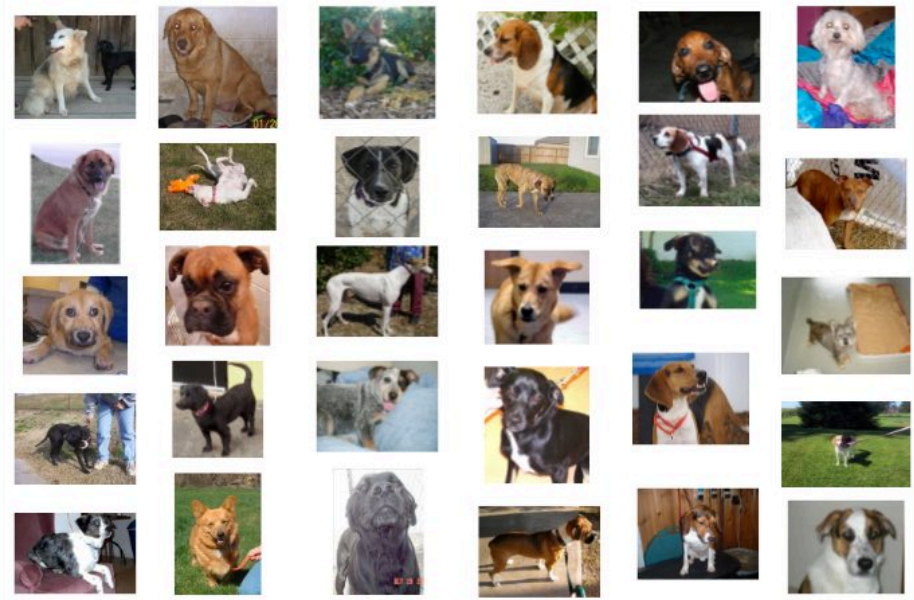
Rather than use a **model** to forecast the weather, we can use **pattern recognition**

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

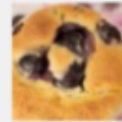


Can a machine learning algorithm tell the difference between:

A chihuahua and a blueberry muffin?



chocolate cookie



[unknown]



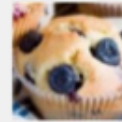
fawn smooth Chihuahua



brown coated Chihuahua



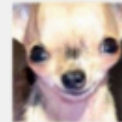
baked blueberry muffin



baked muffin



white chihuahua



beige short coated puppy



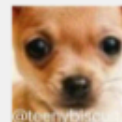
fawn smooth Chihuahua



tan smooth Chihuahua puppy



blueberry muffin



blueberry cupcakes



fawn smooth Chihuahua



three smooth Chihuahua puppies



muffin

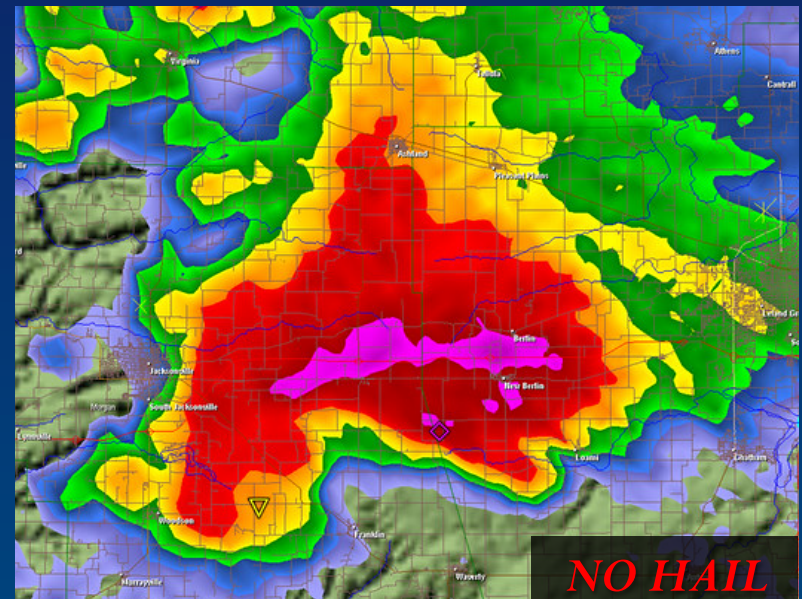
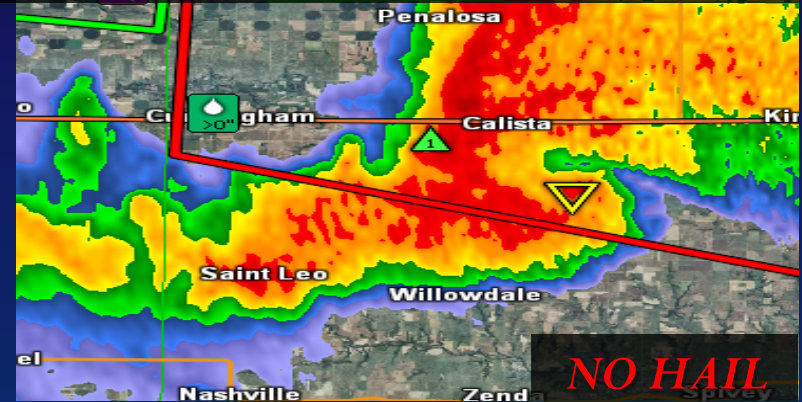
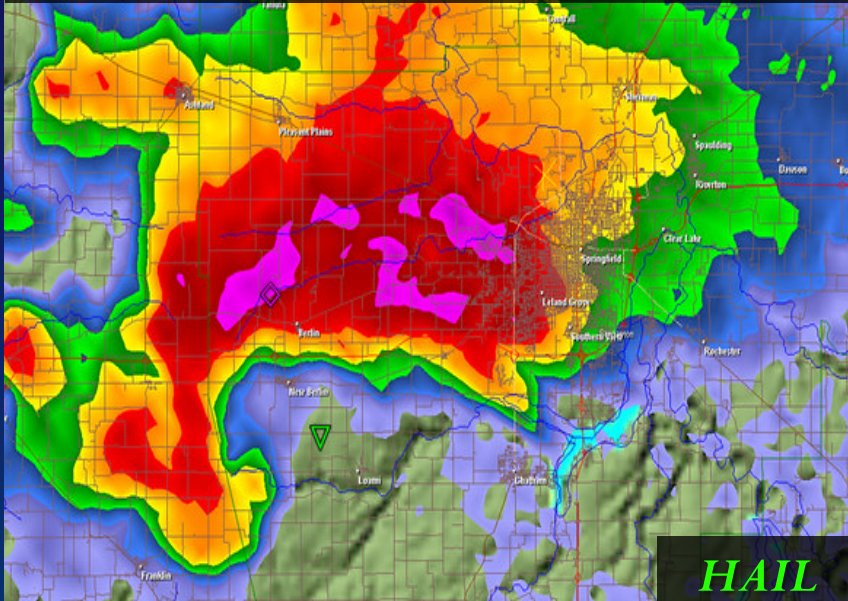


white and black muffin

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

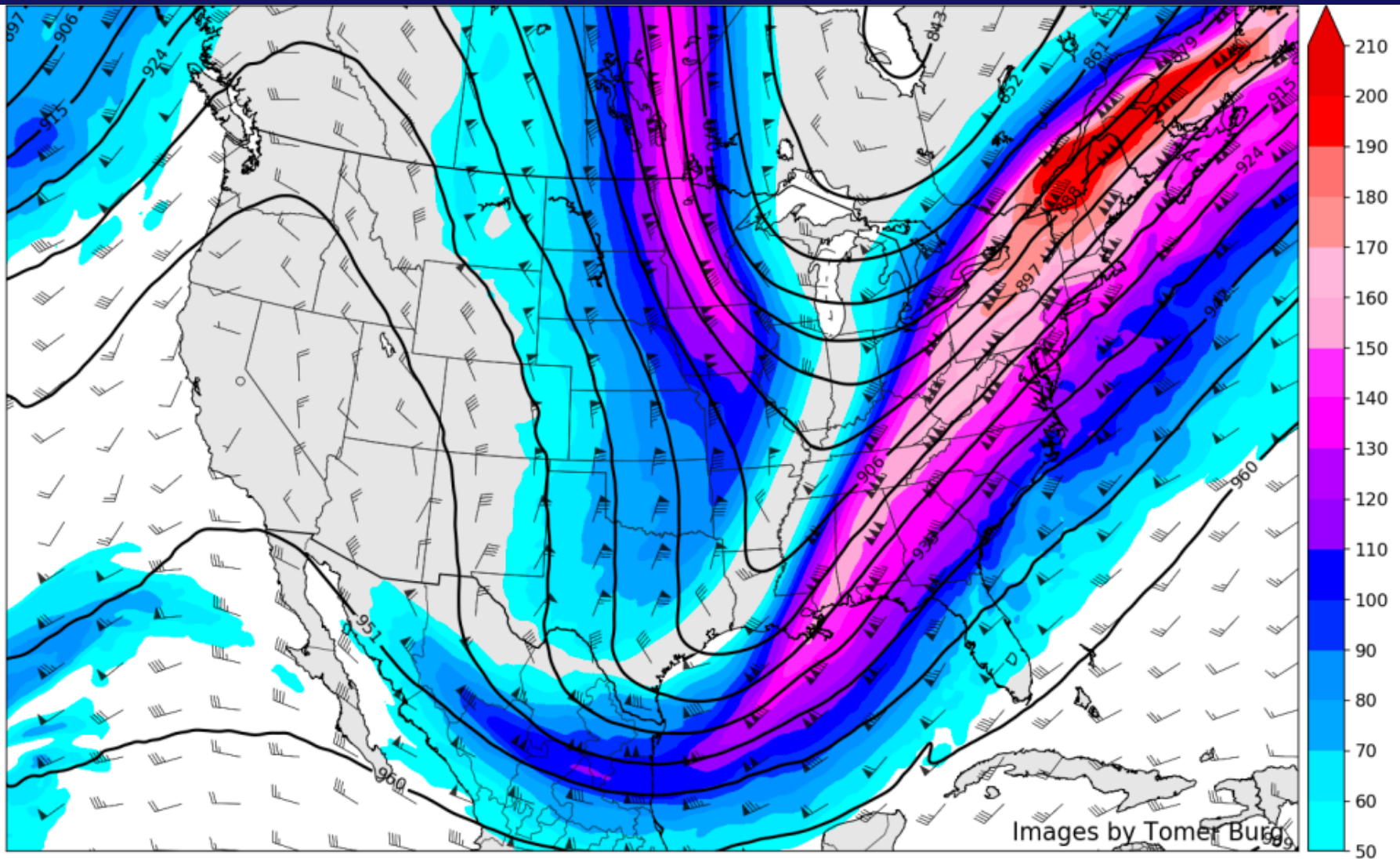
Artificial intelligence and weather forecasting

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**

- 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!



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

Special thanks to SEFCU for
supporting Explore UAlbany!

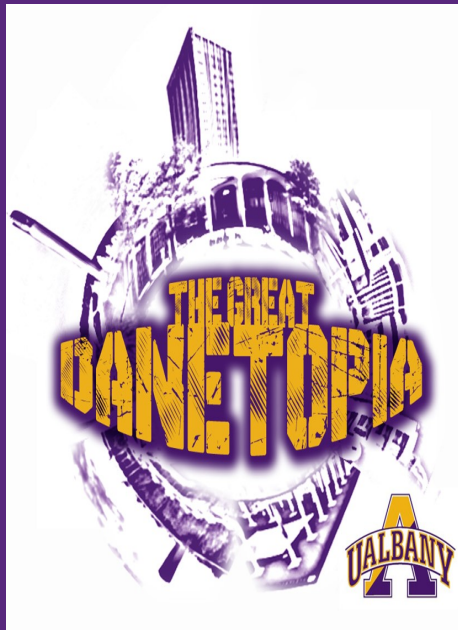


Next Steps to Success...

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



 **STUDENT ENGAGEMENT**
UNIVERSITY AT ALBANY State University of New York

*Office of the Vice President
for Undergraduate Education*

Munch with the Majors

Date: Tuesday, September 24th, 2019

When: 6:30 PM - 8:30 PM

Where: Campus Center, 2nd floor

Come learn first-hand about the majors and minors that interest you from key faculty and staff from across campus.

Ask questions about:



We will have an **apple theme!**

Enjoy apple desserts, cider, and Apple® raffles including an Apple Watch® and iTunes® gift cards!



Take your professor to lunch!
..... (it's on us)

Food for Thought will cover the cost of your professor's or advisor's breakfast, lunch, or dinner in any of the residence dining halls at UAlbany.

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- Learn about doing research or discuss internship possibilities
 - Get to know an admired faculty member one-on-one
 - What better way to ask for a letter of recommendation?!
- Say thank you for that great class or letter of recommendation

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