

**Hovering on the Edge of Predictability -  
Late Season “Surprise” Winter Storm Buries  
East Central Wisconsin on March 25, 2023**



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NOAA National Weather Service  
Green Bay, Wisconsin

# What We Will Cover

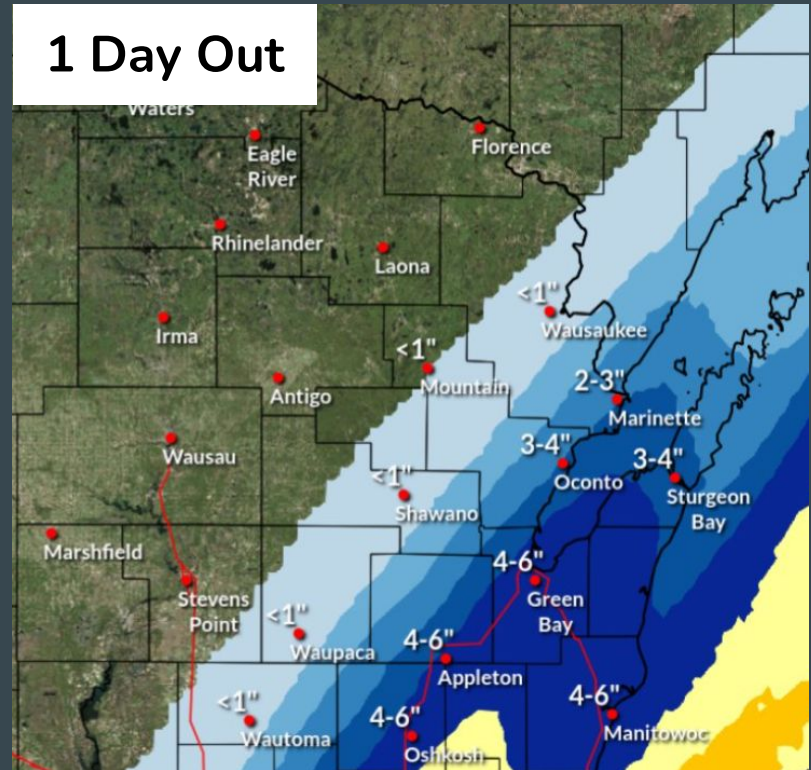
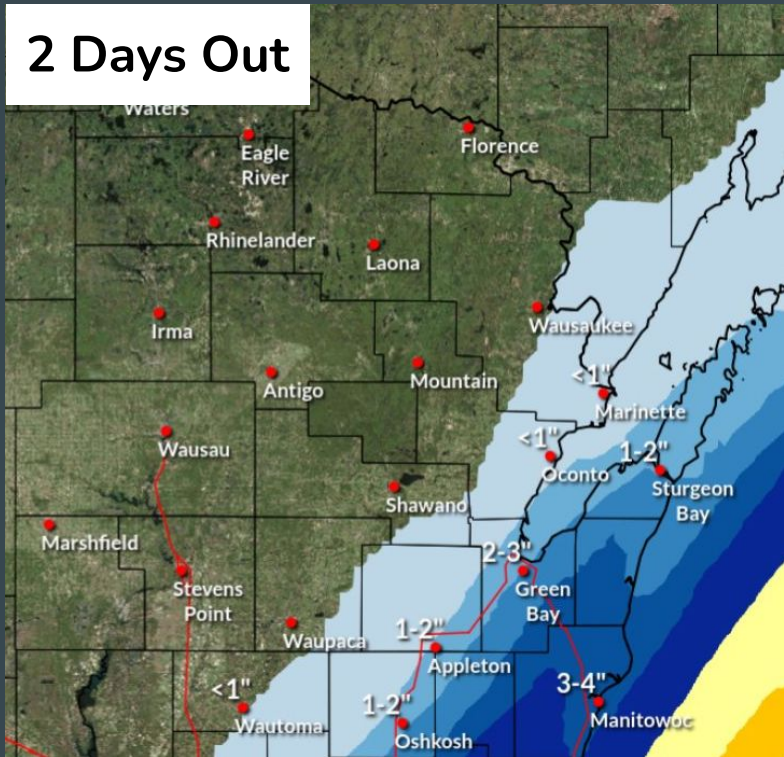
- What Was Forecast/What Happened
- Synoptic/Mesoscale Analysis
- Model Trends/Snow Forecasts
- Messaging Timeline
- Moving Forward...how do we handle systems like these?

**What Was Forecast?**

**What Happened!**

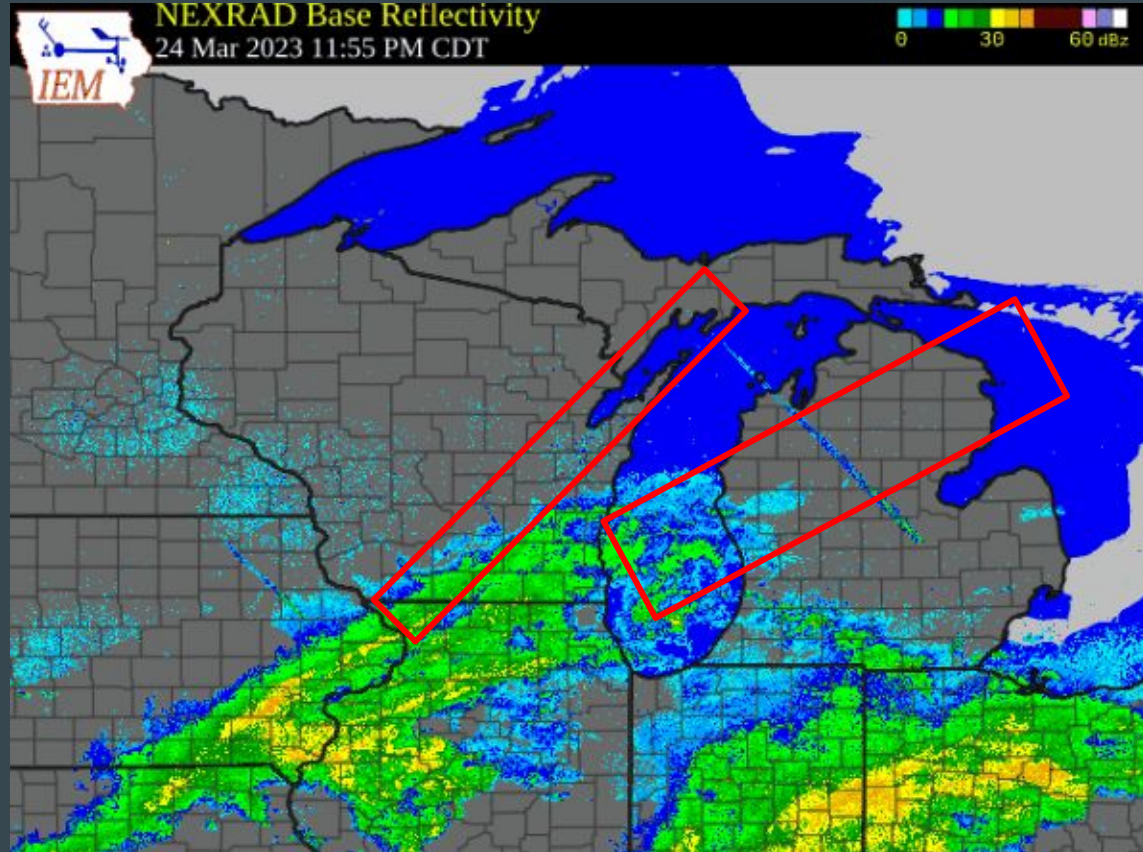
...

# What Was In The Forecast?



# What Happened!

12:05 AM to 4:30 PM March 25



- ★ TWO primary precip areas formed
- ★ One across northern IL, expanded northeast and then moved across Lower MI
- ★ Second area is strongly banded in nature and appears to develop on the NW flank of the primary precip shield.



# What Happened!

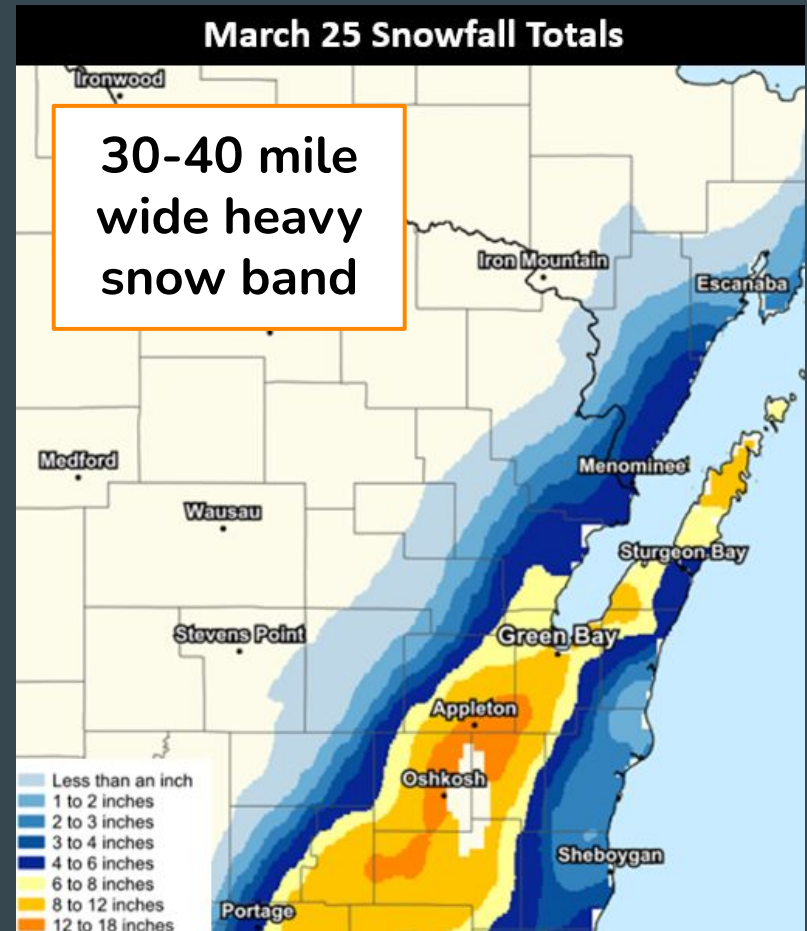


I HEARD ONE  
TO THREE...  
INCHES...  
NOT FEET!

MUST HAVE  
BEEN A TYPO...  
1-3" = 13"!?!?

# What Happened!

Menasha 2 N	20.0"
Neenah	17.5"
De Pere	14.5"
Chilton	13.7"
Appleton	13.5"
Kaukauna	13.0"
Oshkosh	12.0"
Green Bay NWS	10.0"
Fish Creek	10.0"
...	...
Two Rivers	2.0"
Waupaca	1.0"



# Synoptic/Mesoscale Analysis



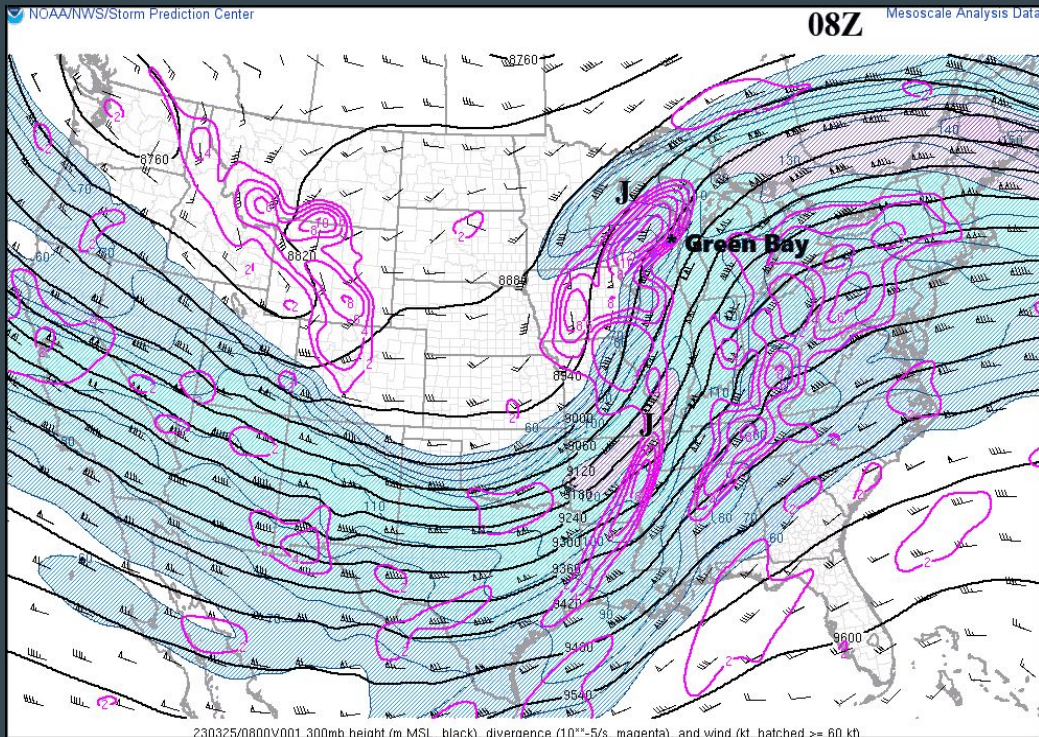


# Synoptic/Mesoscale Analysis



Was it just a matter of a shift in the surface low track or something more???

# Synoptic/Mesoscale Analysis



## RAP 300mb Analysis

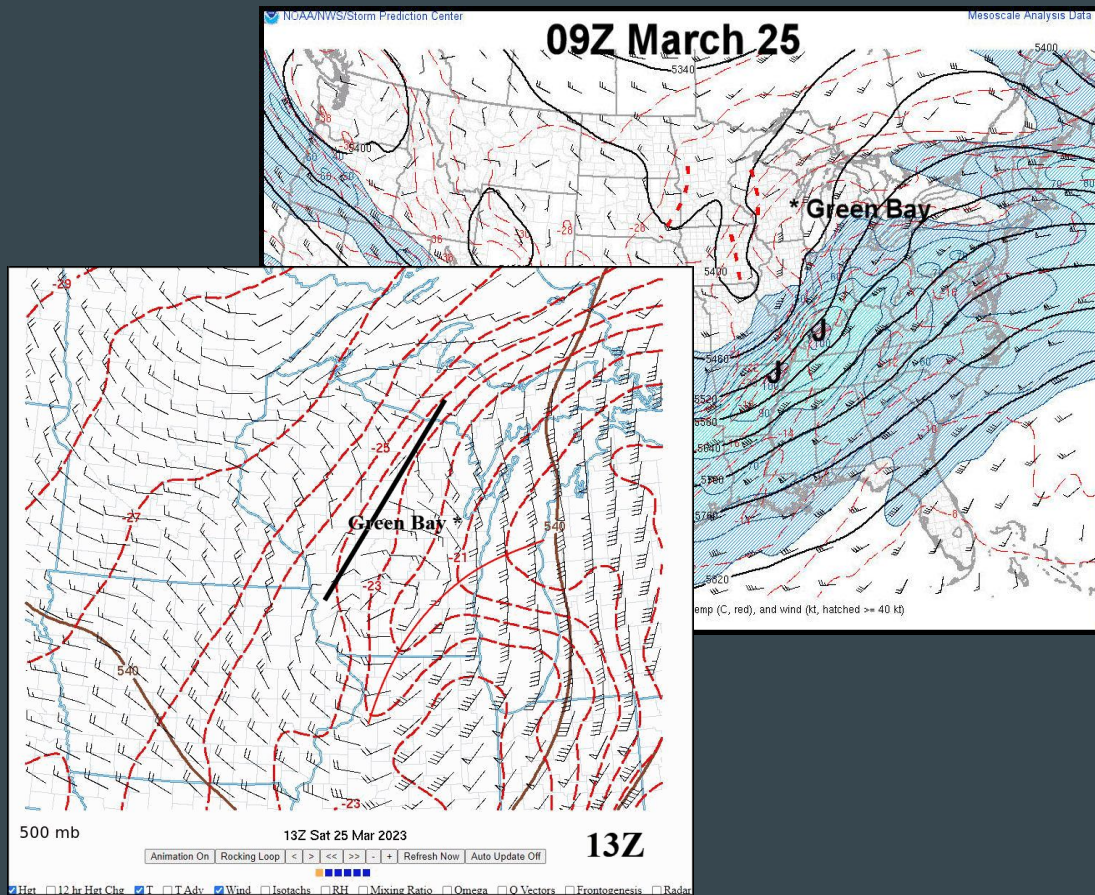
- ★ Very well developed coupled jet structure with strong divergence over WI
- ★ Favorable RRQ of northern stream jet streak
- ★ System became strongly negatively tilted



# Synoptic/Mesoscale Analysis

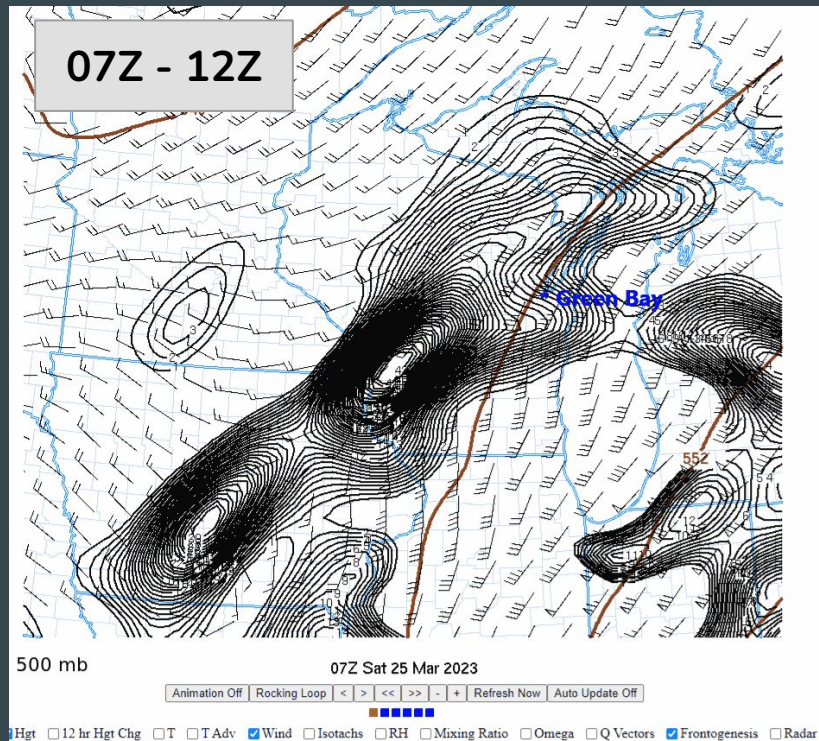
- ★ (Upper-right) Possible phasing of transient impulses with primary negatively-tilted shortwave trough early on March 25
- ★ (Lower-left) Pronounced mid-level convergence/deformation axis (black line) swings east and interacts with possible TROWAL (red line)
- ★ Mesoscale snow band that formed over eastern WI correlated well with these features.

## RAP 500mb Analysis

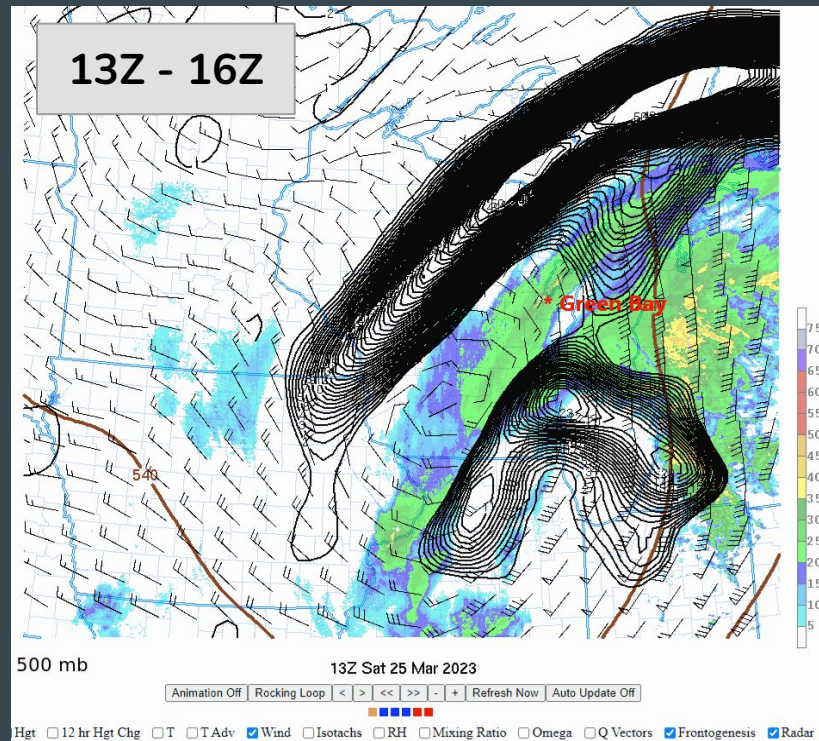


# Synoptic/Mesoscale Analysis

Axis of strong mid-level frontogenesis



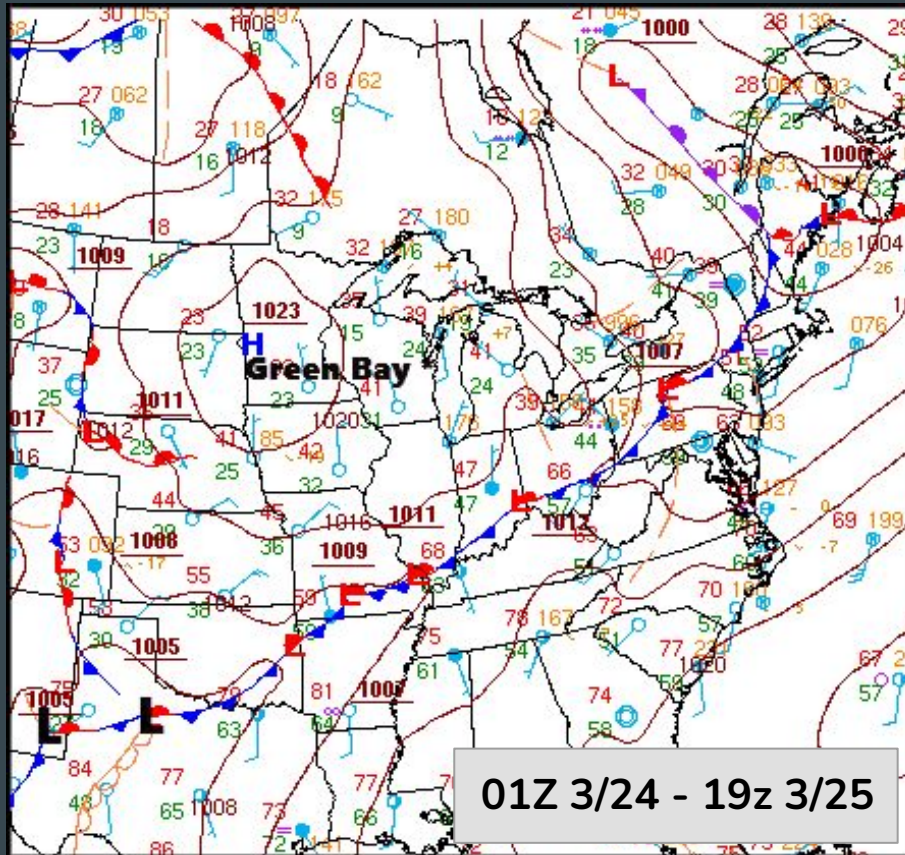
Snow band aligned well with FGEN axis



The “upward” ageostrophic response to the frontogenesis will be on the southeast side of the frontogenesis axis



# Synoptic/Mesoscale Analysis



## Surface Analysis

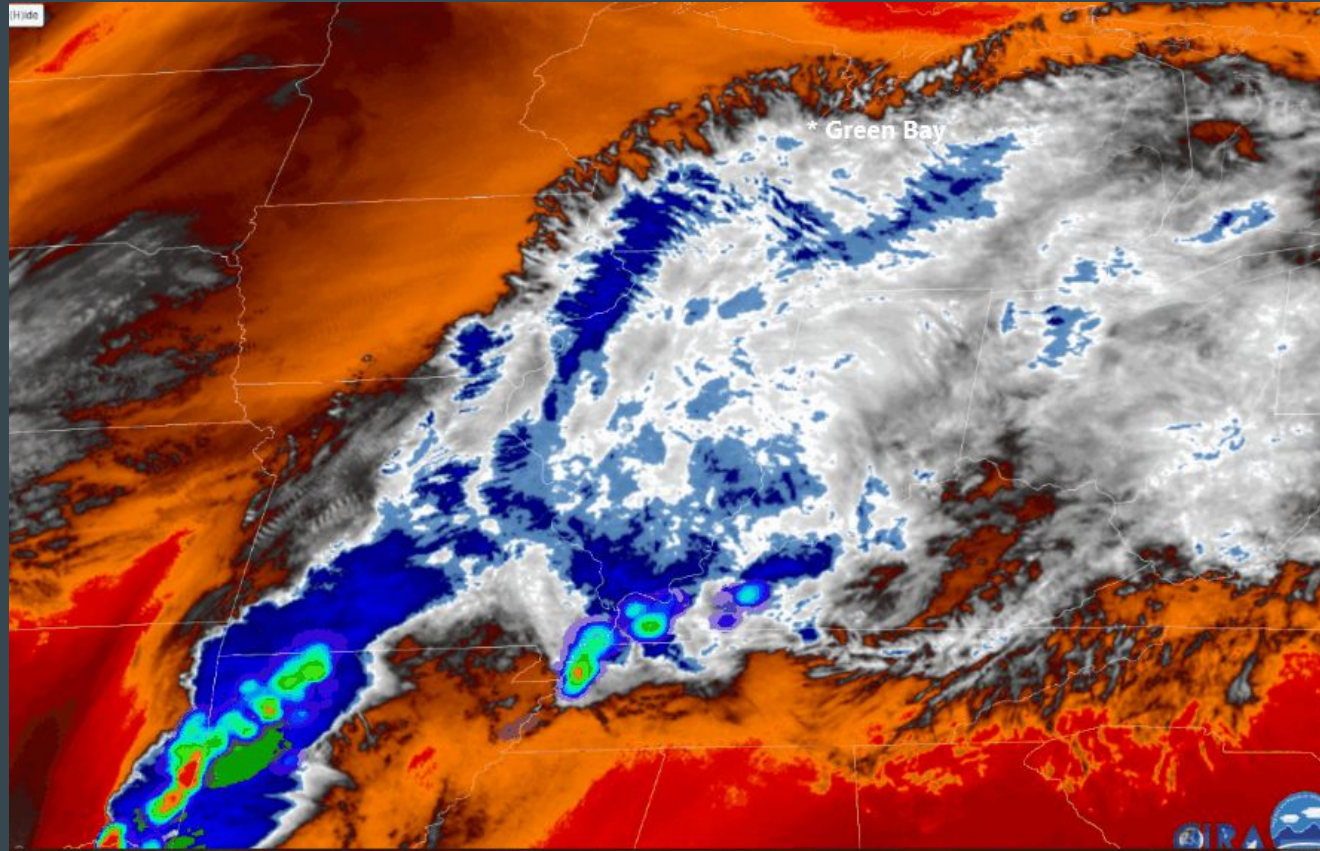
- ★ Surface cyclogenesis over southern Plains
- ★ Complex surface analysis with system occlusion as low moved into northwest IN
- ★ Surface cyclone deepened more rapidly as it moved from IL to central MI

# Synoptic/Mesoscale Analysis

18Z March 24 to 18Z March 25

## Low-level WV

- ★ Dynamic System
- ★ Deepening
- ★ Primary shortwave ejects from Plains to Great Lakes
- ★ Convective clouds



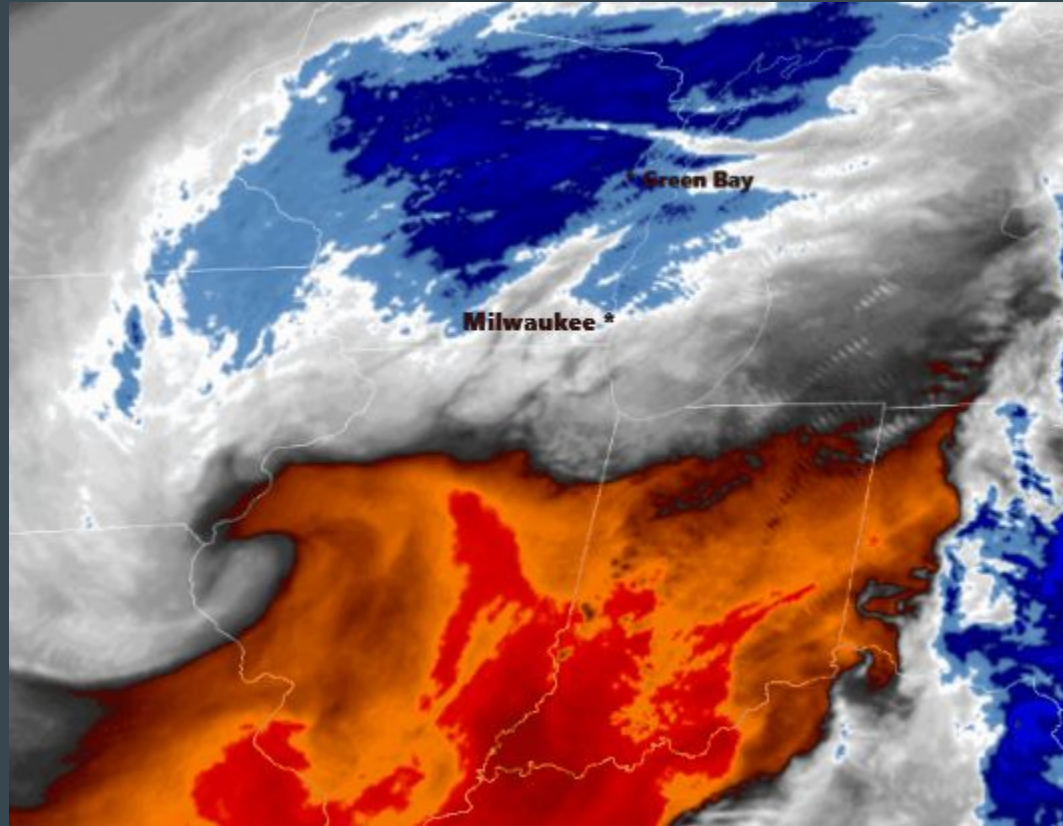


# Synoptic/Mesoscale Analysis

06Z to 15Z March 25

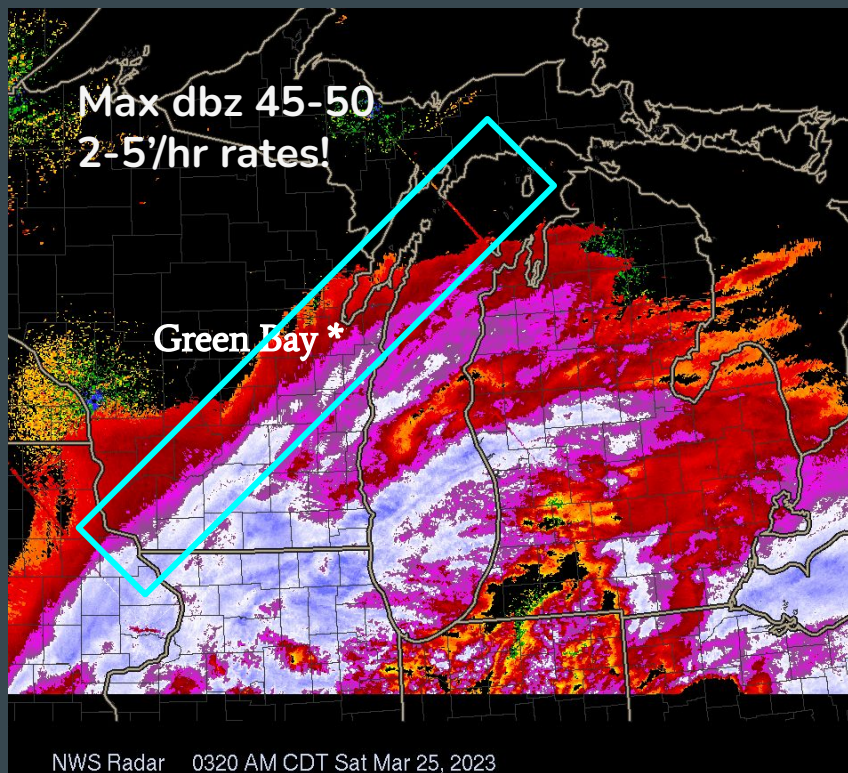
## Mid-level WV

- ★ Cooling cloud tops over Lower MI with lightning.
- ★ Unstable air transported into WI (TROWAL?)
- ★ Recall strong mid-level frontogenetic forcing is ongoing over eastern WI.

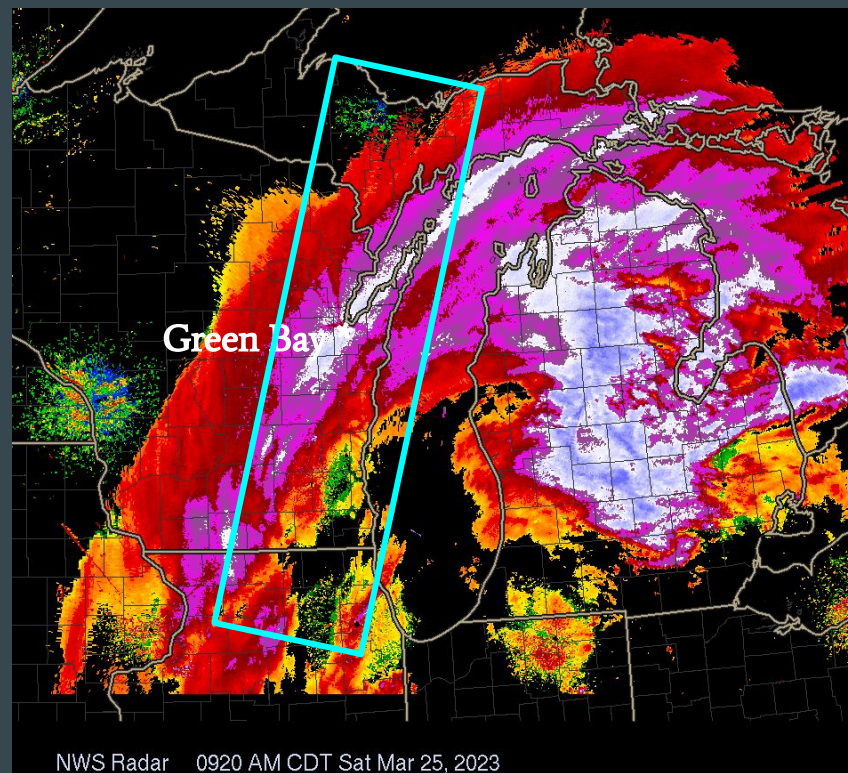


# Synoptic/Mesoscale Analysis

3:20 AM to 7:05 AM March 25

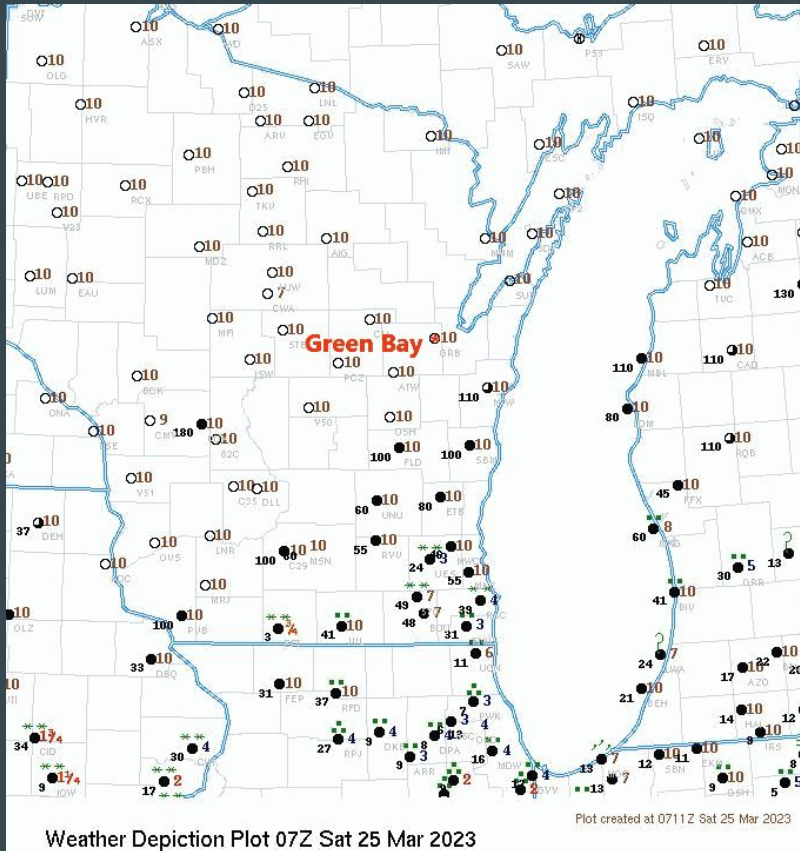


9:20 AM to 1:05 PM March 25



Two distinct precipitation areas evolved during the morning of March 25th

# Synoptic/Mesoscale Analysis

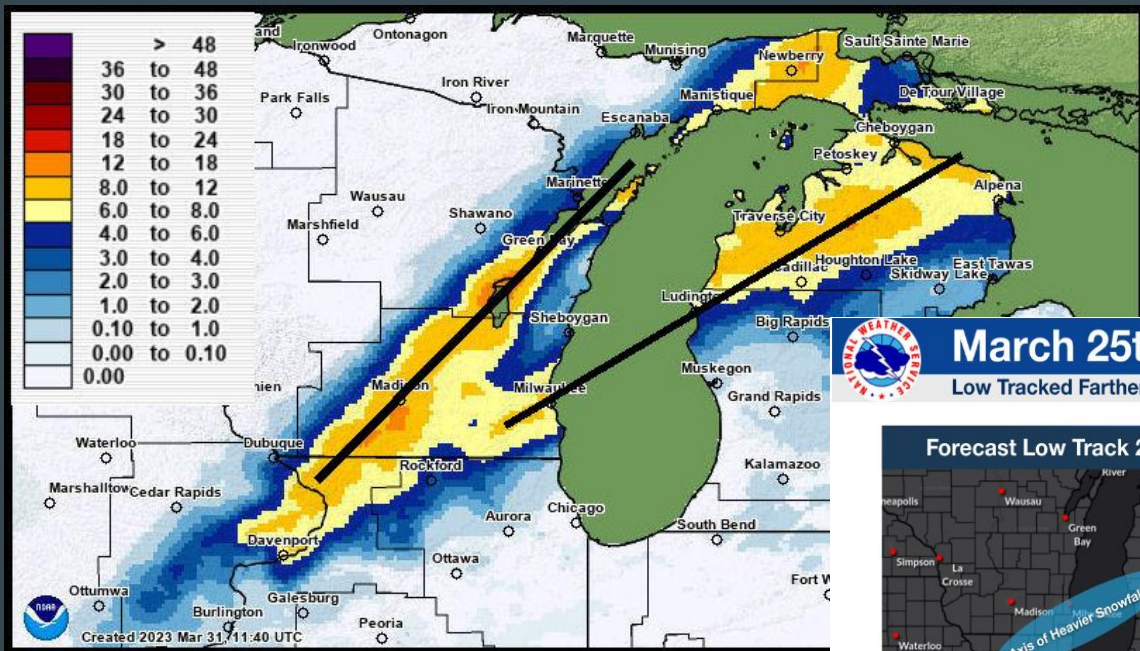


## Weather Depiction Analysis

- ★ Heavy snow (< 1/2 mile) quickly expanding NNE into the GRB forecast area
- ★ Meanwhile, another area of heavy snow was also expanding NE from SE WI to NW Lower MI
- ★ Snowfall rates in east-central Wisconsin **2-5 inches/hour**



# Synoptic/Mesoscale Analysis



The SURPRISE was the intense narrow frontogenetic band that developed (and was not well forecast) on the northern edge

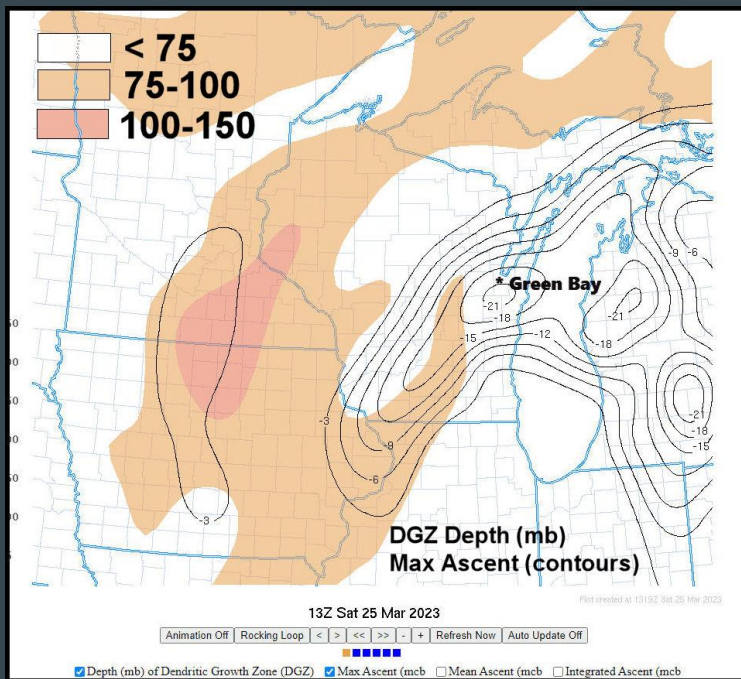
**March 25th: What Happened** March 25, 2023 11:34 AM  
Low Tracked Farther Northwest, Bringing Higher Totals Farther West

Two observed axes of heavy snow

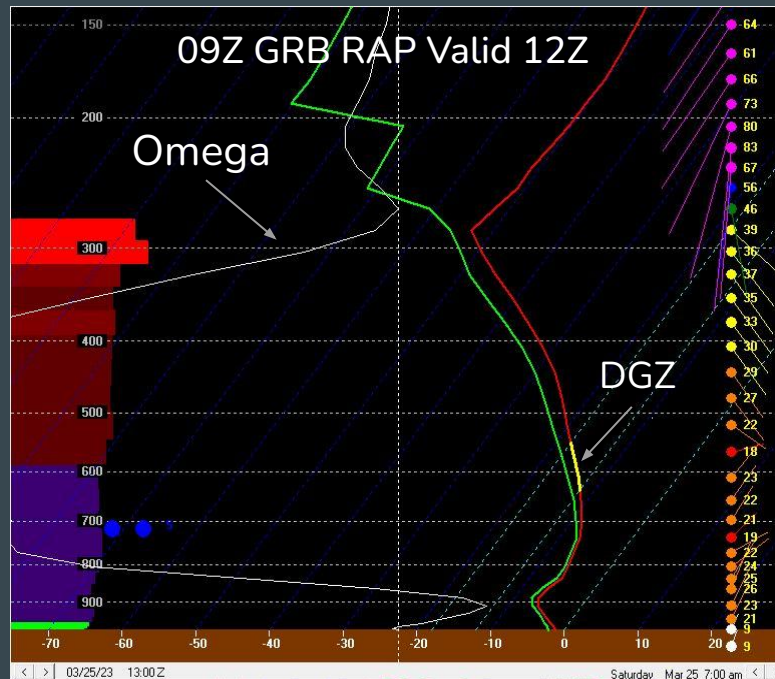


# Synoptic/Mesoscale Analysis

DGZ not particularly deep but vertical velocity very strong!



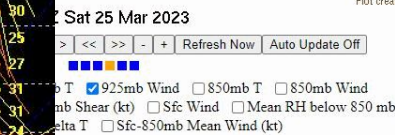
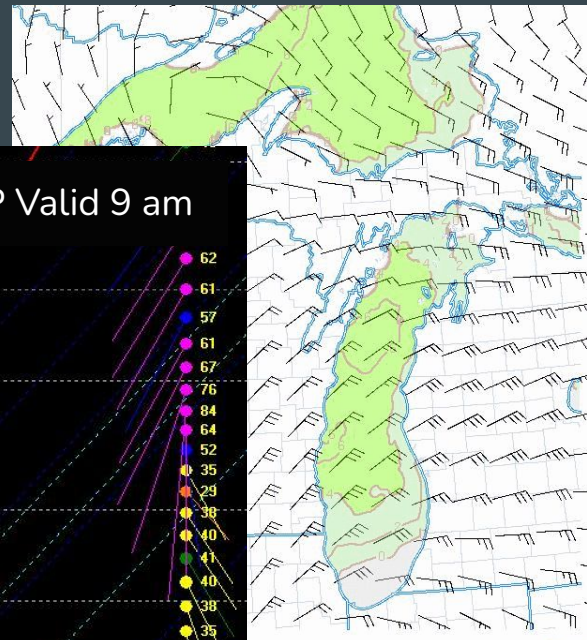
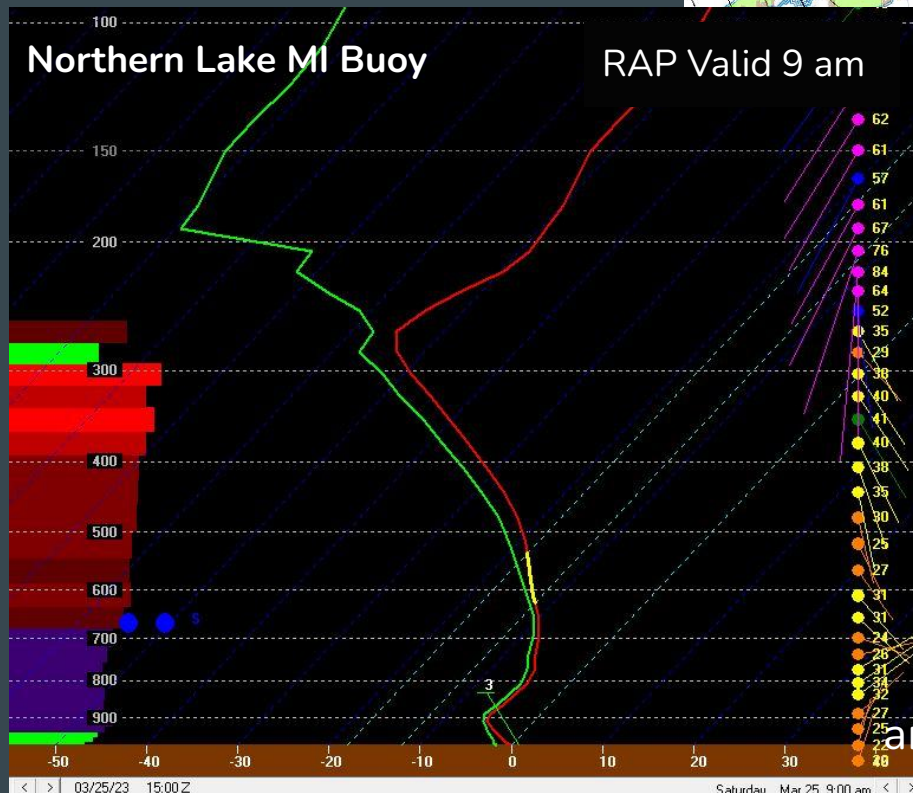
13Z RAP DGZ & Maximum Ascent



12Z GRB Observed

# Synoptic/Mesoscale Analysis

- ★ LES parameters not favorable for lake enhancement
- ★ Delta-Ts: 8°-10°
- ★ Winds veered quickly



RAP 925 Wind and Sfc-850 Delta T



# Synoptic/Mesoscale Analysis - Summary

- Coupled upper jets
- System trended stronger & deeper. Negatively tilted. Possible phasing
- Possible TROWAL airstream enhanced frontogenetic response
- Mesoscale band on NW edge forced by strong/persistent frontogenesis
- DGZ not deep (75-100 mb) but VVEL within DGZ very strong
- LES enhancement did not appear to be a factor
- Two heavy snowfall areas
- Perceived “northern/western shift” better explained by development of narrow frontogenetically forced snowband rather than “shift” in storm track.

# Model Trends/Snow Forecasts



# Model Trends / Snow Forecasts

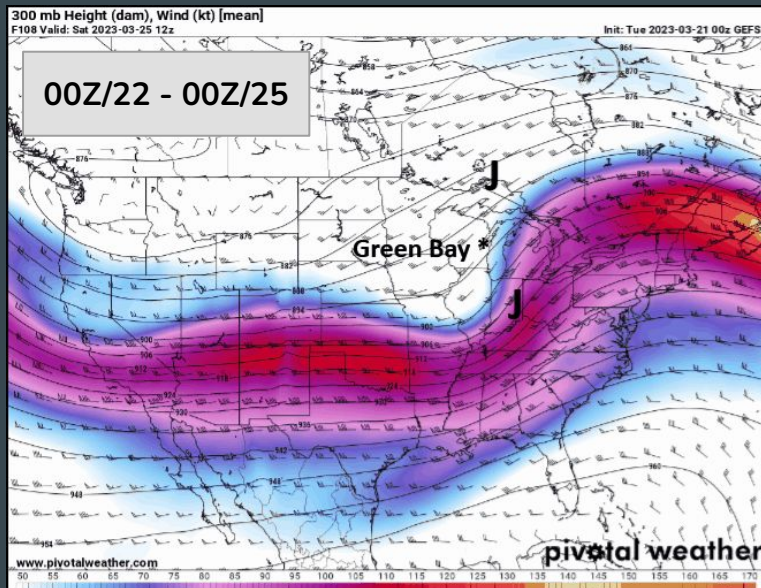
- Deterministic & Ensemble Comparisons (GFS, GEFS, EC, NAM)
- CAMs (HREF, RAP)
- WPC/Probabilistic Snow Forecasts

Were there any signals that might have alerted the forecaster to the possibility of greater forcing/mesoscale banding further west?

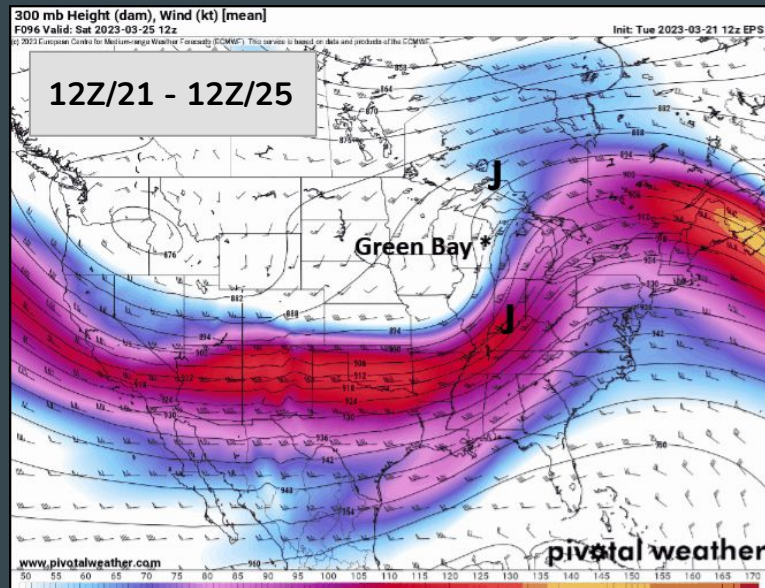
# Model Trends / Snow Forecasts

GEFS/EPS Dprog/Dt

GEFS/EPS: Similar handling of upper-level synoptic pattern. Trended stronger with southern stream jet energy, westward extension of northern stream jet, and increasing signal of coupled jet structure over Wisconsin.



300 mb - GEFS Trend Valid 12Z March 25

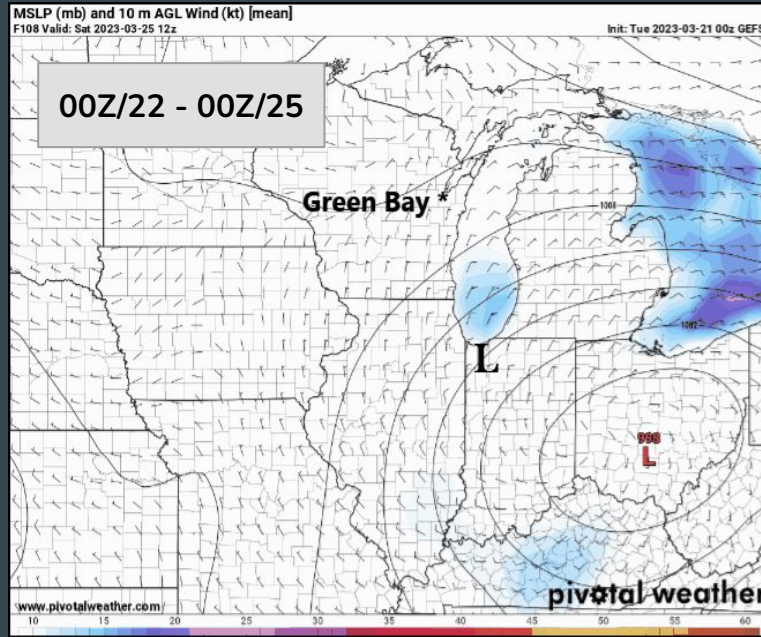


300 mb - EPS Trend Valid 12Z March 25

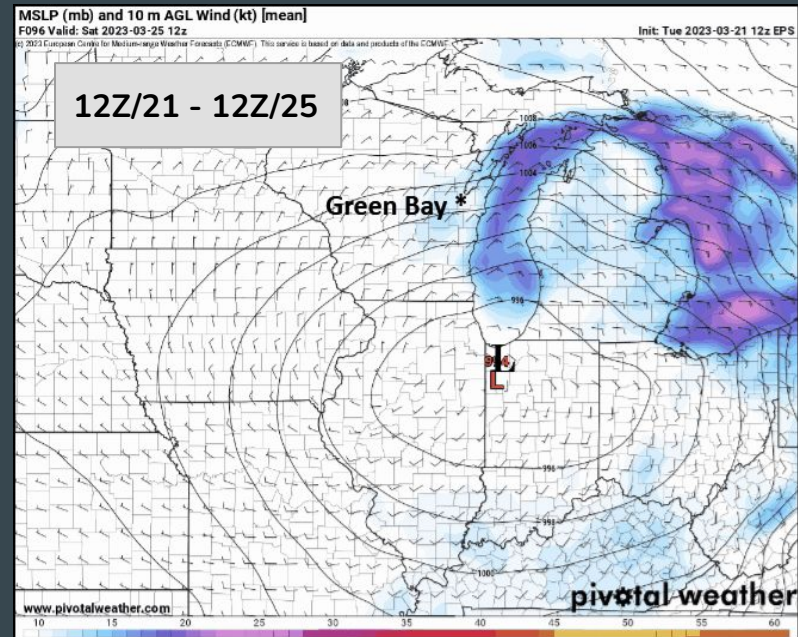
# Model Trends / Snow Forecasts

GEFS/EPS Dprog/Dt

MSLP Trend: EPS (right) seemed to demonstrate the most run-to-run consistency overall



GEFS MSLP Valid 12Z March 25

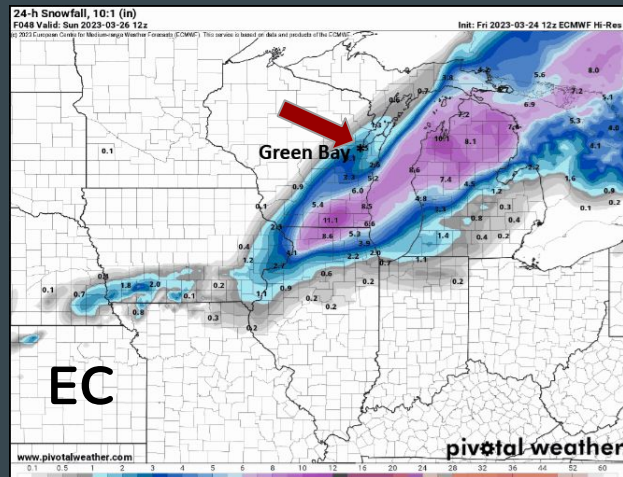
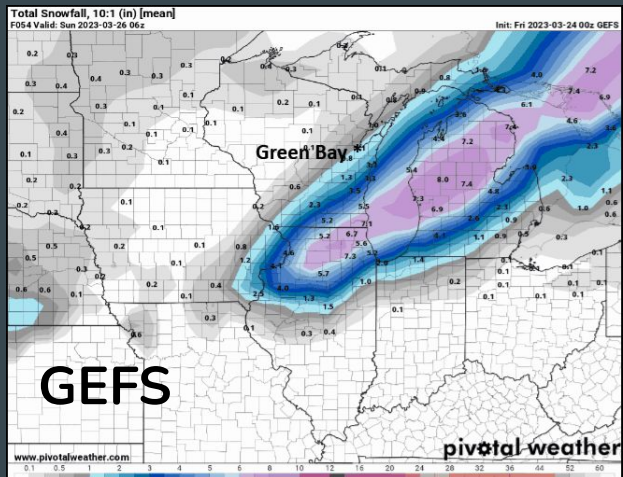
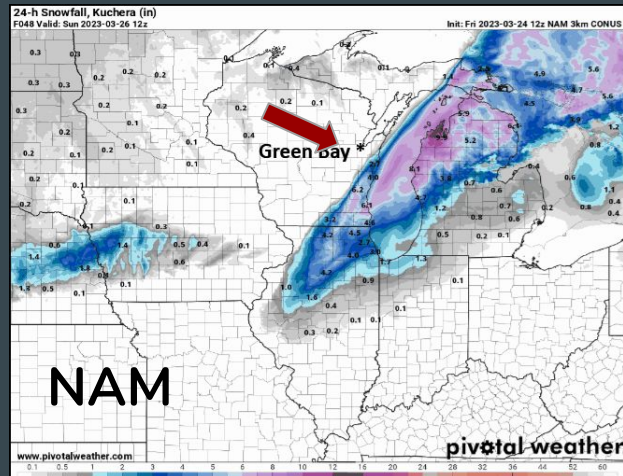
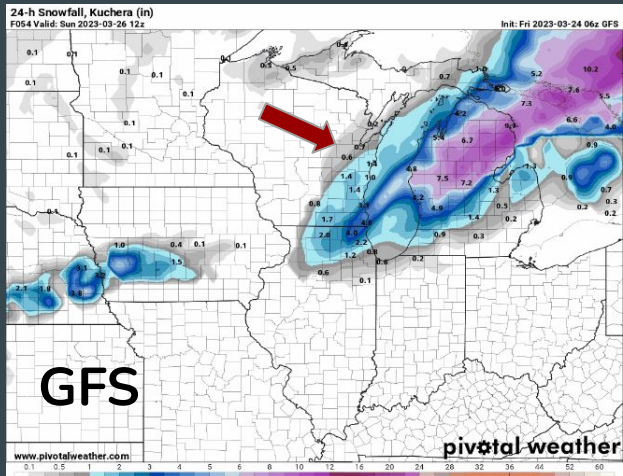


EPS MSLP Valid 12Z March 25



# Model Snow Forecast Trends

- ★ Deterministic guidance began to capture a banded signal ~ 24 hours out
- ★ ECMWF demonstrated best run-to-run consistency
- ★ Although some medium range guidance was beginning to capture mesoscale banded structure, none suggested 12 hour snowfall would exceed warning criteria in east-central WI.



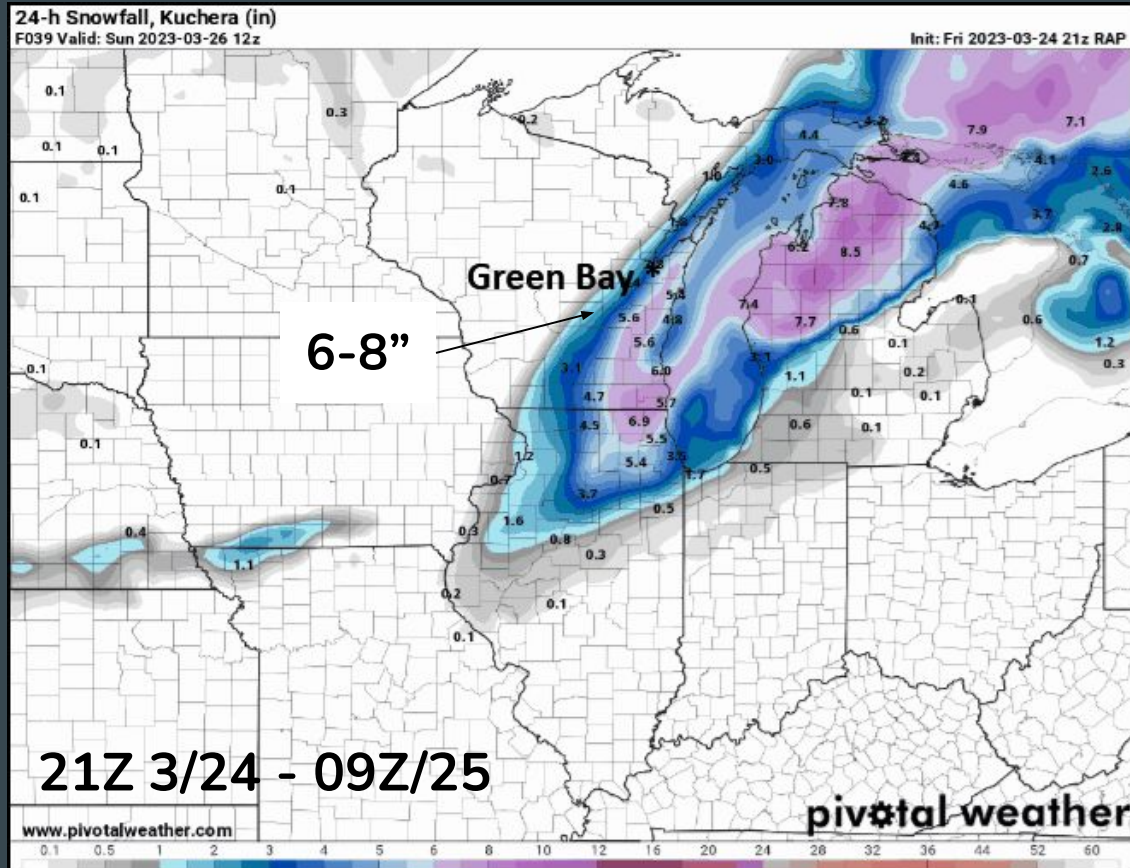


# Model Trends / Snow Forecasts

RAP

## RAP Dprog/Dt

- ★ 24hr Snowfall valid 12Z 3/26
- ★ RAP resolved signal better within 12-24 hours of event

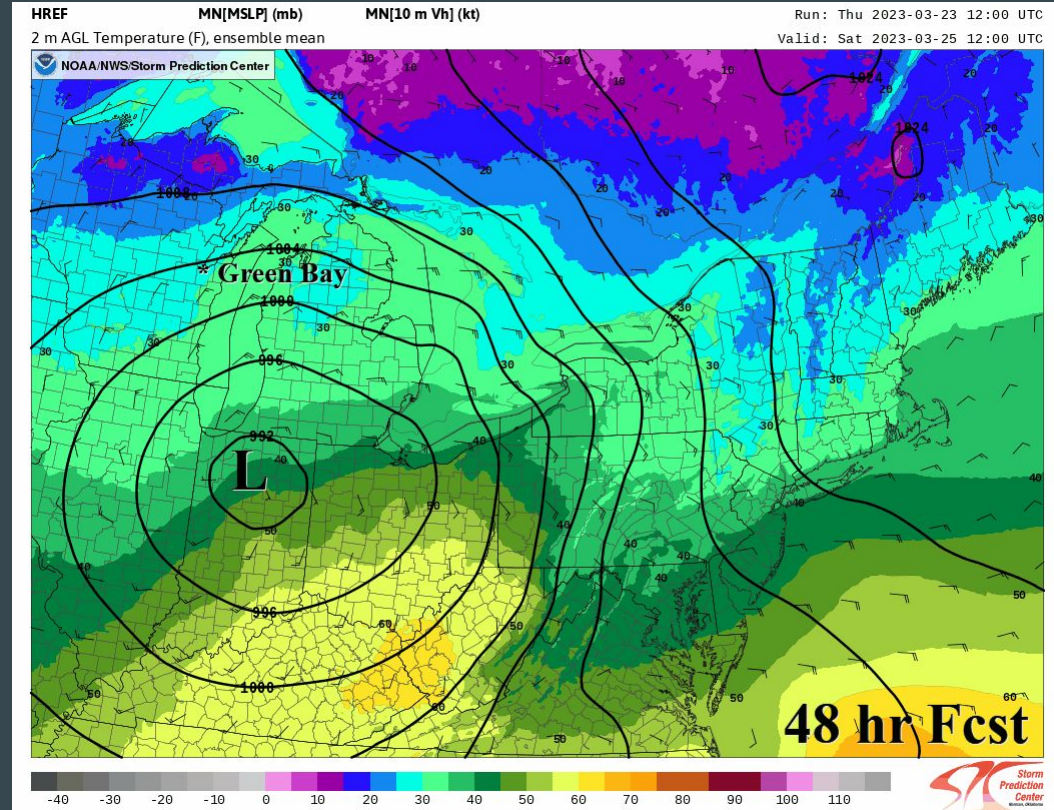


# Model Trends / Snow Forecasts

CAMS HREF

## HREF Mean MSLP

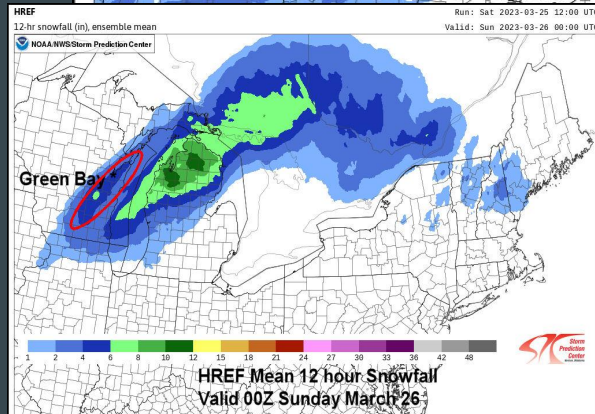
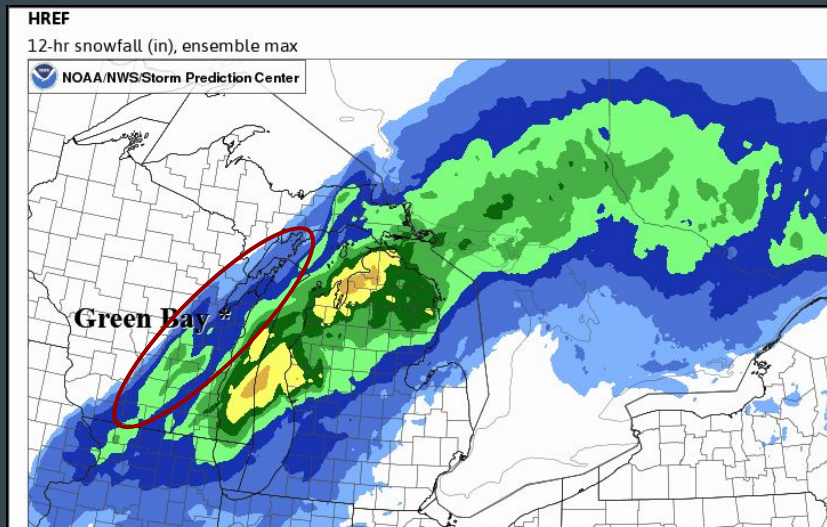
- ★ 12Z 3/23 - 00Z/25 Cycles
- ★ Valid 12Z March 25
- ★ Consistent Placement
- ★ Deepening Trend



# Model Trends / Snow Forecasts

## HREF Max 12 Hour Snow

- ★ 00Z 3/24 - 00Z/25 Cycles
- ★ Valid 00Z March 26
- ★ Amounts trending higher in excess of warning criteria (6-10"+) in east-central WI



< 12hr Mean

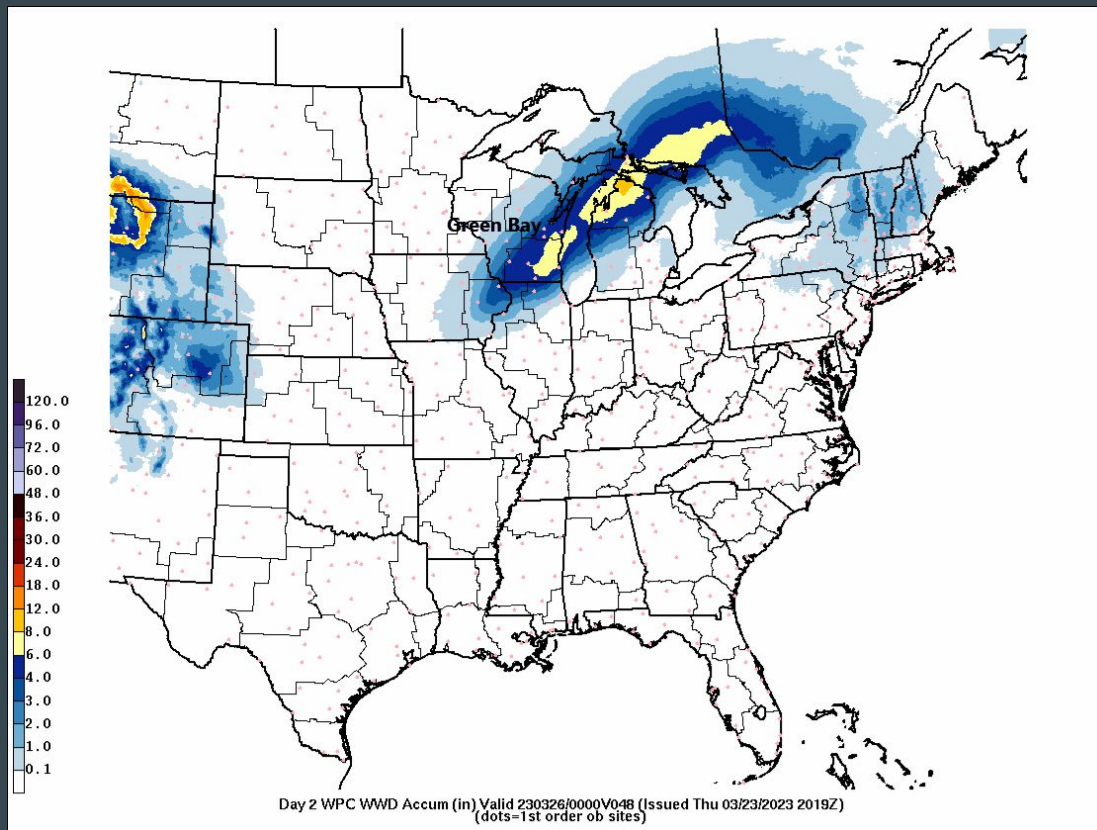


# Model Trends / Snow Forecasts

WPC

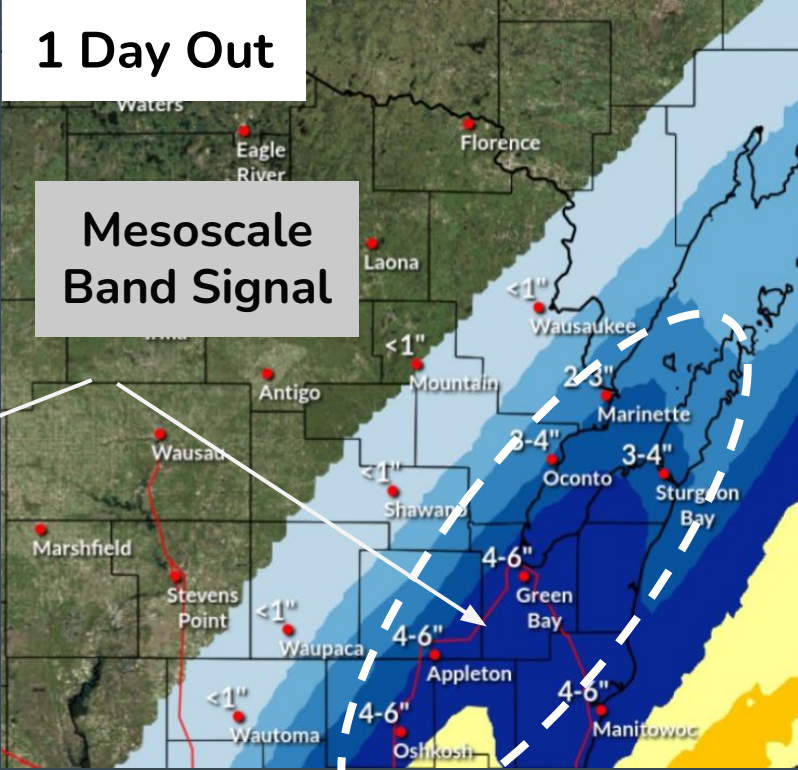
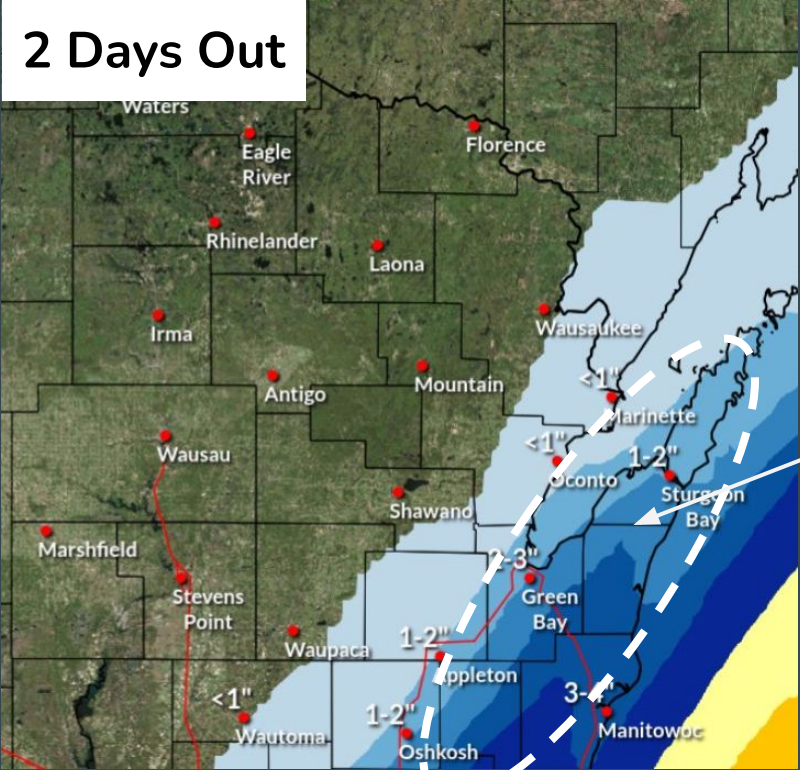
## WPC Forecast Guidance

- ★ Generally, WPC followed suite
- ★ Initially trended further east, then captured mesoscale banded signal
- ★ Increased forecast totals (6-8") over east-central WI with 08Z March 25 forecast.



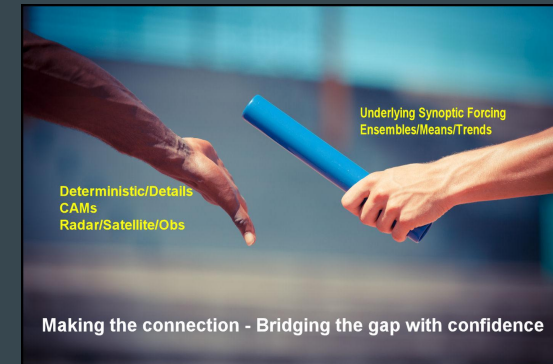
# Model Trends / Snow Forecasts

## GRB Snowfall Forecasts



# Model Trends / Snow Forecasts - Initial Thoughts Summary

- EPS guidance similar in trending stronger with synoptic-scale features/forcing. Overall positioning of upper-level large-scale features consistent. ECMWF showed best run-to-run consistency.
- Trend toward more pronounced coupled jet structure.
- Medium range deterministic guidance eventually caught onto the signal of a more discrete banded structure further west. None suggested warning criteria snow for east-central WI.
- CAMS (HREF) generally resolved trend in mesoscale banding potential. 12 hour ensemble maximum snow was closest to reality. Not too bad, just too late.
- Marrying ensemble mean trends of key synoptic-scale features (negative tilt, strengthening jet energy, couple jet signal) with the added spatial resolution of CAMs (HREF) as event neared, might have increased confidence to trend toward warning criteria in east-central WI.





# Messaging Timeline



# Messaging Timeline



**AM AFD...**

Will need to watch this system if there is any shift to the north.

**AM AFD...**

ECMWF has a decent precipitation event setting up across the area...will likely be in the form of snow.

**PM AFD...**

Any shift to the west could bring wintry weather to the area.

**PM AFD...**

ECMWF has continued its western trend...GFS and Canadian have trended only slightly further west.

# Messaging Timeline



**AM AFD...**

ECMWF continues to bring the precipitation shield furthest west...**5 and 9** inches across eastern WI...

**PM AFD...**

models have come into **better agreement...**

...ECMWF still has the furthest west solution...**6 to 10** inches...

...fairly **sharp cutoff...**

...snow may **partially melt...**

...NAM solution is **dry** for the whole forecast area...

...bulk of the snow would be **falling during the day...** partial melting and compacting...

# Messaging Timeline



AM/PM HWO...  
accumulating snowfall is  
looking more likely...

...a lot of uncertainty in  
the storm track.

**NWS Green Bay** @NWSGreenBay · Mar 22 ...

The next chance for active weather will be southern stream system that arrives Friday night into Saturday. There is decent potential for some snow accumulation with this system across east-central Wisconsin, but the exact track could still change. [#wiwx](#)

THURSDAY		
36 to 44°		
Partly to Mostly Cloudy Skies Dry Conditions		
FRI	SAT	SUN
Chance Late	PM Snow	Mostly Dry
Next Chance for Snow Friday Night into Saturday Morning		
38-45°	38-43°	40-48°

**ALT** NATIONAL WEATHER SERVICE  
GREEN BAY, WI 54903-1000

**GREEN BAY** • Local Weather Warnings Start Here

# Messaging Timeline



AM AFD...

ECMWF continues to be the most aggressive...Canadian...had double the qpf than the ECMWF...GFS was furthest east...

...per coordination with surrounding offices...**increase the chances of snow late Friday night.**

PM AFD...

still **uncertainty** in snowfall amounts...

...bulk of the snow would be **falling after sunrise**...roads should be warm enough (or treated)...

...**if a stronger snow band** with higher snowfall rates sets up over the area, cannot rule out the potential for some slushy snow on roadways.



# Messaging Timeline



AM AFD...

ECMWF continues to be the most aggressive...Canadian had double the qpf than ECMWF...GFS was further

PM AFD...

still uncertainty in snowfall amounts...

AM/PM HWO...

accumulating snow... still a lot of uncertainty.

of the snow would be per sunrise...roads should be enough (or treated)...

...per coordination with surrounding offices...increase the chances of snow late Friday night.

...if a stronger snow band with higher snowfall rates sets up over the area, cannot rule out the potential for some slushy snow on roadways.

# Messaging Timeline



NWS Green Bay @NWSGreenBay · Mar 23

Tranquil conditions are expected today and Friday, then snow and wind are in the forecast for Saturday. There is still a lot of uncertainty in the storm track and expected snowfall amounts across the area with this system, thus stay tuned to future forecasts.

## 4 Day Planner



More snow on the way?  
Winter won't go away!

Thu	35-43°		Hights a little below normal
Fri	35-46°		Calm before the storm
Sat	34-41°		Difficult travel possible
Sun	37-46°		Snow melt begins again

NWS Green Bay @NWSGreenBay · Mar 23

A winter storm will bring an accumulating snowfall as it moves across the western Great Lakes Friday night & Saturday. There is still a lot of uncertainty in the storm track, precipitation amounts which will impact snowfall amounts, & where the axis of heavy snow will fall. #wiwx

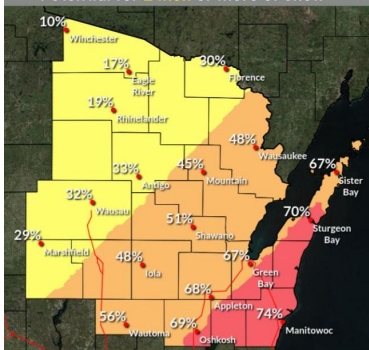
## SNOW LIKELY

Late Friday night & Saturday

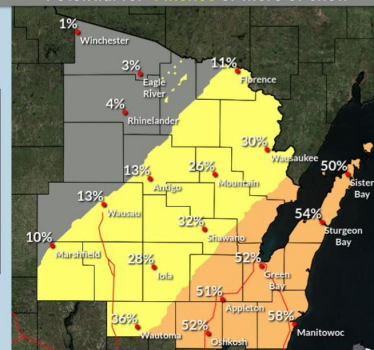
A wintery system will bring accumulating snowfall to east-central Wisconsin Friday night, with lesser amounts to the northwest. The track of this system could still shift, changing where the accumulating snowfall ultimately sets up. Allow extra time to reach your destination on Saturday morning.

- IMPACTS: Snow-covered & slippery roads and low visibilities for motorist on Saturday.

Potential for 2 inch or more of snow



Potential for 4 inches or more of snow



# Messaging Timeline



AM AFD...  
models continue to shift  
**southeast...**

...**3 to 5** inch range across Calumet  
and Manitowoc counties, with **2 to 4**  
inches in the surrounding counties

...bulk of the snow...**falling during**  
the daytime hours...

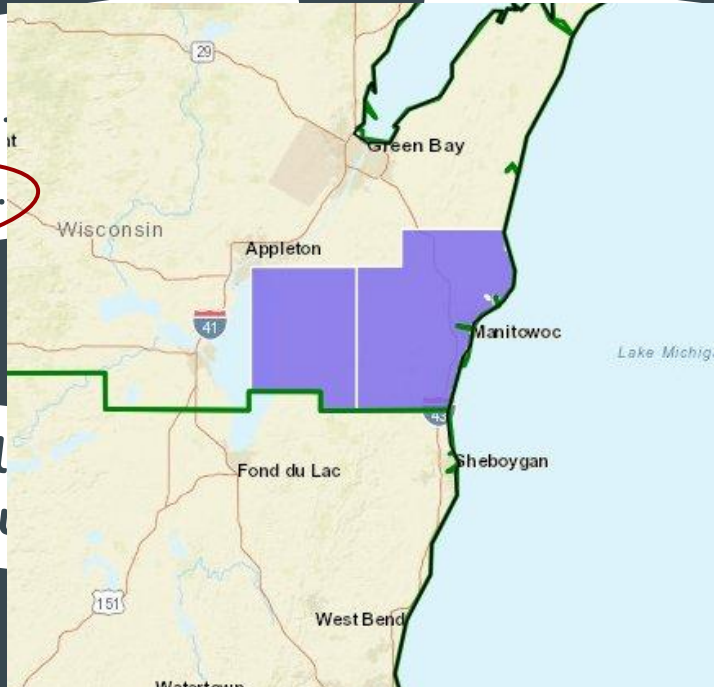
Snowfall amounts **drop**  
**off precipitously** as you  
head north and west...



# Messaging Timeline



AM AFD...  
models continue  
southeast.



h range across Calumet  
oc counties, with 2 to 4  
e surrounding counties

...bulk of the snow...fal  
the daytime ho

amounts drop  
pitously as you  
rth and west...

# Messaging Timeline



PM AFD...  
sharp cut-off...

...left exit region of the upper jet...**strong mid-level Q-G and FGEN forcing**...snow reaching east-central WI by **12Z Saturday** with only a minor accumulation at this point.

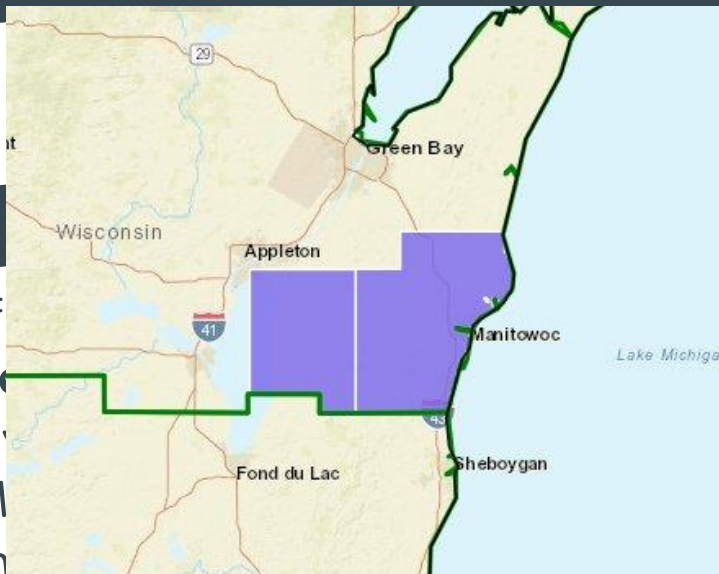
AM/PM HWO...  
slippery or snow-covered roads developing...a few inches of accumulating snow...some **uncertainty**... stay tuned for the latest information.

# Messaging Timeline



PM AFD...  
sharp cut-off...

...left exit region of  
jet...strong mid-level  
FGEN forcing...snow  
east-central WI  
Saturday with on  
accumulation at



AM/PM HWO...  
ery or snow-covered  
s developing...a few  
es of accumulating  
...some **uncertainty**...  
tuned for the latest  
information.

No changes to headlines or  
snow forecast



# Messaging Timeline



NWS Green Bay @NWSGreenBay · Mar 24

A storm system will bring accumulating snowfall to northeast Wisconsin from tonight through Saturday afternoon. The highest amounts will likely occur over east-central Wisconsin where 3 to 5 inches will be possible.

[#wiwx](#)

## EARLY SPRING SNOW

Late tonight - Saturday afternoon



### WHAT

A storm system will bring snow to the area late tonight & ending on Saturday afternoon



### AMOUNTS

Highest amounts of 3 to 5 inches over east-central Wisconsin. Lower amounts to the north and west.



### IMPACTS

Snowy roads and slippery travel. Wind gusts to around 35 mph could create some minor blowing and drifting snow and lower visibilities.

## Forecast Snowfall Amounts

1 AM Saturday - 7:00 PM Saturday



# Messaging Timeline



NWS Green Bay @NWSGreenBay · Mar 24

A storm system will bring accumulating snowfall to the area from tonight through Saturday afternoon. The highest amounts are expected to occur over east-central Wisconsin where 3 to 5 inches of snow is forecast.

[#wiwx](#)

## EARLY SPRING SNOW

Late tonight - Saturday afternoon

### WHAT

A storm system will bring snow to the area late tonight & ending on Saturday afternoon



### AMOUNTS

Highest amounts of 3 to 5 inches over east-central Wisconsin. Lower amounts to the north and west.



### IMPACTS

Snowy roads and slippery travel. Wind gusts to around 35 mph could create some minor blowing and drifting snow and lower visibilities.

NATIONAL WEATHER SERVICE  
BREMEN, OHIO



## EARLY SPRING SNOW

Saturday



### WHAT

A wet snowfall is expected for locations in east-central WI & along the lakeshore between early Saturday morning & early Saturday afternoon. North/northwest winds to gust to around 30 mph.



### AMOUNTS

About 1 to 5 inches. Highest amounts forecast in Calumet & Manitowoc County. Expect a sharp cutoff to the north & west.



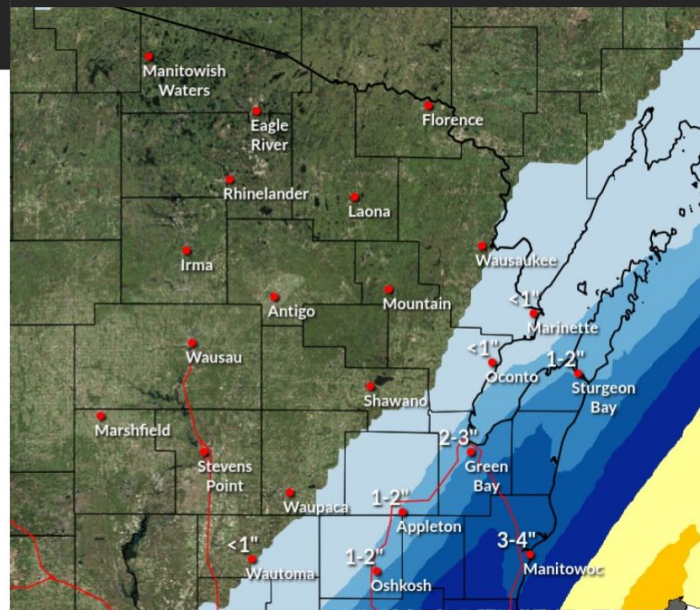
### IMPACTS

Roads to become slushy & slippery in spots. Poor visibility at times. Any blowing or drifting snow should be at a minimum due to the wet consistency of the snow.

GRI  
NATIONAL WEATHER SERVICE  
OCEANIC AND ATMOSPHERIC ADMINISTRATION

## Forecast Snowfall Amounts

Saturday

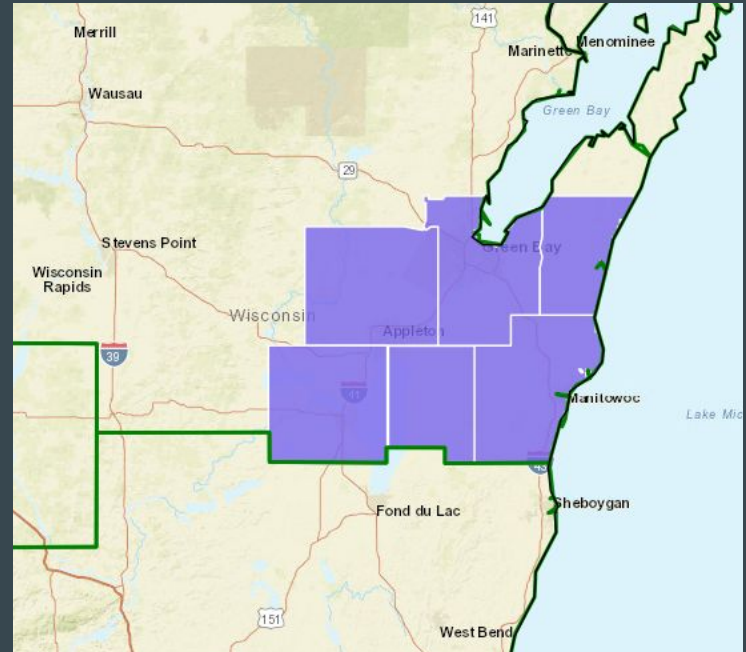


GREEN BAY • Local Weather Warnings Start Here

# Messaging Timeline



7:47 AM AFD...  
area of frontogenesis and  
vertical lift has **developed**  
**across the Fox Valley** this  
run...**3 to 6 inch** range this run  
as the heaviest snow has  
**shifted a bit northwest...**





# Messaging Timeline



**7:58 AM AFD UPDATE...**

impressive snow band associated with strong frontogenesis/deformation has set up from the Fox Valley northeast into Door County...

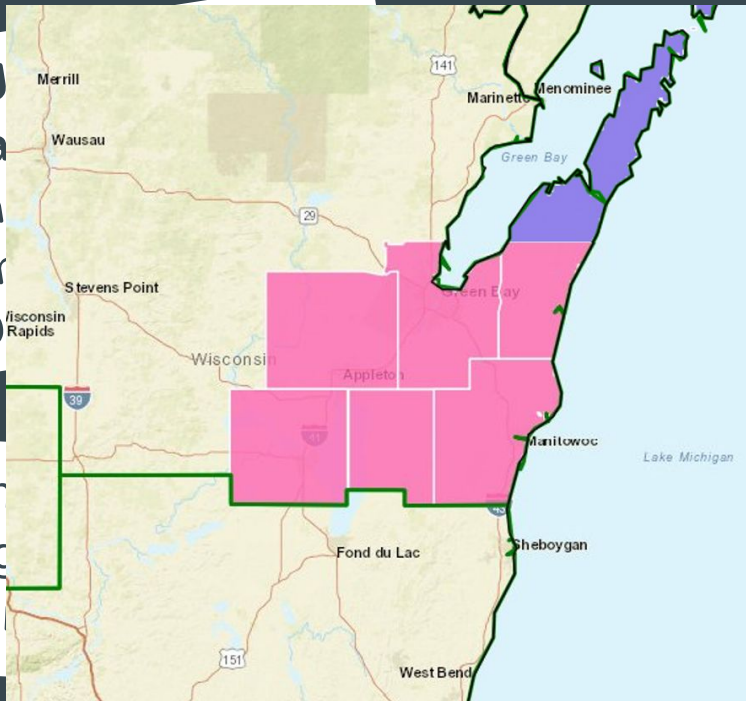
...rates of 2-4 inches/hour, with localized snowfall amounts as high as 6 to 10 inches since 5 am...

...Omega/RH/T timesections show potential for significant snows (**crosshair signature**) to continue through about midday before waning.

# Messaging Timeline



7:58 AM AFD U  
impressive snow ba  
with strong frontogen  
has set up from th  
northeast into D



...rates of 2-4  
...es/hour, with  
...ized snowfall  
...s as high as 6 to  
...s since 5 am...

...Om  
...sig  
...cont

...ential for  
...ure) to  
...e waning.

# Messaging Timeline



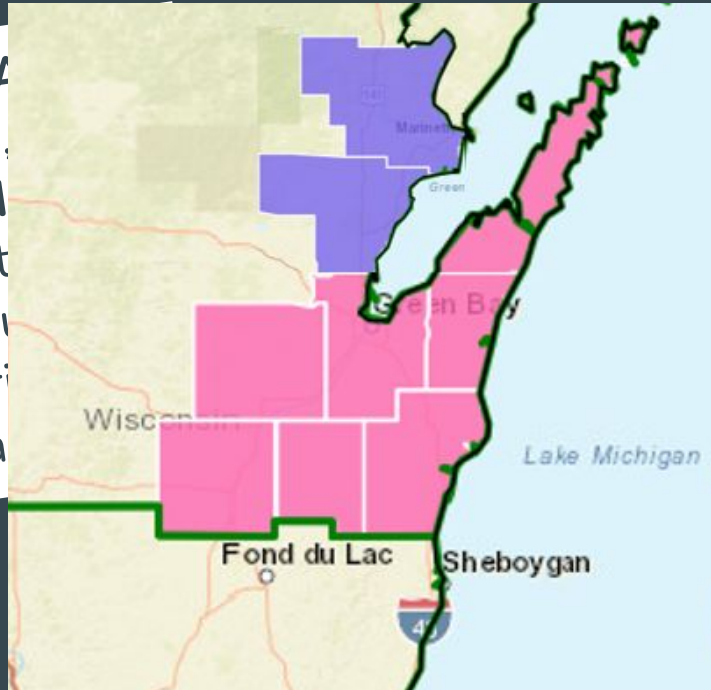
**9:03 AM AFD UPDATE...**  
over the past hour, the **heavy snow band had pivoted northwest** to cover most of Door County, and...into the Marinette/Oconto areas.

...The northwest movement of the **band appears to have halted**, so we are not expecting any additional westward expansion of the headlines.

# Messaging Timeline



9:03 AM AFD UPDATE  
over the past hour,  
heavy snow band  
pivoted northwest to  
most of Door County  
and...into the Marinette  
Oconto area



the northwest  
end of the band  
to have halted,  
we not expecting  
additional westward  
expansion of the  
headlines.



# Messaging Timeline



3:20 AM HWO...  
several inches of  
accumulating  
snow...**hazardous road  
conditions and low.  
visibility.**

8:39 AM HWO...  
...**heavy snow** to the Fox Valley and  
lake shore areas through midday...in  
**excess of a foot** of heavy, wet  
snow. Snow covered roads and poor  
visibility will result in **hazardous  
travel conditions.**

# Messaging Timeline



**NWS Green Bay @NWSGreenBay · Mar 25**

An early Spring storm will bring snow to northeast Wisconsin today. Several inches are possible, highest from the Fox Valley to the Lakeshore. The snow will likely create slippery and slushy travel conditions. Quiet weather, along with some sunshine, returns on Sunday.

[#wiwx](#)

SUN	MON	TUE
Partly cloudy	Mostly cloudy	Partly cloudy
35-47°	35-44°	33-44°

GREEN BAY • Local Weather Warnings Start Here

2 3 2,572



**NWS Green Bay @NWSGreenBay · Mar 25**

A wet snowfall remains on track to impact northeast Wisconsin today. The highest amounts will likely occur over east-central Wisconsin where 3 to 6 inches are currently forecast. Expect slushy and slippery roads over eastern Wisconsin today!

[#wiwx](#)

**EARLY SPRING SNOW**  
Today

**WHAT**  
A wet snowfall is expected for locations in the Fox Valley & along the lakeshore through mid-afternoon today. North or northwest winds to gust to around 35 mph.

**AMOUNTS**  
About 3 to 6 inches. Expect a sharp cutoff to the north & west.

**IMPACTS**  
Roads to become slushy & slippery in spots. Poor visibility at times. Any blowing or drifting snow should be at a minimum due to the wet consistency of the snow.

Forecast Snowfall Amounts Through 7 PM Today

GREEN BAY • Local Weather Warnings Start Here

4 4 10 3,689

# Messaging Timeline



NWS Green Bay @NWSGreenBay · Mar 25

739 AM | Narrow band of heavy snow moving through the Fox Valley and east-central Wisconsin. Very high snowfall rates of 2"+ per hour. Road conditions have deteriorated quickly. Use extreme caution if traveling here this morning. [#wiwx](#)



NWS Green Bay @NWSGreenBay · Mar 25

Lots of snow in a very short time across the Fox Valley and east-central Wisconsin. If you've measured snow this morning, head to our Facebook page and let us know how much: [facebook.com/photo/?fbid=58...](https://facebook.com/photo/?fbid=58...)

[#wiwx](#)

## Send us Your Snowfall Measurements

Comment on this post with:

1. Location
2. How much snow you've received so far
3. What time the snow started
4. **BONUS:** Include a picture



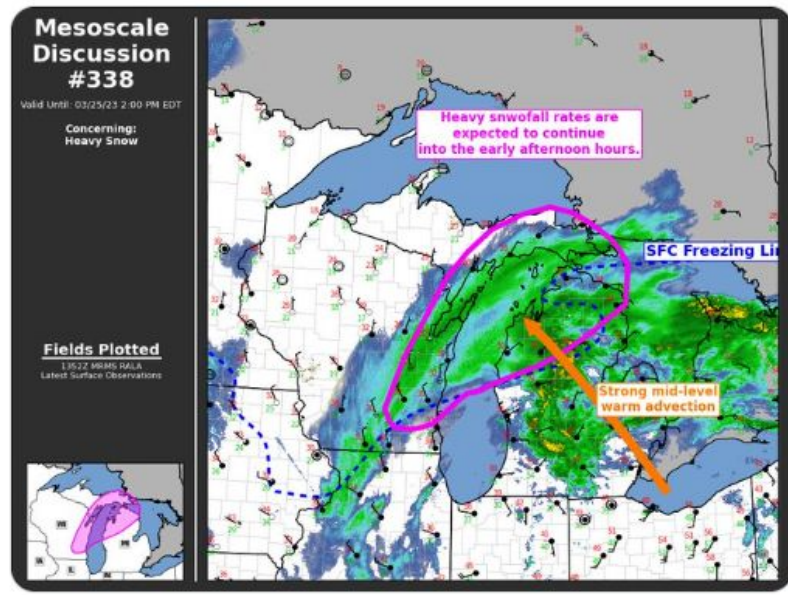
# Messaging Timeline



You Retweeted

NWS Storm Prediction Center @NWSSPC · Mar 25

8:56am CDT #SPC\_MD 0338 , #miwx #wiwx,  
[spc.noaa.gov/products/md/md...](https://spc.noaa.gov/products/md/md...)



NWS Green Bay @NWSGreenBay · Mar 25

Just a small sampling of the many reports we have received today. Thank you so much! Be sure to share your FINAL reports after the snow has ended.

Amounts vary greatly across the area, so it will be common for what you see here to not match your backyard.

#wiwx





# Messaging Timeline



## Positive SM Comments

“...how and where the fgen band set up - even a difference of 10-15 miles w [or] e of where it was predicted to setup has massive implications...”

“...The western expansion and advertised sharp cutoff were always in question and was a massive variable.”

“Late season storms are extremely difficult to predict...I can't wait for spring. I just wanna ride my bike...”

“I have to feel a little bad for the NWS people. They do their damned best to forecast as accurately as they can, but [people] will always whine.”



# Messaging Timeline



## Negative SM Comments

“Wow that one was only a foot off 😞 Good job guys”

“Got this one way wrong”

“I’m gonna unlike this page these predictions aren’t true”

“Are the weather models really this bad or is it perhaps the people reading and interpreting them?”

“Last night NOAA weather app said half an inch of snow..LMAO”

How were your models this bad? NWS is still only saying 4-6” in the winter storm warning. This is massive snow and you had us going to be believing it was 1-3”

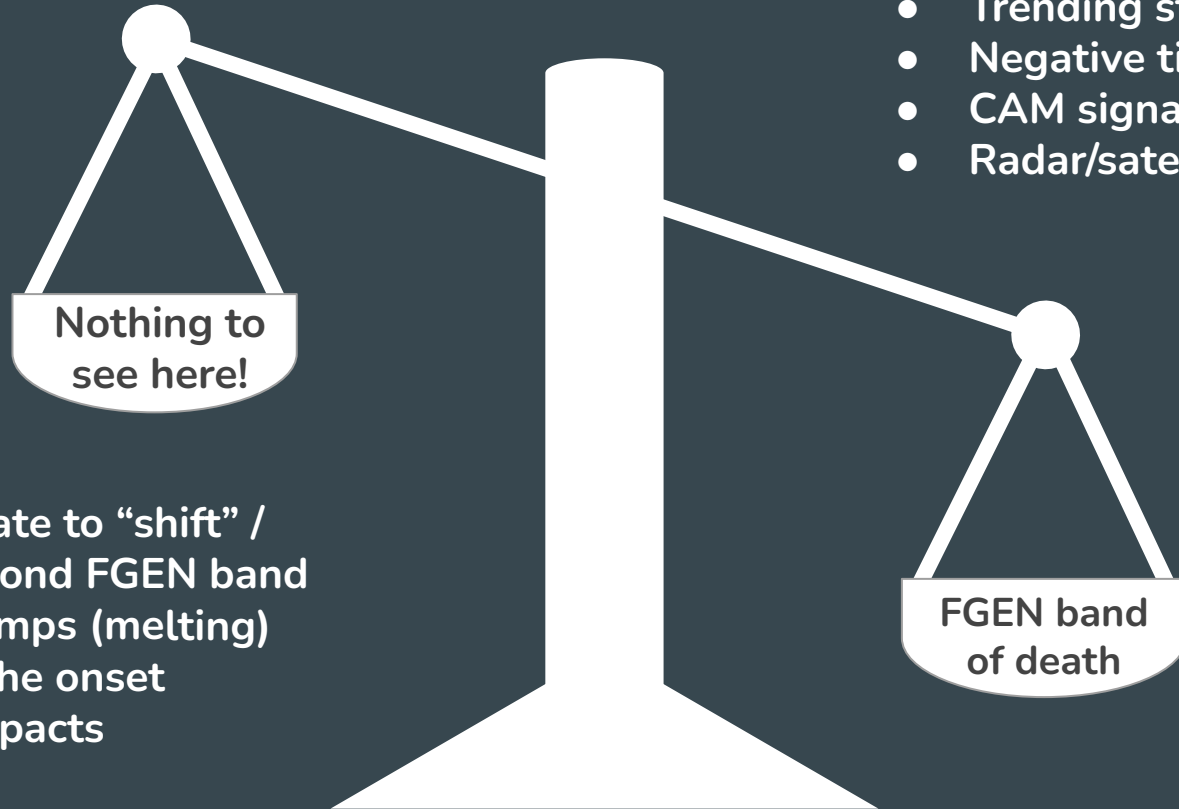
“Who is the meteorologist that blew this forecast?”



# Moving Forward



# Moving Forward - Forecaster Dilemma



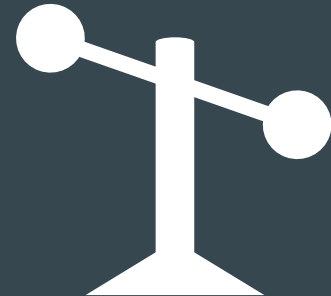
- Guidance late to “shift” / resolve second FGEN band
- Warmer temps (melting)
- Dry air at the onset
- Minimal impacts

- Synoptic signals
- Trending stronger
- Negative tilt/coupled jets
- CAM signals
- Radar/satellite



# Moving Forward

- How to improve forecaster's knowledge/confidence in effectively bridging large-scale synoptic trends/ ensemble trends/ signals with deterministic guidance/CAM signals?
- When to use probabilistic snow forecasts, high end amounts/worst case scenario in public/partner messaging?
- When do you “take the leap” when trends late in the game deviate notably from previous trends?
- Is making reactive last minute adjustments to headlines & messaging the best we can do in these situations? Should we explore other tools/ methodologies to handle the threats/impacts in these type of scenarios?



# Acknowledgements



*Gene Brusky, Mike Cellitti, Rebecca Kruk, Phil Kurimski*



**Thank you!**

...

*Questions / Comments / Discussion*