Addressing the Snow Accumulation Challenge at CIWRO/NSSL

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WPC Winter Weather Experiment Seminar Series

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Motivation

- With winter precipitation, impacts are generally tied to how much – or even whether – frozen precipitation accumulates
- For some events, it's clear that most, if not all precipitation will accumulate

Image credit: Brian Herzog, *Flickr*

Motivation

- For other events, though, warm road/object temperatures limit accumulations – and therefore impacts.
- Sometimes, heavy rates can overcome warm surfaces
- How do we know when heavy snow + warm surface yields impacts?

Image credit: Doug Bradley, *Flickr*

Motivation

- The remainder of this presentation will focus on these two problems – rate vs. surface temperature – for snow accumulation
  - Daniel Tripp covered ice accumulation rate on December 7 – will do so again at AMS Annual Meeting!
- First, I will present a current effort to create a two-dimensional snow intensity product from radar observations
- Then, I will present updates to the existing Probability of Subfreezing Roads (ProbSR) MRMS product

Part 1: Radar-derived Snow Intensity

Background

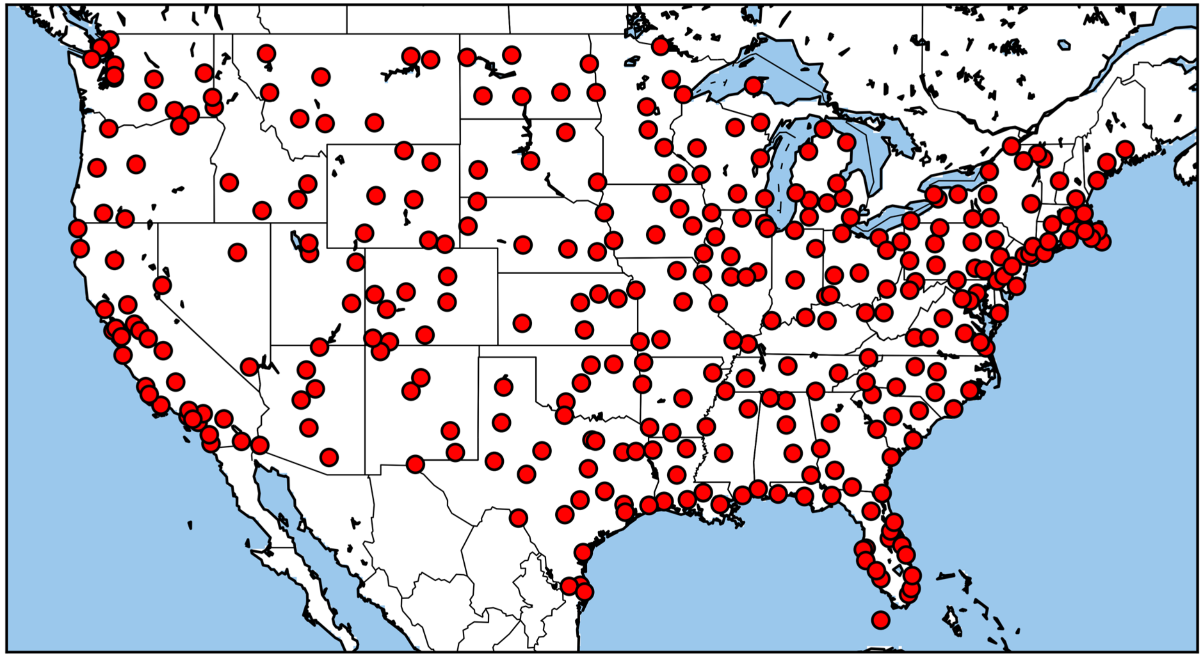
- Real-time snow rate is a parameter of interest
  - Better information would benefit both forecasting and decision support
- Fundamental problem: snow rate isn't observed at adequate spatial/temporal resolutions

Image credit: *RawPixel.com*

Visibility and Snow Intensity

- ASOS Snow Intensity reports are often used as a stand-in for snow rate
- Snow Intensity is categorical (light, moderate, heavy), and based on visibility
- The visibility-to-snow rate relationship is problematic at times (Rasmussen et al. 1999)
- Spatial and temporal resolution of visibility observations are far greater than other snow rate observations

ASOS Sites



Deriving Snow Intensity

ASOS Snow Intensity Categories:

Light: $V \geq 0.75$ mi. (1.2 km)

Moderate: 0.25 mi. (.4 km) < $V \leq 0.50$ mi. (.8 km)

Heavy: $V \leq 0.25$ mi. (.4 km)

- Visibility can be calculated from extinction, which is what the ASOS measures:
- Daytime visibility: $V_{day} = -\frac{\ln(\varepsilon)}{\sigma_e}$ (Koschmieder 1924)
- Nighttime visibility: $V_{night} = 1.31\, V_{day}^{0.71}$ (Boudala et al. 2012)

Where $\boldsymbol{\sigma_e}$ is extinction (km^{-1}), and **ε** is the brightness threshold (here, we used 0.02)

Calculating Extinction

- Bukovčić et al. (2021) developed a relationship between liquid precipitation rate (S, mm/hr) and extinction (σ_e)
- Solving for extinction as a function of precipitation rate:

$$\sigma_e = \gamma(3+\mu)\frac{S * (4+\mu)^{(1+\beta+\delta)}}{\left[1.2 * \alpha_o * \ f_{rim}^{1.5} * d_0 * \left(\frac{p_o}{p}\right)^{0.5} * D_m^{(1+\beta+\delta)} * \gamma(4+\mu+\beta+\delta)\right]}$$

- To simplify, we're going to use typical values for μ (PSD shape parameter); α_o and β (snow density factors) ; d_o and δ (terminal velocity factors)

Calculating Extinction

$$\sigma_e = \gamma(3+\mu)\frac{S * (4+\mu)^{(1+\beta+\delta)}}{\left[1.2 * \alpha_o * f_{rim}^{1.5} * d_0 * \left(\frac{p_o}{p}\right)^{0.5} * D_m^{(1+\beta+\delta)} * \gamma(4+\mu+\beta+\delta)\right]}$$

- With representative values[1] (μ=0 for an exponential distribution, and α_o = 0.15, β = -1, d_o = 0.7, and δ = 0.23), the expression reduces to:

$$\sigma_e = 8.47 * \left(\frac{p}{p_o}\right)^{0.5} * \frac{S}{D_m^{0.15} * f_{rim}^{1.5}}$$

- The remaining degrees of freedom are median particle diameter (D_m) and particle riming factor (f_{rim})
- <u>Objectives</u>: how does this expression verify? Do D_m and f_{rim} choices substantially impact verification statistics?

[1] Based on observations in Oklahoma

Data Sources

- DJF observations from:
  - ASOS at 398 largest commercial airports – 2017 to 2023
    - Highest intensity within 10 minutes of XX:00 (correspond to HRRR valid time)
  - MRMS dual-pol instantaneous precipitation rate
    - No gauge correction passes to simulate a real-time product
  - Surface pressure from HRRR
    - A 2D field using this methodology wouldn't be able to use ASOS station pressure
- These data were used to calculate extinction, then visibility
  - Used NSSL's experimental Spectral Bin Classifier p-type algorithm in MRMS to determine where snow fell
    - Did not include mixes (RASN, PLSN, etc.)

Derived Visibility Tests

- Based on range of values observed in Oklahoma

- **Low**: Small, less-rimed particles
  - $D_m = 1$ mm
  - $f_{rim} = 1.2$
- **High**: Large, more-rimed particles
  - $D_m = 3$ mm
  - $f_{rim} = 1.8$
- **Reflectivity**:
  - Thresholds based on percentiles of the data
    - 86% of observations in this dataset are light, 97% of observations are mod or light
  - **Light** < 14 dBZ; **Moderate** < 18 dBZ and ≥ 14 dBZ; **Heavy** ≥ 18 dBZ

Two-Category Test

- Here, we test the performance of the visibility using two categories of snow intensity; "heavier" (moderate+heavy combined), or light.

Observed

Predicted

	Moderate+Heavy	Light
Moderate+Heavy	TP	FP
Light	FN	TN

Verification Stats - Categories

Low	
POD	**72**
FAR	78
Bias	3.3
HSS	21
EDI	**30**

High	
POD	39
FAR	**65**
Bias	**1.1**
HSS	**29**
EDI	8

Reflectivity	
POD	56
FAR	78
Bias	2.5
HSS	20
EDI	22

- Low experiment has a highest POD/EDI; High experiment has lowest FAR/Bias, and highest HSS

Constraining the dataset

- Limit to sites within 75 km of a radar, and with a dewpoint depression of 1.5 °C
  - Minimize impacts of radar overshooting and sublimation

Low	
POD	72
FAR	78
Bias	**3.3**
HSS	**21**
EDI	33

T_d+ Dist	Low
POD	**90**
FAR	**75**
Bias	3.7
HSS	**21**
EDI	**46**

Gerrity Skill Score (GSS)

- GSS (Gerrity, 1992) allows comparison of more than two categories
- The GSS is weighted by the difficulty of the categorization
  - The less frequent a category occurs, the more a correct diagnosis is worth

$$GSS = \sum_{i=1}^{3}\sum_{j=1}^{3} p_{ij} s_{ij}$$

Where:

p is a measure of probability

s is a scoring weight based on the category's frequency

Next slide: GSS results using the constrained (< 75 km, 1.5 °C T_d depression)

Observed

Predicted

Low	Light	Moderate	Heavy
Light	**<u>3150</u>**	78	15
Moderate	2470	**<u>469</u>**	78
Heavy	231	217	**<u>126</u>**

Low
GSS = 0.48

High	Light	Moderate	Heavy
Light	**<u>4953</u>**	304	37
Moderate	863	**<u>432</u>**	147
Heavy	35	28	**<u>35</u>**

High
GSS = 0.33

Reflectivity	Light	Moderate	Heavy
Light	**<u>3802</u>**	207	45
Moderate	1604	**<u>373</u>**	81
Heavy	445	184	**<u>93</u>**

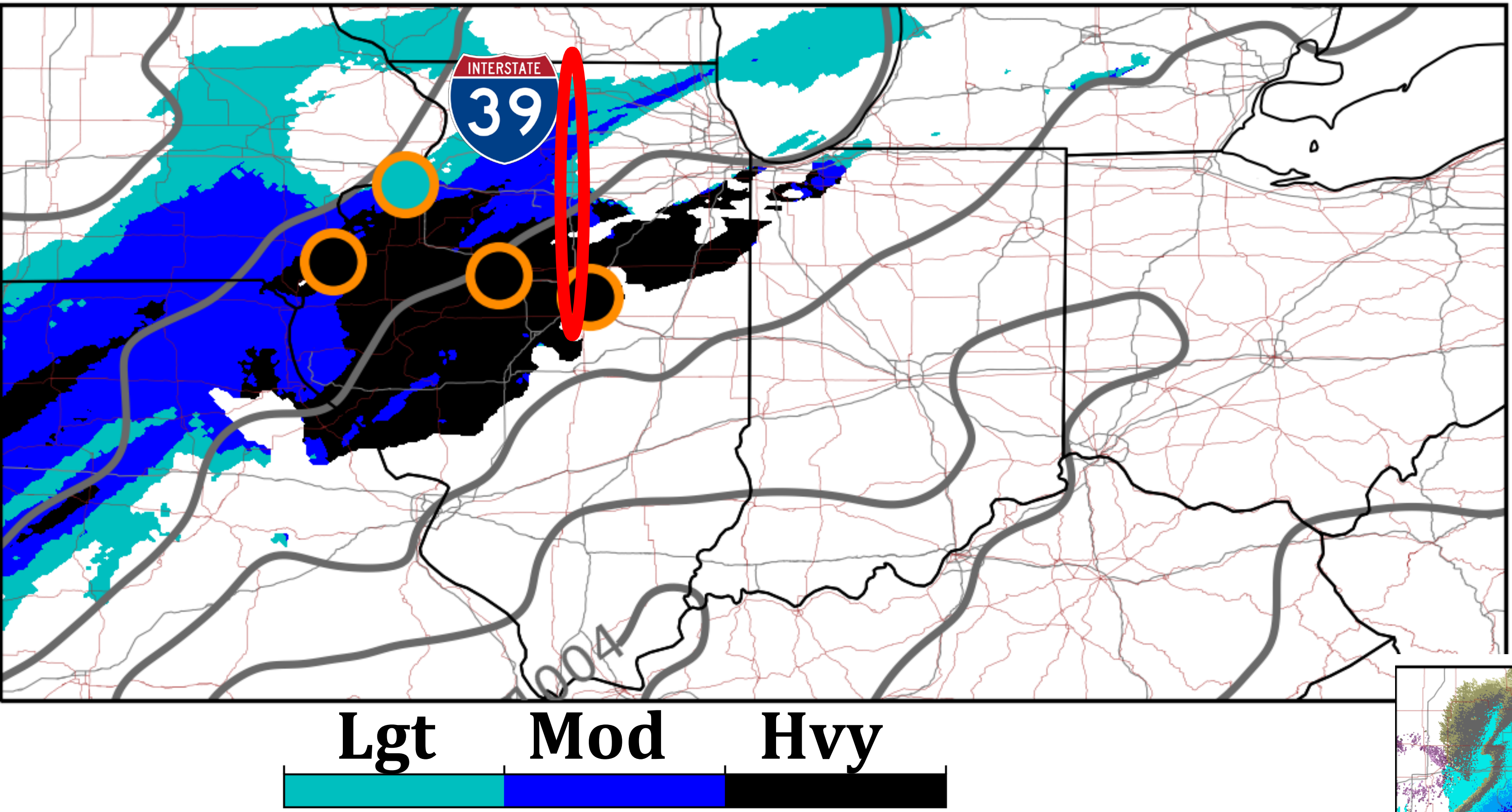
Reflectivity
GSS = 0.36

Case Study – 17 February, 2022

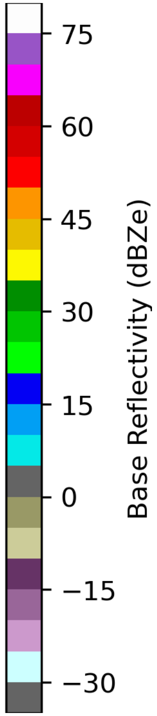
- Heavy, sudden-onset snow caused dangerous travel conditions in northern IL
- 100+ car pileup on I-39 starting at 2015 UTC that closed the Interstate until the next day

Image credit: *Brandon Rixstine/ WGLT*

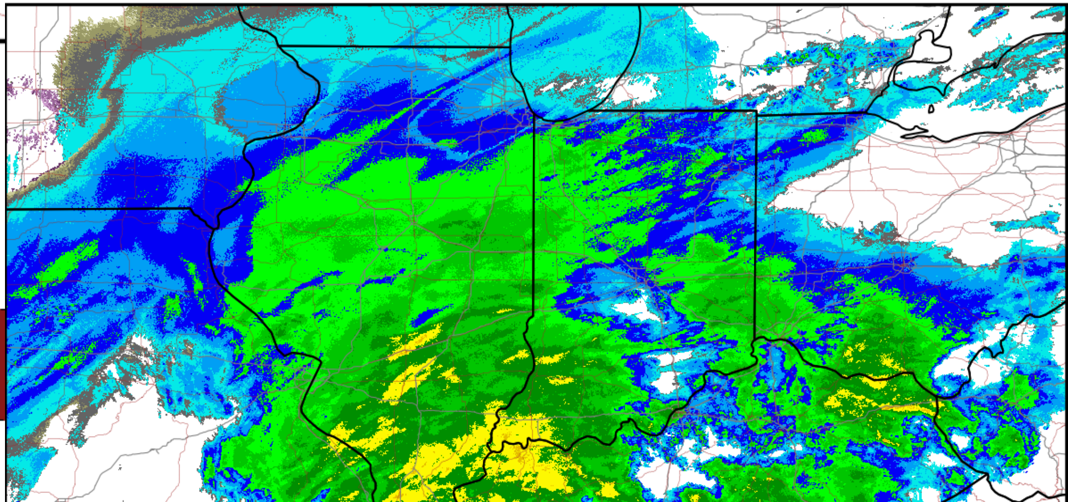
Snow Intensity Analysis – 1800 UTC



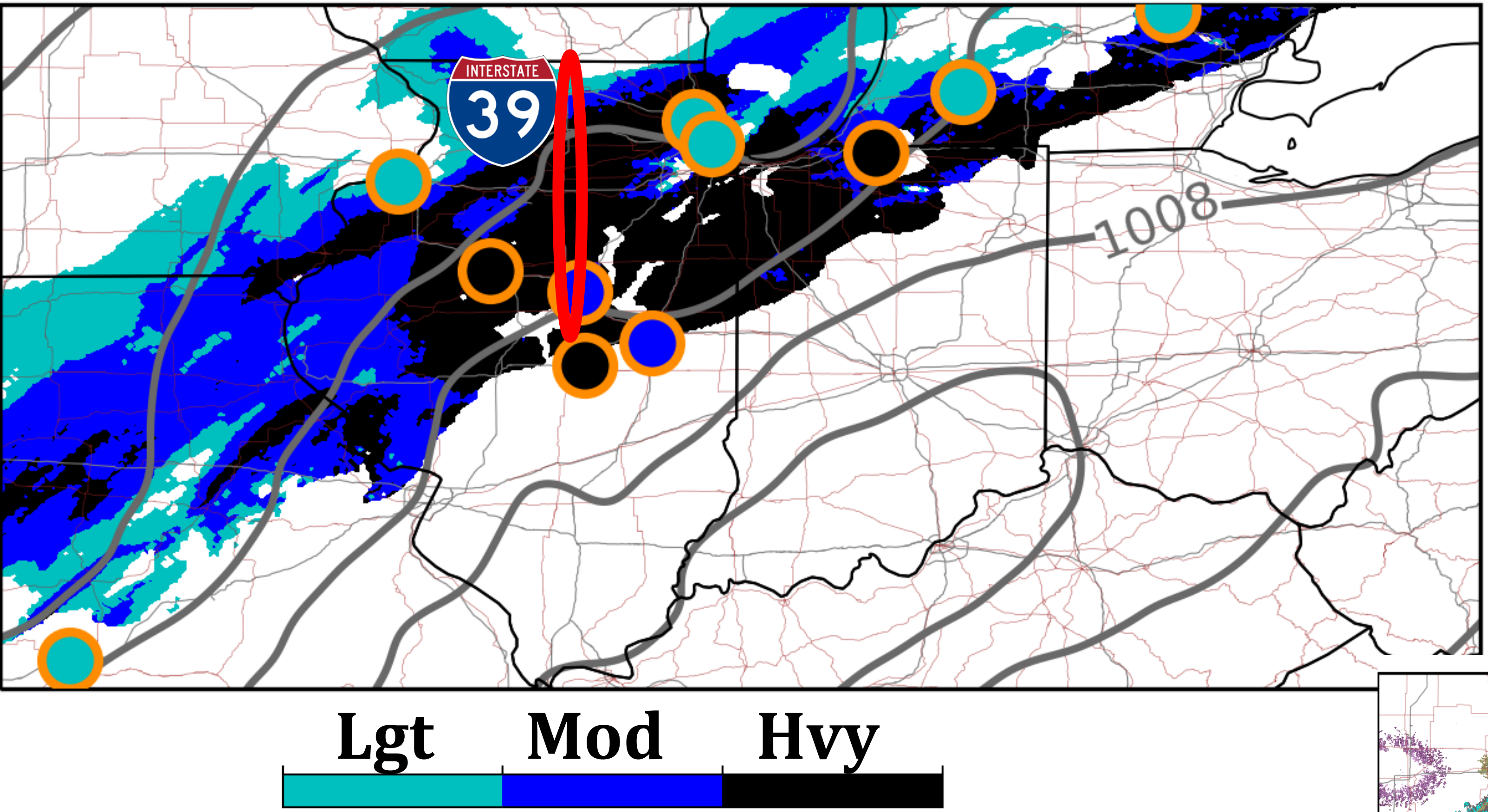
- Snow arriving from the SW has sharp intensity gradient



Orange circles – All ASOS sites reporting snow

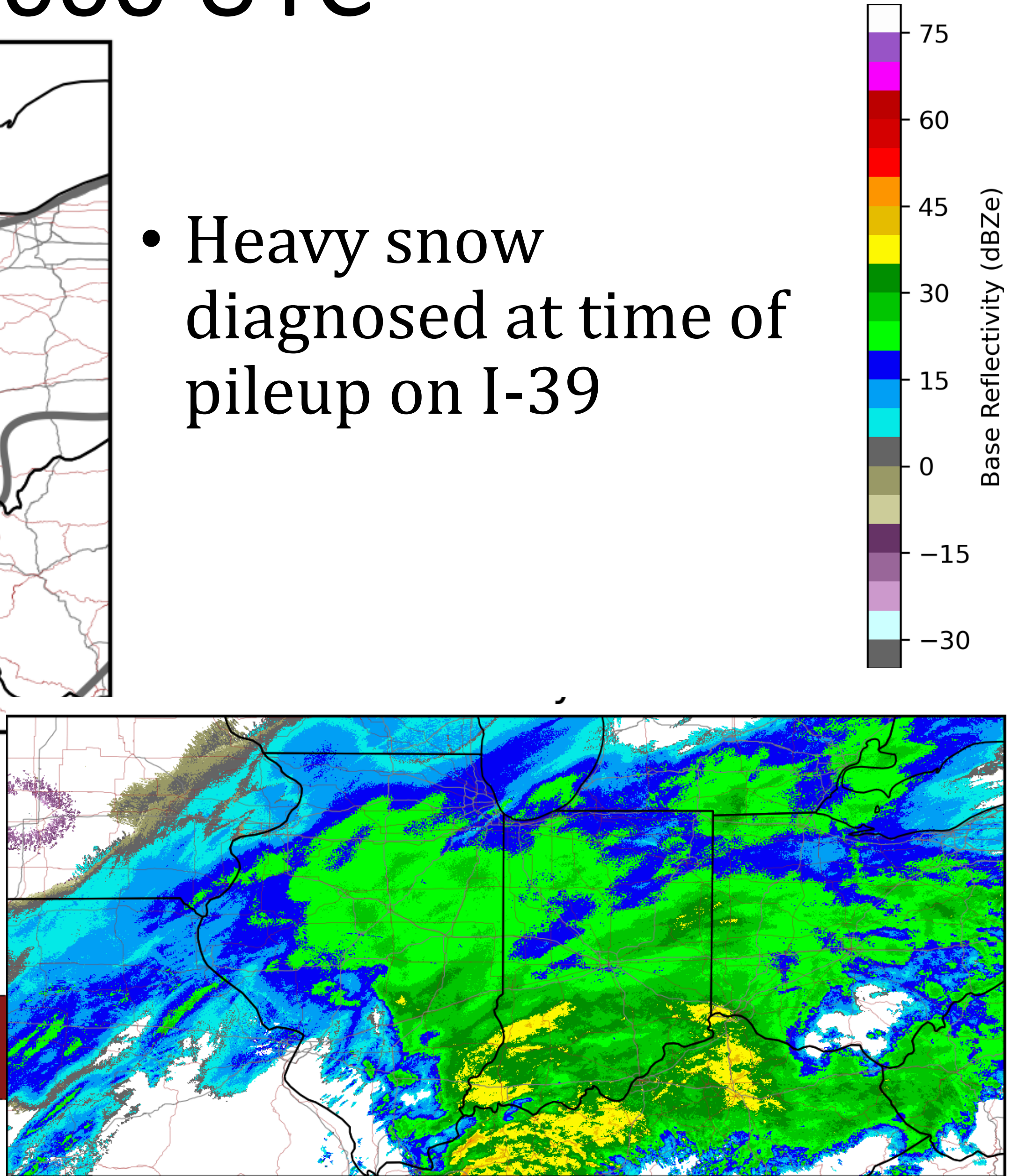


Snow Intensity Analysis – 2000 UTC



Orange circles – All ASOS sites reporting snow

- Heavy snow diagnosed at time of pileup on I-39



Part 2: Probability of Subfreezing Roads (ProbSR) Update

Probability of Subfreezing Roads - ProbSR

- ProbSR is a random forest ML model
  - What it predicts: the probability that the *road surface temperature is below freezing*
  - What it doesn't predict: the probability *the road accumulates ice*
- ProbSR is trained on Road Weather Information System (RWIS) data
- HRRR fields as predictors

Image credit: *Utah DOT, Flickr*

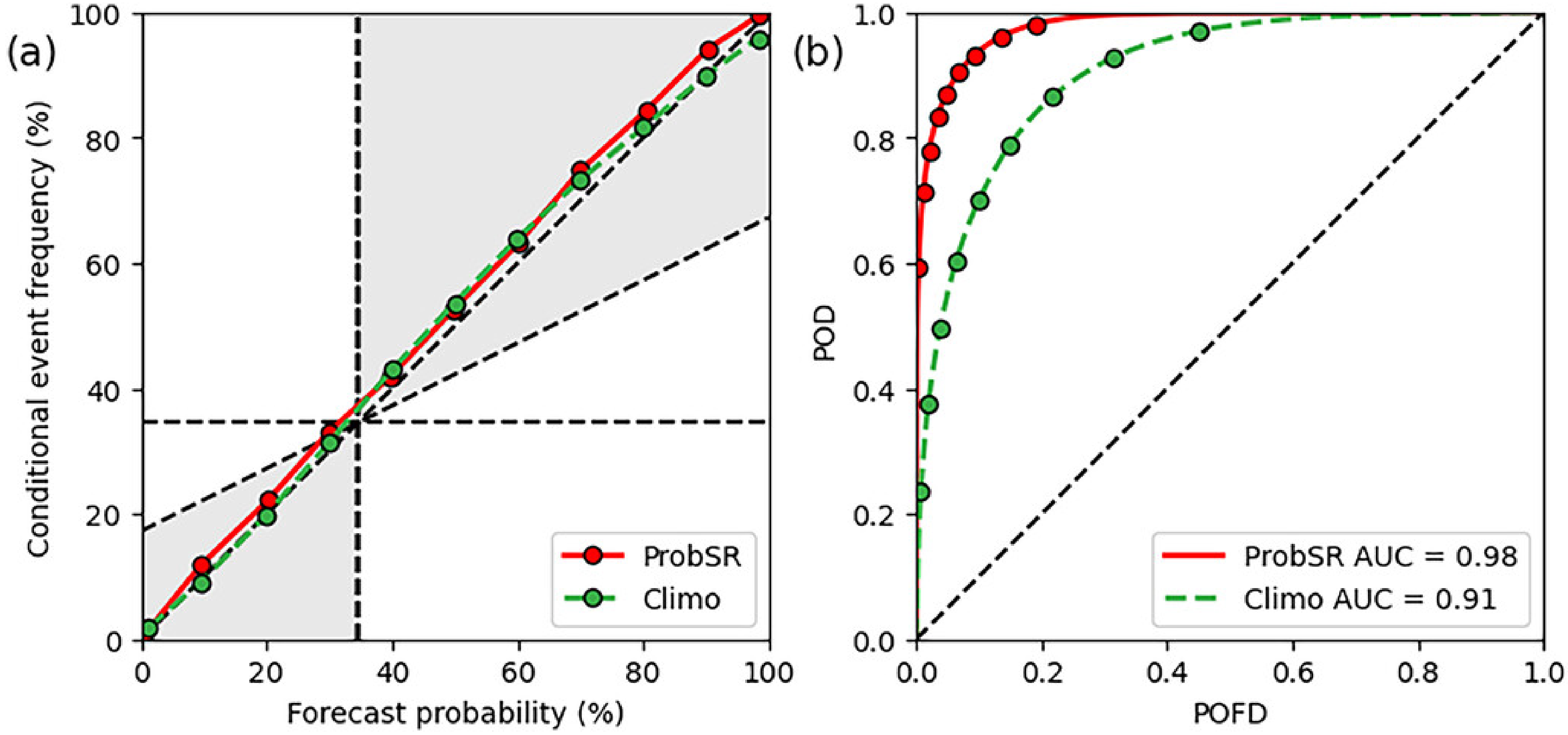
ProbSR - Predictors

Input predictors	Input predictors
Surface temperature (T_{sfc})	2-m temperature (T_2)
Friction velocity	10-m wind speed (gust)
Latent heat flux	Sensible heat flux
Consecutive hours below freezing T_{sfc}	Consecutive hours above freezing T_{sfc}
Consecutive hours below freezing T_{2m}	Consecutive hours above freezing T_{2m}
Downward shortwave radiation flux	Downward longwave radiation flux
2-m dewpoint	Mid–cloud cover percentage
No. of days from 10 Jan	Urban land use/land cover flag

Baldwin et al. (2023)

ProbSR Performance - General

- Probabilities for both Climatology and ProbSR are well-calibrated
- ProbSR has a higher Probability of Detection and lower Probability of False Detection than Climatology
    - ProbSR algorithm statistically performs very well overall
    - You can always improve … where is ProbSR less performant, can we increase its skill?

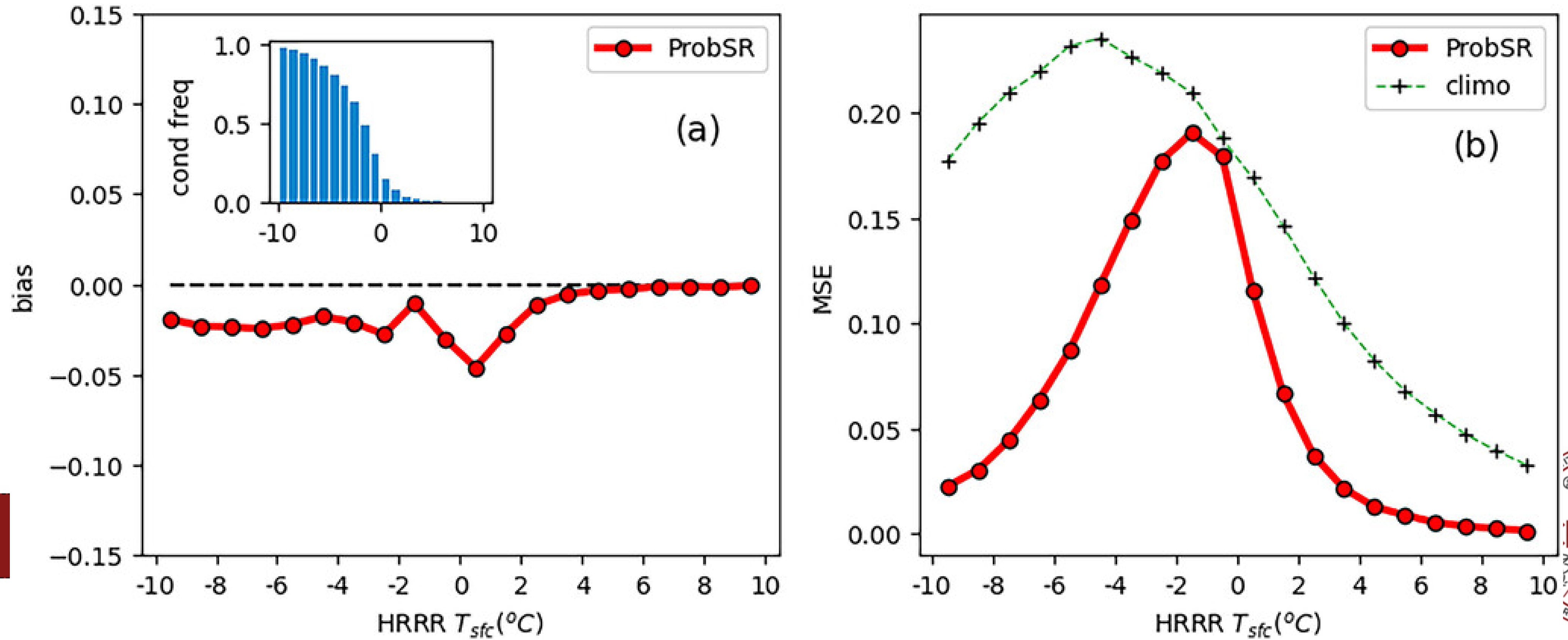


Baldwin et al. (2023)

ProbSR Performance – by Temperature

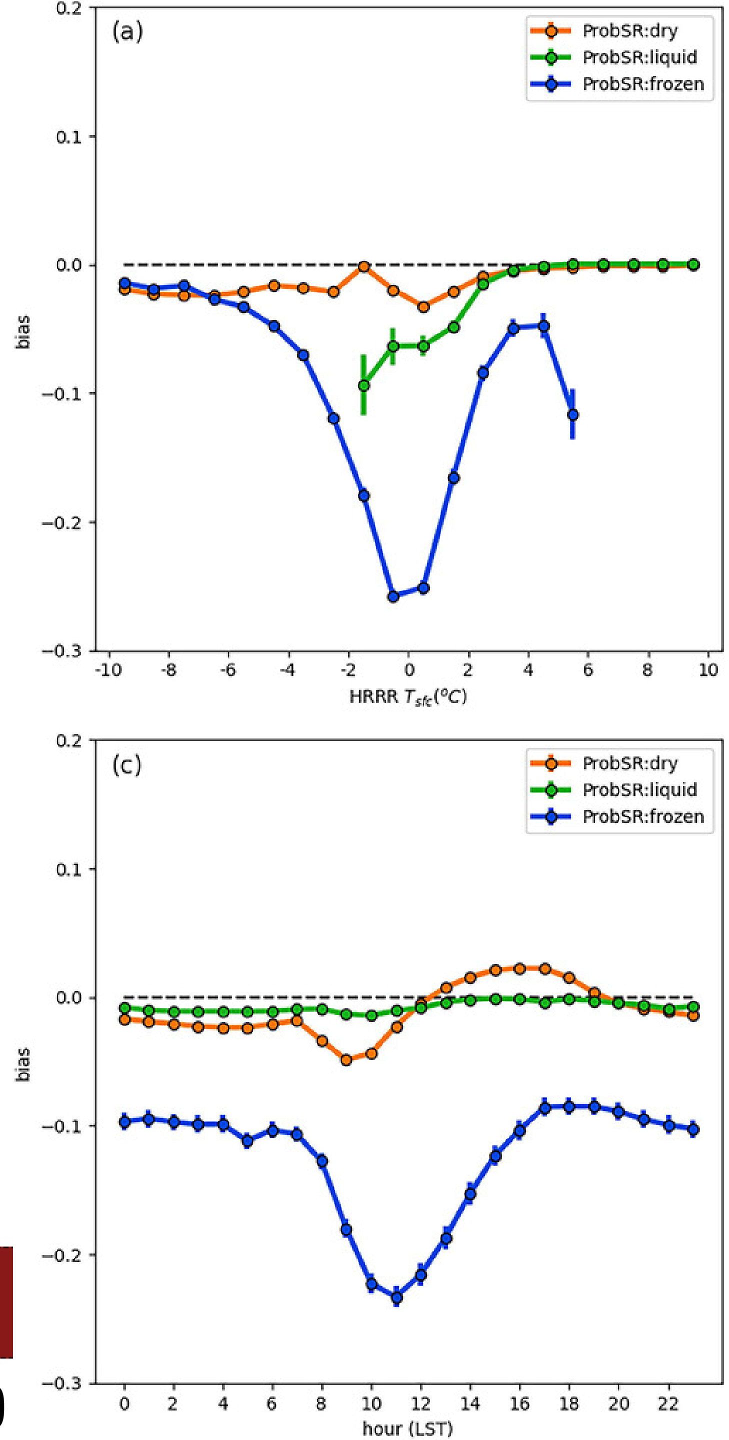
- ProbSR has a warm bias – probabilities too low – below about 2 °C
- ProbSR also is least skillful relative to climatology between -2 °C and 0 °C
  - Always reduces error vs. climatology

Baldwin et al. (2023)



ProbSR Performance - Precip

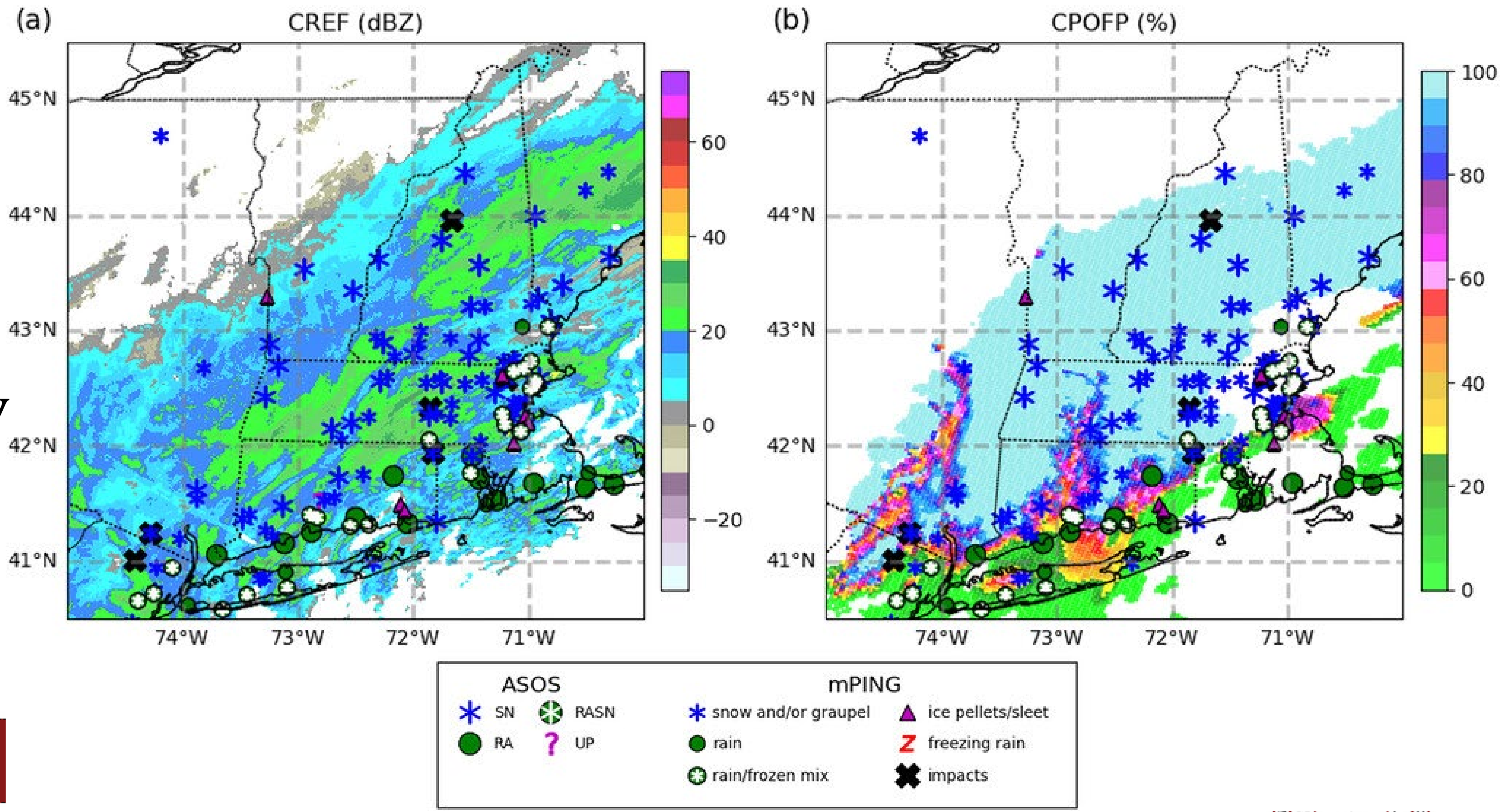
- It turned out that the near-zero bias was most present where frozen precipitation was falling
- Impact is maximized between -2 °C and 2 °C surface temperatures, and between 0900 LST and 1600 LST.



Baldwin et al. (2023)

Case Study - 1800 UTC 23 Jan 2023

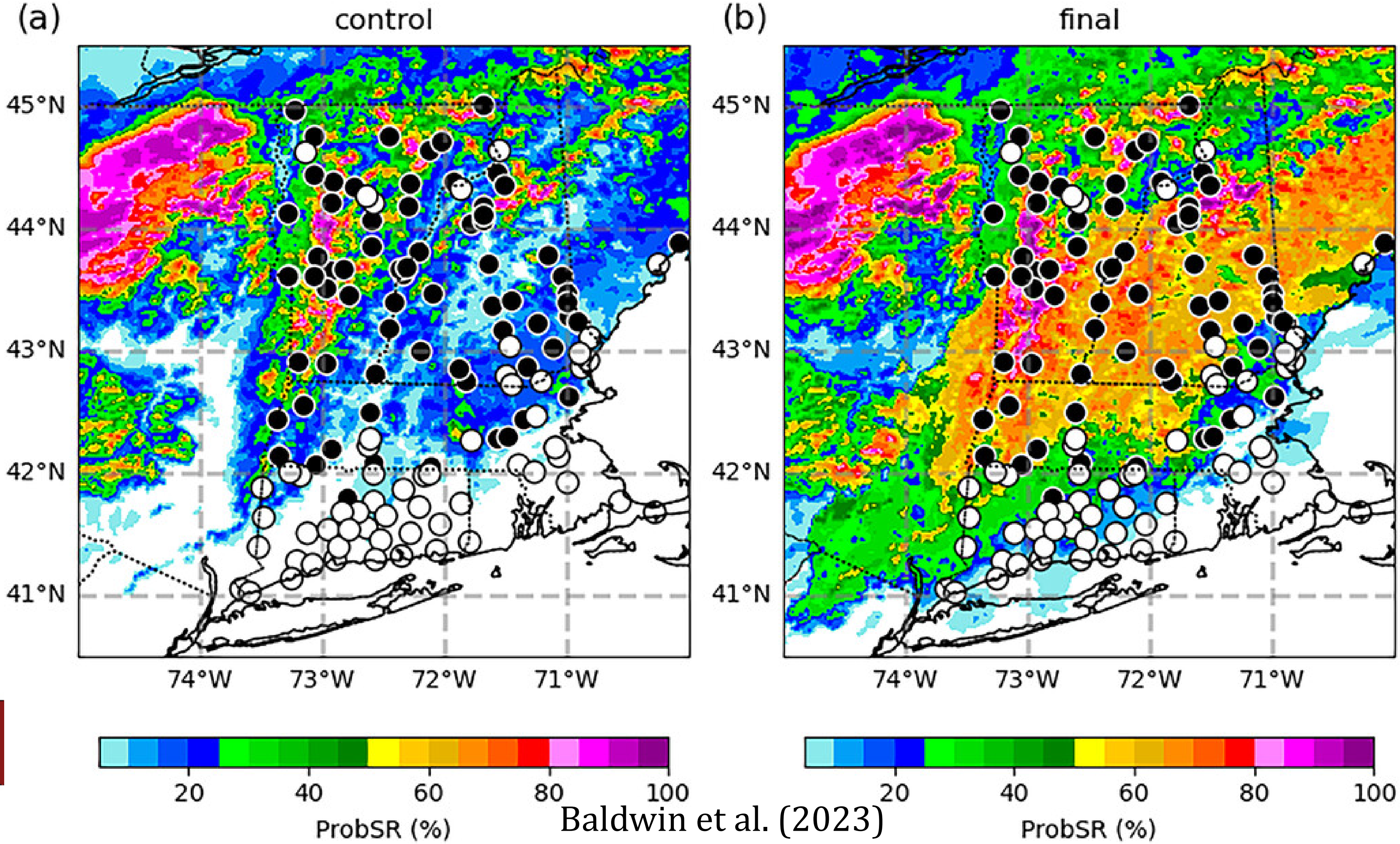
- Snow event across NE
- Rain near coast, snow inland
- HRRR generally captured precipitation type transition well



Baldwin et al. (2023)

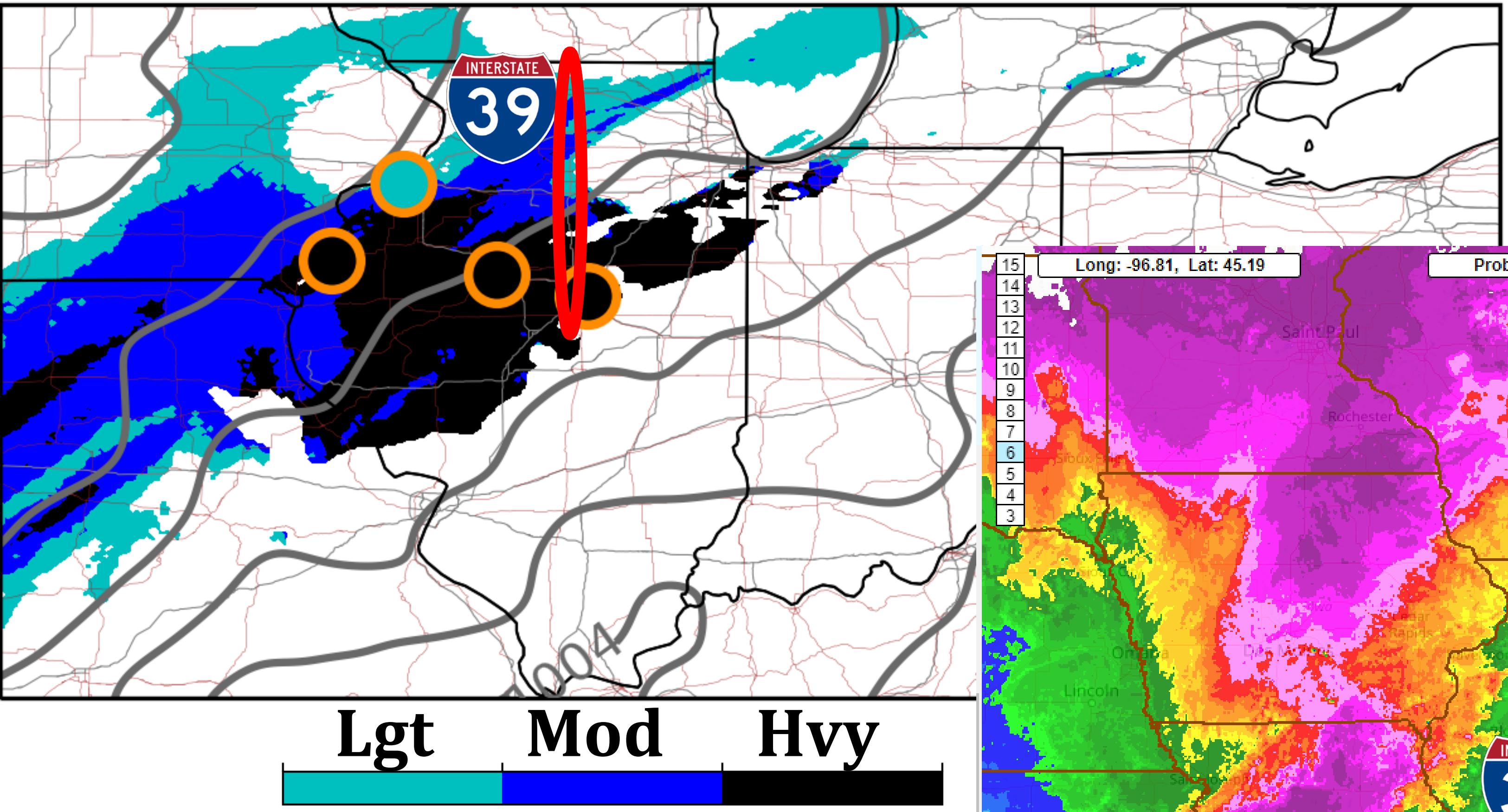
Case Study - 1800 UTC 23 Jan 2023

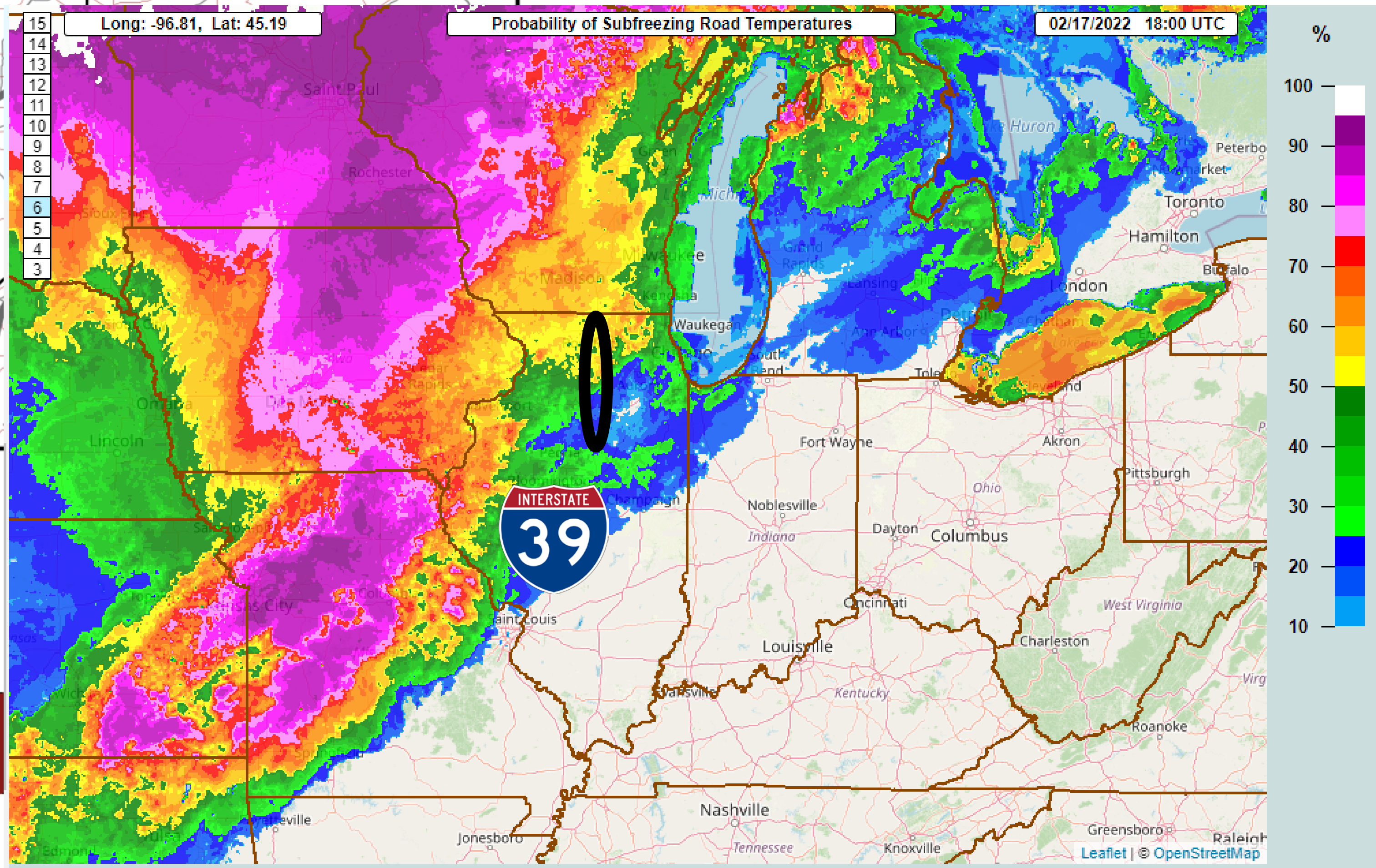
- Control version of ProbSR significantly warmer (lower probabilities)
- Black circles – subfreezing RWIS observations
  - New ProbSR has higher probabilities where subfreezing roads present



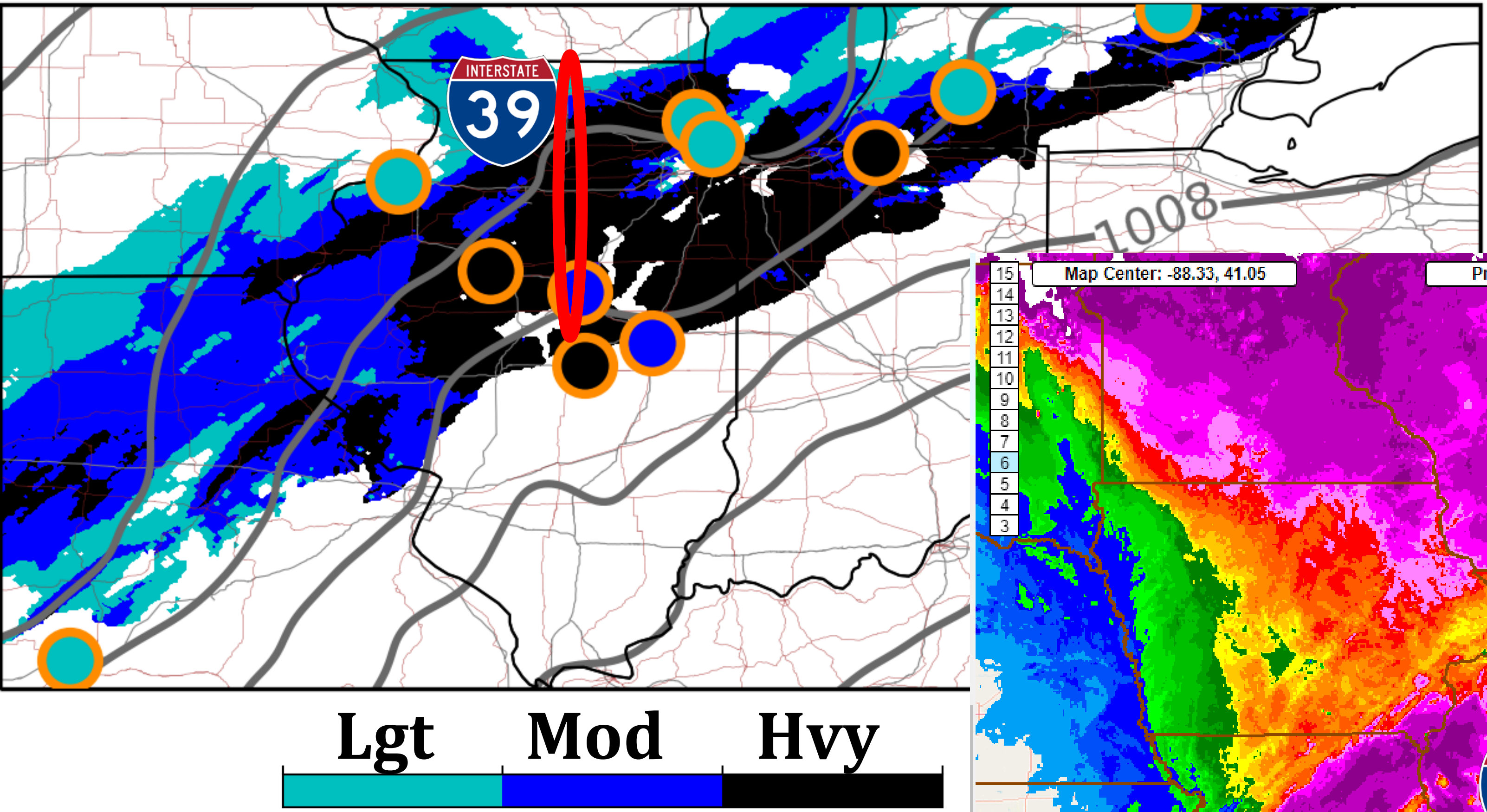
Baldwin et al. (2023)

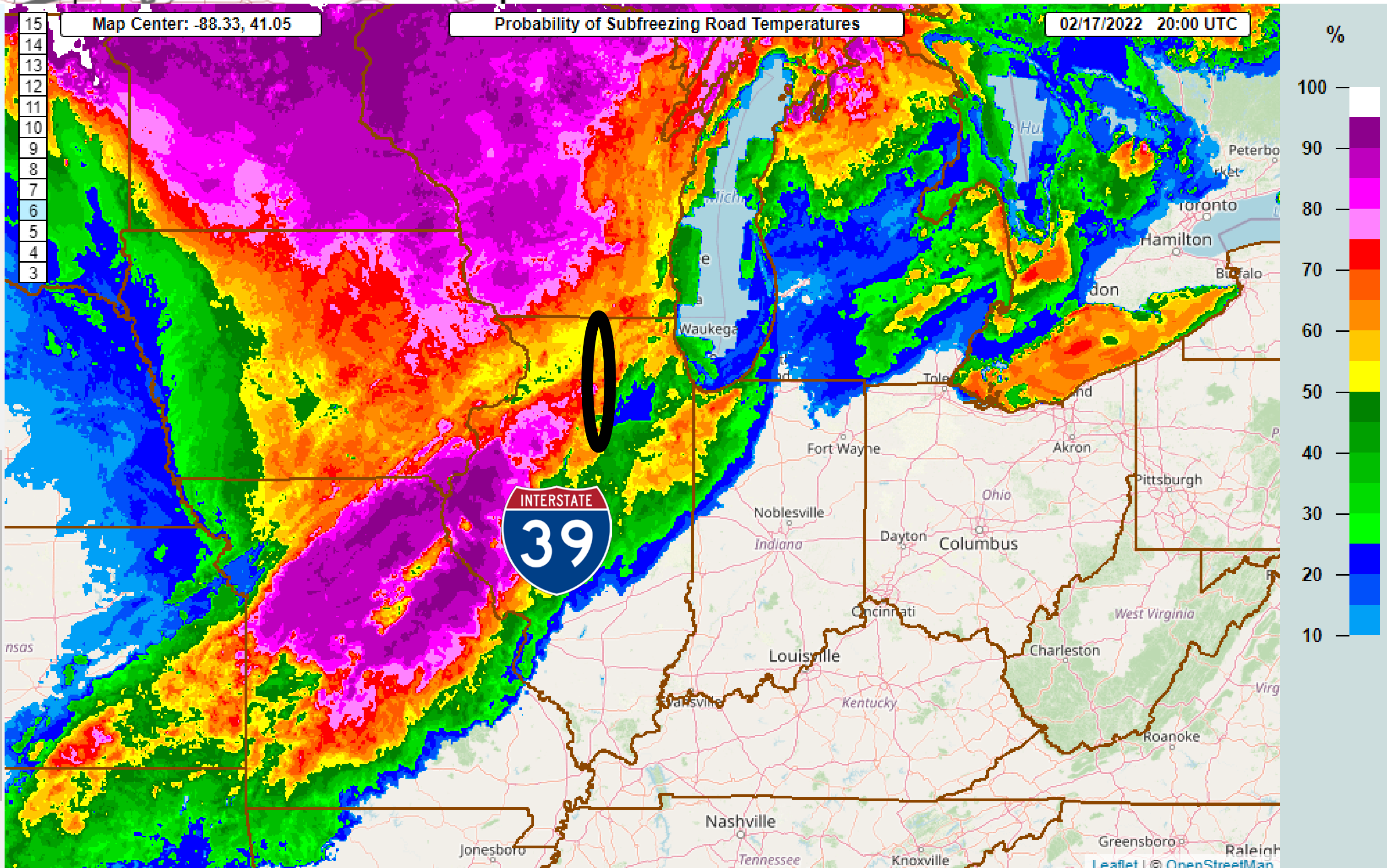
Combining the products – 1800 UTC 17 Feb 2022





Combining the products – 2000 UTC 17 Feb 2022





Before we go…

Two of the products mentioned here are available on our experimental MRMS web viewer! (To access, you be using a NOAA IP address)

https://mrms-dev.nssl.noaa.gov/qvs/vmrms/viewer/

Under "Transportation":

- Spectral Bin Classifier (SBC) Precipitation Type Analysis
- ProbSR (road prob) – Probability of Subfreezing Roads Analysis
  - Also available via LDM

Questions? Issues? Comments?

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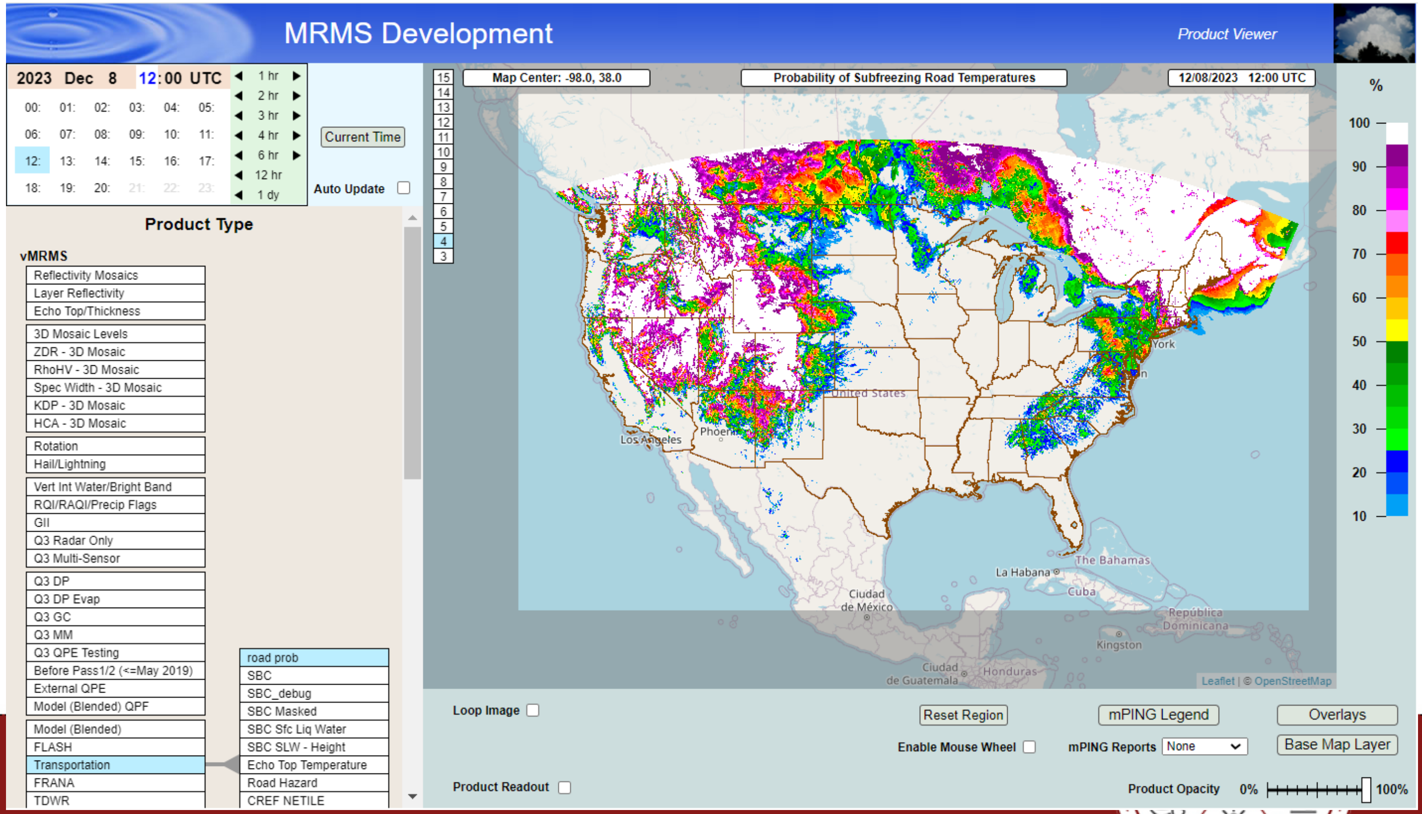

Closing Thoughts

Email: andrew.rosenow@noaa.gov

- Radar-derived extinction outperforms reflectivity to diagnose snow intensity with simple, prescribed parameters
  - Could use underlying visibility analysis instead of snow intensity
- How you verify impacts what parameters give you the “best” performance
  - Largest # of observations vs. heaviest observations (metrics vs. impacts)
- ProbSR had reduced performance with frozen precipitation falling; including HRRR frozen precipitation in the learn set improved performance

Future work:

- Verify snow intensity using larger off-hour dataset
- How well does snow intensity work with AWOS?
- Can meteorological parameters (moisture, distance from radar, etc.) be used to improve derived visibilities?
- Use technique for FAA-mandated Snow Intensities -> Deicing Holdover Times (AMS 2024!)
- Combine ProbSR and snow rate to address snow accumulation

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