# 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

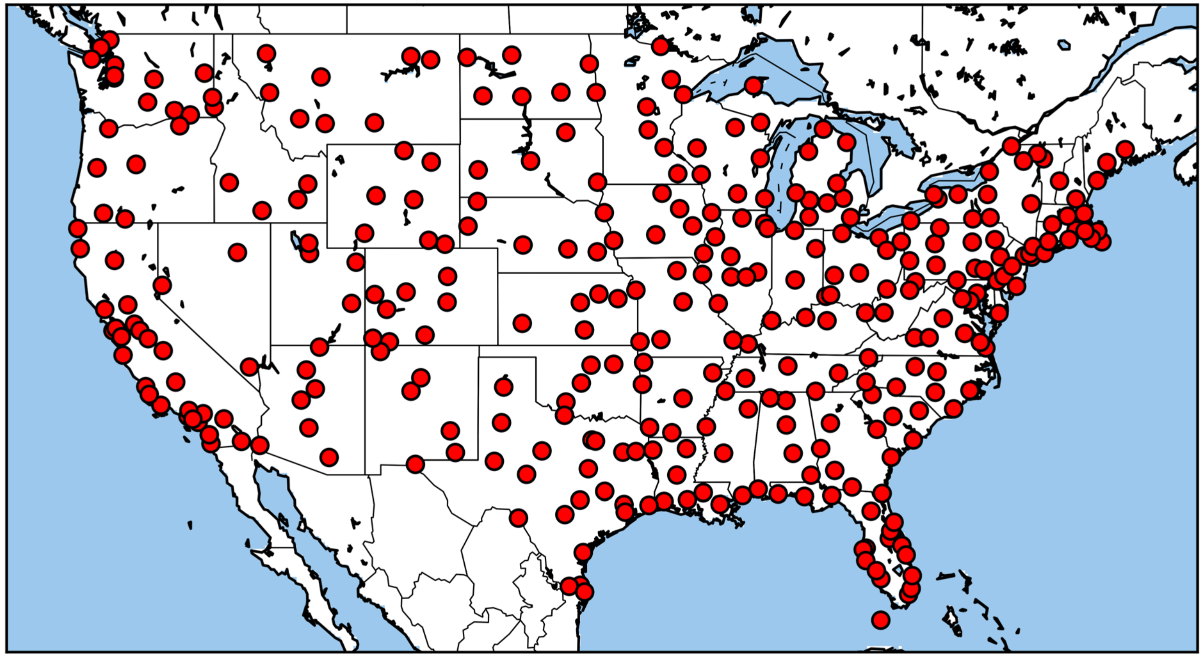
- Real-time snow rate is a parameter of interest
  - Better information would benefit both forecasting and decision support
- Fundamental problem: snow rate isn't observed at adequate spatial/temporal resolutions

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 $\boldsymbol{\varepsilon}$ 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 ($\sigma_e$)
- Solving for extinction as a function of precipitation rate:

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

- To simplify, we're going to use typical values for $\mu$ (PSD shape parameter); $\alpha_o$ 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] ($\mu$=0 for an exponential distribution, and $\alpha_o$ = 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 | **3150** | 78 | 15 |
| Moderate | 2470 | **469** | 78 |
| Heavy | 231 | 217 | **126** |

**Low**
**GSS = 0.48**

| **High** | Light | Moderate | Heavy |
|---|---|---|---|
| Light | **4953** | 304 | 37 |
| Moderate | 863 | **432** | 147 |
| Heavy | 35 | 28 | **35** |

**High**
**GSS = 0.33**

| **Reflectivity** | Light | Moderate | Heavy |
|---|---|---|---|
| Light | **3802** | 207 | 45 |
| Moderate | 1604 | **373** | 81 |
| Heavy | 445 | 184 | **93** |

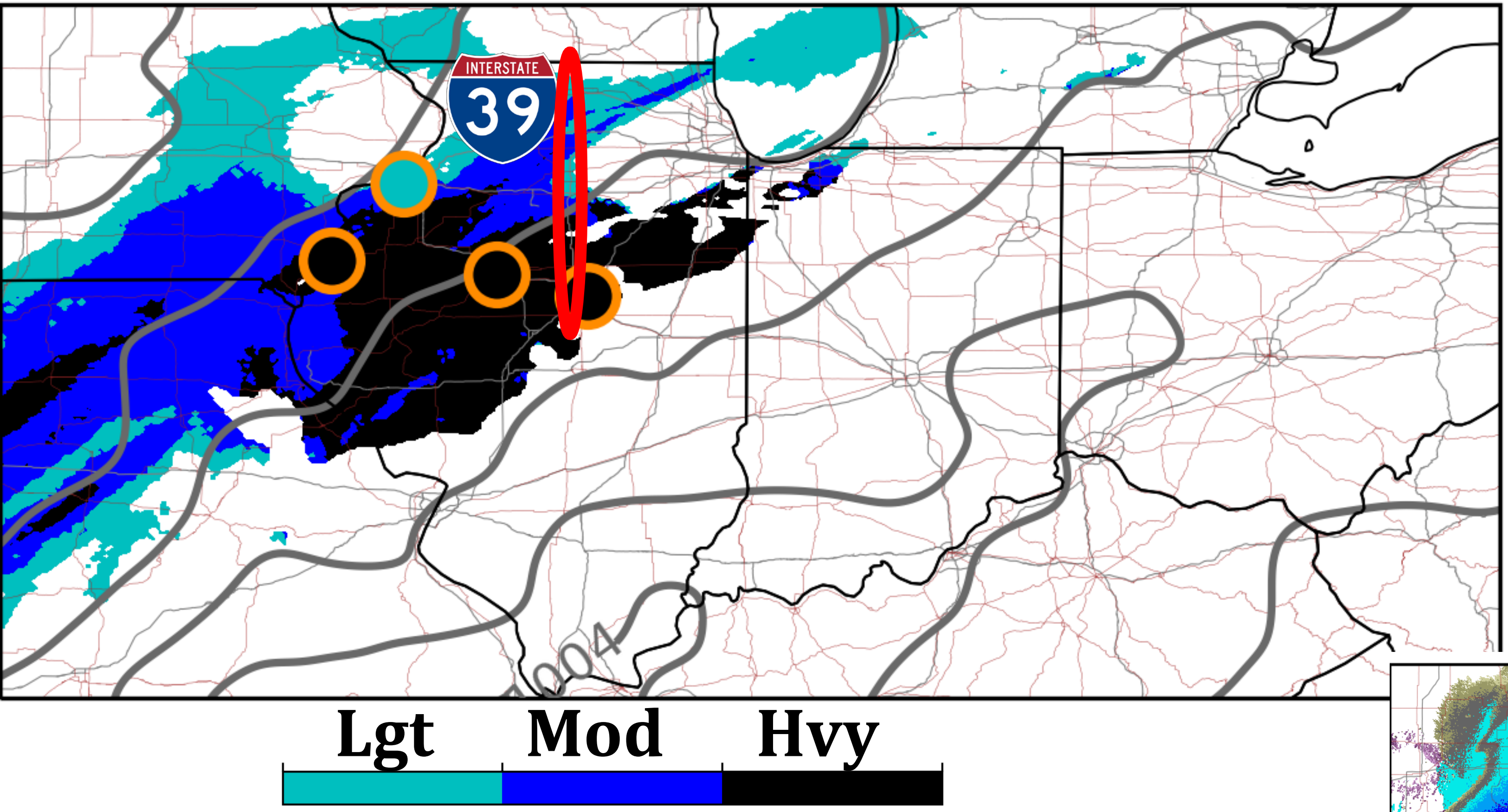
**Reflectivity**
**GSS = 0.36**

# 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

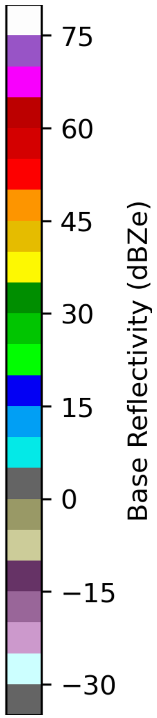
Image credit: *Brandon Rixstine/ WGLT*

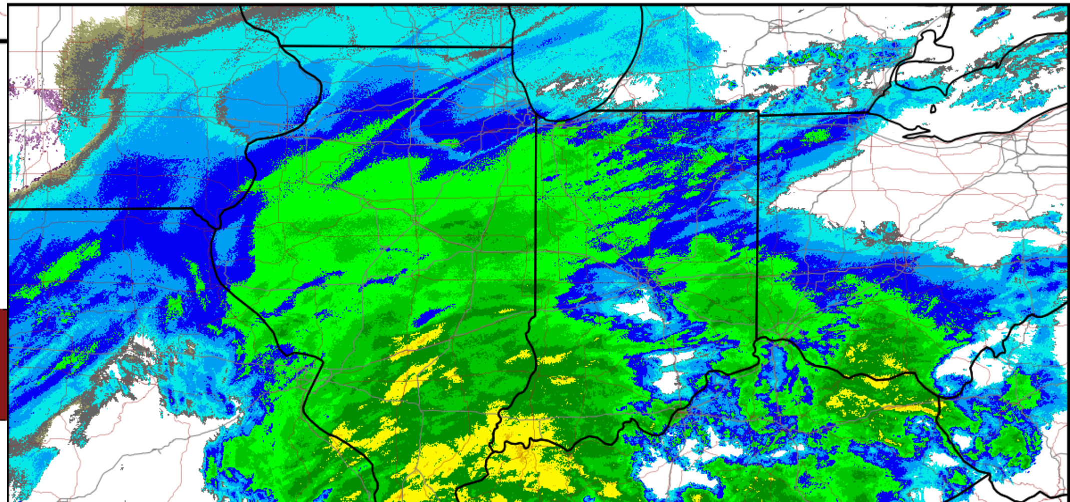
# Snow Intensity Analysis – 1800 UTC



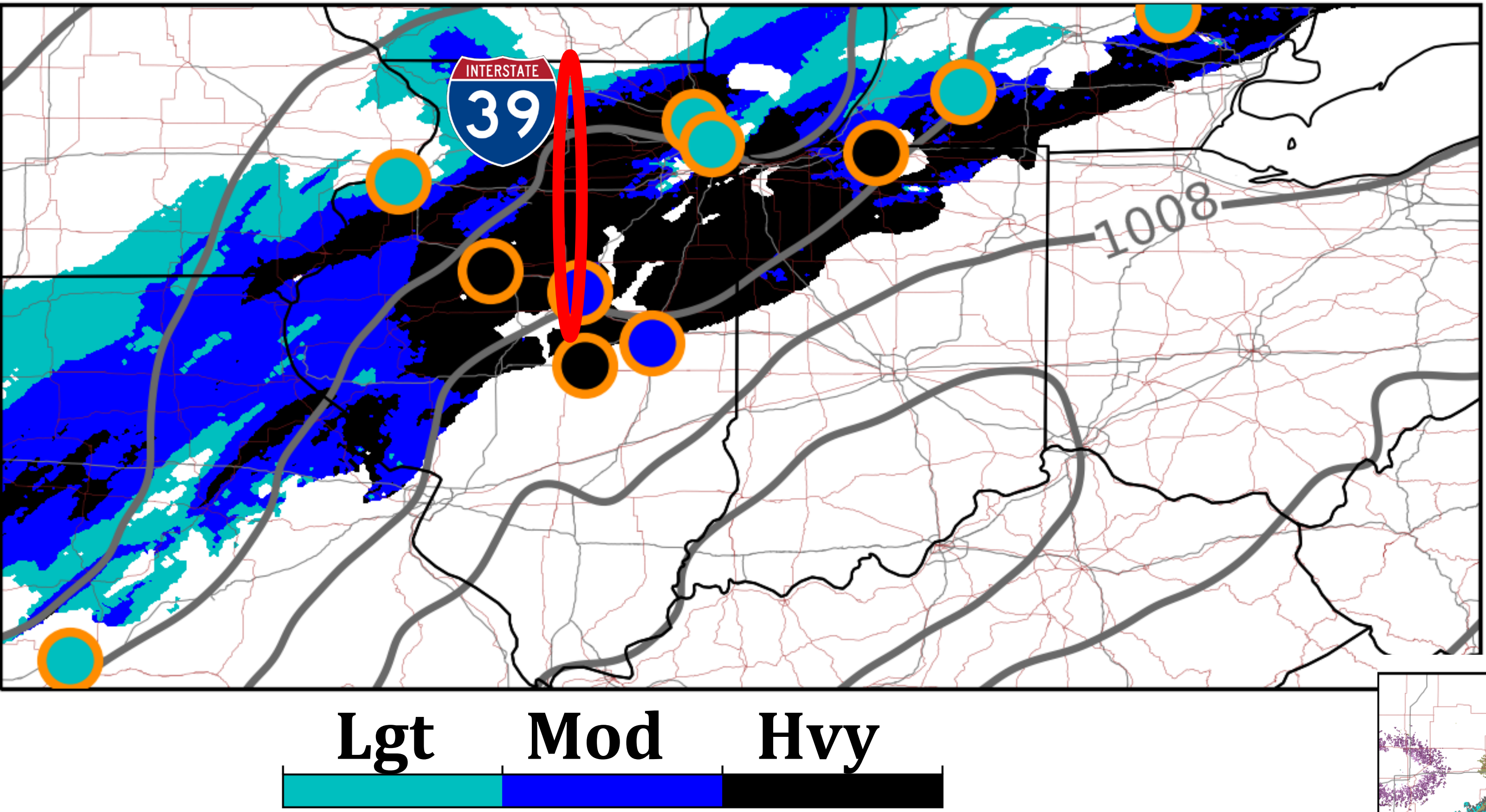

Orange circles – All ASOS sites reporting snow

- Snow arriving from the SW has sharp intensity gradient



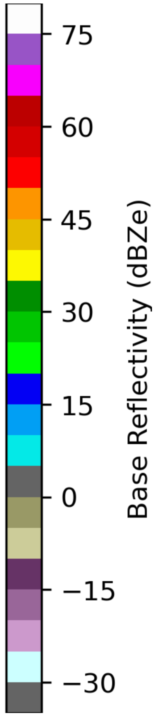



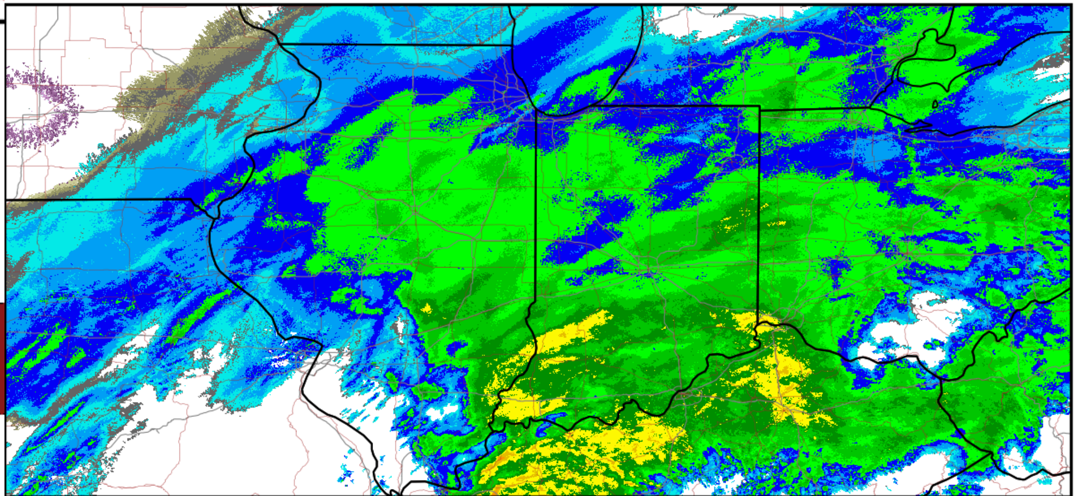
# Snow Intensity Analysis – 2000 UTC




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*

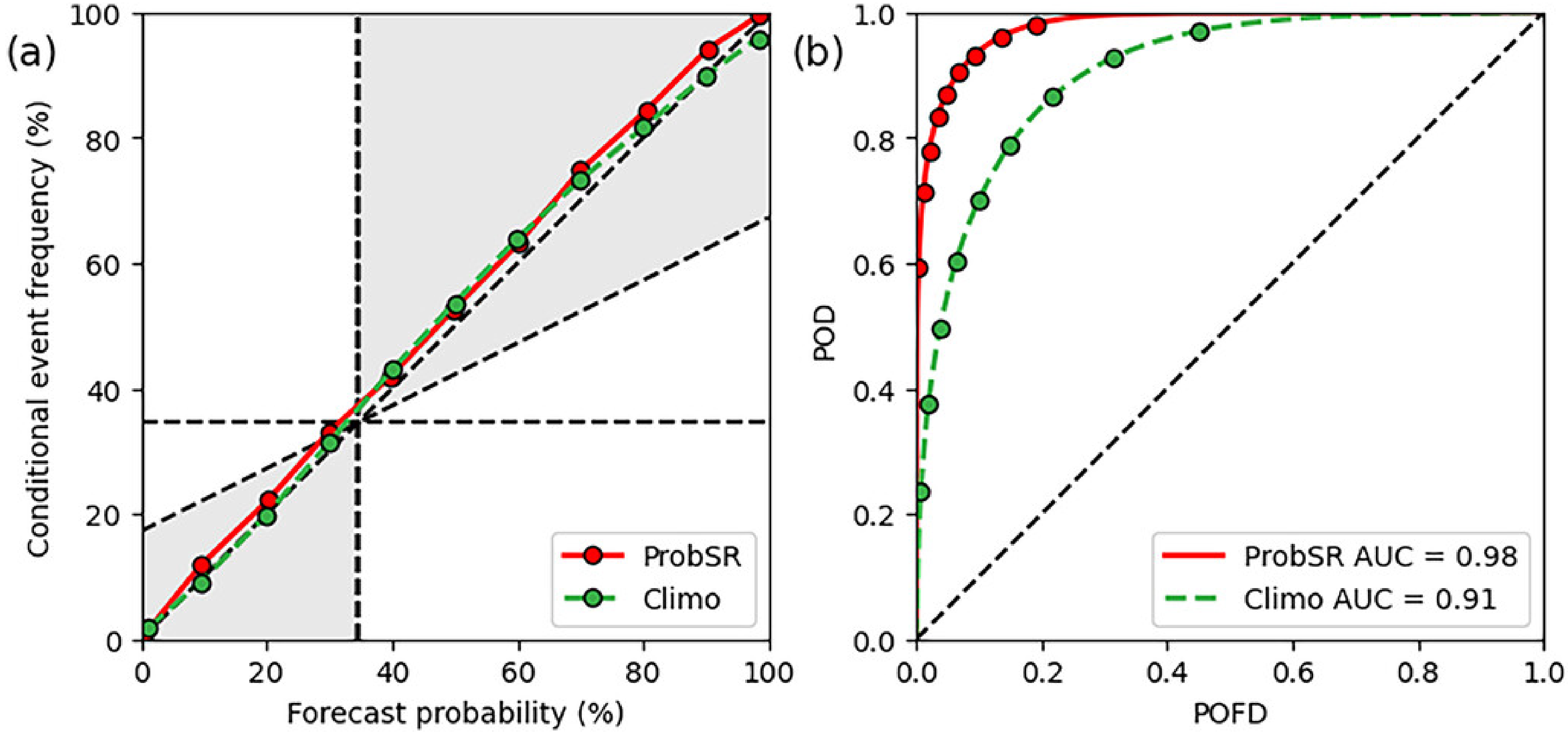
# ProbSR - Predictors

| 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?

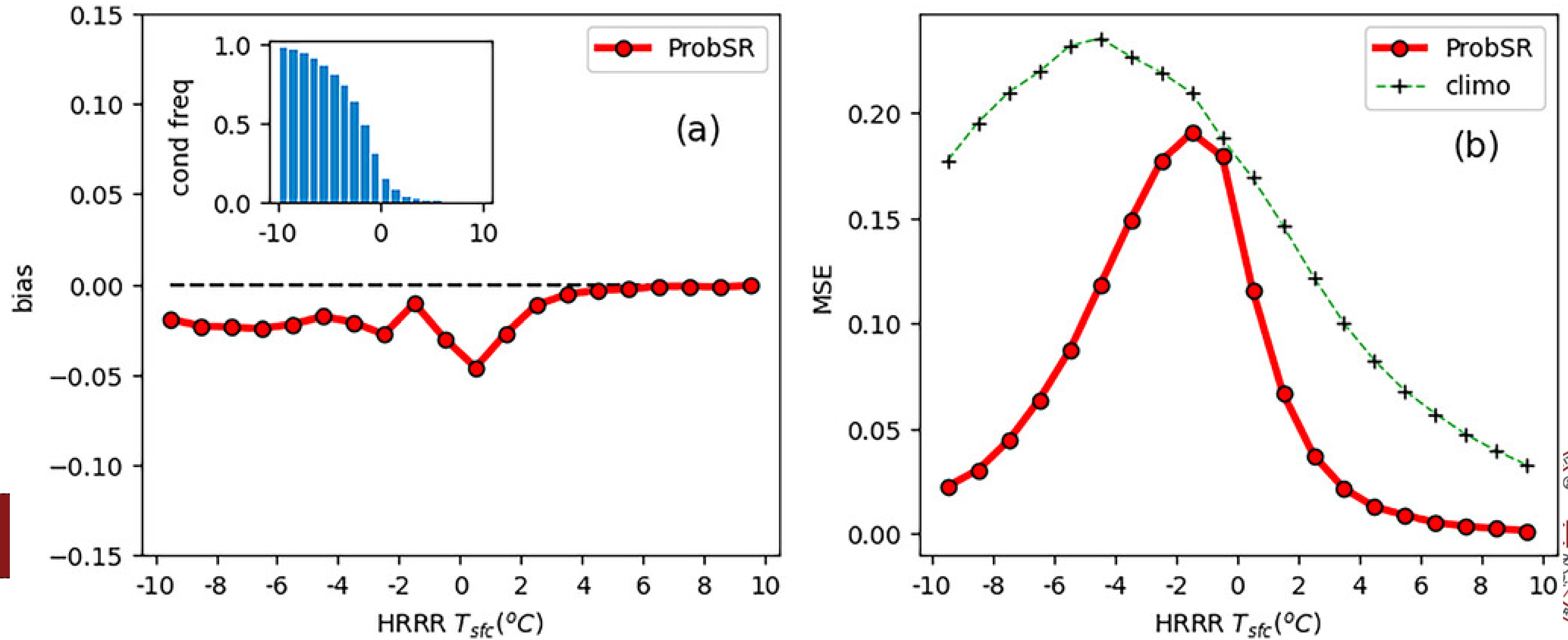



Baldwin et al. (2023)

# ProbSR Performance – by Temperature

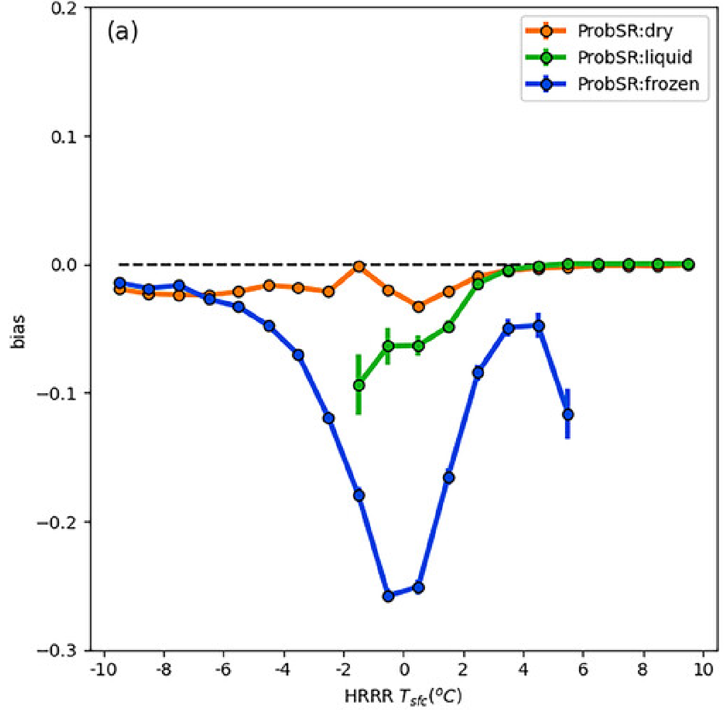
- ProbSR has a warm bias – probabilities too low – below about 2 °C
- ProbSR also is least skillful relative to climatology between -2 °C and 0 °C
  - Always reduces error vs. climatology

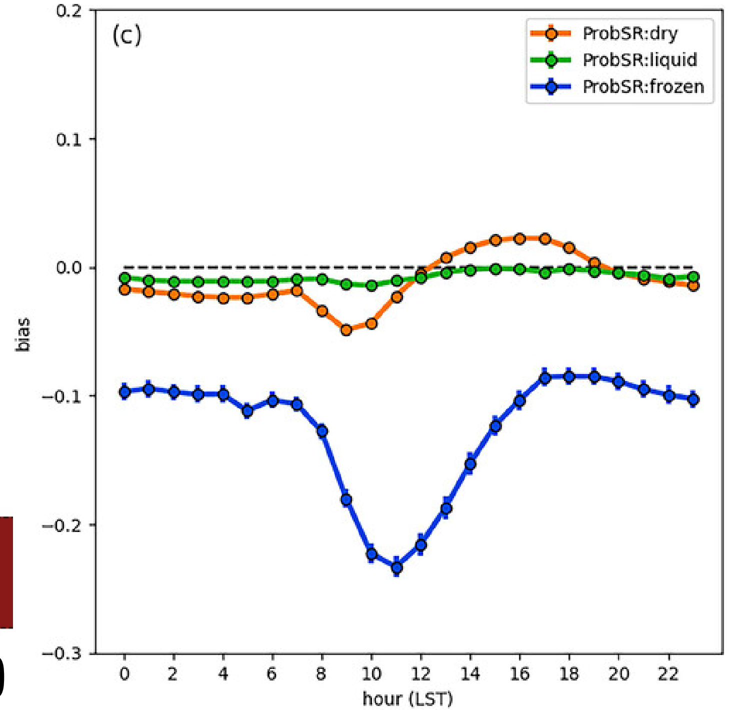
Baldwin et al. (2023)



# 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.

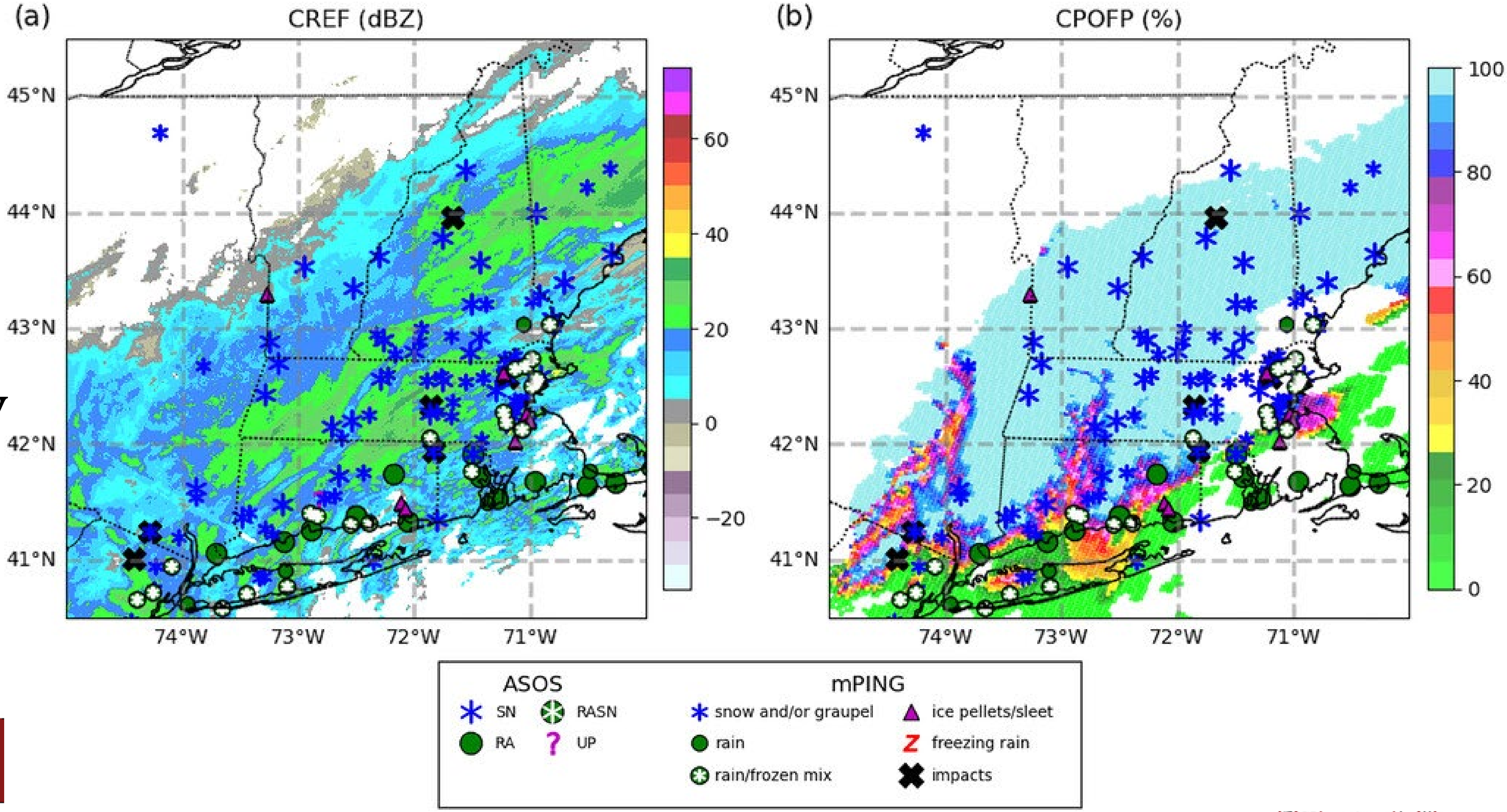



Baldwin et al. (2023)

# Case Study - 1800 UTC 23 Jan 2023

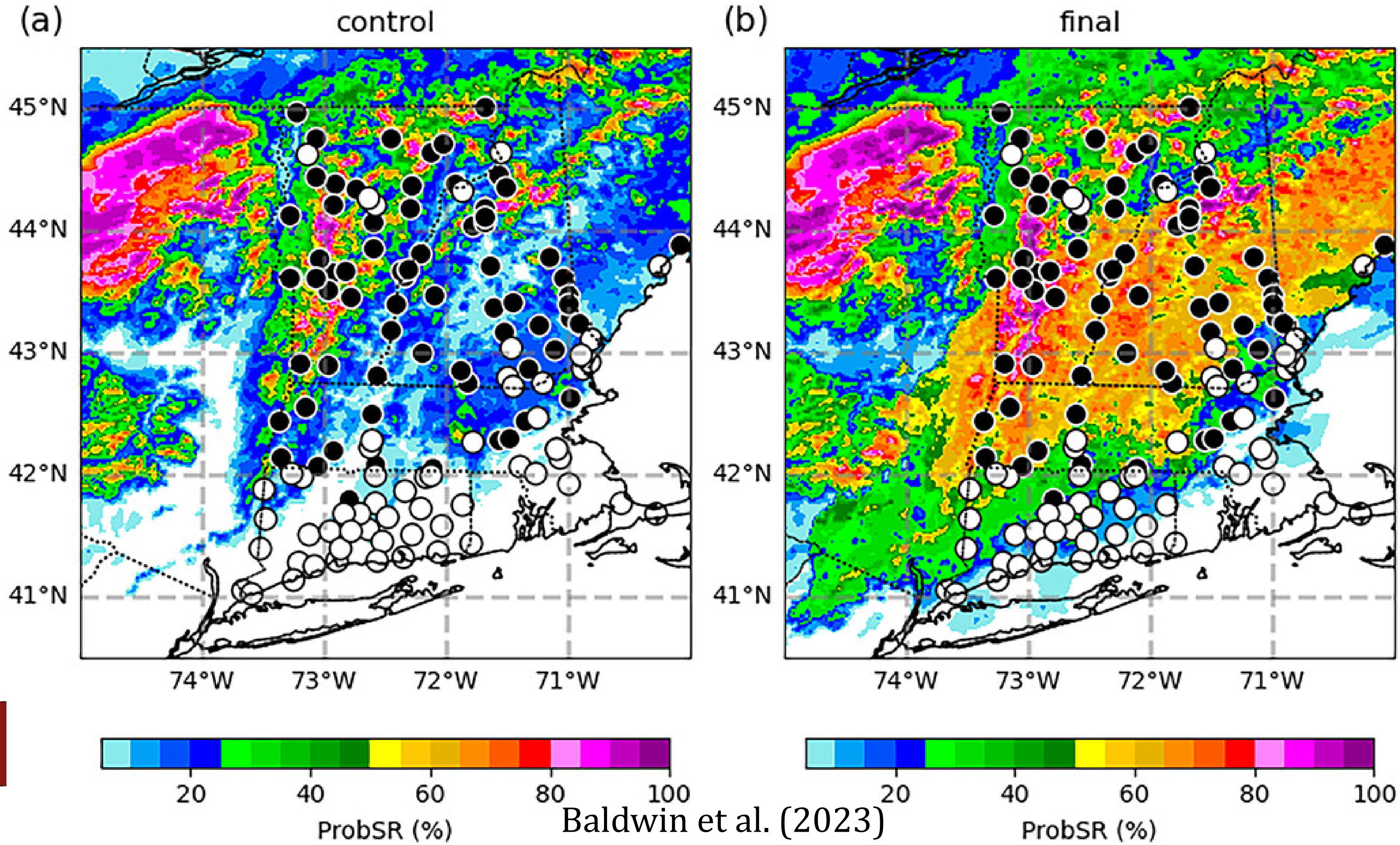
- Snow event across NE
- Rain near coast, snow inland
- HRRR generally captured precipitation type transition well




Baldwin et al. (2023)

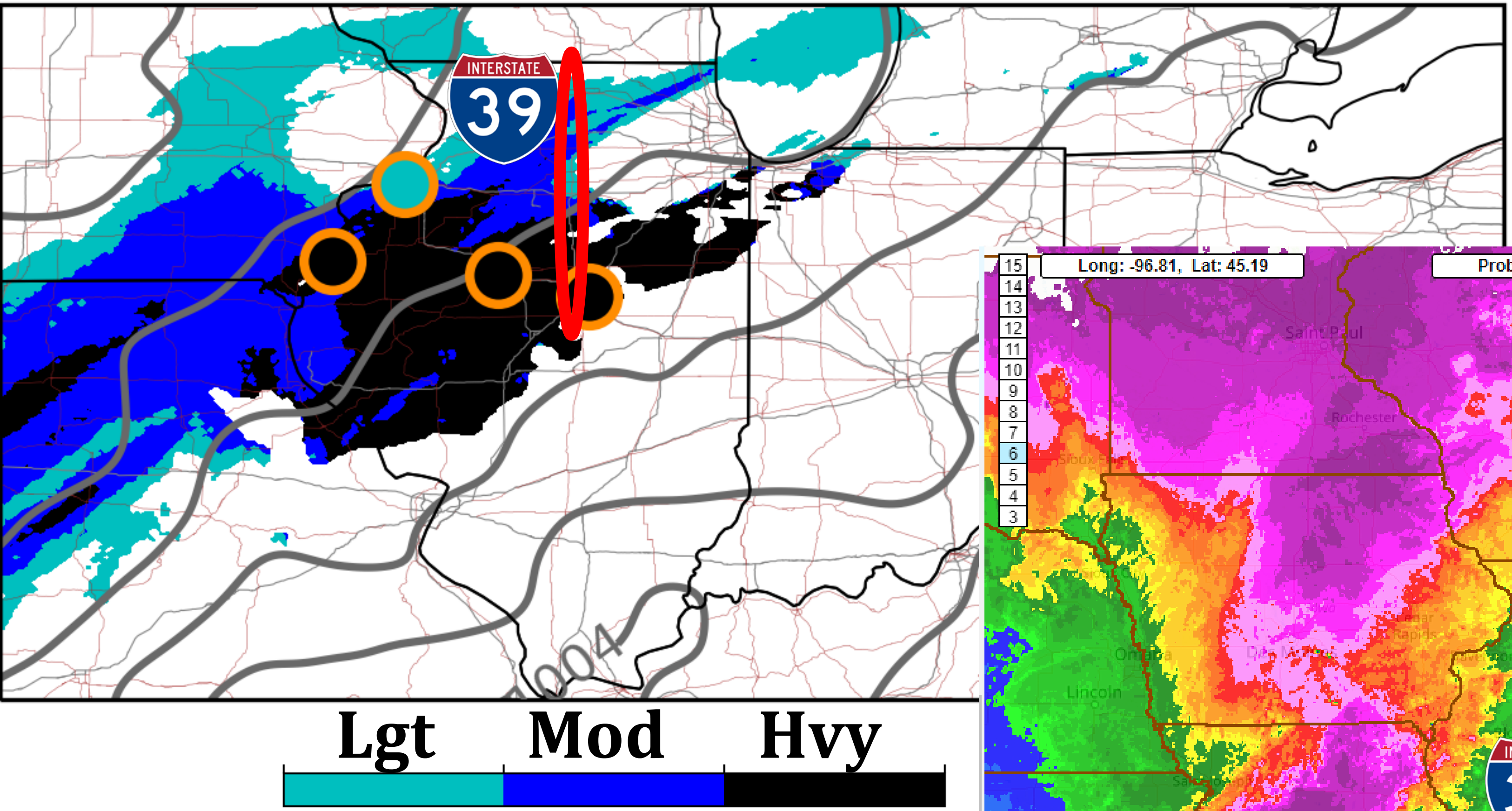
# Case Study - 1800 UTC 23 Jan 2023

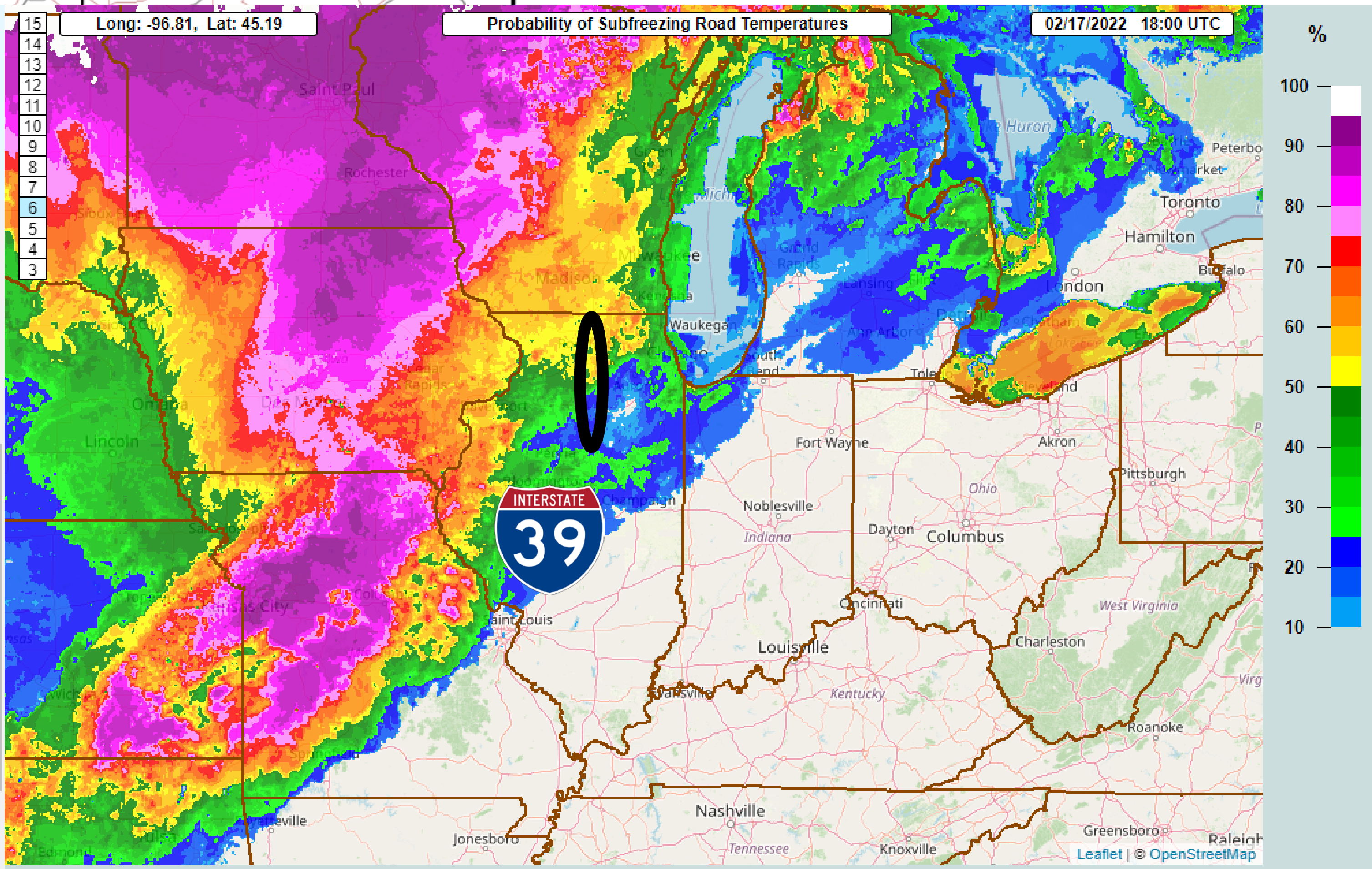
- Control version of ProbSR significantly warmer (lower probabilities)
- Black circles – subfreezing RWIS observations
    - New ProbSR has higher probabilities where subfreezing roads present



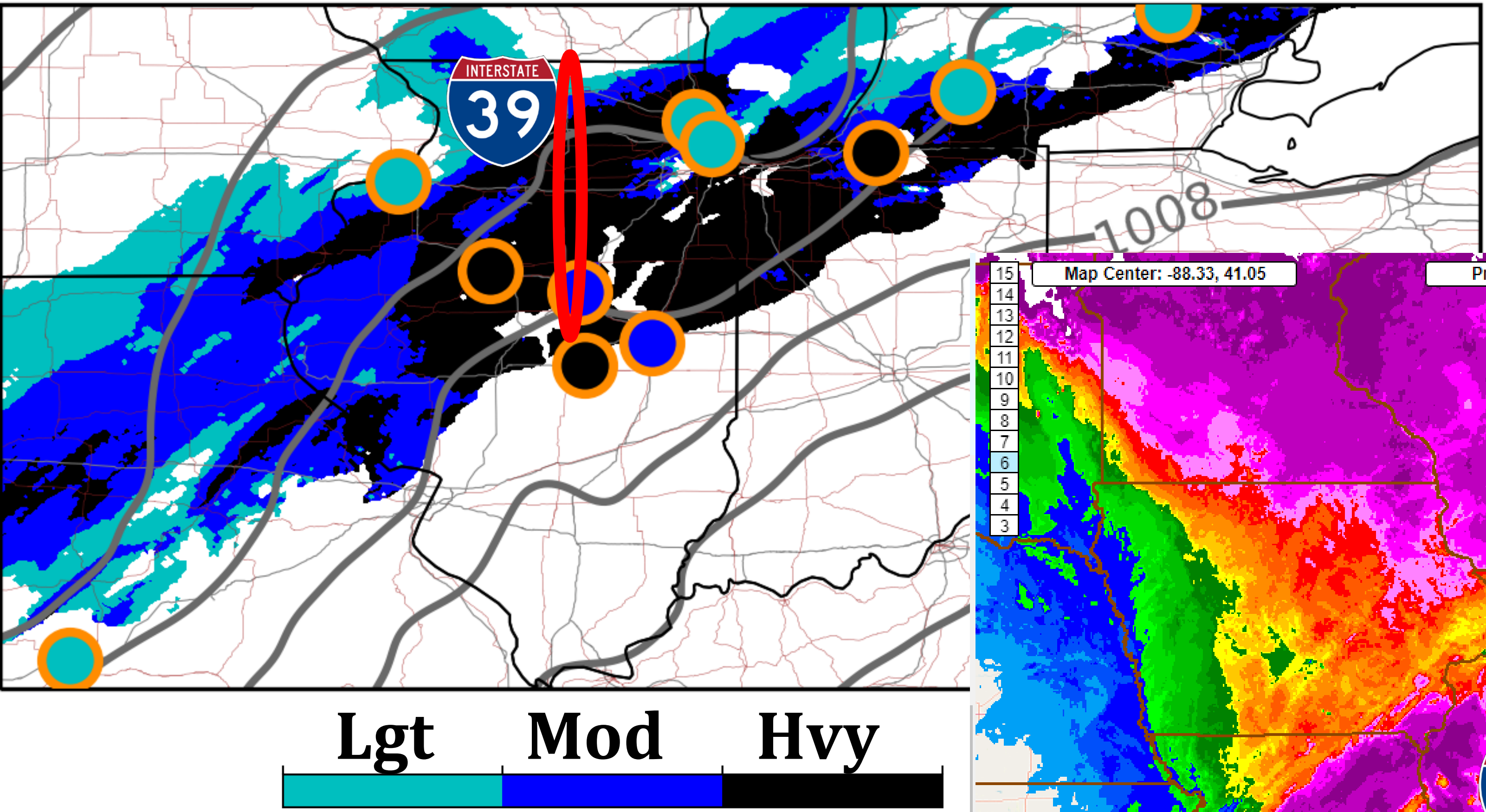

Baldwin et al. (2023)

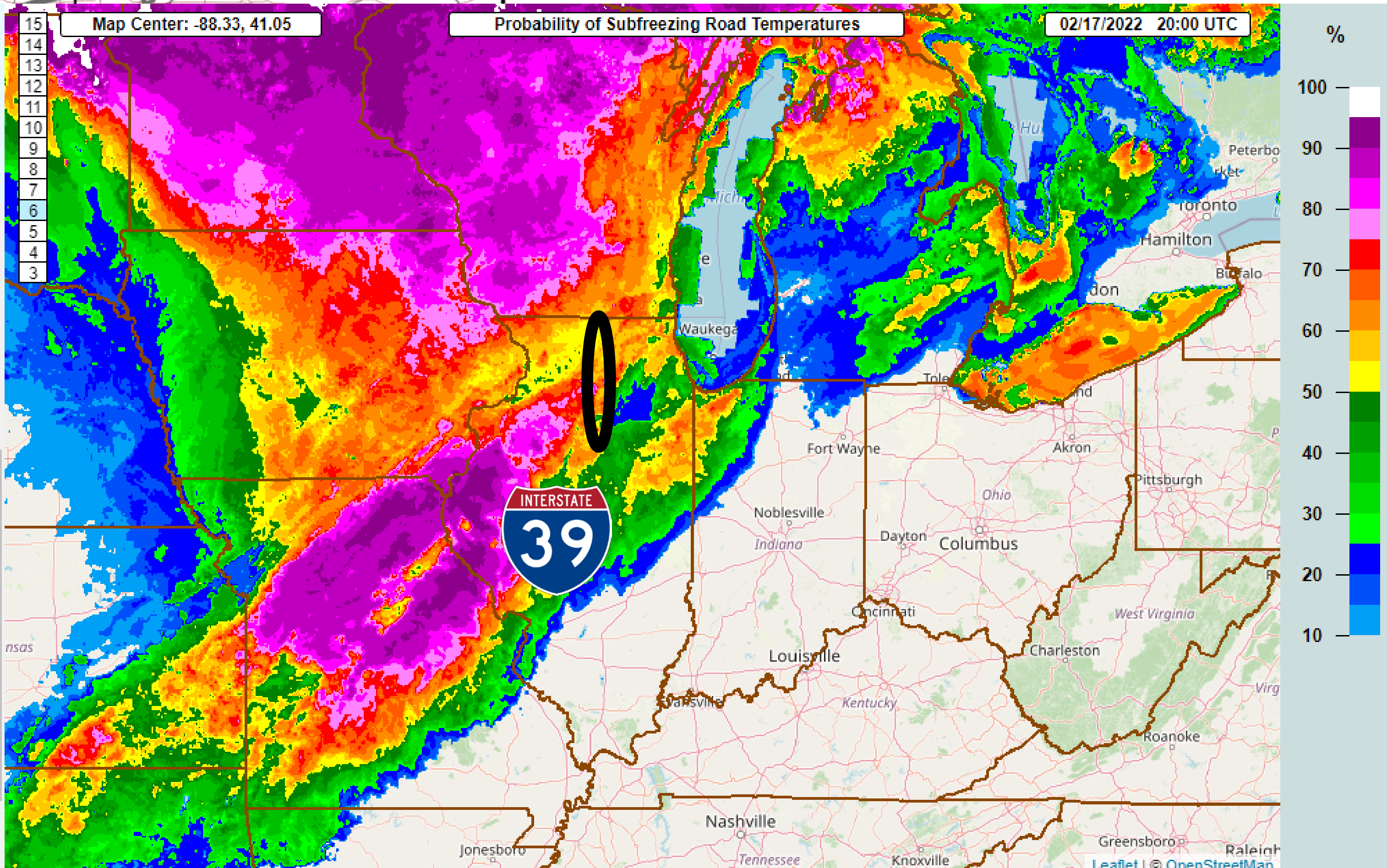
# Combining the products – 1800 UTC 17 Feb 2022



# Combining the products – 2000 UTC 17 Feb 2022



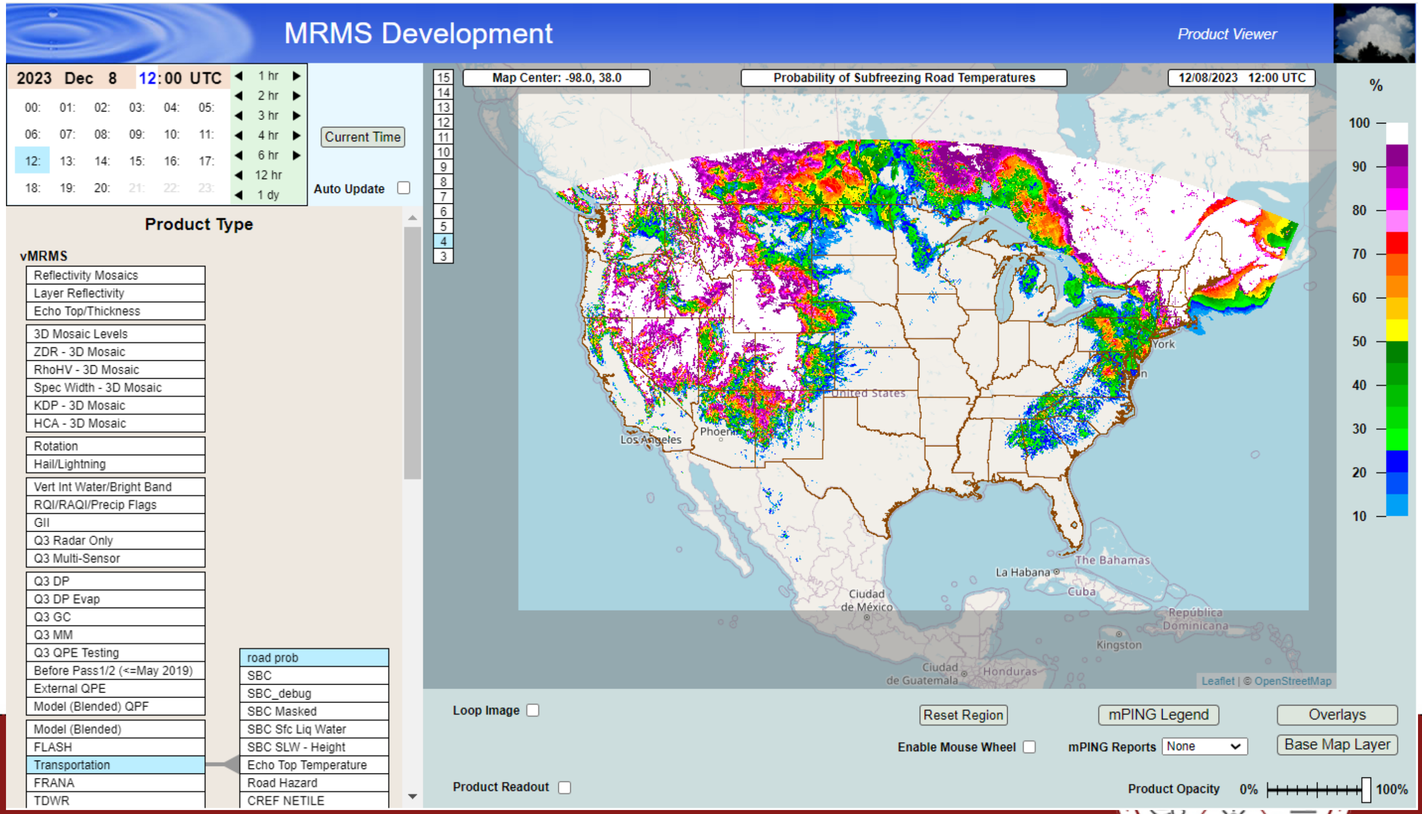
# Before we go…

**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

- 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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