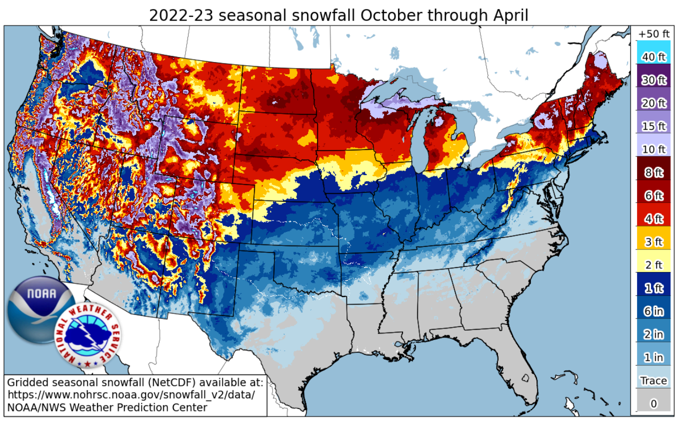
13th Annual Winter Weather Experiment: Findings and Results



15 November 2022 - 15 March 2023
Weather Prediction Center
Hydrometeorological Testbed

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Table of Contents

1. Introduction **3**

2. Science and Operations Objectives **3**

3. Experiment Findings and Results **4**

3.1 Review of the 2022-23 season 4

3.2 Seasonal verification 7

3.3 LANTERNs 8

3.3.1 Case Evaluations 11

a. Lake Effect Snow Events 11

b. Western Snow Events 11

c. Midwest Snow events 13

d. Northeastern Snow Events 15

4. Summarized Themes **16**

5. Other WWE Activities **18**

5.1 Seminar Series 18

5.2 Spectral Bin Classifier Focus Groups 19

6. Acknowledgements **20**

Appendix A: NBMv4.1 Deterministic Snow Weighting **20**

1. Introduction

In support of the ongoing mission to improve National Weather Service (NWS) products and services for winter weather, the Hydrometeorology Testbed (HMT) within the Weather Prediction Center (WPC) conducted the 13th annual Winter Weather Experiment (WWE) during the 2022-2023 winter season. The WWE provides collaborative research to operations (R2O) experience bringing together members of the forecasting, research, and academic communities to evaluate and discuss winter weather forecast challenges. This year's WWE was unique in leveraging the NWS LANTERN program to allow field personnel to lead evaluations of the National Blend of Models (NBM) case studies. WWE also hosted a series of focus groups for a new precipitation type algorithm. Recent WWE successes include improvements to the NBM, incorporation of snowsqualls to the mPING crowd-sourcing data app, and increased discussion on the creation of winter specific verification metrics. Building on the success of previous years, the WWE was once again fully remote where retrospective case studies were utilized to examine the experiment objectives. The WWE also hosted invited presentations throughout the entire WWE season.

2. Science and Operations Objectives

The main objective of the every WWE is to provide feedback to model guidance developers, and Principal Investigators of funded projects related to winter weather forecast challenges. As new guidance and tools are developed, we work together across operations and research to make improvements that benefit the science and communication of hazards for winter weather.

The initial goals of the 13th Annual Winter Weather Experiment were:

- Evaluate the utility of operational and experimental high resolution convective-allowing deterministic and ensemble models (CAM), via objective and subjective evaluations focusing on:
    - Lake effect snow forecasting upgrades,
    - Hourly Precipitation type,
    - Snow accumulation, snow rates and timing,
    - Evaluate Snow to liquid ratios,
- Evaluate the utility of the NBMv4.1 probabilistic and deterministic snow amounts, p-type, and its strengths and weaknesses for use in operations,
- Evaluate the impact of the WPC QPF using the NBM POWT and SLR (with and without reduction),
- Discuss relevant operational challenges, through our LANTERN volunteers, and how the ensembles and deterministic models can be applied.

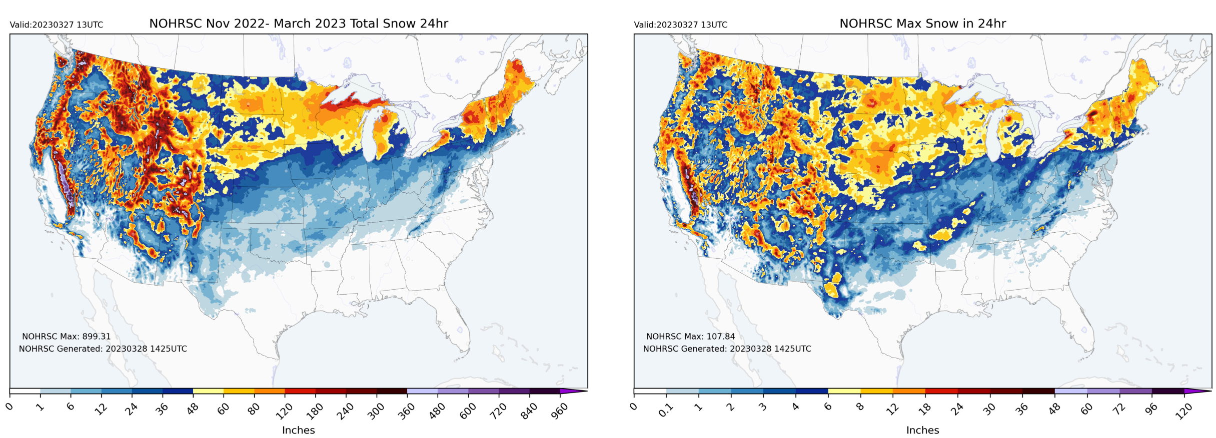
However, due to HMT staffing changes and unavailability of CAM data the WWE had to refocus its objectives. The updated objectives for the 13th WWE were:

- Evaluate the utility of the NBMv4.1 probabilistic and deterministic snow amounts, p-type, and its strengths and weaknesses for use in operations,
- Discuss relevant operational challenges, through our LANTERN volunteers, and how the ensembles and deterministic models can be applied.

3. Experiment Findings and Results

3.1 Review of the 2022-23 season

The WWE began collecting case studies around 15 November, thus a brief summary of the November through March snowfall and the season's characteristics is shown in Figure 1; for simplicity, 1-4" snowfall events will be referred to as low end and events with 8"+ will be called high end. According to observations from the National Operational Hydrologic Remote Sensing Center version 2 (NOHRSC[1]) snowfall accumulation, the western US received the bulk of the high end and low end snow days, with the northern tier of the US (midwest and northeast) receiving just less than half of the total snow accumulation and low end days (~30 days compared to over ~60). There were few high end 24-hour snowfall events across the eastern 2/3 of the CONUS; roughly 2-4 days. The big story east of the Rockies were the persistent lake effect events and the Buffalo Blizzard of December. Otherwise there were 1-2 big events across the midwest that provided the bulk of the snow for the season across this region (compare total snow and max 24h snow).



[1] NOHRSCv2 snowfall analysis can be found here: https://www.nohrsc.noaa.gov/snowfall/

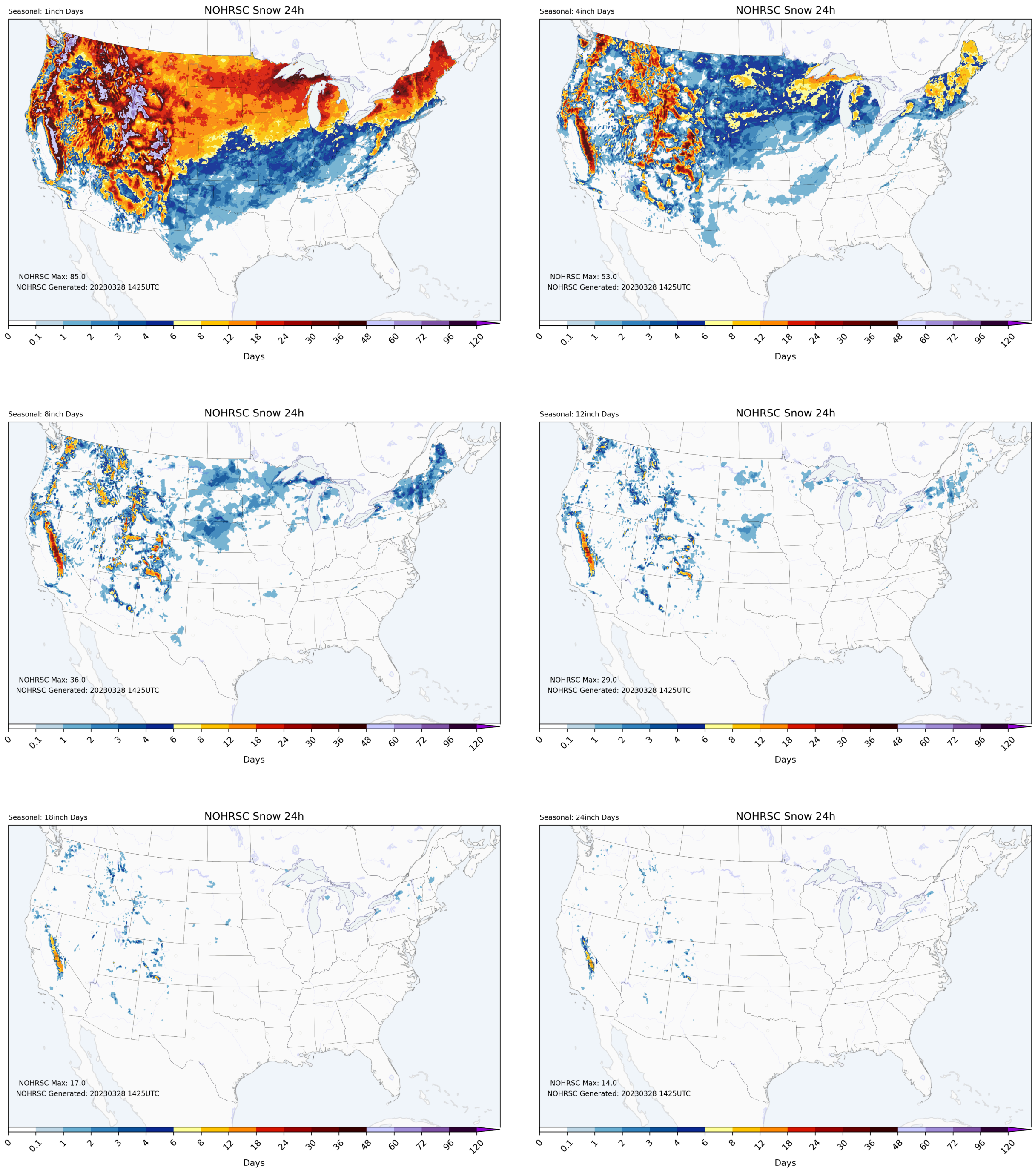


Figure 1: a. Total snow accumulation for each 24hr period from 1 Nov through 1 April, b. Maximum 24h snowfall, c. 1” snow day frequency, d. 4” snow day frequency, e. 8” snow day frequency, f. 12” snow day frequency, g. 18” snow day frequency, h. 24” snow day frequency.

The Oct-April seasonal snowfall and anomaly (Fig. 2) reveal that the eastern US was much below normal and the mountain west much above normal. The mountains in California were an impressive +240” while much of the intermountain west were +120” anomalies. Despite the active west, much of the rest of the country was at or below normal relative to the 14 yr climate.

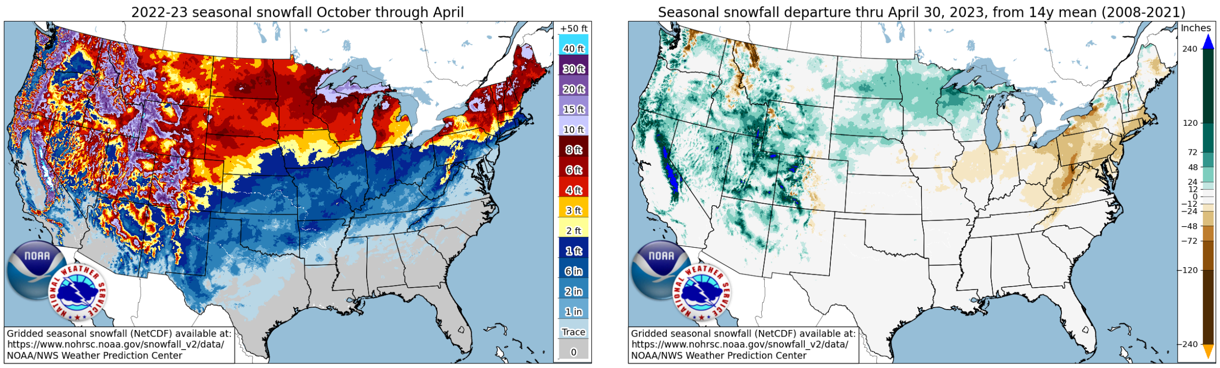


Figure 2: Seasonal snowfall (left) and anomaly (right) relative to 2008-2021.

The western US was quite active with 31 atmospheric rivers (Figure 3) impacting California, Oregon and Washington from November through March 29th, 2023. The WPC issued Excessive Rainfall Outlooks (EROs) for California on 30 unique days (Table 1). The mountain snows were large and persistent and this led to some late season impacts as high temperatures soared and led to intense snowpack melt and rain on snow floods into the Spring.

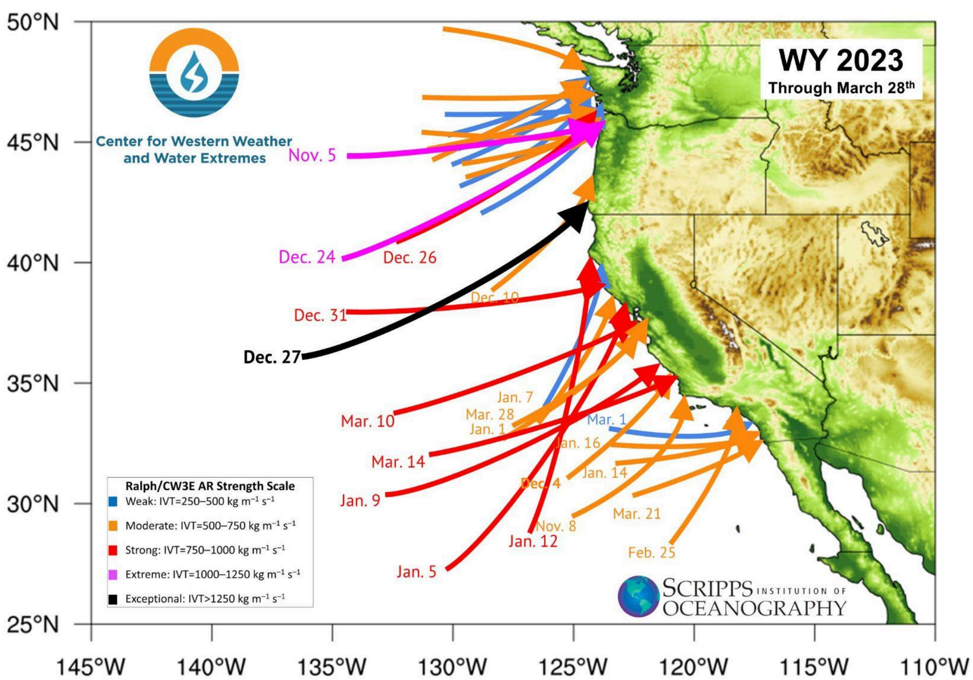


Figure 3: Atmospheric Rivers impacted the Western US during the 2022-2023 Winter season. Source: https://twitter.com/Scripps_Ocean/status/1641204862179241984?s=20

Table 1: Highest ERO risk level for each pacific coast state by month, Marginal (Ma), Slight (S), Moderate (Mo) and High (H).

State	CA				OR				WA			
Month/Risk	Ma	S	Mo	H	Ma	S	Mo	H	Ma	S	Mo	H
Nov	3		1		2	1			1	1		
Dec	3	6			3	4			5			
Jan	2	5	5		8	3			3			
Feb		1	1									
Mar	5	3	3	2	2	1	1		1			
April												
Total	13	15	10	2	15	9	1	0	10	1	0	0

3.2 Seasonal verification

The intense western and northern snow seasons allowed a comparison between the WPC and NBMv4.1 (split between v4 and v4.1 after 17 January 2023). While the NBM is quite competitive across all thresholds for Day 1, its performance decreases slightly by day for 1” and decreases more robustly by threshold as you get to day 3. Note that the NBM bias increases by threshold on day 1, but does the opposite on days 2-3. The addition of the CAM data and its weighting scheme has a dramatic effect on deterministic snow especially when comparing day 2 to day 1. Without CAM information on day 3, the NBM bias is at or below 0.5 for the 8 and 12” thresholds.

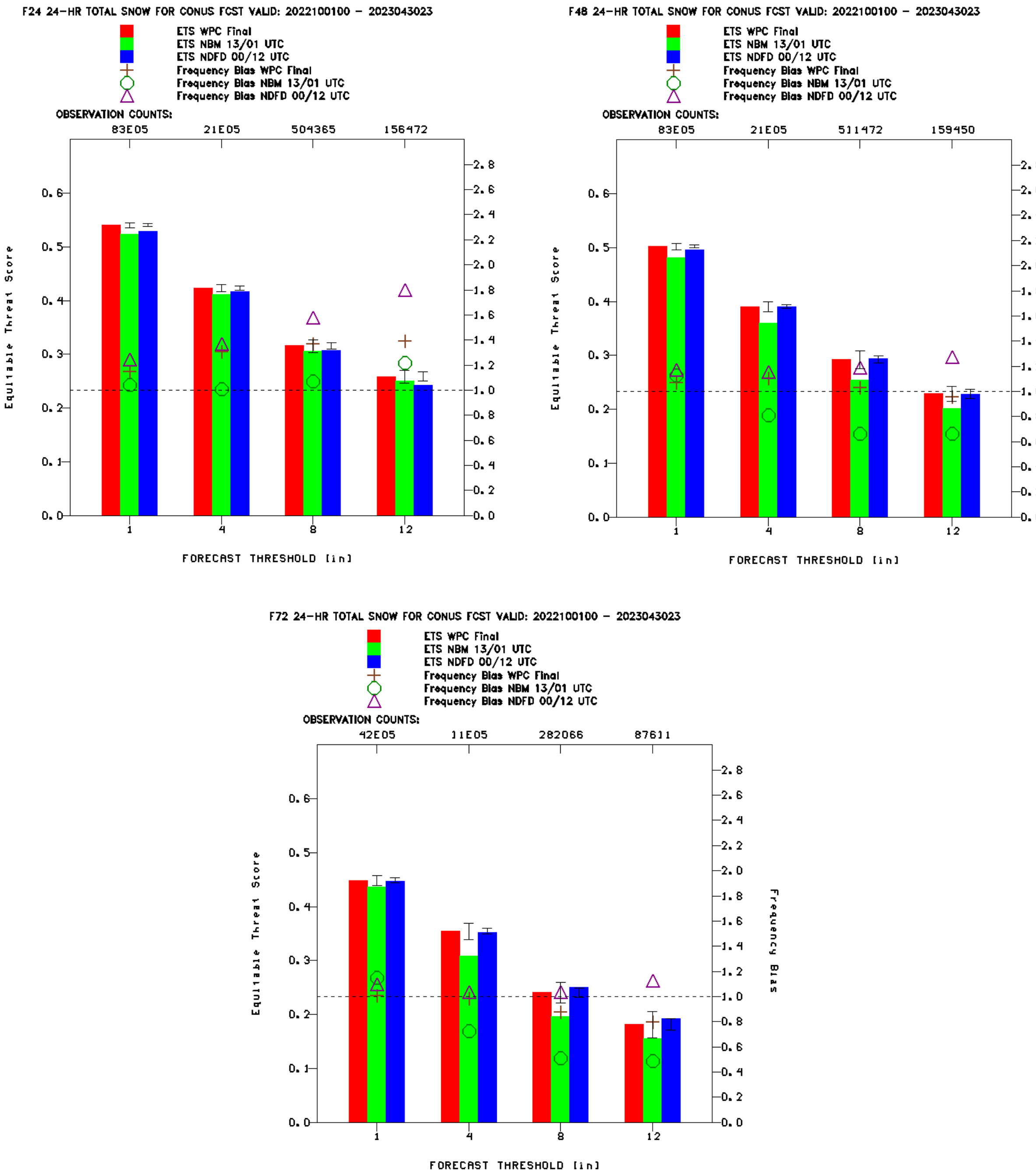


Figure 4: WPC, NBM, and NDFD ETS/frequency bias computed for the entire season (October-April) by threshold across the day 1 (24h, 12z-12z; left), day 2 (middle), and day 3 (right) periods.

3.3 LANTERN Volunteers

As a new addition to HMT collaboration efforts, this year's WWE gained additional personnel from the Leveraging Abilities Needs Talents Energies Resource Network (LANTERN) volunteer program. This program allowed interested WFO forecasters a chance to learn more about HMT, WWE, and be involved in the testbed process. More specifically, the LANTERN volunteers were tasked with selecting and facilitating discussion on operationally relevant cases with forecasting challenges focused on the use of NBMv4.1. These forecast challenges were related to the broader goals of using the NBM data in a "probabilistic thinking" framework for real world events. LANTERN volunteers were asked to select cases they thought embodied forecast challenges they see in their WFO region, and challenges associated with the use of NBM data in either forecasting, messaging, or both.

Logistically, each Evaluation meeting consisted of the LANTERN volunteer walking through the case review, explaining the forecast challenges associated with the event, and then briefing participants for each forecast day. Participants were given 10-15 minutes to review the data and answer simple multiple choice survey questions. The generic survey was created with the purpose of focusing participants' attention to the 1, 4, 8, or 12 in snowfall amounts and threshold probabilities to provoke discussion. Based on the data our discussions focused on the usefulness of the data in this hindsight bias framework. HMT staff facilitated the session with the help of each LANTERN volunteer. The average evaluation session took 2.5-3 hours. In total, WWE hosted 12 LANTERN case studies. The details of the LANTERN case studies can be found in Table 2.

Table 2: The LANTERN case studies and chosen discussion domains

LANTERN Volunteer	Case dates	Location	Phenomena	Presentation
Brian Tentinger	11/20-11/21/22	Great Lakes	Lake effect snow	Link
Michael Ginnick	12/23-12/24/22	Great Lakes	Lake effect, Blizzard	Link
David Stark	1/18-1/19/23	NE, SD, IA	Snow/ptype	Link
David King	1/23-1/24/23	Northeast US	Snow	Link
Alex Lukinbeal	11/30-12/1/22	WA, ID, MT	Snow	Link
Tyler Kranz	2/22-2/23/23	OR	Snow	Link
Zach Uttech	2/16-2/17/23	IA, IL, WI	Snow	Link
Robert Haynes	2/22-2/23/23	Northeast US	Snow	Link
Nick Carletta	2/22-2/23/23	MN	Snow	Link
Amanda Young	1/9-1/10/23	CA, NV	Snow	Participant only
Kidwell	12/10-12/11/22	CA	Snow, snow level	Link

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Brian Tentinger	11/20-11/21/22	Great Lakes	Lake effect snow	Link
Michael Ginnick	12/23-12/24/22	Great Lakes	Lake effect, Blizzard	Link
David Stark	1/18-1/19/23	NE, SD, IA	Snow/ptype	Link
David King	1/23-1/24/23	Northeast US	Snow	Link
Khan	1/21-1/22/23	Ohio Valley	Snow	Link

Each LANTERN volunteer was responsible for building a case review and briefings for each of the day 3, day 2, and day 1 periods. NBM data from the 01z cycle was used for each days' forecast. HMT provided graphics from our retrospective CONUS and regional images, as well as NBM GIS display web pages for deterministic snow and threshold exceedance probabilities. A summary of the domains for the LANTERN cases can be found in Figure 5. Events were evenly distributed over CONUS with cases in the Northeast, Ohio River Valley, Upper Midwest, Great Plains, Nevada/California, and the Pacific Northwest.

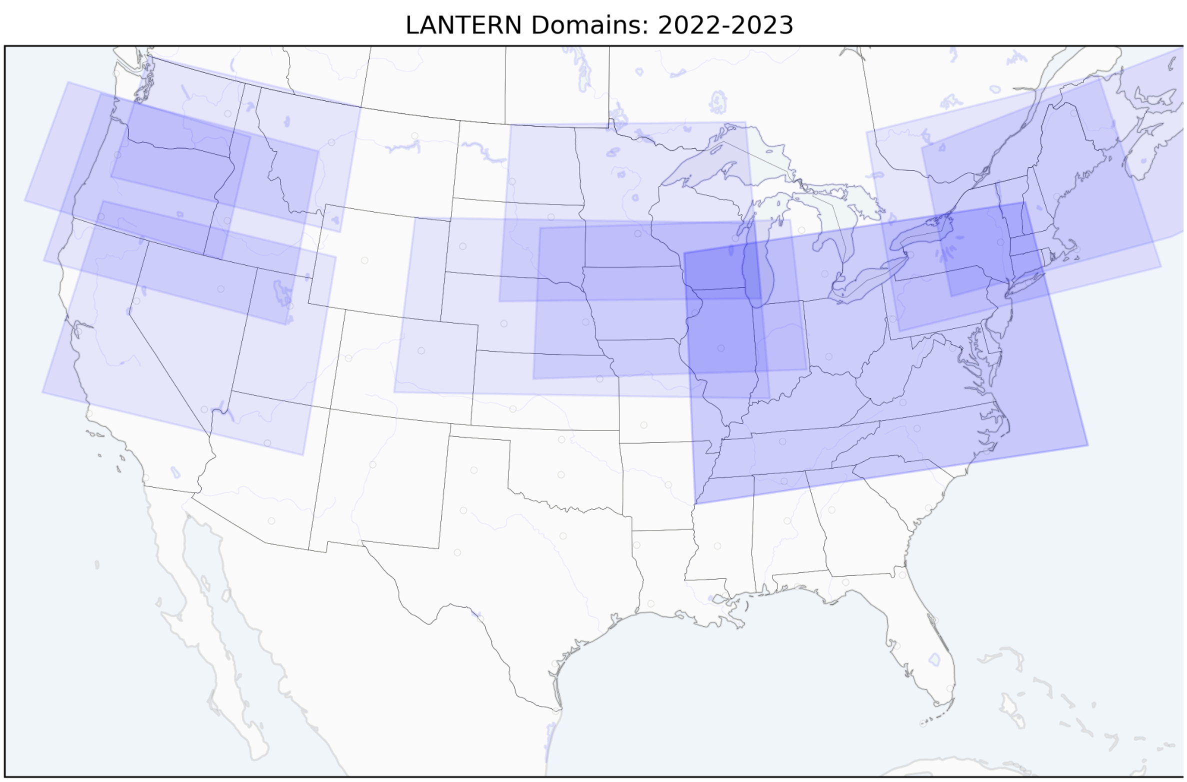

Figure 5: Domains selected by our LANTERN volunteers to generate graphics for discussion

3.3.1 Case Evaluations

An overview of the cases presented by the LANTERN volunteers is presented in the following section. For figures specific to each case review please refer to the individual case presentations. The links to the presentations can be found in Table 2.

a. *Lake Effect Snow Events*

WWE had two case studies of lake effect snow across the Buffalo CWA from November and December 2022 (Table 2). The November case study occurred across Lake Ontario eastward into Lewis, Oswego and Oneida counties in New York with amounts of 12-21”. NBM probabilities increased from day 3 at 20% to day 1 at 30% for 8” or greater, and increased marginally for 12” or greater from 10% to 20%. However the probabilities had a location error of north and west relative to observations. The event was relatively small in scale and when accounting for the scale of the event the NBM performed well. During the evaluation session attendees agreed they would have liked to have seen higher 18” probabilities. The forecasters, in real-time, were messaging 18-24” of snow, the NBM only had 12-18” deterministically by Day 1.

The December Buffalo blizzard was a long duration lake effect snow event with an intense deepening cyclone that became slow moving and resulted in southwesterly winds across Lake Erie for almost 2 days. The 24 hour period ending 23 December 2022 saw almost 27” of snow with three 6 hour periods of 6-8” of snow. The NBM had day 3 probabilities for 12” of snow of 40% and increasing through day 2 with 70%, with 18” probabilities increasing from 0 to 40%. Deterministically, it again took until day 1 for the NBM to forecast 18-24” for this event. Other guidance available to forecasters in real time had already determined by day 4 that this event would bring large totals, thus the NBM probabilities were disappointing. In order to use the NBM for messaging purposes participants stated they would have to relabel a lower threshold of snow exceedance to a higher threshold to message the higher end snow exceedance probabilities.

b. *Western Snow Events*

WWE had three case reviews of events occurring over the Western CONUS. The event ending 1 December 2022 had mountain snows exceeding 12” across WA, ID and MT. The overrunning warm front on top of cold valleys was the primary driver for this event. It was noted by participants that the valleys and mountains in such close proximity gives the appearance in NOHRSC of a smooth event and point observations far exceed some of the gridded totals, and likewise some grid point totals far exceed some of the point observations. The Day 3 NBM deterministic had widespread snow across WA which narrowed substantially to the mountains by Day 2/1. The introduction of the mesoscale models influenced the deterministic snow to focus on the mountains exclusively and the probabilities for 8, 12” in 24h was in good agreement with this scenario. The probabilities did trend upwards to the east in the Kalispell mountains. The overall forecast was seen as a net win with the understanding that the valleys where the people reside are the most difficult to get correct due to the fine scale nature of the terrain and downsloping effects (e.g. Fig 7).

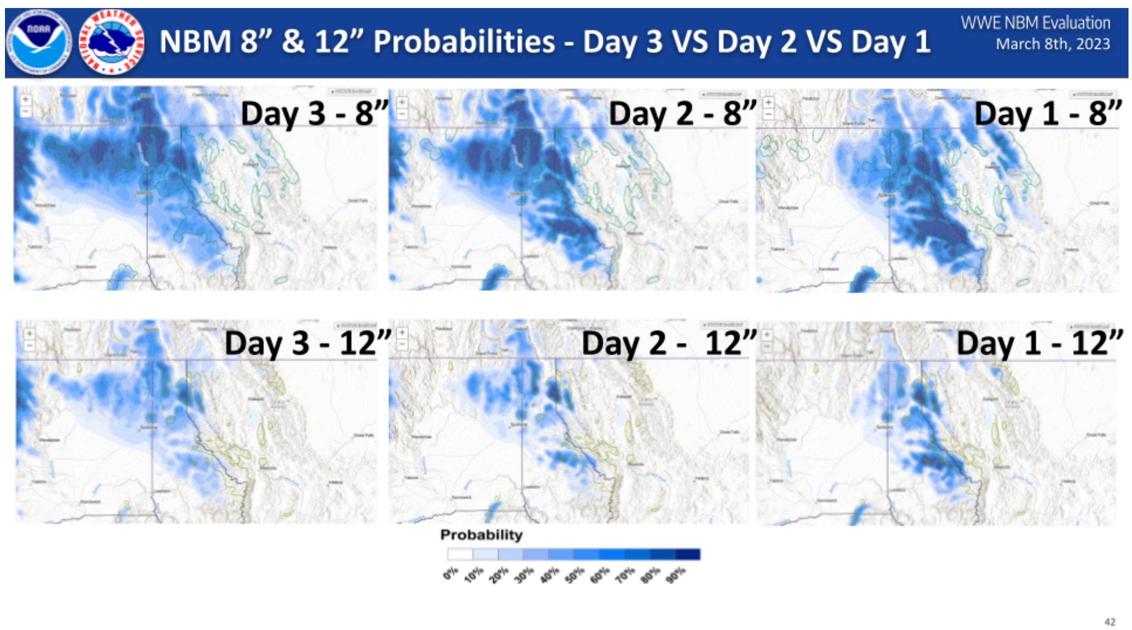

Fig 7: Probability evolution from day 3 through day 1 for the 8 and 12” snow thresholds.

The event ending 23 February 2023 across the Pacific Northwest was Portland, OR’s second snowiest day (10”) on record with a good swath of 12” just inland from Portland south into northern California. The LANTERN presentation focused on some aspects of Portland's forecast seeing 1” probabilities around 40-50% for much of day 3 to day 1 period (Fig 8) with low end probabilities for 4” at day 2 only. A stalled low was just offshore and focused snowfall across Portland. All of the model guidance had the event as a mountain snow event for all 3 days. The extreme mesoscale nature of the event would be difficult for any model and thus the NBM techniques are not to blame. The predictability of this event is thus much lower as most of the guidance seems inadequate-for-purpose especially with any sort of lead time. In this case even a probabilistic approach to capturing an extreme event was unable to help the forecasters.

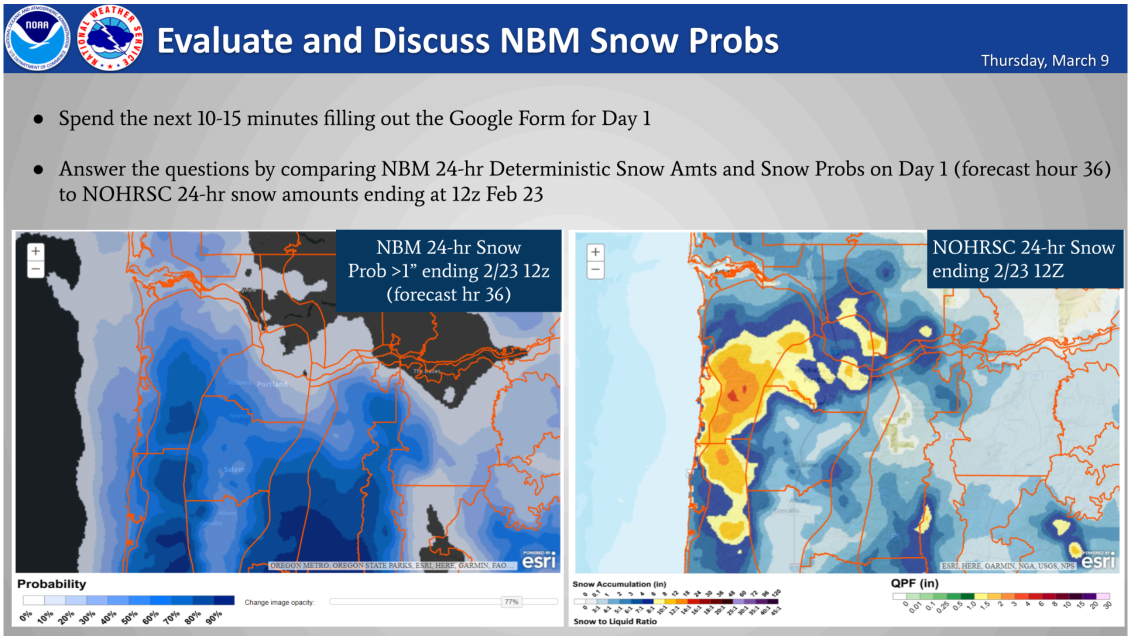

Fig 8: A comparison between the NBM 1" in 24hr probability with the observed NOHRSC snowfall for the Portland case study.

c. Midwest Snow events

WWE had 4 case reviews with events occurring in the Midwest. The case study ending 19 January 2023 in the Great Plains was a precipitation type and snow event for much of Nebraska and northern portions of Iowa. About 2 ft of snow fell, with accompanying drifts in central Nebraska, while the Omaha area received a quick 1-2" before the warm nose led to mixed precipitation types. The day 3 to day 1 NBM probabilities for 12" increased from 20 to 30 to 50%. Participants felt that the probabilities were a bit slow to ramp up and would like to see these higher end (18"+) thresholds above 10% to assist in messaging to partners. However, the snow probabilities increased for the Omaha area, thus diminishing some of the positive effect of the ramp up. The larger scale nature of this case made participants feel like the NBM should be catching on sooner but ultimately didn't help the overall mission of capturing the mesoscale details. This is not a surprise given the coarse resolution of the global models, but detailing the event through messaging means providing clear trends. In real time, the Omaha WFO had been messaging a chance for p-type problems but the NBM snow probabilities were not necessarily favorable for messaging the nuance of the event (Fig 9).

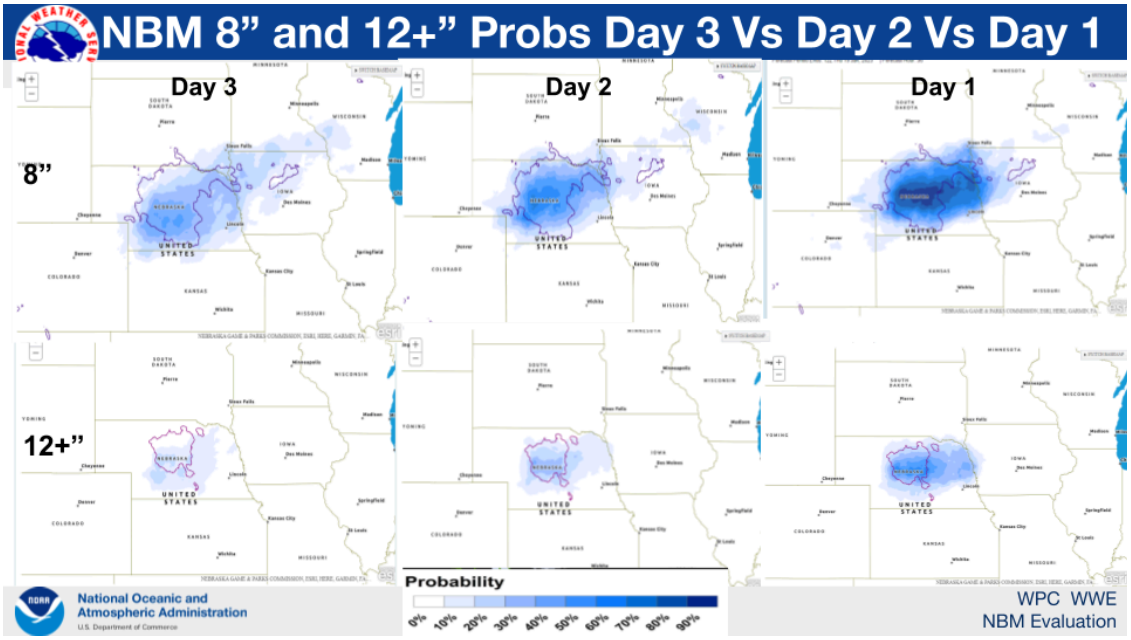

Fig 9: The NBM snow exceedance probabilities for the day 3 to day 1 periods for 8 and 12” of snow.

The case study ending 17 February 2023 across Iowa, Wisconsin and Michigan was a primarily snow event forced by a decaying positively tilted trough. Snow totals were right near watch and warning criteria with near surface temperatures at or slightly above freezing. This meant that heavier precipitation could stay as snow through the event. The Day 3 4” probabilities hovered around 50-60% with deterministic snow around 4”. Participants would have preferred to see higher 8” probabilities to build confidence in a higher end event. By Day 2, 8” probabilities jump up to 30% from 10% (Fig 10), as does deterministic snow. While the trend is good, the area of the snow jumps much further south. This trend continued into Day 1, and had some good and poor characteristics for cities like Milwaukee, WI (12”) and Davenport, IA (6-8”), respectively. The deterministic snow never really followed the evolution of the probabilities. This case was considered typical, with primarily sub-warning criteria over a large swath with a few higher end locations. While it's fair to say that the NBM probabilities helped late, building confidence using probability alone is difficult.

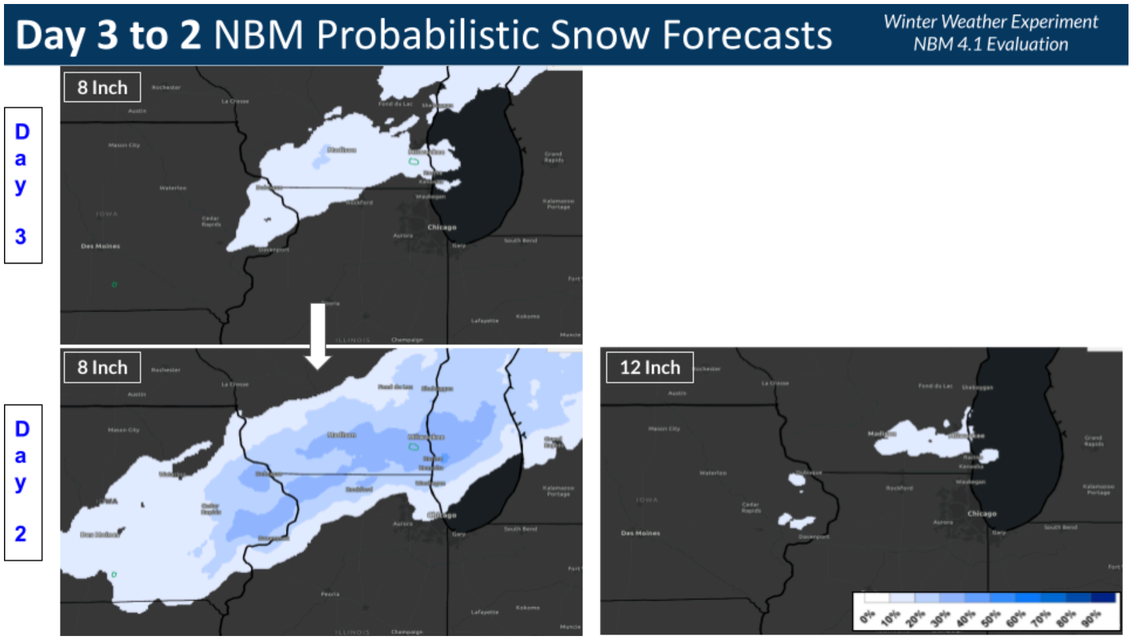

Fig 10: The NBM snowfall exceedance probabilities for the day 3 to day 2 at the 8 and 12" snowfall thresholds.

The case ending 23 February 2023 in SD, MN, and WI brought widespread 6-12" of snow in 24 hours. The NBM deterministic had decent placement of the primary snow axis for all 3 days, with probabilities generally offering confidence of this event in MN. South Dakota 8" probabilities were consistently high and displaced (southward on days 3-2 and northward on day 1) but there was general agreement that the forecasts from the NBM were good enough to warrant higher confidence.

d. *Northeastern Snow Events*

WWE had 2 events focused over the Northeastern CONUS. 6-12" of snow fell across VT, NH, and ME ending 24 January 2023, in an event characterized by some precipitation type challenges along the coast of New England from Long Island into Maine. This case presented a real challenge since deterministic snowfall from the NBM was lower than 6" in 24h for day 3 to day 1. Probabilities were initially displaced north and northeast and there was a timing error from all the guidance. This was a lower predictability case study, and the higher threshold probabilities (6, 8" in 24h) were all below ~50% through day 1. Participants were quick to note the timing errors, in that the model solutions were faster than the event observations. There was discussion of how confidence from the probabilities was lacking until day 1, but the major decisions for watches and warnings came well before that. This case did not get the usual change in probability character at

Day 2 from the mesoscale guidance and thus reliance on guidance was suboptimal from a prob-IDSS viewpoint.

The event ending 23 February 2023 over the Northeast was a challenging case as it represented an over forecast for snow operationally. Warm temperatures aloft and somewhat lower precipitation rates led to precipitation type challenges across the northeast from NY to Maine. NBM probabilities for 4” were consistent on days 3 and 2 with an uptick on day 1. However the 8” probabilities fluctuated with a decrease on day 2 and a strong ramp up on day 1. Effectively, day 3 and day 1 look similar while day 2 is the outlier. In reality the heaviest snow was too far north in the forecasts and the forecast was inconsistent; that said the probabilistic did match the deterministic and this had some effect on the confidence on day 2. In this case, the predictability of the event was the main challenge along with the fluctuating guidance.

4. Summarized Themes

While each case had unique challenges, there were several themes identified by participants throughout the evaluation sessions.

1. A number of cases were examined where mesoscale processes (lake effect, mesolows, etc) were the key to predicting the maximum snow amount and location of heavier snow. The coarser data from global models and those models inability to predict at these scales meant underlying forecast failure was likely. Half degree data was not adequate for purpose. This was true in a variety of ways no matter the forecast lead time.
2. Synoptically driven, widespread events are more predictable in general at most lead times examined here (Days 3 (84h) to 1 (36h)). However, timing differences play a critical role in and around our event definition. WWE used a 24hr period, ending at 12z, so this has a different effect compared to say NWS forecasts which might emphasize a whole event perspective.
3. The influence of CAMs on the deterministic snowfall from the NBM can be large, especially in Day 1 where all CAMS contribute up to 66-70% (Appendix A) of the deterministic snow weights, depending on the forecast hour. The weighting scheme is impactful in a number of ways:
    a. At Day 2 the weighting can result in jumps in snowfall IF the timing of the snowfall (assuming the amount is also large) occurs prior to forecast hour 42 (WWE used the 01z NBM).
    b. At Day 1 the weighting can result in a jump if the timing or snowfall amounts change relative to day 2, and/or more members produce higher snowfall totals regardless of timing.

    c. Thus how the snow falls can be just as important in the interpretation of the NBM guidance at various forecast lead times. Always consult the weighting charts.
4. The consistency between the deterministic and probabilistic snowfall probabilities seemed reasonable for almost all of the cases we examined. However, postage stamps were not available to cross validate our assumptions.
    a. The concept of weighted deterministic snow and then equally likely ensemble members for probability generation can sometimes lead to inconsistency. It would be advisable to generate a global-only and mesoscale-only model suite to demonstrate consistency and identify where and how these competing and different adequate-for-purpose datasets contribute to the probabilities.
    b. Participants expressed a few different ways of thinking about threshold snow probabilities that are consistent with: 1. Operational products and 2. Probabilistic principles. For example, having an event with 12-18" maximum snowfall, participants wanted to at least see greater than 10% probabilities to indicate that some places would have higher end amounts, regardless of location specifics/accuracy. This is consistent with the ProbSnow 90 percentile. The exceedance probabilities could then be used to gain confidence at the higher snow thresholds. In many cases, the forecast exceedance probability was larger than 10% when snow at that threshold did not fall. There are no hard and fast rules that dictate consistency between the real world and model land in probability terms.
    c. In quite a few cases, the trend of the probabilities was "in the right direction" and seldom was this at odds of the trend of the deterministic snowfall.
5. Overall, the evaluation sessions revealed that forecaster use of data needs to be considered in two contexts: 1. consistent forecasts help build confidence, but forecasters shouldn't expect consistency for every case, and 2. The scale of the event needs to be factored into the use of the probabilistic outcomes. Cases with mesoscale detail and thus lower precision/accuracy will not be handled well by global models at coarse resolution. The probabilities from any ensemble system are not equally adequate for purpose across the entire spectrum of events. This leaves forecasters in a precarious situation as guidance at 60-84 hours lacks detail. While the RRFS will replace the HREF and extend guidance to 60 hours, this is still not an option until FY25. Regardless, the evaluation sessions show that forecasters are highly creative in using the NBM probabilities to develop insight into the forecast, but as always, need to understand the event and the capability of the NBM, in order to create consistent and reliable probabilistic forecasts and/or messaging.

5. Other WWE Activities

5.1 Seminar Series

Following previous years success, the WWE again hosted a weekly seminar series. Seminars were held weekly on Tuesdays. Topics ranged over a variety of winter weather issues with 50 - 100 attendees each week. Due to storage constraints, these seminars were not recorded; however, the slides have been archived with links in the table below.

Date	Title	Authors
11/15/22	FV3-LAM-Based CAM Ensemble & Consensus Products for the HMT Winter Weather Experiments	Keith Brewster
11/29/22	Impact Verification at Ontario Storm Prediction Centre	Ryan Rozinskis
12/6/22	Fine-scale structure and organization of snowstorms: Results from IMPACTS and PLOWS	Bob Rauber
12/13/22	Transportation-Centric Winter Severity Index and Connections to Synoptic Environments	Curtis Walker
1/17/23	Developing an Hourly Winter Storm Severity Index for Transportation Applications	Dana Tobin
1/24/23	The NWS Winter Program: Enabling Innovation to Achieve Consistent, Collaborated Products and Messaging	Eric Guillot
1/31/23	Navigating Snow Rate Roadblocks on the Path to Snowfall Decision Support	Andrew Rosenow
2/7/23	Collaborated Snow Squall Messaging and Forecasting	Josh Weiss
2/14/23	Using METplus to Assess Impactful Snow Events	Tracy Hertneky
2/21/23	NOAA's Rapid Refresh Forecast System	Matt Pyle
2/28/23	Advancing the UFS/RRFS Lake-Effect Snowfall Predictions via the Coupled Lake Model FVCOM	Christiane Jablanowski
3/7/23	Evaluating Stochastic Parameter Perturbations in High-Resolution Rapid Refresh Ensemble (HRRRE) Forecasts of Mixed-Precipitation Events during the 2021-2022 WPC-HMT WWE	W. Massey Bartolini
3/14/23	Probabilistic ML Ensemble Forecasts of Rainfall and Snowfall for HMT Testbed Experiments using HREF and FV3-LAM	Nate Snook

5.2 Spectral Bin Classifier Focus Groups

In addition to the LANTERN evaluation sessions, this year's WWE was responsible for organizing a series of focus groups where NWS forecasters were invited to provide feedback on the development of a precipitation type algorithm. The Spectral Bin Classifier (SBC) is a precipitation type algorithm developed at Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO) and National Severe Storms Laboratory (NSSL). The SBC is a numerical model that uses a drop size distribution paired with a vertical profile of temperature, pressure, and dew point to derive p-types both at the surface and aloft. The resulting depiction is vertical level and drop size dependent p-typing. The various ways in which this data could be used and displayed for the benefit of forecasters was the topic of the focus group.

Several points related to the SBC and the precipitation type forecast process were raised throughout the focus groups. These themes are discussed below.

1. The SBC's ability to provide benefit to forecasters is going to be tied to filling uncertainty and decision support holes in the current forecasting paradigm. Regarding uncertainty, forecasters identified the adoption of NBM precipitation type probabilities as both a challenge to adoption of the SBC and a potential opportunity. While it will be important to ensure any SBC products can be used in the context of probabilistic precipitation type, it also represents an opportunity to better understand these probabilities, and give forecasters an option to make major corrections to NWP guidance in cases such as those where, for instance, a 0% probability precipitation type is observed. We recommend further exploring particular challenges for WFO forecasters related to precipitation type, and identifying data or visualization techniques necessary to fill these holes.

2. Forecasters were mostly interested in exploring the capabilities presented when they could be tied to a specific area of responsibility. Forecaster workload is a topic that was brought up repeatedly both in terms of interrogating data and adding new products to their repertoire. It took forecasters awhile to understand some of the additional SBC capabilities that fell outside their typical forecast process, as they seemed to have not thought about precipitation type from that perspective. CIWRO/NSSL recommend increasing the interaction between forecasters and researchers in the research process. This will allow forecasters to think outside their day-to-day box more, and give researchers the chance to align their results better with forecaster needs.

3. Verification of precipitation type continues to be an issue. Two forecasters outright stated that they do not use existing precipitation-type guidance due to not trusting it. Many other forecasters expressed reservations about trusting precipitation-type guidance in certain situations, and the combination of the black box nature of the guidance and inability to verify the output in real-time make the adoption of new precipitation type tools more difficult, particularly as more and more guidance becomes probabilistic. We recommend the development of tools or systems to better synthesize any and all quality, real-time precipitation type observations. Additionally, a framework should be developed to enable forecasters to use point observations of precipitation type to verify probabilistic output from NWP in real-time.

6. Acknowledgements

The WWE team would like to sincerely thank our LANTERN participants. Your expertise and insights into each case was invaluable to making our experiment a success! Thanks to Sarah Trojniak for building the HMT Retro image website. Lastly, the team would like to thank all of HMT and WPC staff that helped us prepare with data troubleshooting and support throughout the experiment. See you all next WWE!

Appendix A: NBMv4.1 Deterministic Snow Weighting

Table A1: A summarized depiction of the NBMv4.1 total weighting scheme (by model system) for deterministic snowfall. HREF membership highlighted in light red.

Model %	1-16	17-19	20-42	43-60	61-84	84+
HRRR	22	17	17			
RAP	8	8	3			
HiResARW	10	11	12			
HResARW2	12	12	13			
HiResFV3	12	13	14	14		
NAM	3	3	4	7	15	
NAMnest	10	13	14	14		
GFS	1	1	1	3	3	4
SREF (x10)	10	10	10	30	30	

GEFS (x30)	4.5	4.5	4.5	12	19.5	36
EC (x50)	7.5	7.5	7.5	20	32.5	60
Total	100	100	100	100	100	100
HREF %	66	66	70	28	0	0

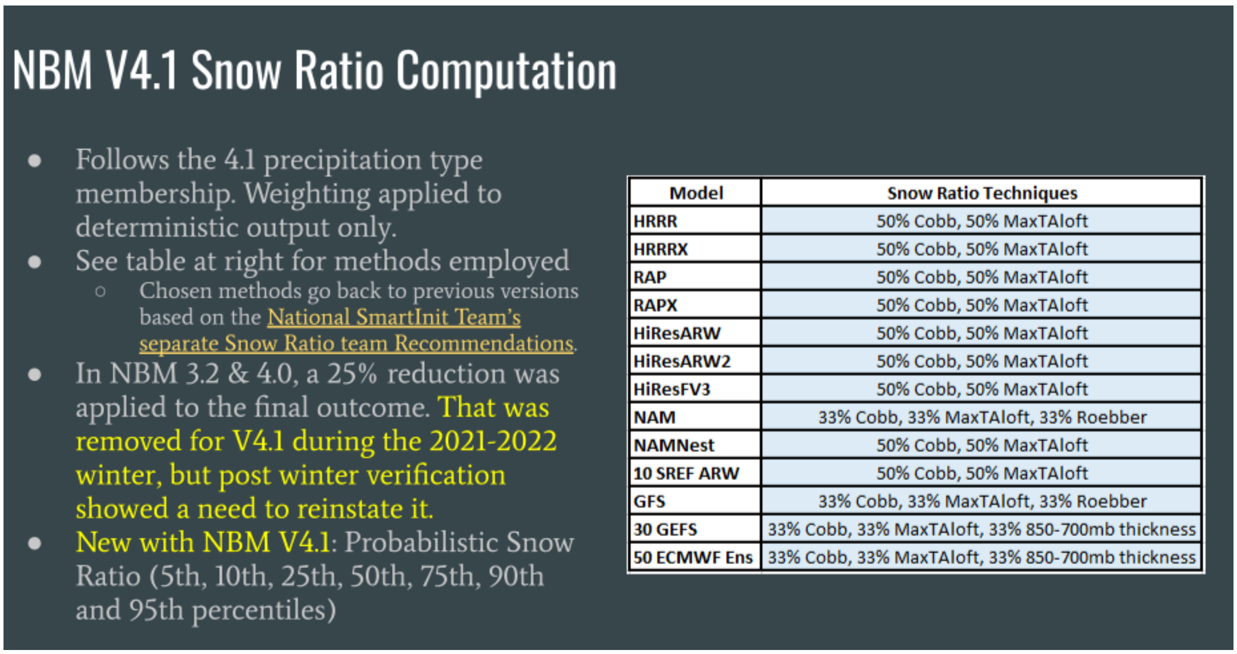

Fig A1: NBM v4.1 snow ratio computation by model depicting all techniques and weights used to derive SLR.