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Evaluation of Cold-Season Precipitation Forecasts Generated by the Hourly Updated 3- km High Resolution Rapid Refresh (HRRR)

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In my study, I compared HRRR model's cold-season precipitation forecast to surface observations.



Goal and Topics Explored



Goal:

Examine the operational HRRR model's ability to generate realistic **precipitation phase and coverage** reaching the ground in support of model development and enhancement efforts for 1-8 hour **cold-season precipitation forecast**.

Evaluation Periods:

1. 7 February 2010 – 7 April 2010, 11 December 2010 – 22 January 2011
2. 30 January 2011 – 31 March 2011

Key Topics:

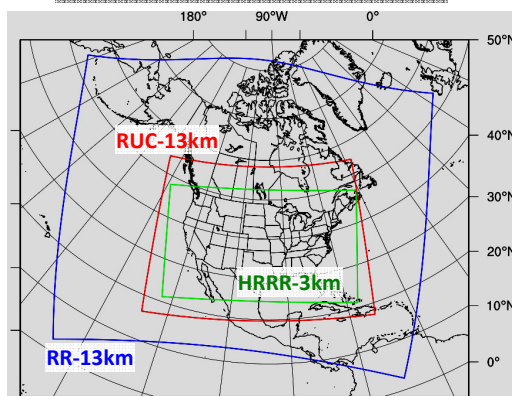
1. Overall forecast skills in the model domain
2. Regional differences -- West vs East comparison

1. The goal was to evaluate HRRR model's ability to generate realistic surface precipitation phase and spatial distribution to support model development and enhancement efforts for cold-season precipitation forecast.
2. Evaluation periods come from two past winter seasons.
3. In my talk today,
 - a) I will first show verification results from the two evaluation periods over the model domain.
 - b) Then, I will discuss briefly talk about the regional differences in the model performance.

Datasets



MODEL High Resolution Rapid Refresh (HRRR)



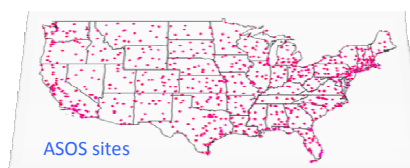
- Hourly updated
- 3-km domain nested inside the RUC.
- Initialized by radar-assimilated 13-km RUC**
- WRF/ARW Core

**From April 2011, the 13-km Rapid Refresh (RR) replaced RUC

OBSERVATION Automated Surface Observing System



<http://www.weather.gov/asos/>



ASOS sites

- Precipitation type from the 1-minute precipitation identification sensors (Light Emitting Diode Weather Identifier)
- Over 800 ASOS sites in the U.S.

1. The model dataset comes from the hourly updated 3-km HRRR model.
2. HRRR used be initialized by the 13-km RUC and since April 2011, it is initialized by the 13-km Rapid Refresh.
3. All of the datasets used in this study comes from the RUC-initialized HRRR model.

1. For verification, I used data from precipitation identification sensors located at more than 800 ASOS stations over the U.S.
2. The precipitation identification sensors, or LEDWI, reports precipitation types every minute.

Side Notes on MODEL:

1. Run by the NOAA Earth System Research Laboratory (ERSL) Global Systems Division (GSD)
2. Initialization by the radar-assimilated **13 km Rapid Update Cycle (RUC)****
3. Domain : 3-km grid spacing covering CONUS, nested inside of RUC
4. Update frequency: 1 hour
5. Core configuration : **Weather and Research Forecasting (WRF/ARW) model**
 Thompson microphysics scheme
 RUC-Smirnova land-surface model
 Mellor-Yamada-Janjic boundary layer scheme
 RRTM/Goddard radiation scheme

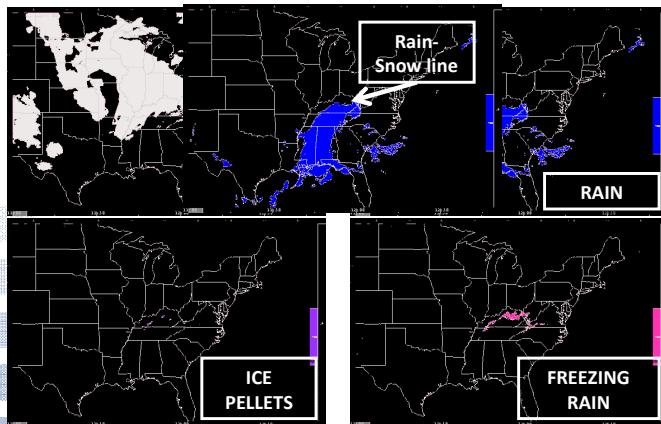
Side Notes on ASOS:

1. The ASOS sites and data are maintained and managed under the ASOS program—a joint effort with NWS, FAA, and DOD.
2. Over 800 ASOS sites are in the U.S.
3. Basic weather elements, e.g., sky condition, visibility, precipitation type and intensity, temperature, wind, etc. are **continuously recorded every minute**.
4. Verification of the HRRR model is done with data from **precipitation identification sensors** (Light Emitting Diode Weather Identifier).
 - Detects and identifies precipitation particles by terminal velocity.
 - Processed with the Present Weather algorithm developed by NWS to determine precipitation types.
 - Precipitation types identified by the algorithm are **rain**, **snow**, **freezing rain**, and **UP** (unknown precipitation).

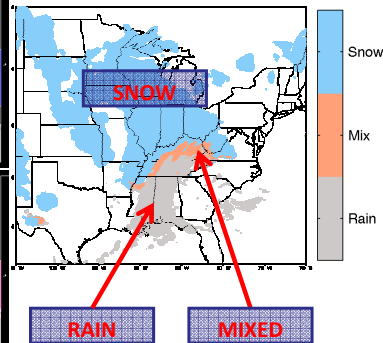
HRRR Precipitation Categories and Phase

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Precipitation categories



Precipitation phase



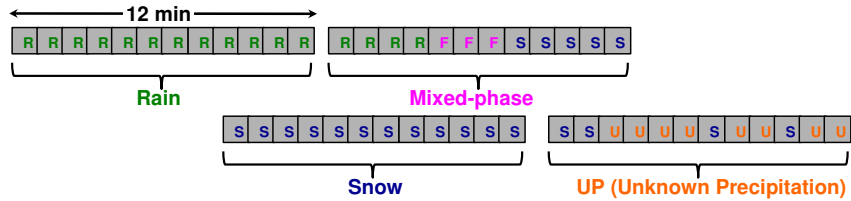
- HRRR gives categorical (yes/no) snow, rain, freezing rain, and ice pellets data fields
- Depicts surface precipitation type at model valid time.
- Mixed-phase := Regions of freezing rain and locations where RAIN and SNOW overlap.

1. HRRR outputs hourly forecast of categorical (yes/no) snow, rain, freezing rain, and ice pellets indicating locations of certain precipitation types at model valid time.
2. These precipitation categories are combined to give three precipitation phase: snow, rain, and mixed-phase regions.
3. Mixed-phase regions in this study includes regions of freezing rain, and locations where categorical SNOW and RAIN fields **overlap**, which essentially is the rain-snow transition zone.

Verification Approach

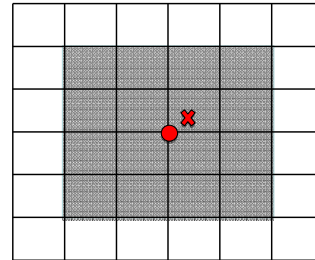


1. "TURTH": Take ASOS data within a **temporal window** of each hourly forecast valid time and assign "SNOW", "RAIN", "MIXED", "UP", and "NP" (no precip).



1. MODEL : Look for each precipitation phase inside a **neighborhood box**
2. Determine HIT, MISS, FALSE ALARM, or CORRECT NULL.

Temporal window : +/- 3, 6, 10, 60 min
 Neighborhood box width : 9, 18, 36, 78, and 156 km.

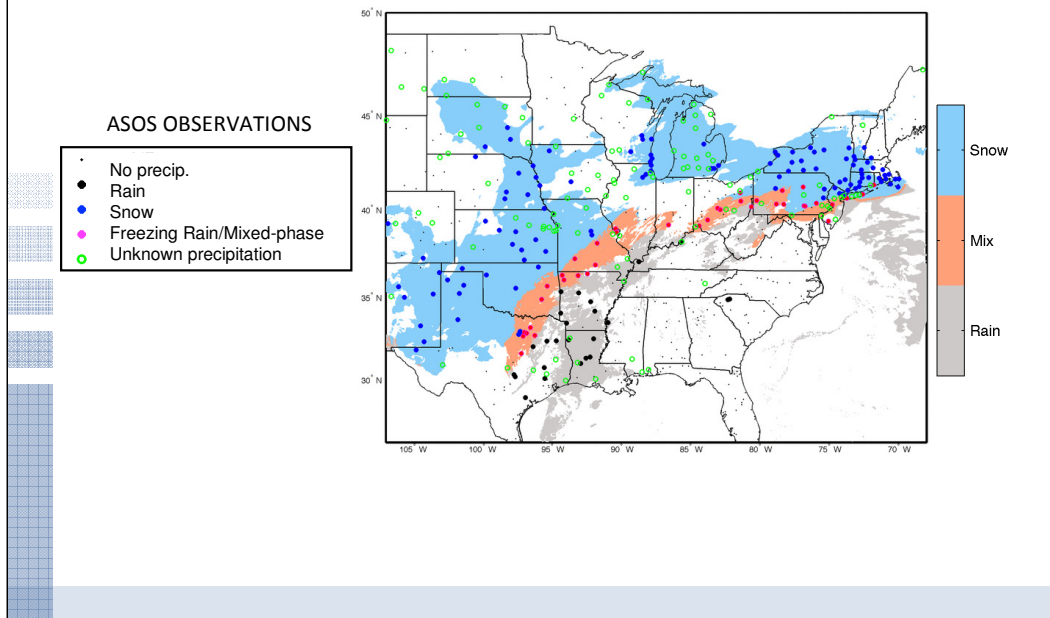


- Closest grid point
- ✕ Surface site

1. In order to compare the model precipitation phase with the 1-min ASOS data, I took precipitation information within a temporal window centered at each hourly model valid time and assigned precipitation phase categories as shown in this graphic.
 - a) If a rain-to-snow transition occurs freezing rain is reported during the time window, then this becomes mixed-phase.
 - b) UP, is an indication of light precipitation occurrence such as light snow and drizzle, which is detected by the sensor but it is too light to determine if it is solid or liquid phase. If UP is most frequently reported, I assign UP as the truth data still indicating presence of precipitation at model valid time.
2. Then looked for each precipitation phase inside a neighborhood box centered at each surface site.
3. Temporal window and neighborhood box sizes tested for sensitivity are listed here.
 - a) The box width of 20 km and time window of +/- 6 min seemed most reasonable, so in my talk today, all results are from this combination of box size and time window.

Precipitation Phase forecast :

4-hour forecast valid 12 UTC 1 February 2011 – 23 UTC 2 February 2011



1. Here is an example of model precipitation phase with ASOS observations indicated by various colored dots.
2. This animation is from a large winter storm on 1-2 Feb. 2011.
3. This event produced a large area of freezing rain, heavy snow in many parts of eastern US, Thunder snow in TX and graupel in regions of MO and IA.
4. The green circles in the northern part of the system are light snow.
5. The green circles in the southeast are light rain

Overall skill scores from all cases in the model domain:

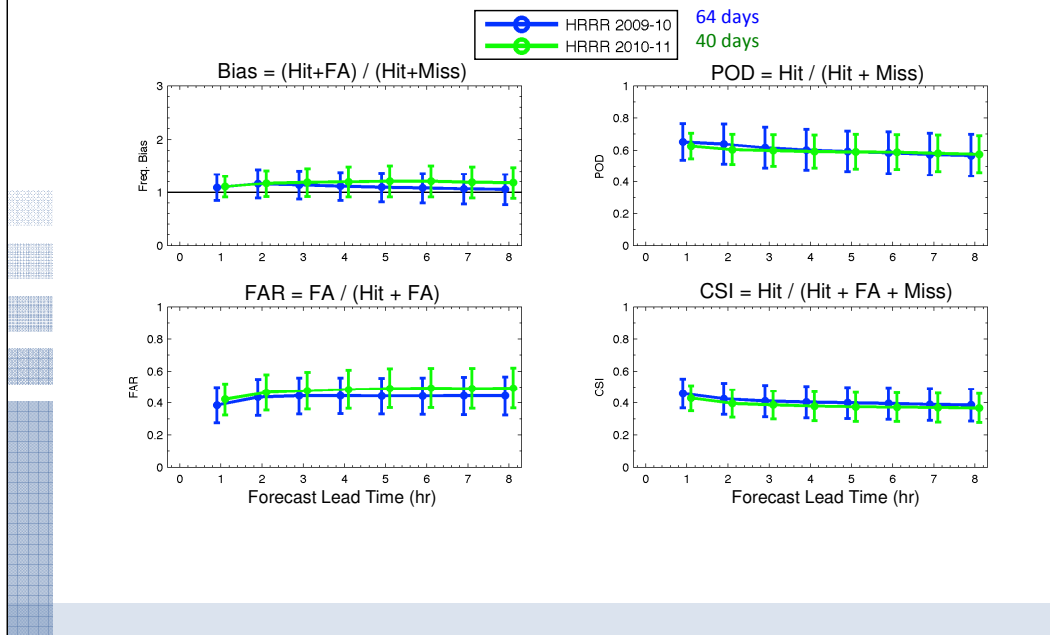
Evaluation Period 1: 8 Feb. 2010-7 Apr. 2010, 11 Dec. 2010-22 Jan. 2011
Evaluation Period 2: 30 Jan. 2011-31 Mar. 2011

Number of days evaluated

Evaluation Period 1	Evaluation Period 2
64	40

1. First, we'll take a look at overall skill scores computed from data from all events in the two winter seasons.
2. From the analysis of the 2009-2010 dataset, we've found that this overlap region was too wide in general compared to observations. So there was a change made to how snow and rain categories were treated in the post-processing routine.
3. The change to the post-processing routine for rain-snow overlapping areas happened in January 2011, so I've broken up the datasets into these two evaluation periods. There are 64 days in the first evaluation period and 40 in the second period.

Precipitation Coverage: All cases from 2009-2010 and 2010-2011

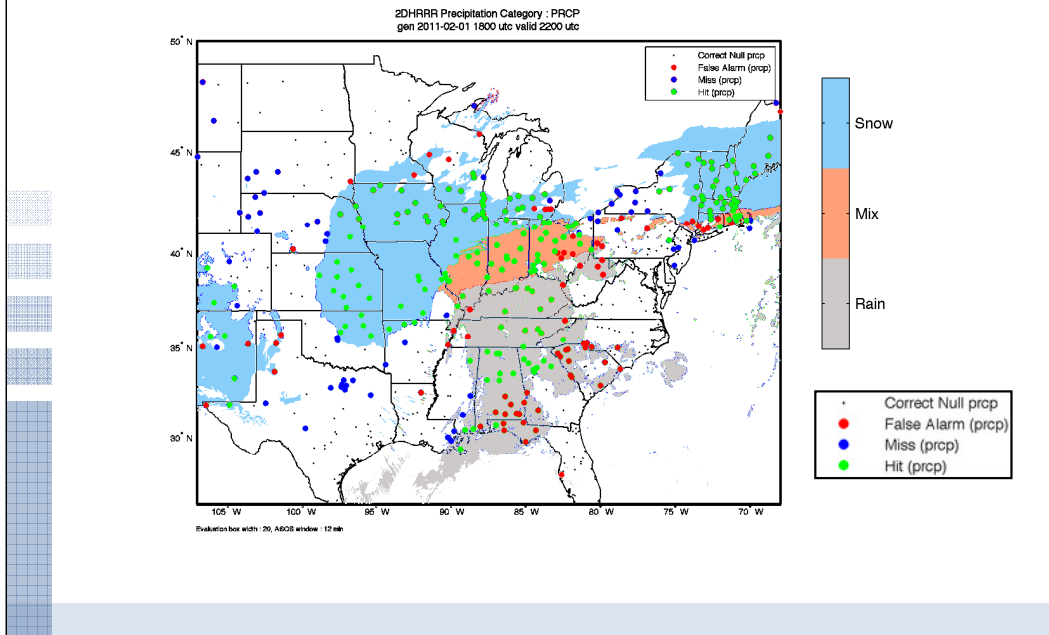


1. This slide shows various forecast skill scores for precipitation coverage plotted as a function of forecast lead time.
2. Points are average values of indicated skill metrics of all events evaluated for the two evaluation periods.
3. The errorbars here are one standard deviation from the mean to indicate day-to-day variability in the skill metrics.
4. Clearly, the plots show that there is no significant difference in performance skills between the two evaluation periods.
5. For both evaluation periods, bias is just slightly above 1 showing that the model performs well, in general.
6. The plot also shows a slight trend with forecast leadtime. However, the change over leadtime is not too large because winter systems are largely synoptically driven.

Side note:

1. **The model precip phase fields uses VIL-based mask, which means there are still regions where precip at the lowest model level (8m in HRRR) is very little (due to evaporation/sublimation/advection...) and should be masked if the mask was created with the lowest level Qs or Qr. Because of the VIL-based masking technique, FA in the current results may be from precipitating particles not reaching the ground.**
2. The fact that FA slightly increased is an indication that the area coverage of precipitation is larger in the newer version.
3. The fact that POD don't change so much between the two versions of the model suggests that the amount of miss hasn't changed.

Locations of HIT, MISS and FA : 22 UTC 1 February 2011 , 4hr forecast



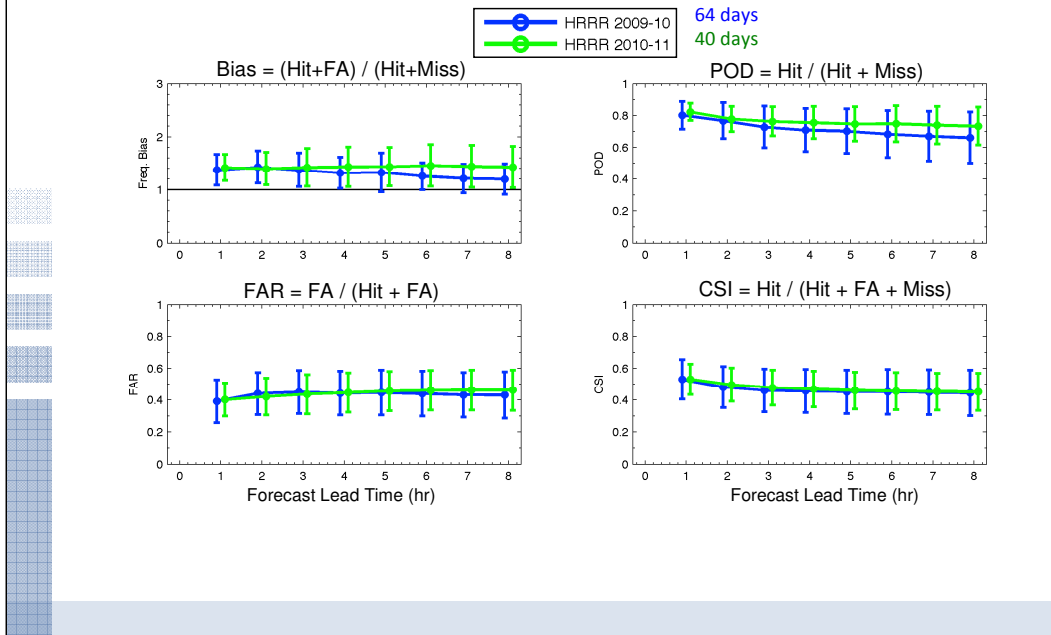
This is a snap shot of HRRR model precipitation phase at 22 utc on 1 Feb. 2011.
Using this snap shot, I want to point out where locations of MISS and FA generally occur for winter systems.

- 1.Both MISS and FA tend to occur at the outskirts of main precipitating regions where precipitation is generally light.
- 2.MISS shown with blue dots are associated with locations of light precipitation, such as light snow and drizzle, based on ASOS data.
- 3.FA are indicated by red dots and they are generally in the locations of light precipitation predicted by the model.

Side notes: locations of hit, miss and fa

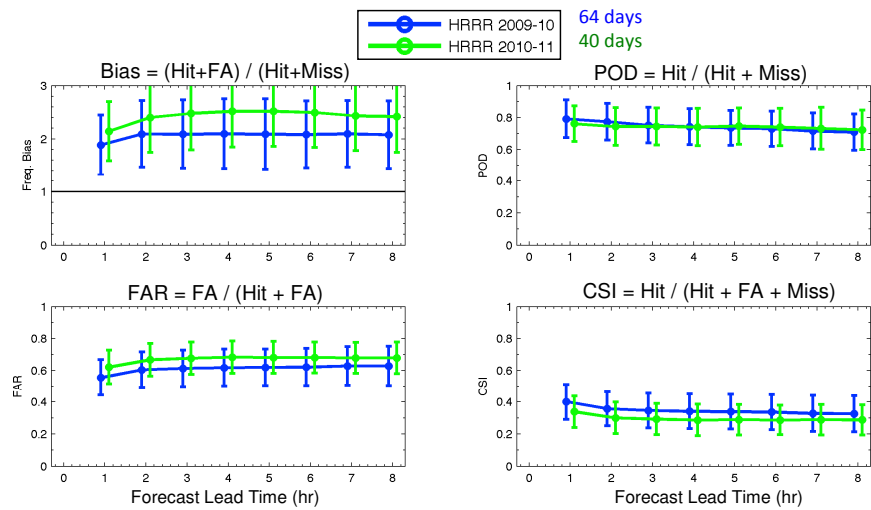
- 1.Outskirts of main precipitation where precipitation is light at the surface and < 5 dBZ ($< \text{VIP } 1a$). Advection, evaporation/sublimation could be taking place.
- 2.Frequently observed is that there are many false alarms at the leading edge of the storm. Perhaps, wind advection of precipitation could be attributed to FA.
- 3.Also noticed is light precipitation missing in the model data in back side of strong storms, for example, in the wrap around region of the low pressure system. Also winds could be one of the reason.

Snow Coverage: All cases from 2009-2010 and 2010-2011



1. Now, this shows skill scores for regions of snow alone.
2. Average bias falls between 1.2 and 1.5, a little higher than precipitation coverage. However, various skill scores are similar to those for precipitation coverage, because snow regions dominates winter storms.
3. There is a little more separation between the two evaluation periods in terms of bias and pod for larger forecast lead times, but they are still with one standard deviation.
4. The key point here again is the model performs fairly well for depicting snow regions.

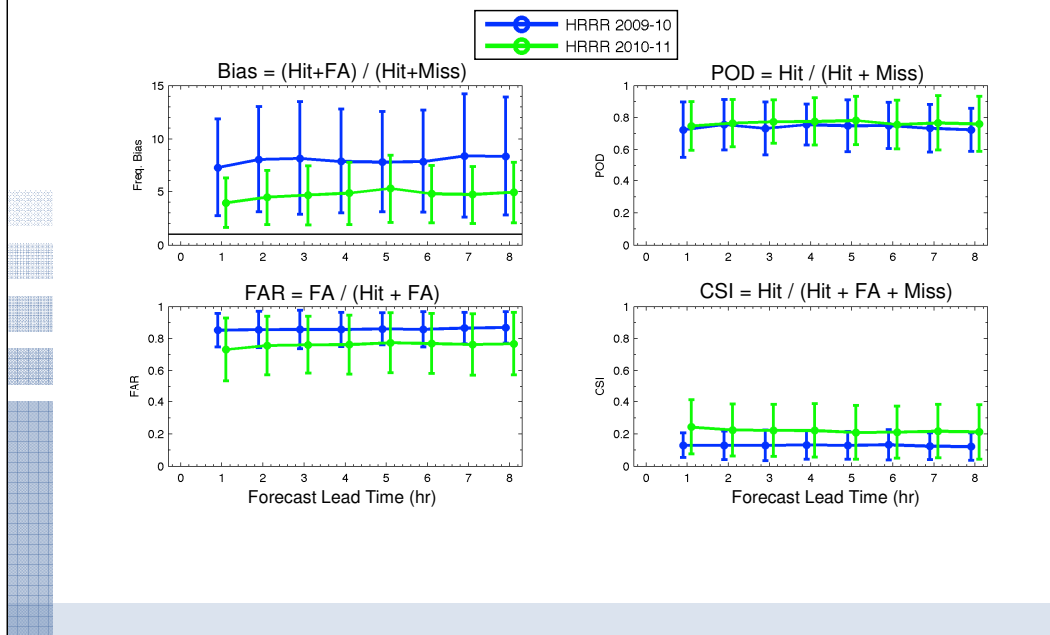
Rain Coverage: All cases from 2009-2010 and 2010-2011



1. For rain, there is a more notable difference in bias between the two periods and the updated model has higher bias and FAR which results in lower CSI. This could be related to type of events in the two evaluation periods.
2. Compared to snow region, there is more day-to-day variability.
3. Also, FAR is higher by 0.2 and thus CSI is lower.

Mixed-phase Precipitation Coverage: All cases from 2009-2010 and 2010-2011

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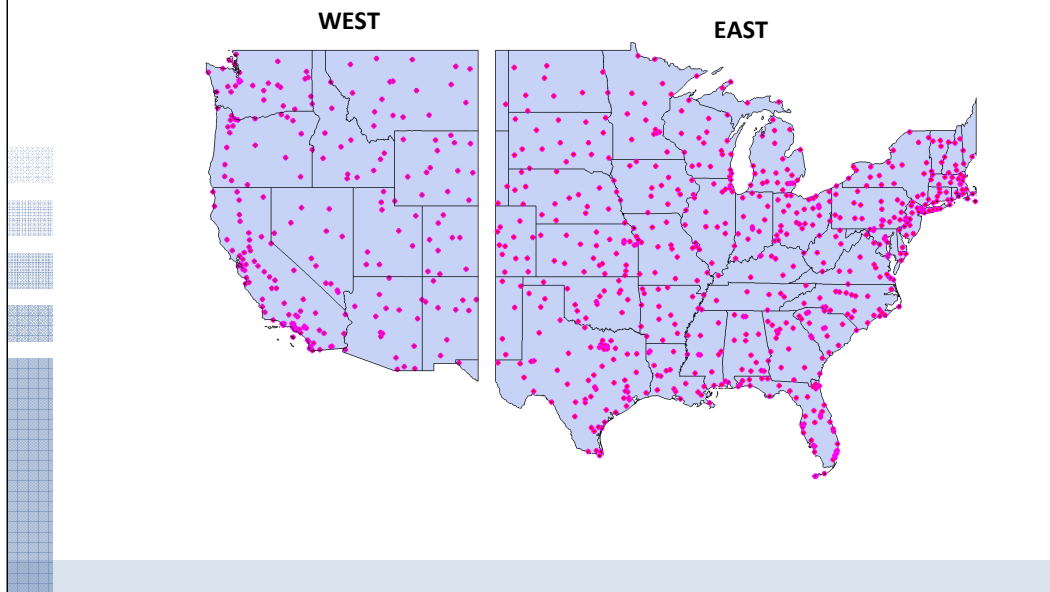


1. In the mixed-phase region, the model shows a significant difference in BIAS, FAR, and CSI between the two evaluation periods although they may be still within the standard deviation.
2. The change made to the post-processing routine improved FAR, and BIAS which lead to an higher CSI.
3. Compared with snow and rain, bias and FAR are much higher. This is because mixed-phase covers much smaller area compared with snow and rain, so point to grid comparison becomes tricky.
4. Also, accurate forecast of mixed-phase precipitation is difficult because of various factors such as surface winds and wet-bulb temperature and geographical characteristics.

Side note:

1. The improvement in the skill scores for mixed-phase region is due to improvement reflected for **WET and WIDESPREAD** events particularly in **the East**.
2. Note the **different y-axis range** for bias for mixed-phase compared to snow, rain, and precip coverage bias plots.

Examining Regional Differences

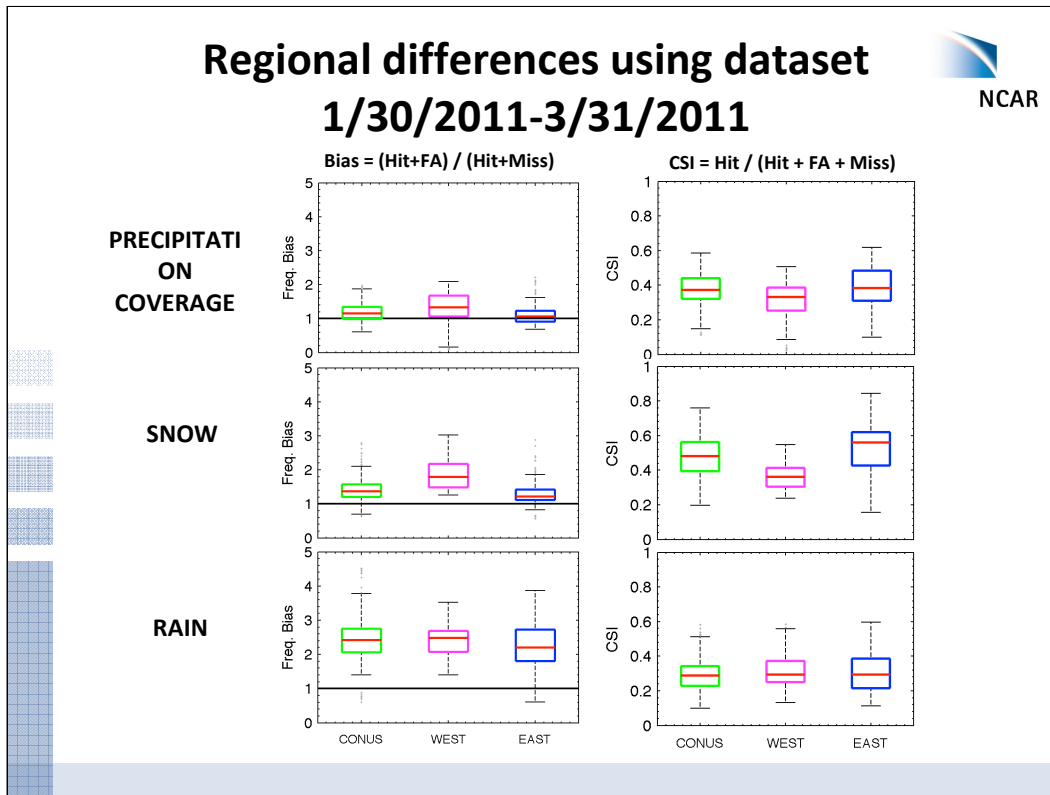


To show regional differences in the model performance I divided the country into WEST and EAST for simplicity.

The Western domain is dominated by complex terrains, and the eastern domain is less complex in terms of elevation changes.

One major caveat here is that ASOS stations in the West are less densely located and that they are not placed to represent all elevation ranges over the complex mountains.

Regional differences using dataset 1/30/2011-3/31/2011

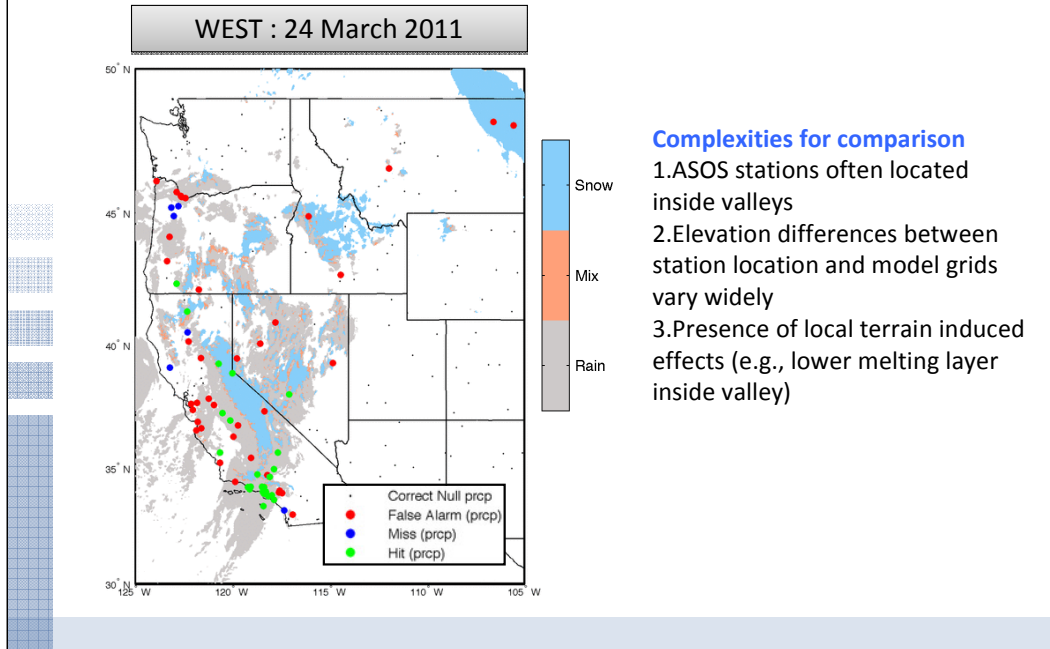


1. Here are box plots of bias and CSI for precipitation coverage, and areas of snow and rain for CONUS, WEST, and EAST.
2. Because the skill scores don't change significantly with forecast leadtimes, data for box plots come from all leadtimes and from all events in the second evaluation period.
3. In general, biases are higher in the West, except that in the area of rain, there is not much statistically significant difference.
4. CSI also shows that in the area of rain, the skill is similar for all three regions. However, in the area of snow, CSI in the western region is much lower than East and CONUS.

Side Notes:

1. The comparison may be impacted by the lack of ASOS sites at high elevations (below freezing elevations) in the West.
2. For precipitation coverage, bias and FAR are higher in the West compared to the East, suggesting that precipitation area could be too widely spread in the current model. (improvements are expected with RR-based HRRR)
3. Besides from the fact that number of observing sites are not many at high elevations in the West, the results here are, in part, related to the factors such as snow and rain shadows, local wind circulations that are complex over the varying terrains of the West.

Pacific frontal systems: Locations of HIT, MISS, and FA



1. There are complexities for model and surface site comparisons for the Western region that are reflected in the results.
2. This can be illustrated from this animation showing a landfalling pacific frontal system on 24 March.
3. Dots are color coded by HITS, MISSES and FA at ASOS sites.
4. Some of the complexity factors are that :
 - a) Locations of ASOS sites being in valleys
 - b) Elevation difference may be present
 - c) And there is presence of local terrain induces effects that makes various snow and rain shadows and impact locations and elevations of rain-snow transition zone.

So slight temporal and spatial offset in the rain-snow transition is unfairly result in FA and MISS.



Summary



1. Examined 1-8 hour forecast of cold-season precipitation coverage and phase generated by HRRR model using surface observations.
2. Datasets from two winter seasons (2009-2010, 2010-2011) over CONUS showed:
 - a) Overall precipitation coverage and snow areas are well depicted. (bias~1.25).
 - b) Rain region has larger bias than snow.
 - c) Mixed-phase precipitation shows bias > 3.
2. Regional differences:
 - a) Model skills are relatively higher in the East compared to the West (snow and precipitation coverage).
 - b) Model verifications complicated in the West.

In summary,

1. I showed verification results of **HRRR's cold season precipitation phase forecast** using surface observations.

2. Datasets from two winter seasons over the model domain showed that

1. Overall, the model is quite robust for depicting precipitation coverage.
2. Area of snow and rain are fairly well predicted.
3. In mixed-phase region, bias is relatively high, indicating that accurate depiction of mixed-phase precipitation is difficult (due to various surface conditions).

3. Comparing West and East,

1. In terms of bias and CSI, there is relatively more robustly higher skills in the East compared to West.
2. But as I pointed out earlier, model verifications are difficult in the West due to **various factors that involves around having complex terrain.**



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Winter storm brings much of America's heartland to a standstill

Weather system stretching across third of US brings snow and freezing conditions from Texas to Maine

Associated Press
guardian.co.uk, Wednesday 2 February 2011 08:50 GMT
[Article history](#)



Lorries struggle in whiteout conditions on the I-70 highway in Missouri. Photograph: LG Patterson/AP

<http://www.guardian.co.uk>

Thank you.