High-Resolution Rapid Refresh Model-Based Climatology and Analysis of Snow Squall Characteristics in the High Plains and Mountain West

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1. Introduction

National Weather Service (NWS) forecasters have recently been encouraged to issue new warnings for a hazardous weather type, snow squalls. Because this type of alert is new, the frequency and intensity of snow squalls must be studied, and the ability of operational high-resolution models to accurately capture snow squalls needs to be assessed.

Snow Squall Warning (SQW) Issuance Criteria:

* *Condition 1: Visibility 1/4SM or less in snow with sub-freezing ambient road temperatures.*
* *Condition 2: Plunging temperatures behind an arctic front sufficient to produce flash freezes, along with a significant reduction in visibility from falling and/or blowing snow.*

2. Objective & Method

This research aims to characterize snow squall frequency and distribution in the HRRR model. A climatology of the SNSQ parameter and its components is presented. This work will support a larger effort to improve the operational prediction of blowing and falling snow and extreme wind events in the Rocky Mountain Region and northern High Plains.

Project snow squall-related objectives include:

* *to develop a HRRR-based blowing snow product, as well as a snow squall product, and to examine the accuracy of the HRRR forecasts for the occurrence and intensity of blowing snow and snow squalls*
* *to use HRRR output for real-time prediction of blowing snow and snow squalls, and to effectively disseminate this information*

Given the relatively small scale of snow squall events, i.e., not captured by global and even some regional numerical weather prediction models, 3-hourly, 00-forecast hour, 3-km HRRR outputs are analyzed for the SNSQ parameter and its component terms (Banacos et al., 2014) for frequency of occurrence in the target domain. Three cool seasons (2016-17 through 2018-19, Sept-May) are examined.

$$\mathrm{SNSQ} = \left(\frac{\overline{RH}_{sfc-2km} - 60\%}{15\%}\right) * \left(\frac{4K - (\theta_e|_{2km} - \theta_e|_{sfc})}{4K}\right) * \left(\frac{\left\|\vec{V}\right\|_{sfc-2km}}{9ms^{-1}}\right)$$

Parameter Calibrated to 1.0	*0-2 km Mean Relative Humidity (Set to 0 if negative)*	*0-2 km Instability (Set to 0 if negative)*	*0-2 km Mean Wind Speed*

Snow squalls require sufficient low-level moisture, instability, and wind speed for development. Terms 1 & 2 of the SNSQ equation represent the ingredients needed for shallow wintertime convective initiation. Term 3 eliminates low wind speed environments not conducive to the linearly organized nature of snow squalls. Boundary layer temperature and lift are evaluated independently. A SNSQ threshold of 0.6 (lower bound IQR of cases, [Banacos et al. 2014]) is displayed here to illustrate spatial and diurnal trends.

4. Summary & Future Work

The snow squall parameter (SNSQ) can be represented in HRRR forecasts and a climatology of the parameter reveals:

* The complex terrain of the High Plains and Mountain West significantly influences the spatial distribution of high relative humidity, high wind speed, and reduced stability occurrences
* Many highly-trafficked interstates in this domain intersect climatological maximums of SNSQ occurrences
* Temporally, more frequent threshold-exceeding SNSQ events are expected in the afternoon and during transition seasons when instability is greatest.

Currently, case studies of warned and unwarned snow squalls in the target domain are being compiled for further study. Future work includes:

* Evaluating the HRRR model's ability to predict snow squalls in complex terrain against observations
* Quantifying the prediction of the hazard components (low visibility, high winds, and flash freezes) of snow squalls
* Disseminating winter weather hazard forecasts
* Developing a higher-resolution HRRR-like WRF simulation to explore resolution dependencies of extreme winter weather in the High Plains and Mountain West
* Validating snow squall warnings

Award:
NOAA/NWS Collaborative Science Technology, and Applied Research (CSTAR): NA19NWS4680005

References:

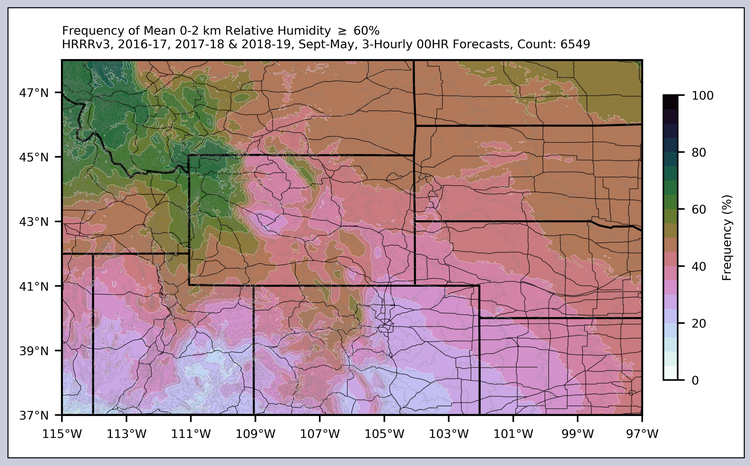
Banacos, P., Loconto, A., and DeVoir, G.: Snow squalls: Forecasting and hazard mitigation, J. Operational Meteor., 2, 130151, doi:10.15191/nwajom.2014.0212, 2014.

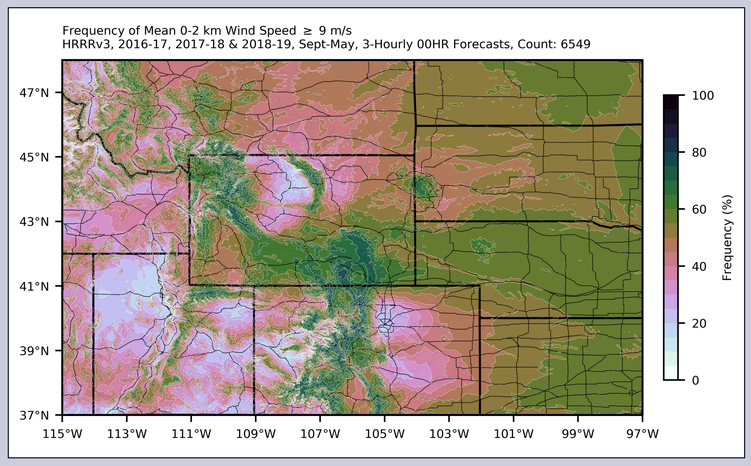
Blaylock, Brian K., et al.: Cloud Archiving and Data Mining of High-Resolution Rapid Refresh Forecast Model Output, Computers & Geosciences, vol. 109, 2017, pp. 43–50, doi:10.1016/j.cageo.2017.08.005.

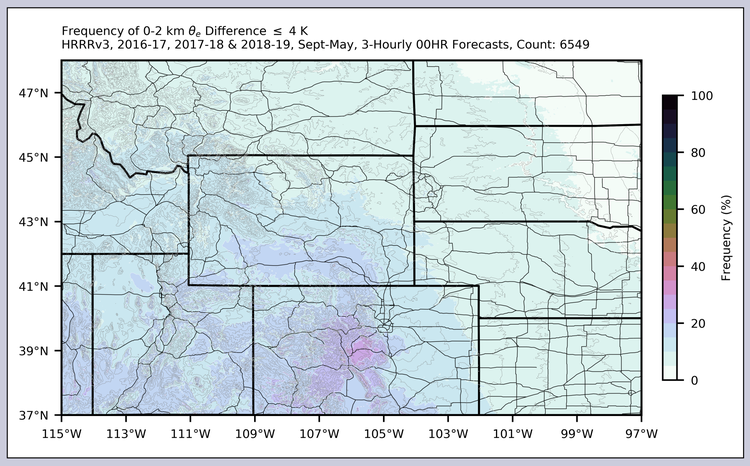
Additional Figures:
QR Code or: https://bit.ly/3a9sQqO

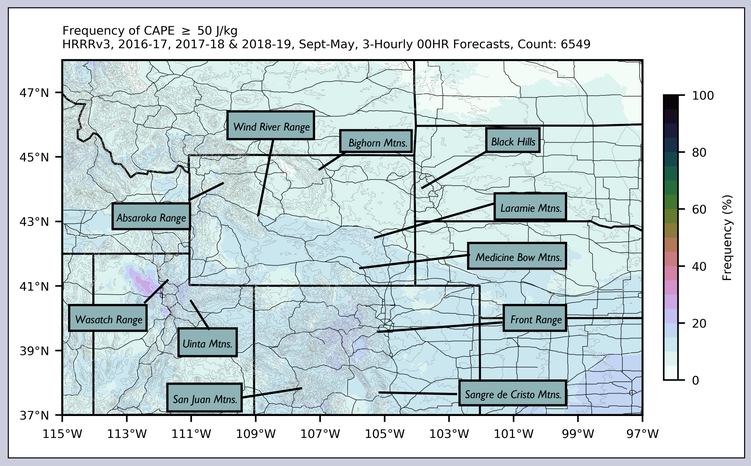
3. Results

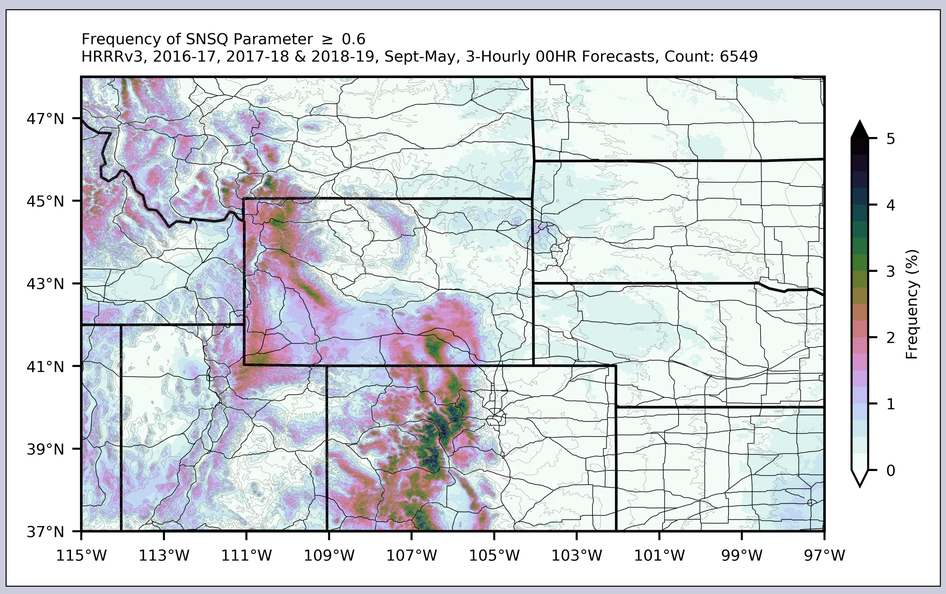
Spatial distribution of SNSQ, relative humidity, instability, and wind speed threshold exceedance frequencies





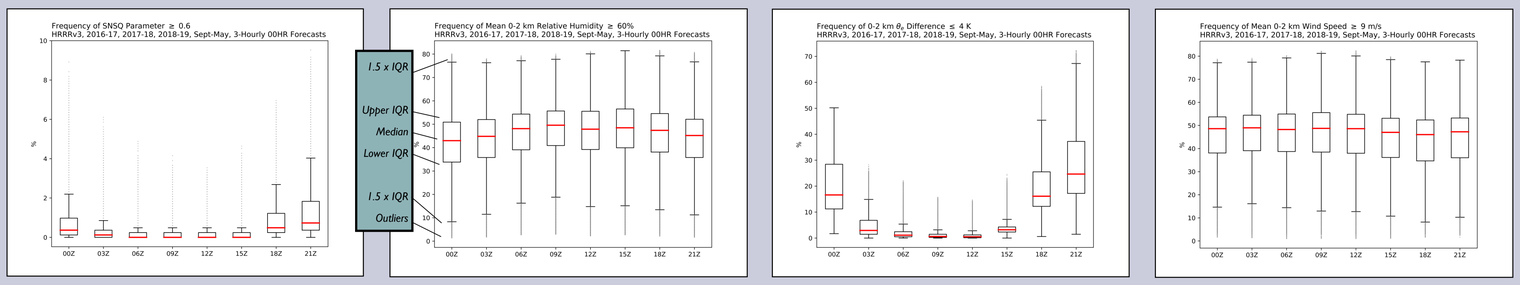






* Terrain influences are resolved in the 3-km resolution HRRR output with significant effects observed in the threshold exceedance frequencies of relative humidity and wind speed. Notably, the Wind River and Big Horn Mountain Ranges act to dry and slow low-level flow. More subtly, the Black Hills influence a downstream corridor that stretches through eastern SD.
* Low-level instability is the major limiting factor in snow squall development across the High Plains and Mountain West.
* The heavily trafficked I-80 corridor in southern WY is a climatological maximum for high winds, blowing snow, and snow squalls.

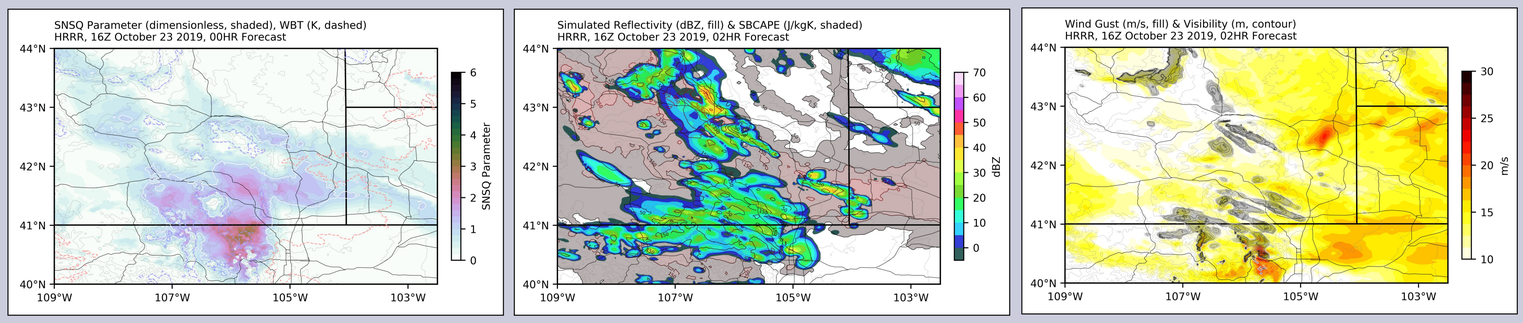
Diurnal and seasonal trends



Diurnal Trends: Frequencies of the SNSQ parameter follow the diurnal stability trend reflecting the dependence on low-level instability. Relative humidity follows a typical (morning maximum, late afternoon minimum) diurnal trend.

Seasonal Trends: Increased occurrences of SNSQ are directly related to occurrences of low-level instability which are maximized during the transition season but are mitigated by wet bulb temperatures greater than 1 °C.

Snow squall event



October 23rd, 2019: A demonstration of the HRRR model's ability to predict snow squalls via the snow squall parameter. SNSQ values (top left) approaching 1.0 along I-25 near Douglas, WY indicate a sufficiently moist & unstable 0-2km layer primed for snow squalls. Forecast reflectivity (top center) verified reasonably well given the convective nature of the squalls. The observed northern line appears less threatening on radar (bottom center) than its southern counterpart, but observations and webcam imagery (bottom right) suggest it is equally as dangerous (gusts > 35mph, vis < 1/2 SM).