Determining Precipitation Type from Maximum Temperature in the Lower Atmosphere

Marc Chenard (NOAA/NWS/NCEP/WPC College Park, MD)

Philip Schumacher (NOAA/NWS/WFO Sioux Falls, SD)

Heather Reeves (CIMMS/Univ. of Oklahoma and NOAA/NSSL Norman, OK)

Background

- Impacts of snow, sleet and freezing rain can be vastly different
- Thus important to accurately forecast which will be the predominant type
  - Forecast amounts of ice and snow rely on an accurate precipitation type forecast
- Current methods result in low skill scores in differentiating between sleet and freezing rain
- Precipitation type algorithms
  - Baldwin
  - Bourgouin
  - Ramer
  - NSSL
- Need for probabilistic precipitation type?
  - If current science can not reliably predict whether sleet or freezing rain will fall, are we doing a disservice to our users if we forecast one over the other…especially given the different impacts?

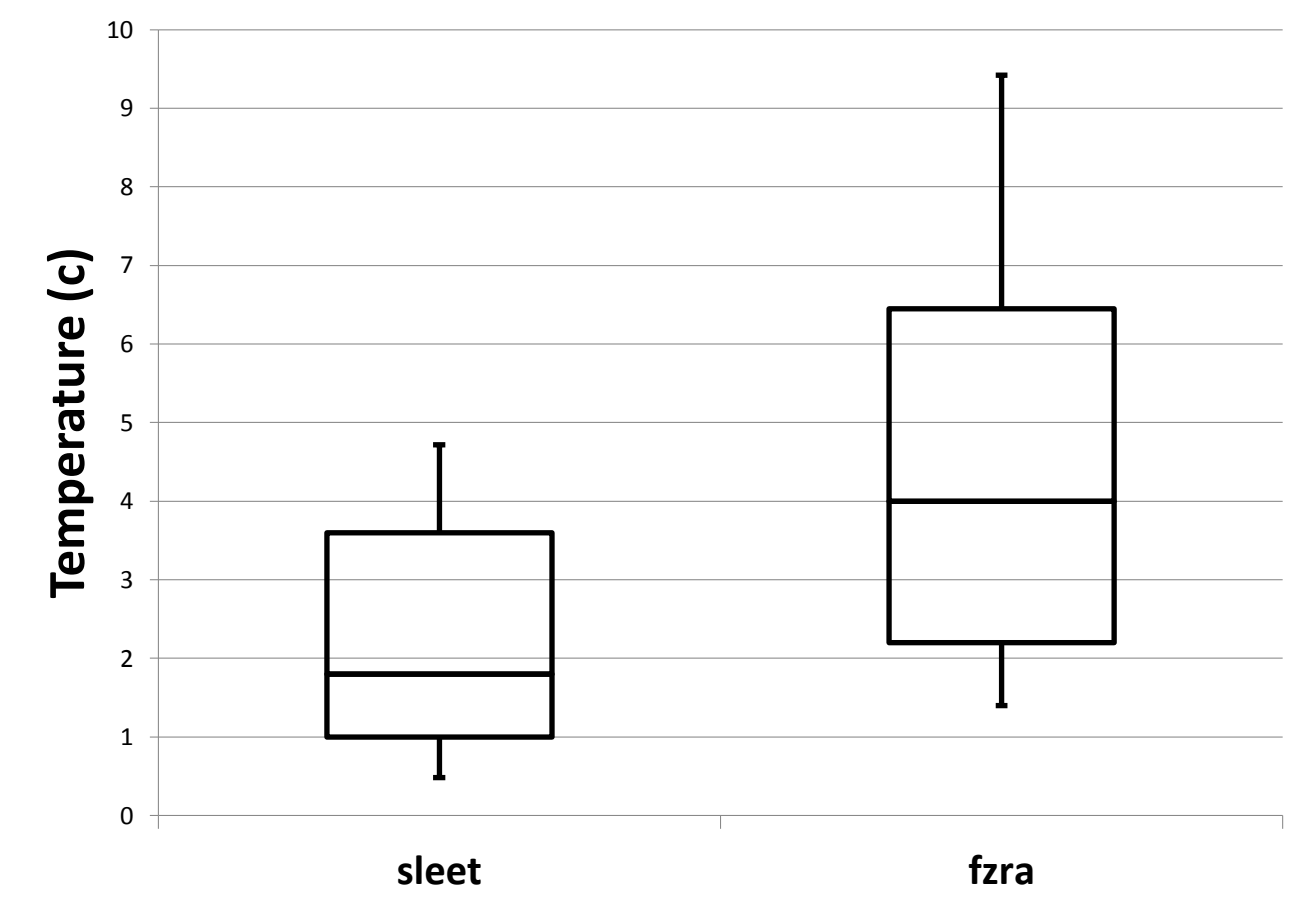
Research Overview

- Goal is to use a large dataset to produce probabilities of different precipitation types based on the maximum temperature aloft
  - Top-down method
    - Ice in cloud
    - Warm layer aloft temperature and depth (melting)
    - Cold layer below (re-freezing)
  - This talk focuses on warm layer aloft contribution
  - Surface based cold layer differences not found to be significant by Reeves et al. 2014
  - Used 500m to 600mb layer and found the max temperature in that layer
  - Rauber et al. 2001 showed a strong correlation between max temperature aloft and depth of warm layer
  - Used dataset from Reeves et al. 2014
    - Winter months 2002-2013
    - Reports from ASOS within 35km of upper air site
    - Only those cases with an elevated warm layer were included
    - 422 freezing rain cases, 125 sleet and 34 snow
- Sounding max temperature aloft data was binned every 0.5C, with probabilities of snow, freezing rain and sleet produced for each bin
- Effects of uncertainty due to model error are then examined
  - Observed soundings perturbed based on typical errors seen in a mesoscale modeling system
  - New probabilities then developed

Potential Sources of Error

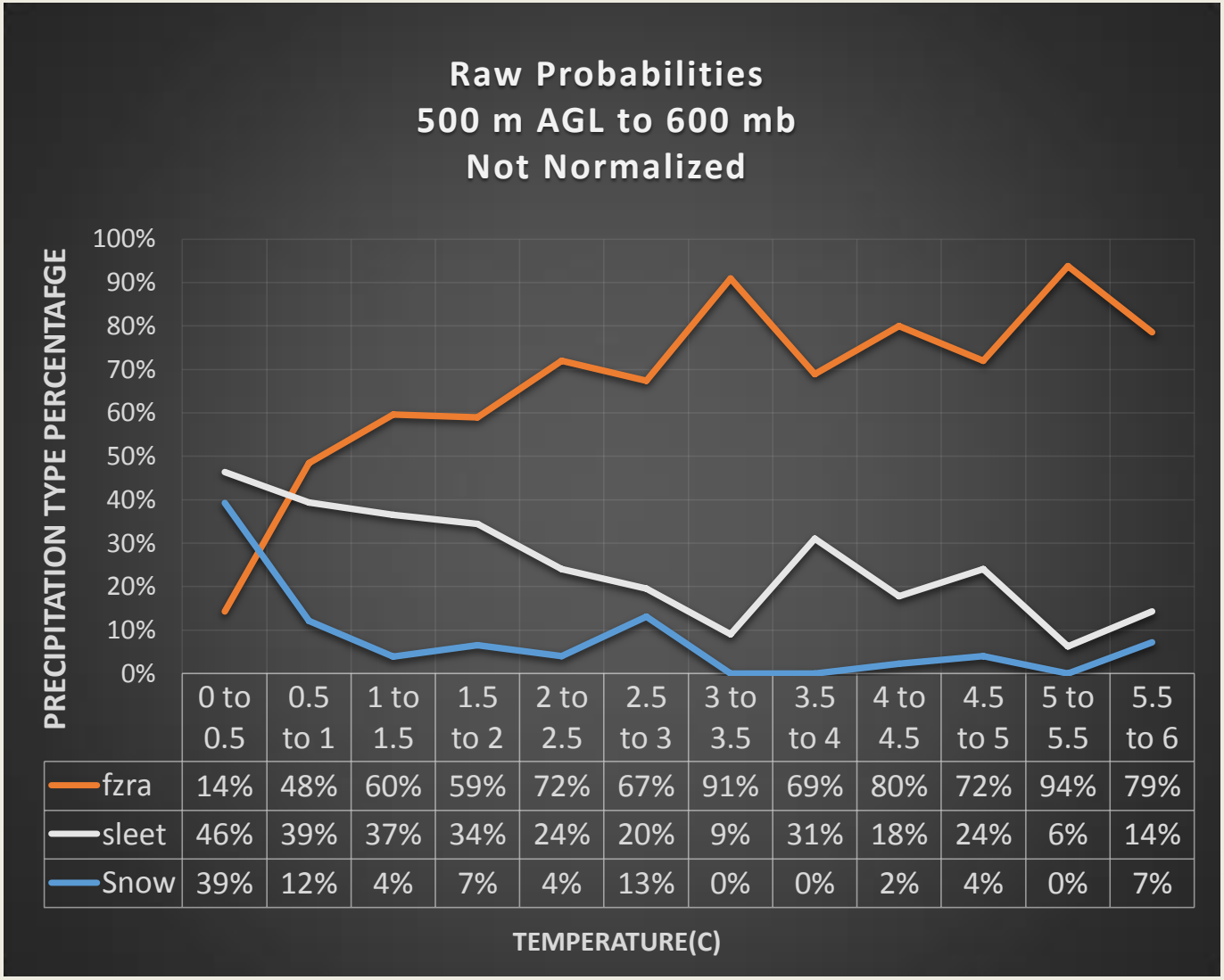
- Unequal amount of sleet and freezing rain cases
  - Sleet is only reported at observation sites augmented by a human.
  - Thus the distribution (3.4X more freezing rain than sleet cases) in the dataset is probably not the true distribution seen in nature.
  - Different methods of normalizing the data were thus used
    - Assume a 1:1 ratio of sleet to freezing rain
    - Assume a 1.7:1 ratio of freezing rain to sleet
    - Little research actually exists on the true ratio of sleet to freezing rain seen in nature. However based on Gay et al. 1991 and subjective experience, it is thought that freezing rain occurs more often than sleet at roughly a 1.5-2:1 ratio
- Some of the freezing rain cases may be the result of no ice in the cloud and not the warm layer
  - Only freezing rain cases in which the temperature profile crossed 0c twice were used in an attempt to eliminate some of these cases. However some may still remain.
  - Could result in a high bias in probability of freezing rain at cooler temperatures (0c to +3c)
  - Future work will include developing a method to eliminate all freezing rain cases that may not have ice present
- Drift of weather balloon and unknown exact launch time may introduce some errors given transitory nature of sleet/freezing rain
- Goal of this research is to isolate the role of this one factor (Maximum Temperature aloft) on observed precipitation type
  - Not intended to propose a complete precipitation type strategy as other factors are also important

Distribution



- 75% of sleet events have a MaxT aloft less than +3.6c
- 75% of freezing rain events have a MaxT aloft greater than +2.2c
- Thus biggest overlap between roughly +2c and +3.5c
- Colder than +2c mainly sleet
- Warmer than +3.5c mainly freezing rain

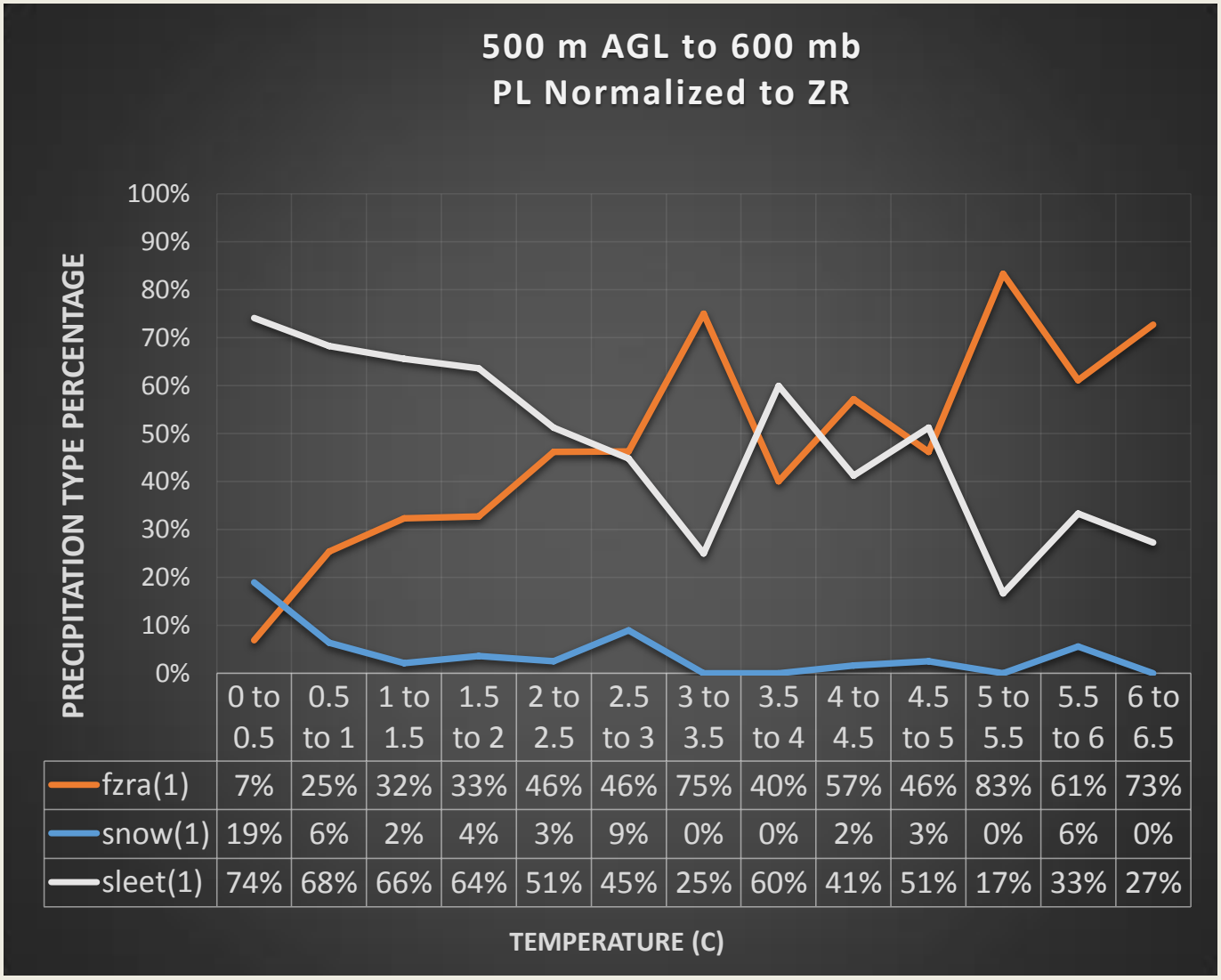
Binned Probability – Not Normalized



	0 to 0.5	0.5 to 1	1 to 1.5	1.5 to 2	2 to 2.5	2.5 to 3	3 to 3.5	3.5 to 4	4 to 4.5	4.5 to 5	5 to 5.5	5.5 to 6
fzra	14%	48%	60%	59%	72%	67%	91%	69%	80%	72%	94%	79%
sleet	46%	39%	37%	34%	24%	20%	9%	31%	18%	24%	6%	14%
Snow	39%	12%	4%	7%	4%	13%	0%	0%	2%	4%	0%	7%

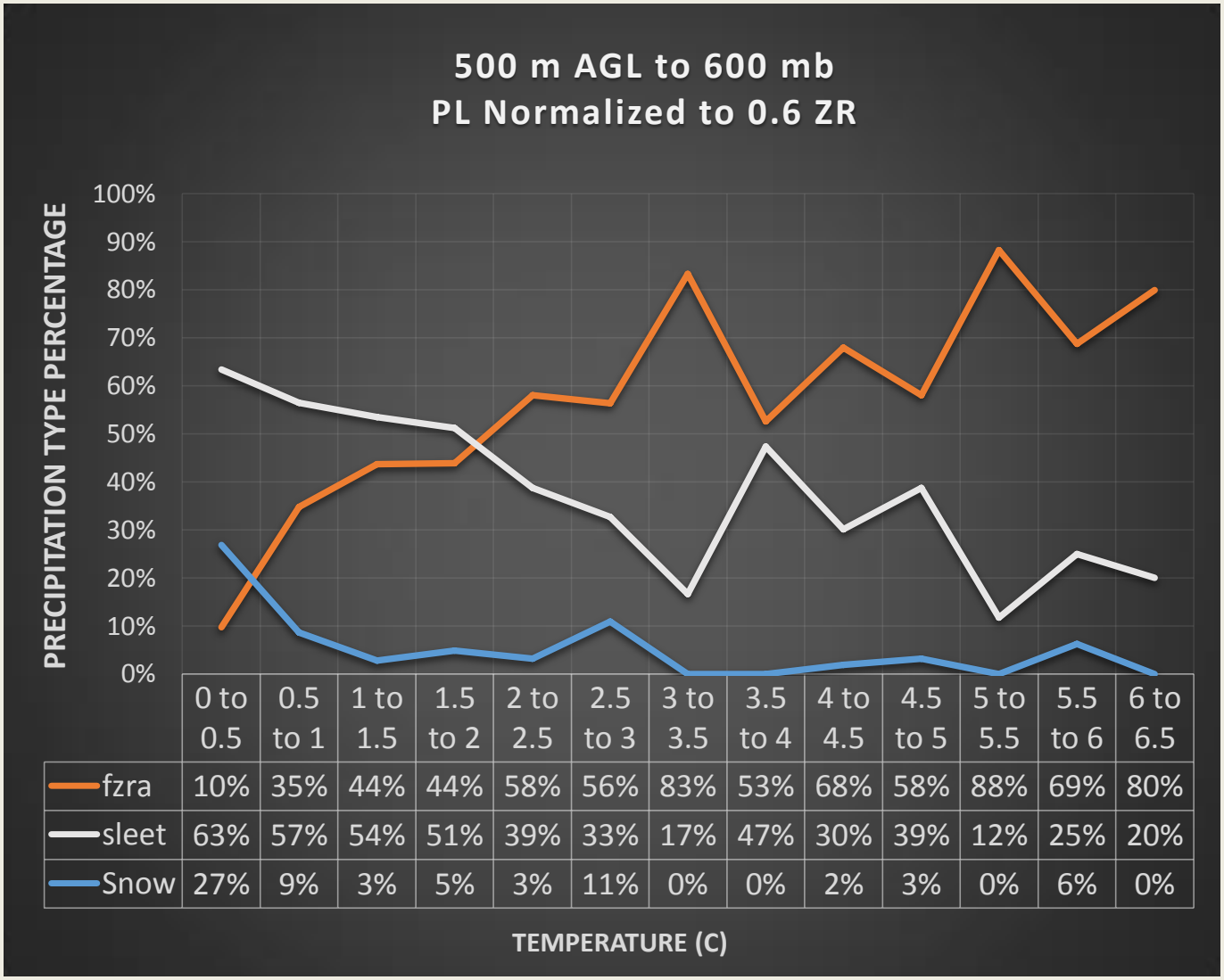
- Sleet has a max probability of only 46%
- Sleet probabilities likely biased too low given the distribution in the data set

Binned Probability - Normalized



	0 to 0.5	0.5 to 1	1 to 1.5	1.5 to 2	2 to 2.5	2.5 to 3	3 to 3.5	3.5 to 4	4 to 4.5	4.5 to 5	5 to 5.5	5.5 to 6	6 to 6.5
fzra(1)	7%	25%	32%	33%	46%	46%	75%	40%	57%	46%	83%	61%	73%
snow(1)	19%	6%	2%	4%	3%	9%	0%	0%	2%	3%	0%	6%	0%
sleet(1)	74%	68%	66%	64%	51%	45%	25%	60%	41%	51%	17%	33%	27%

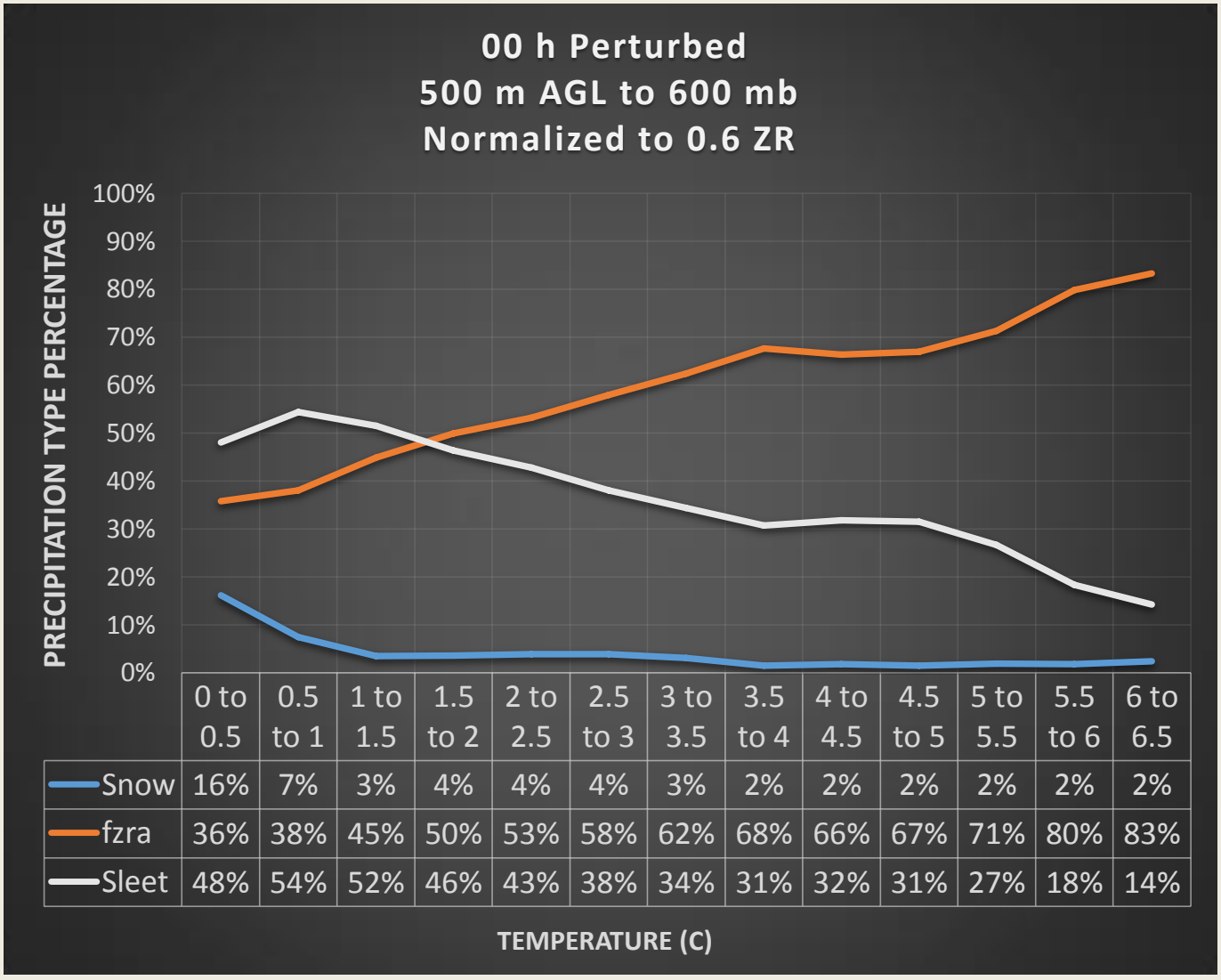
Binned Probability - Normalized



	0 to 0.5	0.5 to 1	1 to 1.5	1.5 to 2	2 to 2.5	2.5 to 3	3 to 3.5	3.5 to 4	4 to 4.5	4.5 to 5	5 to 5.5	5.5 to 6	6 to 6.5
fzra	10%	35%	44%	44%	58%	56%	83%	53%	68%	58%	88%	69%	80%
sleet	63%	57%	54%	51%	39%	33%	17%	47%	30%	39%	12%	25%	20%
Snow	27%	9%	3%	5%	3%	11%	0%	0%	2%	3%	0%	6%	0%

- Sleet max probability is 63% and is highest probability precipitation type between 0c and +2c
- If assume a precipitation type becomes dominant at a 60% probability…no type is dominant between +0.5c and +3c
- Sleet is dominant between +0c and +0.5c
- Freezing rain generally becomes dominant at > +3C, although some probability of sleet remains

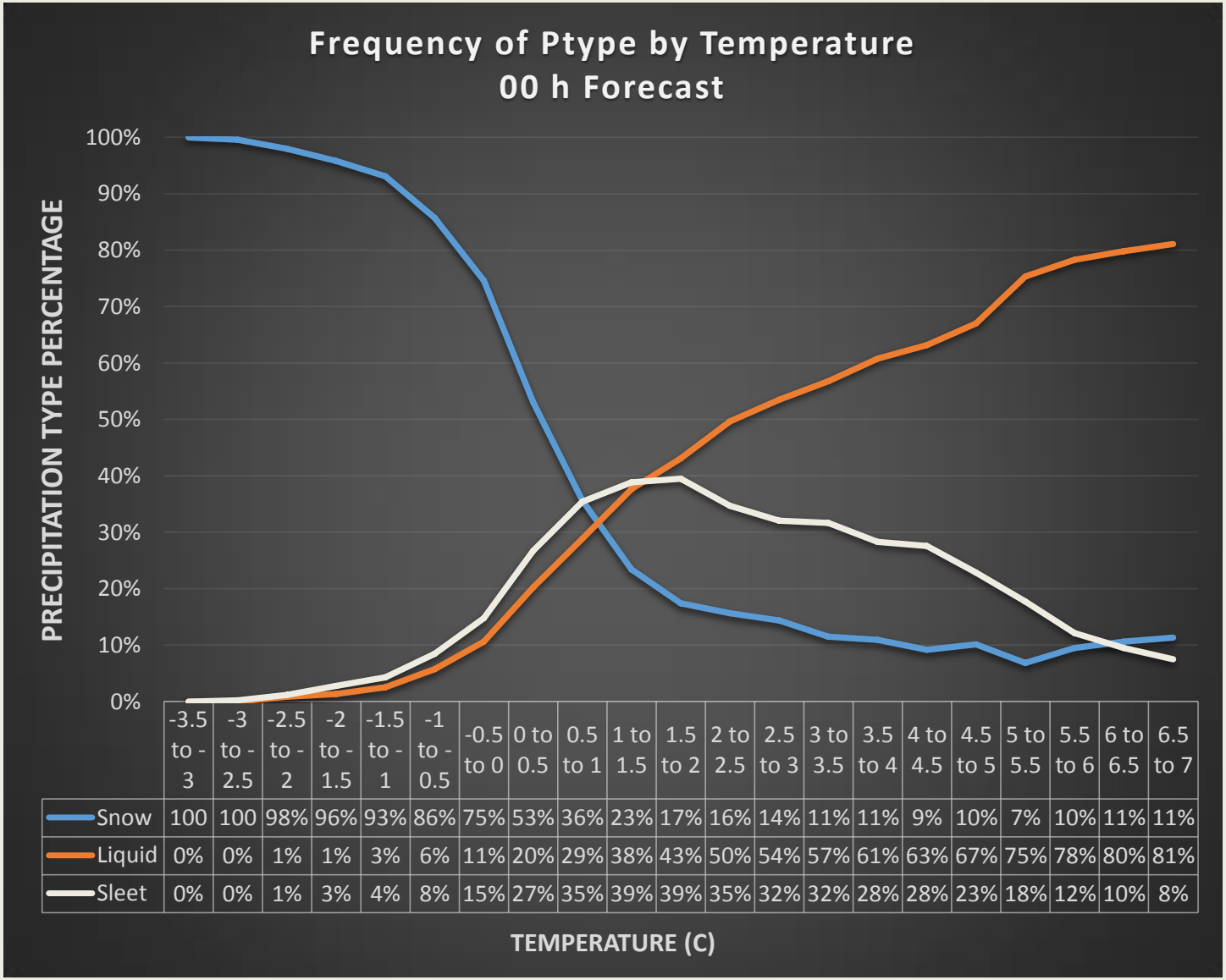
Probability 00hr Perturbed



	0 to 0.5	0.5 to 1	1 to 1.5	1.5 to 2	2 to 2.5	2.5 to 3	3 to 3.5	3.5 to 4	4 to 4.5	4.5 to 5	5 to 5.5	5.5 to 6	6 to 6.5
Snow	16%	7%	3%	4%	4%	4%	3%	2%	2%	2%	2%	2%	2%
fzra	36%	38%	45%	50%	53%	58%	62%	68%	66%	67%	71%	80%	83%
Sleet	48%	54%	52%	46%	43%	38%	34%	31%	32%	31%	27%	18%	14%

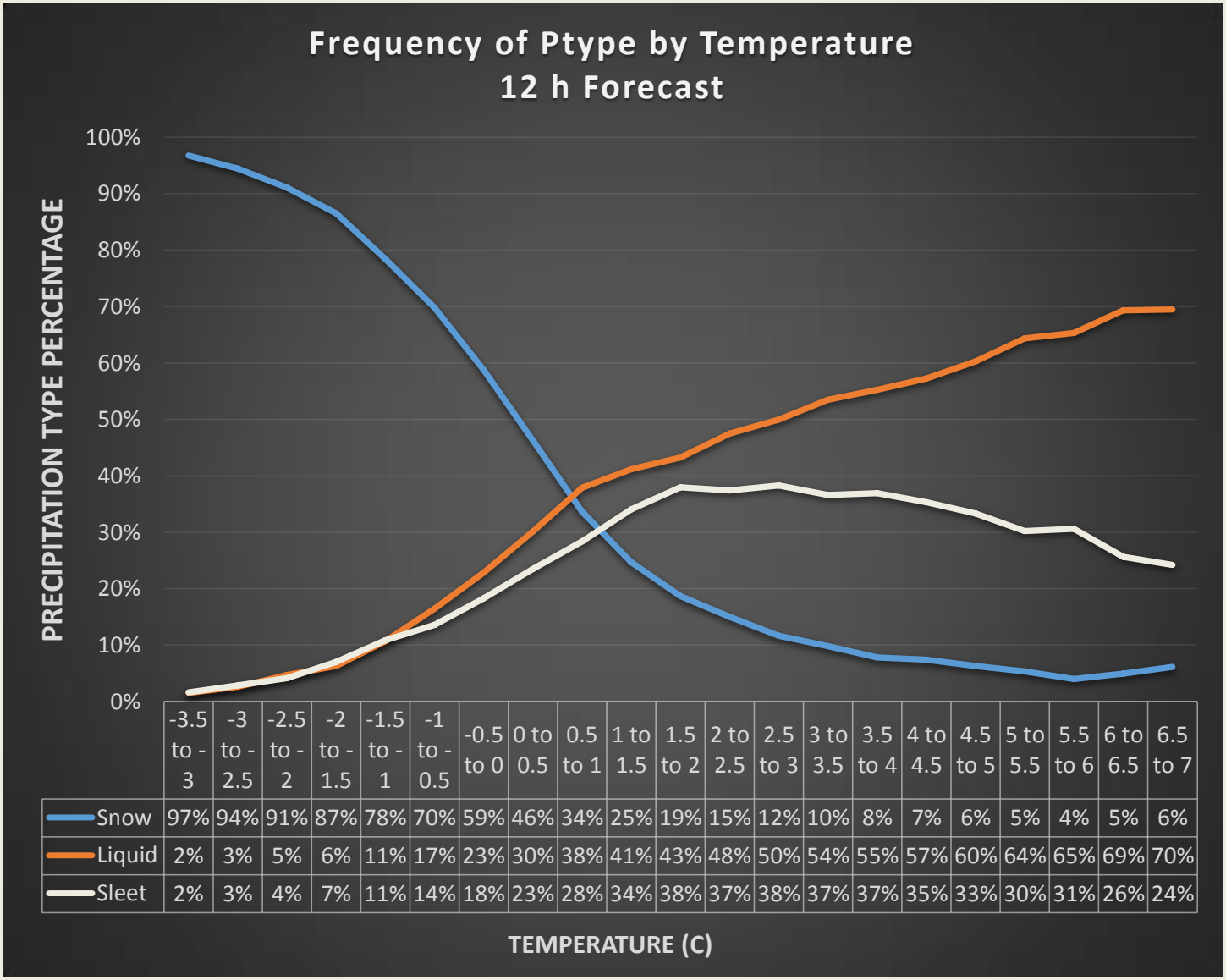
- 2,526 snow cases…10,646 sleet and 39,469 freezing rain
- More cases so probability curves are smoother
- Sleet probabilities decrease with a max of 54% between +0.5c and +1c and is only most likely between 0c and +1.5c (0.5c less than non-perturbed data)
- Freezing rain probability still become dominant at +3c
- Sleet probability stays around 30% from +3c to +5.5c and between 10%-20% between +5.5c and +6.5c
- Surface based cold layer could be playing a factor here. Future work will include a way to isolate those cases

All Cases Perturbed



	-3.5 to -3	-3 to -2.5	-2.5 to -2	-2 to -1.5	-1.5 to -1	-1 to -0.5	-0.5 to 0	0 to 0.5	0.5 to 1	1 to 1.5	1.5 to 2	2 to 2.5	2.5 to 3	3 to 3.5	3.5 to 4	4 to 4.5	4.5 to 5	5 to 5.5	5.5 to 6	6 to 6.5	6.5 to 7
Snow	100	100	98%	96%	93%	86%	75%	53%	36%	23%	17%	16%	14%	11%	11%	9%	10%	7%	10%	11%	11%
Liquid	0%	0%	1%	1%	3%	6%	11%	20%	29%	38%	43%	50%	54%	57%	61%	63%	67%	75%	78%	80%	81%
Sleet	0%	0%	1%	3%	4%	8%	15%	27%	35%	39%	39%	35%	32%	32%	28%	28%	23%	18%	12%	10%	8%

All Cases Perturbed



	-3.5 to -3	-3 to -2.5	-2.5 to -2	-2 to -1.5	-1.5 to -1	-1 to -0.5	-0.5 to 0	0 to 0.5	0.5 to 1	1 to 1.5	1.5 to 2	2 to 2.5	2.5 to 3	3 to 3.5	3.5 to 4	4 to 4.5	4.5 to 5	5 to 5.5	5.5 to 6	6 to 6.5	6.5 to 7
Snow	97%	94%	91%	87%	78%	70%	59%	46%	34%	25%	19%	15%	12%	10%	8%	7%	6%	5%	4%	5%	6%
Liquid	2%	3%	5%	6%	11%	17%	23%	30%	38%	41%	43%	48%	50%	54%	55%	57%	60%	64%	65%	69%	70%
Sleet	2%	3%	4%	7%	11%	14%	18%	23%	28%	34%	38%	37%	38%	37%	37%	35%	33%	30%	31%	26%	24%

Summary of Results

- Data suggests that it should be rare to forecast only sleet, with probabilities maximizing only between 54%-63%
- Instead using a mix of sleet and freezing rain should be considered in most cases
- Freezing rain should only be forecast as the sole precipitation type when max temperatures in the warm nose are high (~ > +5c or +6c)
- When model error at forecast hour 0 is accounted for, distributions become smoother
  - Sleet probabilities decrease and freezing rain probabilities increase between 0c and +2c
- As model forecast hour is increased distributions broaden
  - By forecast hour 12 sleet never has a higher probability than freezing rain
  - By forecast hour 12 sleet probabilities increase at values > +2.5c
  - By forecast hour 12 snow probabilities drop to 70% by the -1c to -0.5c bin
  - Snow probability drops off quickly around 0c...suggesting tools that use a top down method should not produce an all snow forecast at any temperature above 0c.
  - Snow probabilities drop below 20% by +1.5c at both 0 and 12 hour forecast times

Summary of Results

- Three Factors to consider when developing Precipitation Type Probabilities
  - (1) Given an observed sounding, what is the precipitation type
    - First section of this study (along with numerous other studies) have looked into this aspect
    - While science has made progress with this, some uncertainty still remains
  - (2) How do these probabilities change when model error is taken into account
    - Second portion of this study briefly begins to look at this aspect
    - Probability Distributions broaden
  - (3) How do these probabilities change when individual model biases are considered
    - Would the same sounding from different models (NAM,GFS,RAP) result in the same precipitation type?
    - Subjective observation suggests the answer is no. Systematic model biases may result in different probability distributions for each model
    - Dr. Kim Elmore from OU-CIMMS has ongoing research looking at using the random forests statistical method to determine precipitation type
    - Among other findings his research has shown that the forests are different for each model considered (NAM,GFS,RAP) and that skill decreases if you use the forests generated from one model on another model
      - May suggest that systematic differences within the models are indeed important to consider when attempting to determine precipitation type from the model

Application

- Probability of Weather Type Tool (PoWT) developed at WFO Lacrosse, WI (Dan Baumgardt, Andy Just)
- Used by local weather forecast offices (WFO) for precipitation type and snow/ice accumulations
  - Similar tool used in the CR Forecast Builder and being developed for the National Blend of Models
- Uses the top-down methodology to generate probabilities of snow, freeing rain and sleet
- These probabilities are then used to derive snow/ice amounts from forecast QPF
  - For Example: If we had 1" QPF in a 6 hour period, with a 25% chance sn, 50% pl and 25% fzra
    - We would get 2.5" sn (assuming 10:1), 1" pl (assuming 2:1 ratio), and 0.25" fzra (assuming 1:1)
- So if we can come up with reliable probabilities, they could be used in this tool
- Makes it easier for the forecaster to derive snow and ice amounts and results in a more scientifically sound forecast
- More consistent forecast from WFO to WFO

Additional Thoughts

- NDFD consistency issues with weather and snow/ice accumulations
  - Many different tools and methods of generating these grids in the field
- What role does the Weather Prediction Center (WPC) play?
  - Produce collaborated 24 hour snow/ice totals that are disaggregated into 6 hour grids for use at the local forecast office
  - However if one wishes to use these grids in a mixed precipitation event it becomes tricky
  - Need to make sure weather grids match snow/ice totals
  - WPC does not produce weather type guidance
  - Thus requires one to work backwards from the amounts to come up with consistent weather grids
  - Can be very difficult in the new era of preferred hourly weather grids
- Potential need to develop method to link WPC snow/ice forecasts to the GFE forecast process at the local office
  - Model probabilities of weather type?
    - Could use similar method as described in this talk and generate precipitation type probabilities from various models…which could be blended as desired by forecaster
  - Could include more information into the algorithm…such as microphysical controls
  - Probabilities from models or NBM are tweaked by WPC, as needed based on model preferences, and sent to the field
    - Have a national Probability of Precipitation Type grid for entire country
  - Field offices make any additional fine-tuning, including adjustments using NDFD surface temperatures