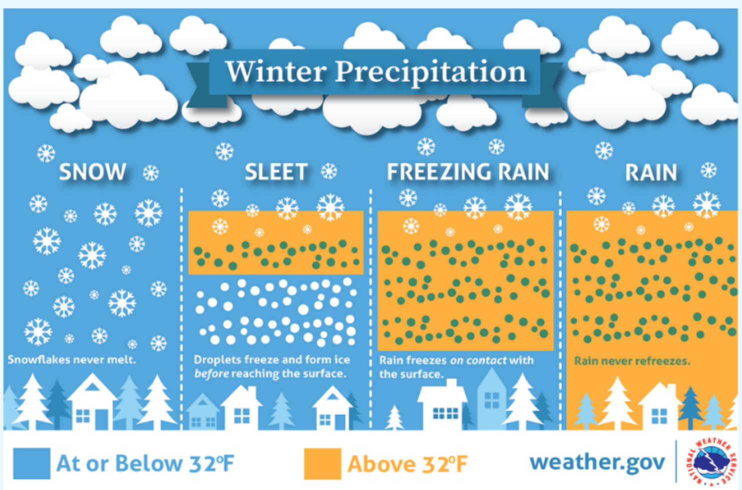
Freezing Rain

What is it?

Freezing rain occurs when snowflakes fall, and enter a deep layer of warm air aloft, and turn into liquid droplets. Before hitting the surface, the droplets enter a shallow cold layer. This does not allow for the droplets to refreeze in time. This droplet is now “supercooled”, and when it hits the ground below 0°C, it creates a layer of ice on the surface. [1]

Supercooled refers to water droplets that remain in a liquid state despite being at temperatures below freezing.



Winter Precipitation

Rain:

Frozen precipitation that falls through a deep warm layer and melts into liquid before reaching the ground.

Sleet:

Frozen precipitation falls through a warm layer and melts, then falls through another cold layer that is deep enough to refreeze the raindrops into pellets before hitting the ground.

Snow:

Frozen precipitation that never melts during its descent to the surface [2]

Ice Storms:

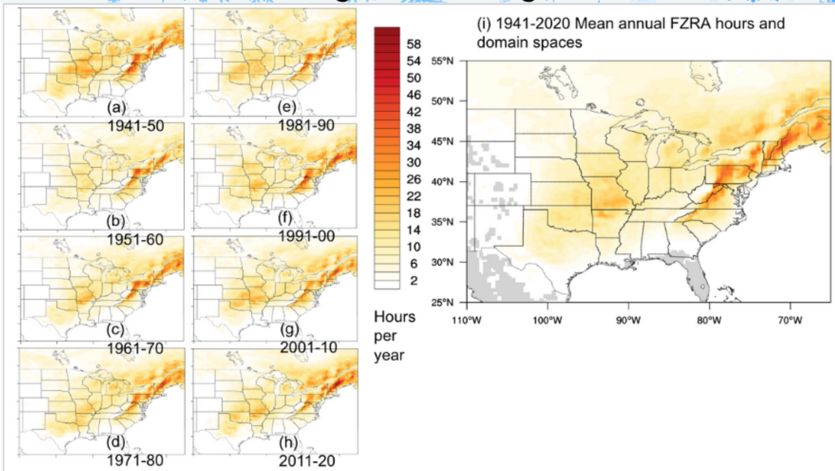
An ice storm occurs when freezing rain accumulates at least 0.25 inches upon contact with surfaces, creating hazardous conditions. [3]

Hazards:

- Freezing Rain in high quantities can bring down trees, utility poles, and communication towers.
- Ice storms can disrupt power and communications for days as utility companies repair damage.
- Bridges and overpasses freeze before other surfaces, making them especially hazardous.
- Even small ice accumulations pose a serious risk to motorists. [4]

Freezing Rain

Climatology of Freezing Rain



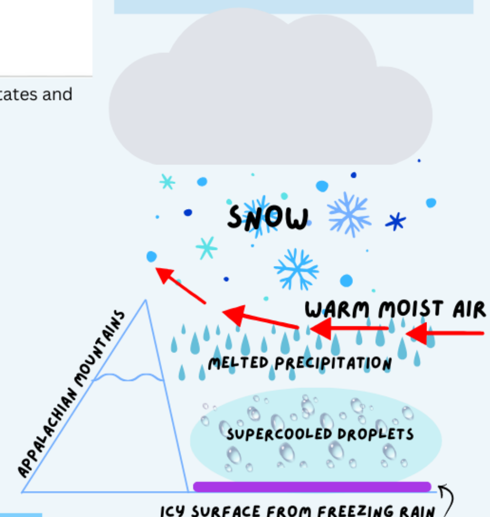
10-Year Average of Freezing Rain Duration, calculated in Hours Per Year, in the United States and Southern Canada, in 10-Year Increments from 1941 to 2020

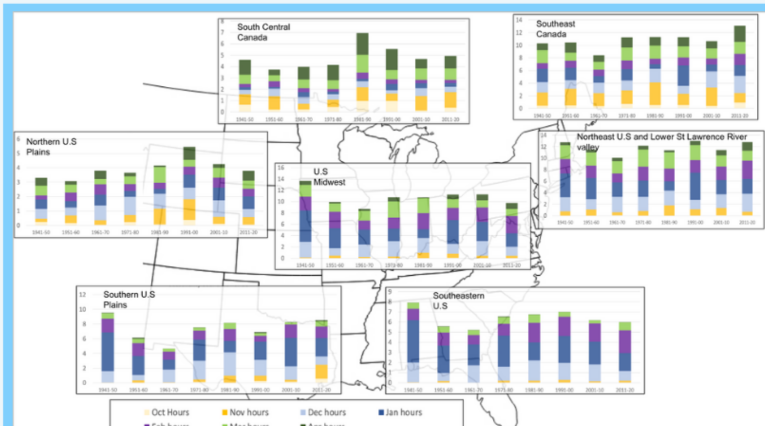
Where can we see freezing rain?

Freezing Rain is most prevalent over the Eastern/North Eastern portion of the United States, the densest accumulation is found east of the Appalachian Mountain, This is as a result of Cold Air Damming

Cold air damming

Cold Air Damming (CAD) occurs when a cold air mass moves southward and becomes trapped (usually) against the eastern side of a large mountain range. A stable layer of warm air aloft prevents the cold air from ascending over the terrain, effectively confining it near the surface. This setup promotes rising motion in the warm air layer, leading to precipitation. When cold air remains trapped at the surface, the likelihood of freezing rain events increases. See the diagram to see how this looks for the Appalachian Mountains.





Breakdown of Freezing Rain Hours per Month by Region in the United States and Southern Canada, in 10-Year Increments from 1941 to 2020.

Historically, freezing rain in the Northern U.S. and Southern Canada occurs primarily from November through April. In the Southern U.S., freezing rain is more common in the later part of the winter season, though the past 40 years have seen an increase in freezing rain hours during November.

References

[1] NOAA. Winter Weather Basics. NOAA National Severe Storms Laboratory.

[2] US Department of Commerce, N. (2024, October 10). Winter preparedness. National Weather Service.

[3] US Department of Commerce, N. (2019, July 31). Ice storms. National Weather Service.

[4] Ice storm. Ice Storm | National Risk Index.

UNIVERSITY of FLORIDA Geography

NSF

WHAT ATMOSPHERIC WEATHER PATTERNS RESULT IN FREEZING RAIN IN EASTERN NORTH AMERICA?

Freezing rain has caused billions of dollars in damages in recent decades, and yet is still one of the least understood forms of precipitation. Freezing rain events occur all over the United States, however the sporadic nature of these events present significant challenges to accurate reporting. This complicates analysis to fill in gaps of knowledge when attempting to research these events.

Dangers of Freezing Rain:

Freezing rain can cause major damage by bringing down trees, power lines, and communication towers, often leading to extended outages. Even small amounts of ice make roads extremely dangerous for drivers.

Our research questions:

- What weather patterns drive the majority of large freezing rain events east of the Rocky Mountains?
- How do these patterns influence the characteristics of the events themselves (e.g., duration, intensity, location),

Our Methods:

- A machine learning technique that uses historical weather events and groups them into different synoptic set-ups (regimes).
- We used data from the European Reanalysis project (ERA5) extending from 1979-2020.

LARGE-SCALE WEATHER PATTERNS:

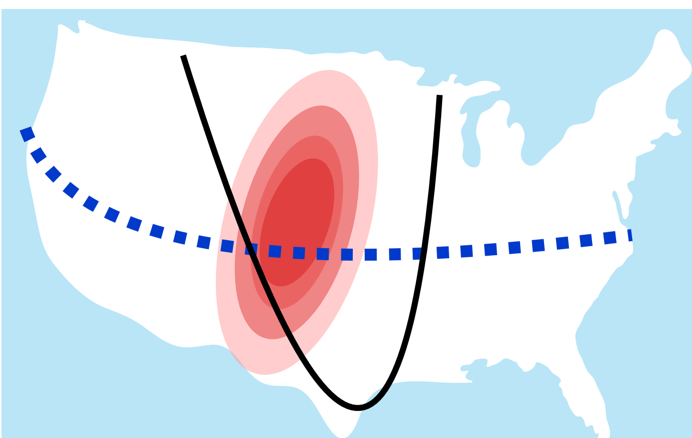
Higher sea level pressure anomaly

Lower sea level pressure anomaly

500-mb height contours (ridge and troughs)

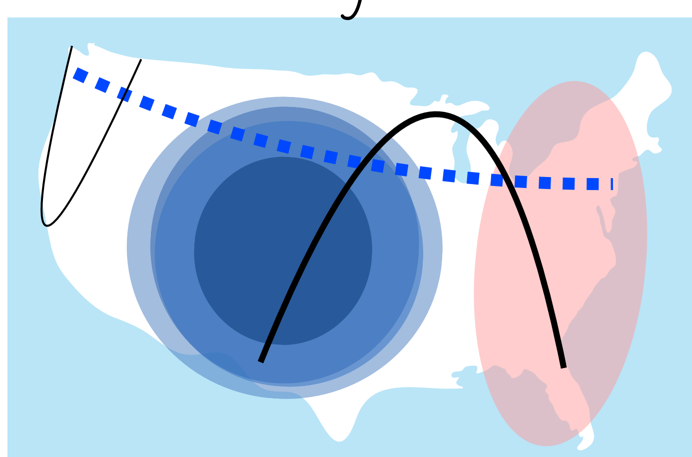
Surface freezing contour

Regime 1



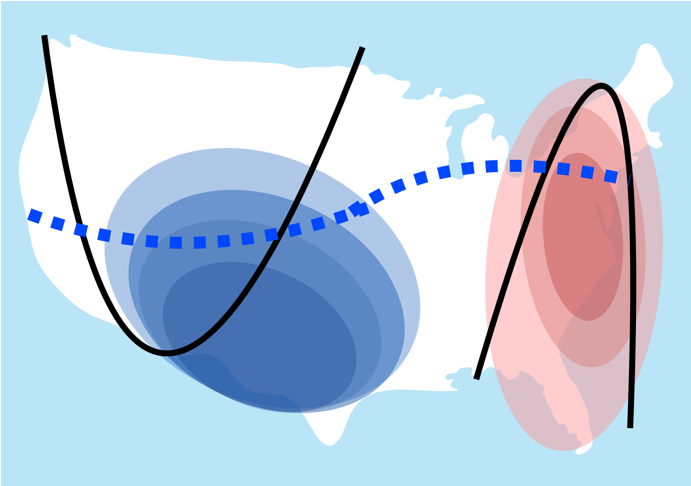
Regime One (R1) shows a classic cold air outbreak across the U.S. A deep dip in the jet stream brings Arctic air south. A strong surface high pressure anomaly forms over the Central U.S., helping push the cold air down. Temperatures drop sharply, especially in the Midwest and Great Plains. This pattern often results in freezing rain in the midwest and south.

Regime 2



Regime 2 (R2) features a trough (upper-level low pressure) over Western North America, similar to R1 but with weaker anomalies, and a dominant ridge (upper level high pressure) centered over the Midwest extending across the Eastern U.S. At the surface, there is a western low pressure and eastern high pressure anomaly. The composite surface freezing contour suggests most events in this pattern are in the north.

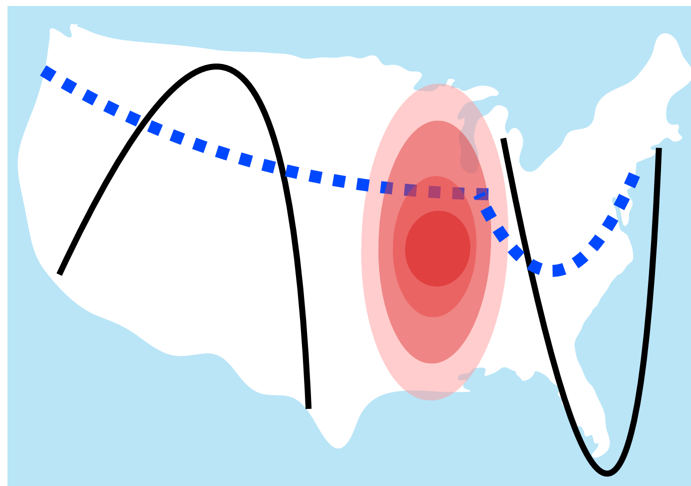
Regime 3



Regime 3 (R3) features a pronounced eastern ridge centered along the U.S. East Coast and a deeper trough over the southern plains. Lower pressure anomalies are featured around the area of the trough in the Southern Plains while an area of Higher pressure is present over the East coast. The composite freezing contour lies in a roughly southwest to northeast orientation.

Regime 4

Regime 4 (R4) is characterized by an eastern trough and a broad ridge over the western half of the domain. The midwest and south region features higher pressure anomalies. Though overall, these anomalies are weaker than in other regimes. Cold air damming east of the Appalachian Mountains is present and shown through the compositetemperature anomaly line, which dips east of the mountains.



FREEZING RAIN DISTRIBUTION

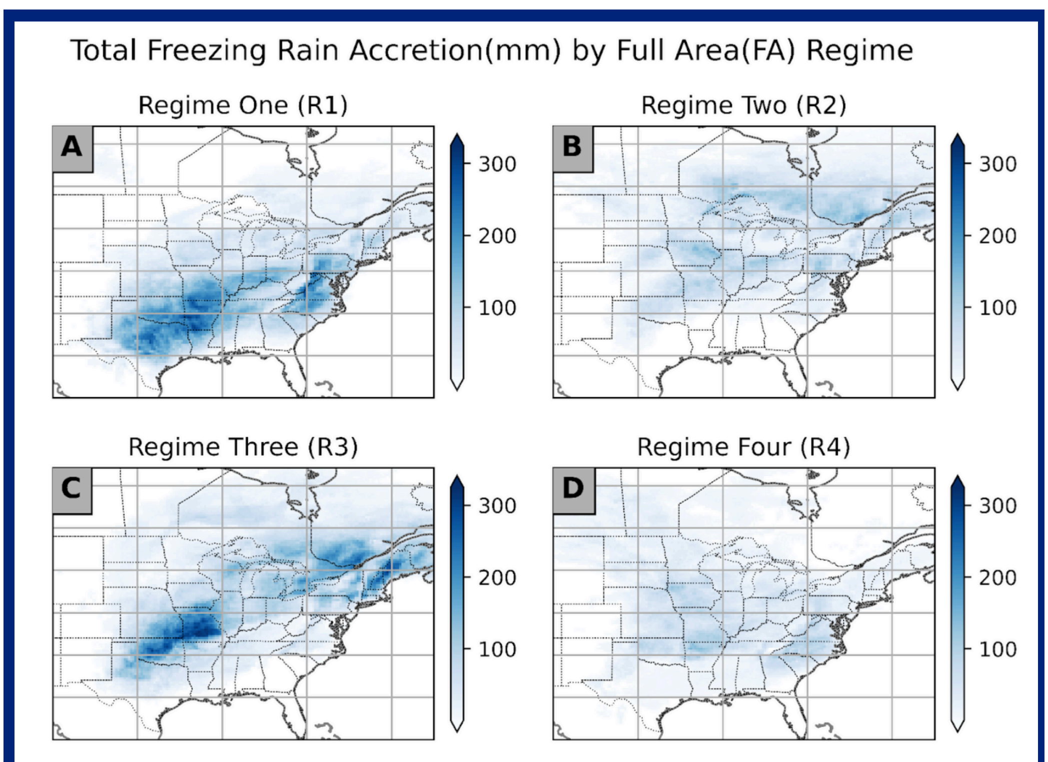


Figure 1: Regimes 1-4 showing total Freezing rain accumulation from using data from 1979-2020, in the Eastern portion of the United States in mm. Accretion is expressed as the sum total across all events in each regime. Adapted from Britton, A. & Mullens, E. (2025).

Regime 1

Freezing rain especially prevalent in Central Texas up through Oklahoma, Missouri, Illinois, Indiana, Ohio, Pennsylvania, West Virginia, Virginia, and North Carolina.

Regime 2

Events are more widely scattered, mostly across the Northern U.S and Southern Canada. Freezing rain patterns

Regime 3

More consistent areas of freezing rain accretion are over Northern Texas,Central Oklahoma, Southeast Kansas, and all throughout the Northeast. Axis similar, but shifted north, compared with R1.

Regime 4

Like R2, events are more scattered, but a bit more to the south and west. Evidence of a maxima east of the Appalachians and in the lower midwest

ATMOSPHERIC PROCESSES:

Heavy Accretion of Freezing Rain

Regime 1: These events often produce freezing rain in a swath extending from Texas through New England, and also east of the Appalachian mountains. This set-up is a typical cold air outbreak (CAO) for a majority of the eastern United States. This implies the presence of an arctic anticyclone which is favorable for a cold and shallow air mass. The dynamical pattern would suggest widespread forcing for ascent (rising air) and slower eastward movement, allowing for long duration freezing rain accretion.

Regime 3 also has a freezing rain pattern stretching across the United States, here the predominant accretion of Freezing rain is present in two main areas, one band in Missouri, and the other within New England. The placement of the eastern ridge and the western trough indicates strong forcing for ascent and sometimes development of a low pressure system (LP) south of the Arctic air. Freezing rain events associated with LP result in stronger rising motion, leading to shorter, more intense storms with greater accretion.

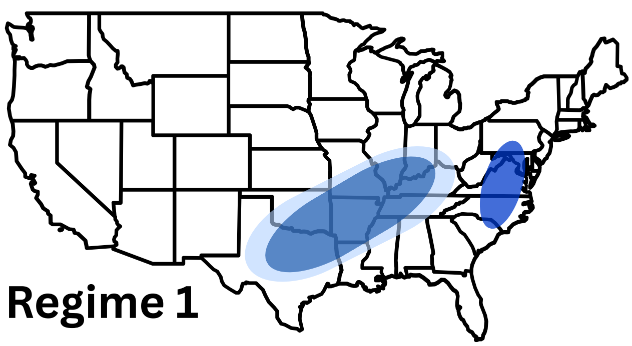
More Variable Freezing Rain Accretion:

Regime 2 is a pattern that has larger differences in where the dominant features set up for any given event. Typically there is a trough over the west and a ridge over the east. This can help warm air push northward causing our surface freezing contour line to be much higher north than seen in Regime 1. This pattern also tends to result in LP development more frequently. Temperature's aren't as cold across much of the region which limits accretion.

Regime 4 differs from the rest of our regimes by having a dominate trough centered over the East coast, and a ridge which spans the entire western half of the U.S. A weak low pressure system and cold temperature anomalies provide forcing for rising air, clouds, and precipitation. The presence of cold temperatures dipping south and higher pressure anomalies in the east allows for formation of freezing rain through the cold air damming mechanism. This is supported through the surface freezing line on Regime 4's diagram near the Appalachians.

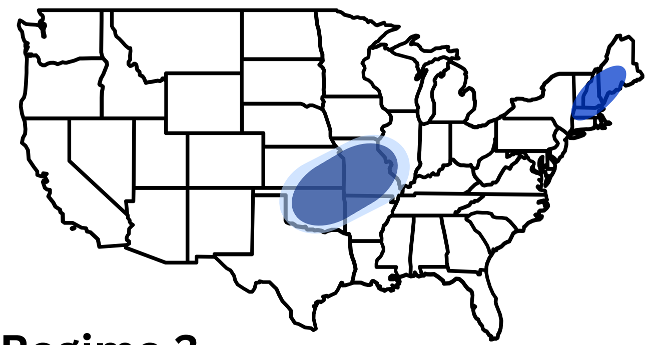
What this means for you

Risk areas for damaging ice accretion under regime 1: N. Texas, Oklahoma, N. Louisiana, Missouri, Illinois, Indiana, Ohio, Pennsylvania, Virginia, West Virginia, & the Carolinas.



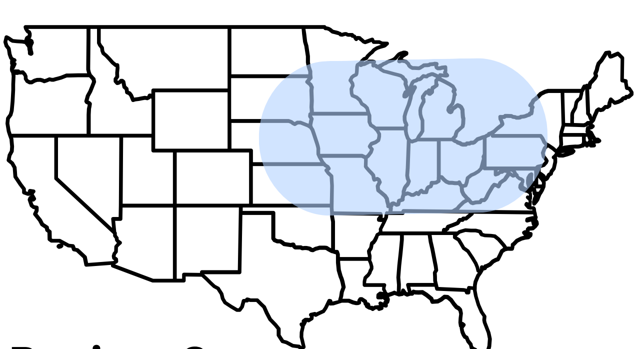
Regime 1

If you live in Oklahoma, Kansas, Missouri, S Illinois, Vermont, Maine, Southeast Ontario, and Southern Quebec, you have highest risk of damaging ice accretion in a setup like Regime 3



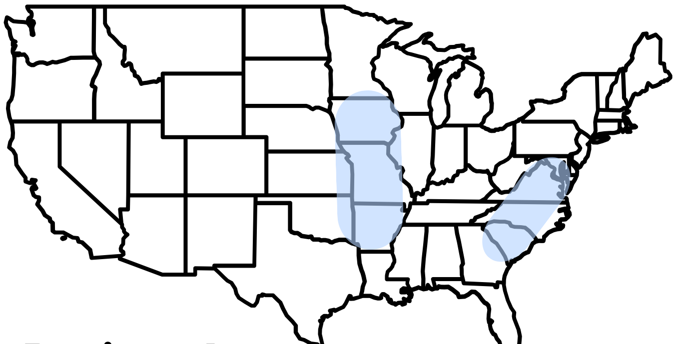
Regime 3

Risk areas for freezing rain accretion are more spread out under regime 2: If you live in the general regions of Southeast Canada and the Midwest, your risk for ice storms is highest under this pattern.



Regime 2

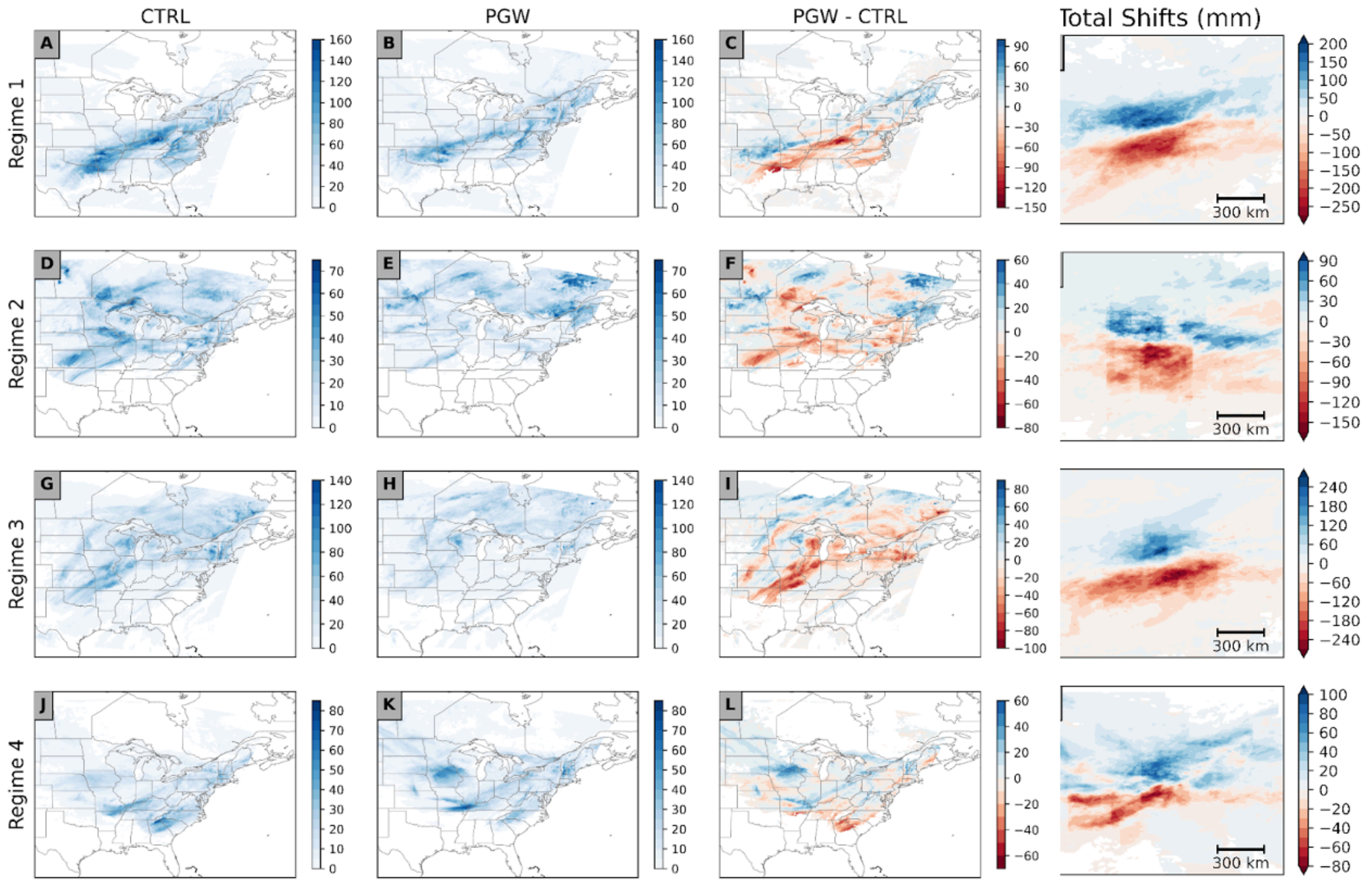
Regime 4 has freezing rain scattered across the eastern half of the United States. If you live east of the Appalachian Mountains, expect freezing rain accretion as a result of cold air damming.



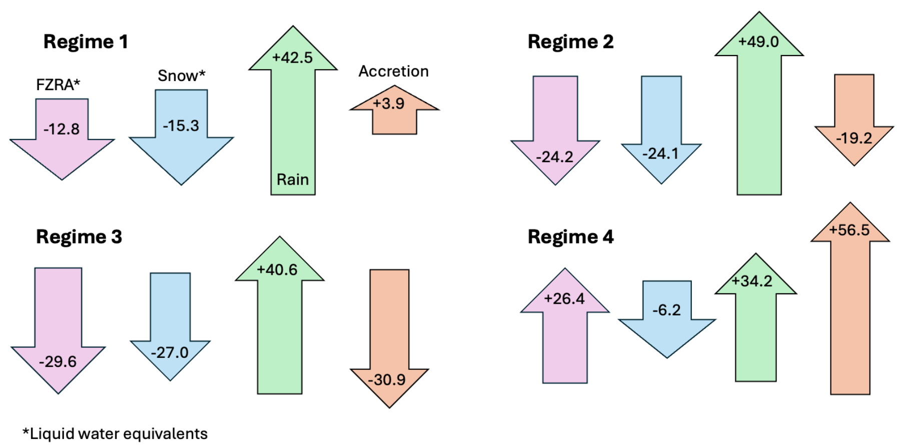
Regime 4

Situation in a warming world:

This study evaluated how events that occurred between 2000-13 (CTRL) would occur if the climate was warmed to a late 21st century under high greenhouse gas emissions, a framework known as 'Pseudo-Global Warming'. (PGW). The data used is called '<u>CONUS1</u>'. As expected, a warmer climate shifts the major axis of freezing rain northward. However, the results also showed that the decline in snowfall exceeding freezing rain. In some locations, freezing rain increased because the warming climate created more favorable conditions due to warmer air. The rain rates also generally increased, through with warmer surface temperatures, accretion of ice on surfaces could become less effective, particularly in areas further south in the U.S. We hope to extend this work to use the latest climate data and tools with this same method.



Freezing rain liquid water equivalent (mm)



Percentage changes in precipitation types as a function of total amounts in each phase, and ice accretion (future - control). Regimes 1 and 4 showed an increase in accretion, particularly the latter. Regimes 2 and 3 showed more substantial declines of freezing rain. All cases showed a large increase in total rainfall.

Acknowledgments

<u>Britton, A. & Mullens, E. (2025)</u>. Temporal and Spatial Analysis of Freezing Rain Regimes over Eastern North America. Department of Geography, University of Florida.

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