A Synoptic Climatology of Winter Storms in the Southern Plains 1993-2011

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1. Introduction

The Southern United States experiences infrequent winter weather, however when it occurs, impacts can be large due to a lack of winter weather infrastructure and preparedness (Grout et al., 2012). Since the year 2000, several damaging winter storms have occurred in the region, many associated with notable accumulations of freezing rain (Kovacik et al., 2010). While national climatologies of winter precipitation have been produced, regional studies are more rare, especially for the south. This work uses the National Climate Data Center (NCDC) Storm Event database and local climate summaries to create a winter weather dataset for the domain encompassing 32-39N and 102-92W. The incidence of precipitation: Freezing (ice and/or sleet) and frozen (snow) was calculated for each climate division. Secondly, two datasets of the 500hPa height fields at the approximate onset time of freezing precipitation were compiled using NARR data for (a) ice and (b) snow dominated events. Given that winter storms commonly occupy a large area, multiple phases of precipitation may occur simultaneously or sequentially over the domain. However, the 'dominant' phase denotes that with has the higher accumulation or the greatest socioeconomic impact. Rotated Principal Component analysis (Richman, 1986) is used to extract common flow fields for snowfall and freezing precipitation. The highest correlated events to each PC pattern are composited and extended back and forward in time by 24 hours. Composites of key variables are used to evaluate common evolutions. The result shown may be used by forecasters or climatologists to aid in recognition and interpretation of winter weather evolution over the region.

Resources and Acknowledgements

Thank you to the following institutions for the use of their data:
National Climatic Data Center (NCDC) 'Storm Event' Archive: http://ncdc.noaa.gov /stormevents
NOAA's Center for Atmospheric Prediction (NCEP-NARR): http://www.esrl.noaa.gov/psd/data/narr/

Thanks also to Dr Michael Richman for assistance in developing the methodology for this work

References

Grout, T, Yang H, J Basara, B Balasundaram, Z Kong, Satish T. S. Bukkapatnam, 2012: Significant Winter Weather Events and Associated Socioeconomic Impacts (Federal Aid Expenditures) across Oklahoma: 2000–10. *Wea. Climate Soc.*, **4**, 48–58.

Kovacik, C., Hocker, J., Shafer, M. 2010: An Analysis of Southern U.S Ice Storm Frequency from 2000-2009. *AMS Extended Abstract. http://www.caps.ou.edu/reu/reu10/papers/Kovacik.pdf*

2. Spatial Climatology

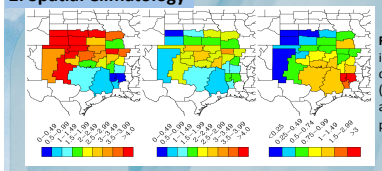
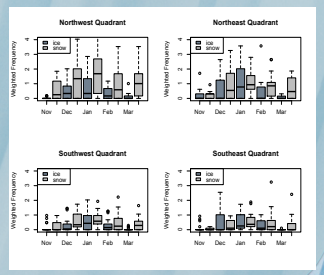


Figure 1: Spatial distribution of snow (left) and ice (center) within the Southern Plains domain, expressed as the number of days (falling precipitation) per year, weighted by the area of each climate division. The right hand panel shows the ratio of ice days to snow days.

Figure 2: Average annual distribution of snow and ice events over 4 almost equal area 'quadrants' over the domain. Values calculated over the winter season (November-March) and are weighted by area.



Summary: Snowfall is more common in the northern and western region, while freezing precipitation most frequently occurs in a southwest-northeast swath across the center of the domain. Freezing precipitation has a narrower temporal range and is most frequent during the peak of boreal winter

3. Synoptic Climatology

The 5 leading patterns associated with freezing precipitation/mixed phase and snowfall events were retained and extended via composite analysis. Figures 3 and 4 (left) show the flow fields (500hPa height, and winds at 250hPa) 24 hours before, to 24 hours after precipitation onset. The right hand side shows sea level pressure and near surface winds prior to winter precipitation.

Summary: ***Freezing Precipitation:*** Upper level trough axis typically further west of the domain with weak or absent surface cyclone development. SLP is higher over the central and northern plains (significant to 99% via Student's T-test) compared with snowfall. Surface cold air is rapidly channeled southward via ageostrophic down-gradient flow between T_{-24} and T_0.

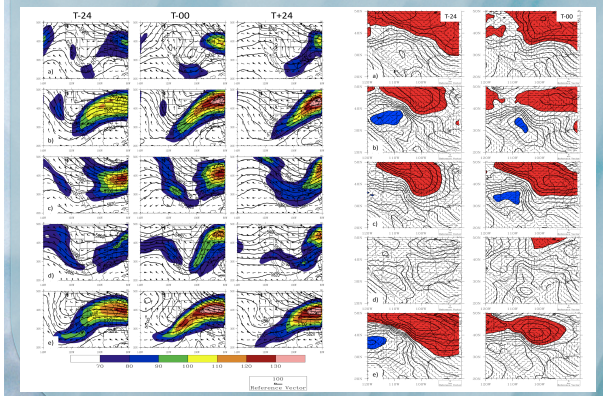


Figure 3: Ice Patterns 1-5 (a-e): Note SLP in intervals of 2hPa. SLP > 1026 hPa (< 1012) = red (blue)

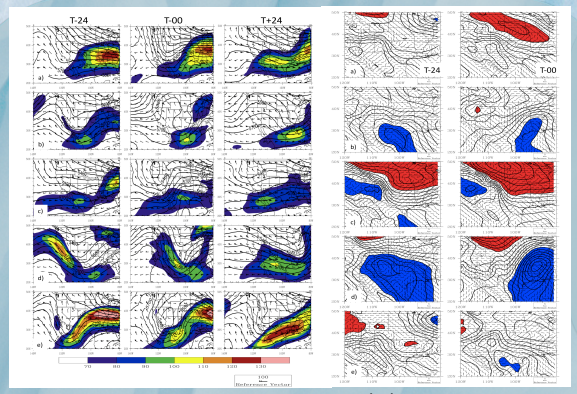
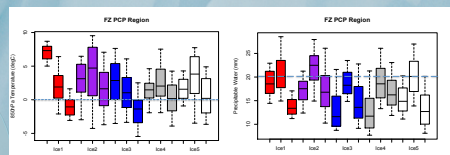


Figure 4: Snow Patterns 1-5 (a-e)



Pattern	# cases	Mean (max) temp: T_0	Mean (max) PWV : T_0	Std anomaly Temp (PWV)	850hPa WSPD (SGP) kt	850hPa WDIR (SGP) degrees 25N (35N)
1	6	SGP: 1.7 (9.6) N: -7.6 (0.0) E: 5.8 (11.4)	SGP: 19.4 (32.5) E: 20.5 (34.7)	< 1.0 (1.5-2) domain	20-25	190 (170)
2	5	SGP: 1.9 (11.3) N: -12.5 (-4.9) E: 8.1 (12.7)	SGP: 19.8 (29.3) E: 24.8 (31.7)	1-1.5 (2-3) domain and east	25-35	170 (240)
3	3	SGP: -6.3 (3.3) N: -20.3 (-8.8) E: 0.9 (10.5)	SGP: 11.6 (21.4) E: 16.7 (28.1)	< 1.0 (0-1)	< 20	230 (190)
4	3	SGP: -1.9 (8.2) N: -12.2 (-4.5) E: 6.3 (11.7)	SGP: 13.7 (28.3) E: 21.8 (33.7)	< 1.0 (1-1.5)	< 20	220 (240)
5	4	SGP: -2.3 (9.2) N: -17.7 (-11.5) E: 4.8 (12.9)	SGP:, 15.6 (28.1) E: 21.7 (30.6)	~1.0 (1.5)	< 20	220 (260)

Figure 5 and Table 1: 850hPa temperature and column precipitable water vapor (PWV) for ice pattern 1-5 at T_{-24}, T_0 & T_{+24} .

The figures show values for the zone of freezing precipitation only, while the table evaluates averages across broader areas including the whole domain (SGP), the northern plains (40-50N, 105-90W) and the eastern U.S (29-38N,95-80E).

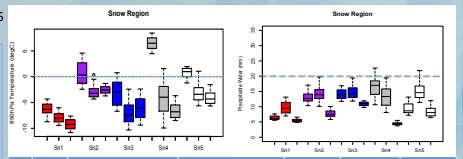
Wind speed, direction, and standardized anomalies are also Evaluated (expressed as xσ, eg. 1 = 1σ)

$$\text{Std Anomaly} = \frac{(x - X)}{\sigma}$$

Figure 6 and Table 2: As Fig. 5 Table 1 but for snowfall.

Summary: Greater spread in temp and moisture with *freezing precipitation* due to the preponderance of a well-defined frontal zone and thus higher gradient over the region. Moisture is associated with trajectories from the Gulf of Mexico for Pattern 1-3. Pattern 2 is associated with the greatest positive anomalies.

Snowfall events have a much narrower distribution in temperature and moisture. In some cases (especially those with a strong surface cyclone) there is a lack of cold air near/at the surface prior to winter precipitation, while in others (1, 3) cold air at low-mid levels is firmly entrenched.



Type	# cases	Mean (max) temp: T_0	Mean (max) PWV : T_0	Std anomaly Temp (PWV)	850hPa WSPD (SGP) kt	850hPa WDIR (SGP) degrees 25N (35N)
1	6	SGP: -6.2 (1.3) N: -17.7 (-8.5) E: -1.0 (8.4)	SGP: 11.7 (21.3) E: 16.0 (29.2)	< 1 (<1)	< 20	230 (90)
2	6	SGP: -0.8 (6.2) N: -7.8 (-1.4) E: 6.0 (11.3)	SGP: 16.2 (27.1) E: 22.8 (35.8)	>1 (1.5-2) domain and east	~20	260 (80)
3	4	SGP: -5.9 (2.7) N: -15.4 (-8.3) E: 1.0 (8.3)	SGP: 14.7 (23.9) E: 19.0 (27.2)	< 1 (1.0-1.5)	< 20	270 (250)
4	5	SGP: -4.6 (4.9) N: -11.4 (2.6) E: 6.9 (12.3)	SGP: 11.3 (20.0) E: 21.5 (32.7)	> 1 (1.5-2.5) east	20-30	260 (10)
5	3	SGP: -1.6 (7.8) N: -6.6 (-3.5) E: 3.7 (11.4)	SGP:, 16.1 (29.9) E: 20.3 (36.0)	> 1 (1.5-2) domain and south	20-25	200 (120)

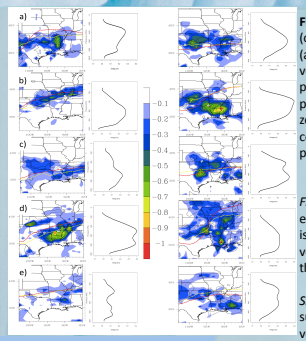


Figure 7: NARR derived vertical velocity (omega-pas^{-1}) at 700hPa for ice patterns 1-5 (a-e) LHS, and snow (RHS). The average vertical profile of omega within the winter precipitation zone is displayed for each pattern. 850hPa (red) and surface (yellow) zero degree isotherms are shown to highlight composite areas of freezing or frozen precipitation.

Freezing Precipitation shows more cases of elongated zonal bands associated with frontal isentropic upglide. The maximum vertical velocity is located in the lower atmosphere in these cases.

Snowfall, especially that in association with surface cyclones shows higher average vertical velocities and a maxima in the mid-upper troposphere.

4. Summary and Conclusions

FZRA Pattern	Location of Greatest Impact within domain	Median (Mean) Duration (hr)	Median (Mean) Liquid Equivalent (in)
1	West, Central & Southwest	6 (14.5)	0.73 (0.64)
2	Southwest through Central and Northeast	24 (30)	1.26 (1.42)
3	Southern & Southeastern	15 (17)	0.40 (0.38)
4	Central and Eastern	9 (9)	0.29 (0.33)
5	Central-South Central and Eastern	18 (18)	0.15 (0.24)

SNOW Pattern	Location of Greatest Impact within domain	Median (Mean) Duration (hr)	Median (Mean) Liquid Equivalent (in)	Snowfall range (in)
1	Central and Northern	15 (20)	0.18 (0.35)	2.6-11.2
2	Northwest and Western	18 (18)	0.60 (0.71)	1.0-13.0
3	Central and Northern	27 (25.5)	0.43 (0.46)	3.1-12.0
4	Central, Eastern, Northeastern	12 (12.6)	0.95 (0.92)	1.1-13.5
5	Northern	24 (23)	0.40 (0.48)	2.7-7.5

Tables 3 and 4 (above): Summary of average location, duration and maximum *winter* precipitation accumulation (using representative stations).

This study has created a regional climatology of winter precipitation for the Southern Plains, with an emphasis on distinguishing synoptic conditions favorable for mixed phase/freezing precipitation, versus snowfall.

500hPa flow fields associated with freezing precipitation are similar, however snowfall is associated with (a) more progressive flow (b) trough axis closer or over domain at T_0 and (c) stronger surface cyclone development. Freezing precipitation is associated with higher pressure observed over the northern/central plains at T_{-24}.

Each pattern differs in its location of impact. Ice Pattern 2 is associated with ice-storms over central portions of the domain, with 4 high-impact events in this category since 2000. Snowstorm flow fields for the western and central/eastern domain are described by snow pattern 2 and 4 respectively.

Future Work will examine airmass trajectories associated with winter storms in the region, particularly with reference to the thermal profile. Given the proximity of the region to the Gulf of Mexico, it is hypothesized that Gulf Sea Surface Temperatures may moderate the melting layer, which will be tested via a modeling sensitivity study.