Description of SGP atmospheric States

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Introduction

This document describes the atmospheric states identified for the SGP region following the approach given in Marchand et al 2009. The 2009 classification was updated in 2012 making use of all ARM Ka-band radar data gathered between 1997 and 2010, along with ECMWF reanalysis data (ERA Interim) for this same period. This expansion allowed for the identification of 21 statistically significant states.

With 21 atmospheric states for the SGP region it can be challenging to keep a mental picture of what they represent. Here we group them into broad categories and then discus how the states within each category differ from each other. We base our broad categories on the near surface winds in the region, as we find this to be a convenient way of separating the different stages of the synoptic-scale weather systems which predominate in the Great Plains.

Marchand, R. T., N. Beagley, N. and T. Ackerman, (2009), Evaluation of Hydrometeor Occurrence Profiles in the Multiscale Modeling Framework Climate Model using Atmospheric Classification, *J. Climate*, **22**, 4557–4573.

Southerlies

States 4, 5, 8, and 17 all have southerly winds throughout the region with the ARM SGP site near a warm front or in the warm sector of a frontal system. States 4 and 17 both feature low pressure to the northwest, high pressure to the southeast and near zonal flow in the upper atmosphere. Both of these states feature warm fronts in the northern part of the region, identifiable by the rotation of winds and the gradients in temperature and relative humidity. While the two states have similar flow patterns, they are distinguished by their temperatures. State 4 is approximately 10 °C warmer than State 17 and occurs primarily during spring and

fall, while State 17 occurs most frequently during midwinter. Thus, while these two states represent a similar large scale dynamical setting, there are important difference in their thermodynamics. For example, State 17 features a lower boundary layer and tropopause as evidenced by the height of the upper and lower cloud peaks, and greater relative humidity in the middle and upper troposphere, all of which affect cloud occurrence. We will see the same sort of distinction among some of the states in the other categories as well.

State 8 also features a northwest to southeast pressure gradient, albeit a weaker one than States 4 and 17. It is a spring/fall state, and has temperatures similar to State 4. In contrast, however, it appears that the warm front is just north of the analysis region rather than within it. As there are warm southerlies throughout the region, we interpret State 8 as a warm sector with a warm front to the north, and the cold front yet to arrive from the west.

State 5 has low pressure to the southwest, high pressure to the northeast and a warm front in the southern part of the domain. Near surface winds are southerly and slightly easterly throughout the domain with the northern half having cool or cold surface temperatures. Mid and upper levels show convergent flow and high relative humidity consistent with deep ascending air.

Cold fronts

States 12, 14, 18, and 20 feature cold fronts within the region. States 12, 14, and 18 all have relatively even rates of occurrence from November through April, with less common occurrences in October and May. These three states represent the progression of a cold front across the region from northwest to southeast. In State 12 the cold front, angled northeast to southwest, is in the northwestern part of the region and has not yet reached the SGP site. The front can be identified due to the strong gradients in temperature and relative humidity, as well as the rotation of the winds from warm southerlies in the southeast to cold northerlies in the northwest. The front is accompanied by a deep low to the west of the SGP site. State 18, which typically follows State 12, has the low and the front just to the east of the SGP site. This state is cooler and more humid than the preceding state as a larger

portion of the region is occupied by the cold northerlies behind the cold front. Following State 18 is State 14, by which time the low has moved out of the region to the east, and the cold front just barely remains in the southeast corner of the domain. While all of these states likely contain a mix of frontal and postfrontal conditions, State 14 is the most postfrontal, making it the coldest of this category.

In terms of dynamics, State 20 is quite similar to State 12, with a cold front just northwest of the SGP site. The key difference between the two states is that State 20 is approximately 5 °C warmer everywhere in the region. State 20 has significant peaks in occurrence in May and October with almost no occurrences in either midsummer or midwinter. As was the case for States 4 and 17, States 12 and 20 share similar large scale dynamical settings, but different seasonality and different thermodynamics. State 20, for example, has lower relative humidity in the mid and upper troposphere, leading to less cloud at those levels.

Northerlies

States 2, 6, 16, 19 and 21 all feature strong northerly flow near the surface becoming more westerly with height and high surface pressures throughout the domain. These states typically follow the various cold front states and are variations of cold air spilling out of the north in the wake of a cold front. Their upper-level winds show them to occur near the bottom of a trough or the very leading edge of a ridge. Of the five, State 2 stands out as 10-15 °C warmer than any of the others. State 2 typically follows State 20, the spring/fall version of the cold front, and is itself a spring/fall state as well. The other 4 states all occur most frequently in winter and are quite cold, with domain mean near surface temperatures ranging from 0-5 °C.

State 19 frequently follows State 14, the last in the sequence of frontal states. State 19 features a high pressure anomaly to the west of SGP and strong northerly flow near the surface that make it the coldest of the classification, State 19 is typically followed by either State 6 or State 21 which are both on the leading edge of the following ridge and feature high pressure across the region. State 6 has a stronger high pressure anomaly, helping to make the flow more northerly, colder,

and substantially dryer than State 21. Accordingly, State 6 is the least cloudy of the classification, with almost no cloud at any level, while State 21 has modest amounts of cloud in the middle levels of the troposphere despite its high pressure.

State 16 does not have a clear position in the sequence of states. Near the surface it has cold northerly flow and high pressure, but in the mid and upper levels the flow is zonal, warm, and humid, leading to the most cloud among the northerly states. We believe this is most likely capturing cases where a relatively weak front has passed to the north of the site, allowing cold air to spill in near the surface, but without having a major impact on the upper level flow.

Anti-cyclones

States 1, 7, and 13 feature strong anti-cyclones over the domain and represent upper level ridges. As with the other categories, there is a spring/fall state here, in this case State 7, which typically follows State 2 of the northerlies. Much like the other shoulder season states, State 7 is notably warmer than the others in this category, in this case by 5-10 °C near the surface. In all three cases the anti-cyclonic rotation produces southerly winds in the western part of the region and northerly in the east. States 1 and 7 have northwesterly flow in the upper levels and have high surface pressure throughout the region, but don't fit amongst the northerly states on account of the near surface southerly flow in the western half of the region. State 13 has zonal flow beginning at 500 mb, and high upper level humidities. We interpret this as moisture riding up and over the ridge. As a result, State 13 is substantially cloudier than States 1 and 7 at all levels.

Summer

States 3, 9, 10, 11, and 15 occur from May to October and deserve their own category as they lack the characteristics of the frontal systems which characterize the winter and shoulder seasons. They are the five warmest states of the classification and feature near-surface southerlies over most of the domain. State 3 has anti-cyclonic winds at the low levels and northwesterly flow beginning at 500 mb. This gives it a circulation pattern very similar to State 7 of the anti-cyclones.

State 15 also has anti-cyclonic flow, centered to the east of SGP at the surface and in the center of the domain at 500 mb. Despite being more humid than States 3 or 10, this subsidence leads to the least cloud among the summer states, which also makes it the hottest state of the classification. States 9, 10, and 11 all have low-level southerly flow throughout the region that becomes westerly with height. State 9 most readily stands out as being both 3-5 °C cooler than the other summer states and much more humid, making it very cloudy at all levels. This most likely represents deep convection in the region. State 10 has a negative pressure anomaly over much of the domain and convergence in the northern part of the domain, making this a "cool front" of the sort that relieve the summertime heat and humidity in the Great Plains. Lastly, State 11 has relatively weak flow over the SGP site and resembles a much dryer, and hence less cloudy version of State 9.