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P79 The Long-term Climatology of Mid-Mississippi Valley Dew points and the Implications for Regional Climate.

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1. INTRODUCTION

Dew point temperature is a measure of how much moisture is in the atmosphere at a given time and place. It is defined as the temperature the air would have to be cooled to, without the further addition of water vapor, before condensation could take place (e.g. Ahrens, 2009). The atmosphere can hold a certain amount of moisture at any given temperature before it becomes saturated, and this relationship is described as an exponential function of temperature and derivable from the First Law of Thermodynamics. In this context, saturation means that evaporation equals condensation at the liquid water – atmosphere interface. From a practical standpoint, it means that the atmosphere can hold approximately twice (one-half) the amount of water vapor for every 10 ^{o}C rise (drop) in surface temperature. The atmosphere is considered saturated when the dew point temperature equals the ambient temperature.

The climatological behavior of dew point temperature is an important quantity to examine because water vapor is the most important greenhouse gas. Water vapor may not necessarily correlate strongly to temperature on the time scale of weather since is not evenly distributed throughout the atmosphere. The amount of water vapor in the atmosphere will vary with time and location, however, most of this gas is found within the lowest 1 – 2 km of the atmosphere (e.g. Hurrell et al., 1995). On the time-scale of climate, the dew point may correlate more strongly with air temperature, but not perfectly.

An climatological examination of this quantity across Missouri has not been performed recently, and a survey of the literature reveals that there are not many climatological studies of this quantity. Most studies of this quantity relate to short term weather prediction or variations (e.g. Stensrud and Yussouf, 2003). The climatological behavior of atmospheric water vapor amounts and the implications for the impact on climate change have been discussed recently in publications such as IPCC (2007) or GCCIUS (2009). Additionally, it has been theorized that the atmospheric water cycle would be more vigourous in a warmer world (GCCIUS, 2009). Thus, the implication would be that in a warmer world, the dew point temperature would be higher along with the observed air temperatures.

Then, the goal of this work is to examine the climatological behavior for dew point temperatures in the Mid-Mississippi valley region. Several studies have been performed in order to examine the long-term behavior of snowfalls (e.g. Berger et al., 2002; Lupo et al. 2005), tornadoes (e.g. Akyuz et al. 2004), or temperatures and precipitation (e.g. Lupo et al. 2007, 2008; Birk et al. 2010) in this region. Following the methodologies of these studies, we will demonstrate that there is strong El Niño-related and possibly interdecadal variability in dew point temperatures. Additionally, we will demonstrate that there has been a statistically significant increase in dew point temperatures.

2. DATA AND METHODS

2.1 Data

The data set used here was the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) gridded re-analyses (Kalnay et al. 1996). These data were archived at NCAR and obtained from the mass-store facility in Boulder, CO. These re-analyses were the 2.5^{o} by 2.5^{o} latitude-longitude analyses available on 17 mandatory levels from 1000 to 10 hPa at 6-h intervals. These analyses include the standard atmospheric variables geopotential height, temperature, relative humidity, vertical motion, *u* and *v* wind components and surface information.

The dew point (^{o}F) information was provided by the Missouri Climate Center (MCC – http://climate.missouri.edu) and they obtained the information through the Midwest Regional Climate Center (MRCC – http://mcc.sws.uiuc.edu). Degrees Fahrenheit were used since this is still the standard unit for the display and archival of surface temperature information in the United States. Additionally, the exact units are not germane to obtaining the climatological character and variability of dew point temperature. The monthly mean dew point temperature was obtained for the cities of Columbia (COU), Kansas City (MCI), Saint Louis (LSX), and Springfield (SGF), MO for a 62 year period from 1948 –

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2009. The study will focus on the COU dew point temperature since these are representative of the regional trends and variability (e.g., Ratley et al. 2002).

2.2 Methods

The methodologies used here to demonstrate interannual and interdecadal variability from a one-dimensional time series are described in Mokhov et al. (2004) and Birk et al. (2010), so only a brief description will be given here. We use here the time series for dew point temperature for each station as was done in Lupo et al. (2007). The main objective was to use the method of cycles in order to identify interannual and interdecadal periodicities within our time series, but using the modifications proposed by Lupo et al (2007).

The statistical tests used in this study could be found in any standard statistical textbook (e.g. Neter et al. 1988). In order to test long-term linear trends the analysis of variance (ANOVA) technique was used which involves the F-test. A standard t-test was also used to test correlations for significance. Distributions of dew point temperatures are normal or nearly normal (e.g., Lupo et al. 2003). Once years were classified by their corresponding phase of ENSO and PDO, means were tested in order to analyze and compare ENSO, and PDO related variability. A two-tailed "standardized test statistic" (z*) was the technique used for the comparison of the sample means (z*). Means for the total time series studied served as the "expected" frequencies of occurrence. All statistical tests assumed the null hypothesis, that no priori relationship is present among the variables being tested and confidence levels of 90% or higher are considered to be significant results here.

2.3 ENSO definition

The ENSO definition used in this study follows the Japan Meteorological Agency (JMA) ENSO index. This is a widely accepted definition of ENSO that that has been used in many other climatologically studies (e.g. O'Brien et al. 1996; Bove et al. 1998; Lupo and Johnston, 2000; Smith and O'Brien, 2001; Berger et al. 2002; Wiedenmann et al. 2002; Akyuz et al., 2004; Lupo et al. 2007; Birk et al. 2010). According to this definition, a particular phase of ENSO (El Niño, La Niña or neutral) is determined based on a 5 month running mean of spatially averaged sea surface temperature (SST) anomalies contained within an area between 4^0S-4^0N, 150^0W-90^0W in the tropical Pacific basin. In order for a particular year to be classified as an El Niño (La Niña) year the SST anomaly must be 0.5^0C (-0.5^0C) or more (less) for 6 consecutive months including the months of October, November and December. Alternatively, values between 0.5^0C and -0.5^0C are classified as a neutral year. The ENSO year is defined to start on October 1st and persists through the following September. So, for example, the 1997 El Niño year started in October 1st of 1997 and persisted through September 1998. A comprehensive list of ENSO years, binned by ENSO phase, dating back to 1945 are found in Table 1. More information regarding the JMA ENSO index can be found on the Center for Ocean and Atmospheric Prediction Studies (COAPS) website.

The Pacific Decadal Oscillation (PDO) is a long-term fluctuation in the Pacific Basin SST that has a period of 50 to 70 years (e.g., Mantua et al. 1997; Minobe, 1997). Mantua et al. (1997) define the two distinct phases of the PDO, known as the positive PDO and the negative PDO. They refer to the high phase of the PDO as the positive PDO (+PDO). This particular phase is characterized by cold western and north central Pacific waters and warm eastern and tropical Pacific waters. An anomalously deep Aleutian low is also a common characteristic of the +PDO. Conversely, the low phase of the PDO, the negative PDO (-PDO) characterizes directly opposite conditions. A complete list showing the period of each phase of the PDO can be found in Table 2.

Table 1. A list of years examined in this study separated by ENSO phase (ENSO definition found at http://www.coaps.fsu.edu/climate_center/). The El Niño year (for example 1969) is defined as starting in October (1969) and ending in September (1970).

La Niña (LN)	Neutral (NEU)	El Niño (EN)
1949	1945-1948	1951
1954-1956	1950	1957
1964	1952-1953	1963
1967	1958-1962	1965
1970-1971	1966	1969
1973-1975	1968	1972
1988	1977-1981	1976
1998-1999	1983-1985	1982
2007	1989-1990	1986-1987
	1992-1996	1991
	2000-2001	1997
	2003-2005	2002
	2008	2006

Table 2: The phase of the Pacific Decadal Oscillation (PDO) (adapted from COAPS).

PDO Phase	Period of Record
-PDO	1910 – 1924
+PDO1	1925 – 1946
-PDO2	1947 – 1976
+PDO1	1977 – 1998
-PDO2	1999 – present

3. LONG-TERM TRENDS

An examination of the annual temperature and dew point trends (e.g. Fig. 1) reveal that in the study region, dew point temperatures have risen since 1948, while temperatures have remained steady. The overall upward trend in dew point temperature in Fig. 1 was significant at the 90% confidence level when using the F-test (e.g. Neter et al. 1988). The results for COU are similar to those of the other cities (not shown here) except that the results for MCI and SGF were significant at the 95% confidence level.

There are two additional points that can be made regarding the long-term trends. The temperature and dew point temperature trends are downward from 1948 to about 1977 (not significant), and then both quantities increase strongly following that until about 2000, and then become steady following this. These patterns follow those of the global temperature trends during these time frames (e.g. Peterson and Baringer, 2009), and the points at where the trends change correspond approximately to shifts in the PDO (see Table 2 and Birk et al. 2010).

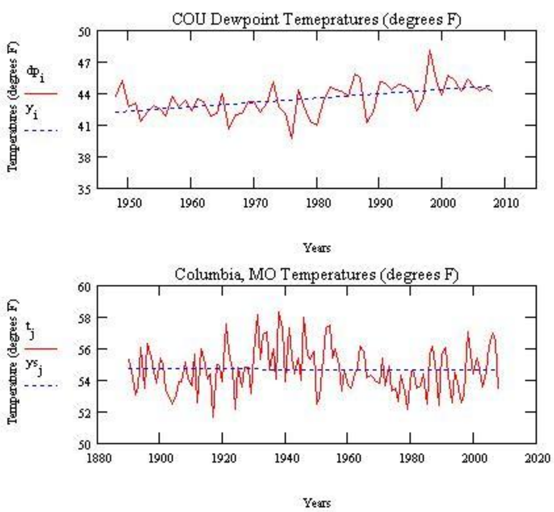

Figure 1. The annual average; (top) dew point temperatures since 1948 (^{o}F), and (bottom) the temperatures since 1890 (^{o}F) for Columbia, MO (COU).

The correlation between dew point and temperature from 1948 – 2008 was 0.34, which was significant at the 95% confidence level using a t-test (e.g. Neter et al. 1988) However, the correlation between dew point and precipitation was even stronger at 0.54. There was a negative, but statistically not significant correlation between temperature and precipitation (not shown) during this time and the trend for precipitation was generally increasing throughout the period. In spite of the high correlations between the dew point and the temperature and precipitation trends, there was strong interannual variability present in the dew point time series and this may be similar in nature to that temperature and precipitation (Birk et al. (2010).

4. ENSO VARIABILITY IN DEW POINT

4.1 The COU dew point time series.

Table 3 shows that in COU, the annual temperatures did not vary appreciably, but that there were strong seasonal differences. The results of Birk et al. (2010) demonstrated that winter season temperatures were warmer for both El Niño and La Niña years in this region, and that in our study region, the variability was stronger in the north than in the south. Neutral years possessed a stronger annual cycle (colder winters and warmer summers), while during El Niño and La Niña, the seasonal cycle was weaker. Variability in each season was fairly strong with the exception of spring.

Table 3. The seasonal temperature means (^{o}F) by ENSO phase (adapted from Birk et al. 2010). Variability is defined as the maximum difference between the anomalies among each phase.

Period	Mean Temp (^{o}F)	El Niño	La Niña	Neutral	Variability
Annual	54.6	0.0	0.1	0.0	0.1
Winter	31.9	0.3	0.6	-0.4	1.0
Spring	54.2	0.0	-0.2	0.1	0.3
Summer	75.8	0.1	-0.7	0.3	1.0
Fall	56.7	-0.6	0.6	0.0	1.2

Using method of cycles (e.g. Mokhov et al. 2004; Birk et al. 2010) would demonstrate that there was statistically significant variability (at the 95% confidence level) in the dew point series on the time scale of 2 and 5 years, which is consistent with that of ENSO. There was very weak interdecadal variability and the mean temperatures were similar across each phase of the PDO. Thus, the ENSO variations became the focus of this part of the investigation.

An analysis of the dew point temperature by season demonstrated that in general, La Niña years had a lower dew point temperature than El Niño or neutral years. For spring or summer, this correlated with cooler temperatures as well as summers with precipitation events that occurred less often over the region (Ratley et al. 2002). A study by Chesser et al. (2008) demonstrated that these seasons were also seasons with more wild fires across Missouri and Arkansas that burned more acreage across the region. For neutral years, the higher dew point temperatures corresponded with higher temperatures in each season, while during El Niño years, the summer dew points were lower while temperatures were close to normal.

Some of the most pronounced seasonal differences across ENSO phases found using Tables 3 and 4 were that La

Niña winters were warm and with higher dew points, while neutral years were colder with lower dew points. The summer season was just the opposite, and, in both cases, the El Niño years were more similar to the La Niña conditions. In order to examine these relationships more closely, the synoptic maps were examined in order to determine if any differences across ENSO phase could be found in the flow regimes. Years which were representative of each phase are examined rather than composites, since compositing can filter out details in the flow regime.

Table 4. The seasonal dew point temperature means (^{o}F) and relative humidity (%) by ENSO phase. Variability is defined as the maximum difference between the anomalies among each phase.

Period	Mean Dtemp (^{o}F)	El Niño	La Niña	Neutral	Varia-bility
Winter	23.0/70	0.4/71	1.0/74	-0.7/69	1.7 / 5
Spring	41.7/63	0.4/64	-1.0/60	0.2/63	1.4 / 4
Summer	64.2/68	-0.4/67	-1.0/66	0.6/68	1.6 / 2
Fall	44.7/64	-0.4/65	-0.2/61	0.2/64	0.6 /4

4.2 Synoptic height fields

In examining winter height fields (Fig. 2) that were representative of the conditions for each category, it is apparent that neutral winters experience deep northwesterly flow out of central Canada. Air masses from this region would naturally be colder and drier than those from oceanic source regions. At both 850 hPa and 500 hPa, these winters were characterized by strong ridging (troughing) in the western (eastern) USA.

For both El Niño and La Niña winters (Fig. 2), the 500 hPa flow is more zonal, and during the El Niño winters, there was an indication of a split jet over North America and an enhanced jet stream across the southern tier of states. At 850 hPa, the El Niño and La Niña winters looked similar except that the height gradients in the El Niño winters were clearly weaker. In both cases, however, there was short wave troughing over the study region and this would be associated with more southerly winds at the surface and a warmer and higher dew point regime. Further, Fig. 2 suggests that air masses impacting the region were more likely to have originated over the Pacific Ocean Basin, and been modified by air from the Gulf of Mexico.

An analysis of the 850 hPa and 500 hPa height maps representative of El Niño, Neutral, and La Niña years for the summer season was performed using Fig. 3. The 500 hPa maps for each phase were very similar across all phases with strong ridging over the plains states. During the El Niño and neutral summers, the ridge axis was located approximately over 105^o W, while the for the La Niña summer, the ridge axis was located 5^o longitude eastward. This may place subsidence associated with ridging more firmly in place over the study region. However, more study would be needed to test this assertion.

The 850 hPa maps were also similar (Fig. 3), except that there were implied differences in the location and strength of the low-level jet (LLJ) (e.g. Mitchell et al. 1995). The LLJ is a semi-permanent feature of the southern Great Plains which exists because of the topography of North America, and is especially prominent during the spring and summer season. The LLJ is a southerly jet which draws moisture out of the Gulf of Mexico, and is often the focal point for strong convection across the region. During the El Niño and La Niña summer samples, the LLJ appears to be located further westward (105-100^o W) and there was a more southwesterly component to the 850 hPa flow over our study region. During the El Niño summer, the LLJ appeared to be weaker as well. This contrasts with the neutral summer location of the LLJ which is located over 100-95^o W, and there is a more southerly component over our study region, with flow coming more directly from the Gulf of Mexico.

5. SUMMARY AND CONCLUSIONS

A climatological examination of dew point temperatures over the Missouri region was examined using data obtained for four locations across the state and from the Missouri Climate Center. The data were monthly average dew point temperatures from 1948 – 2009. The data provided for the upper air maps and analysis were obtained from the NCAR-NCEP re-analyses archived in Boulder, CO. After examining the long term trends, the data were stratified by ENSO and PDO phase and the following results were obtained.

A long term trend of dew point temperature demonstrated that these are on the increase across the region and that these trends were significant at the 90% confidence level or higher of each location. The dew point temperature time series correlated strongly to air temperature record and it was evident that trends in dew point over sub-time intervals were congruent with temperature trends both locally and globally. Dew point temperature correlated even more strongly with long-term precipitation trends as well.

Within the dew point time series, interannual variability was apparent and using previously published methods, it was determined that there was statistically significant (at the 95% confidence level) ENSO-related variability. In particular, El Niño and La Niña winters were warmer and associated with higher dew point temperatures than ENSO neutral winters. An examination of synoptic maps demonstrated that during the neutral winters, there was deep northwesterly flow over the region. This likely explains why these years were drier and colder than the overall average. During El Niño and La Niña winters, flow across our region was more zonal aloft, and 850 hPa troughing was responsible for higher dew point temperatures across the region.

During the warm season, it appears that neutral summers were warmer and more humid (higher dewpoint temperatures), while El Niño and La Niña years were drier and cooler. The location and strength of the LLJ may explain these differences, in that the LLJ was located further east and stronger during neutral years bringing more moisture into the study region from the Gulf of Mexico than during El Niño or

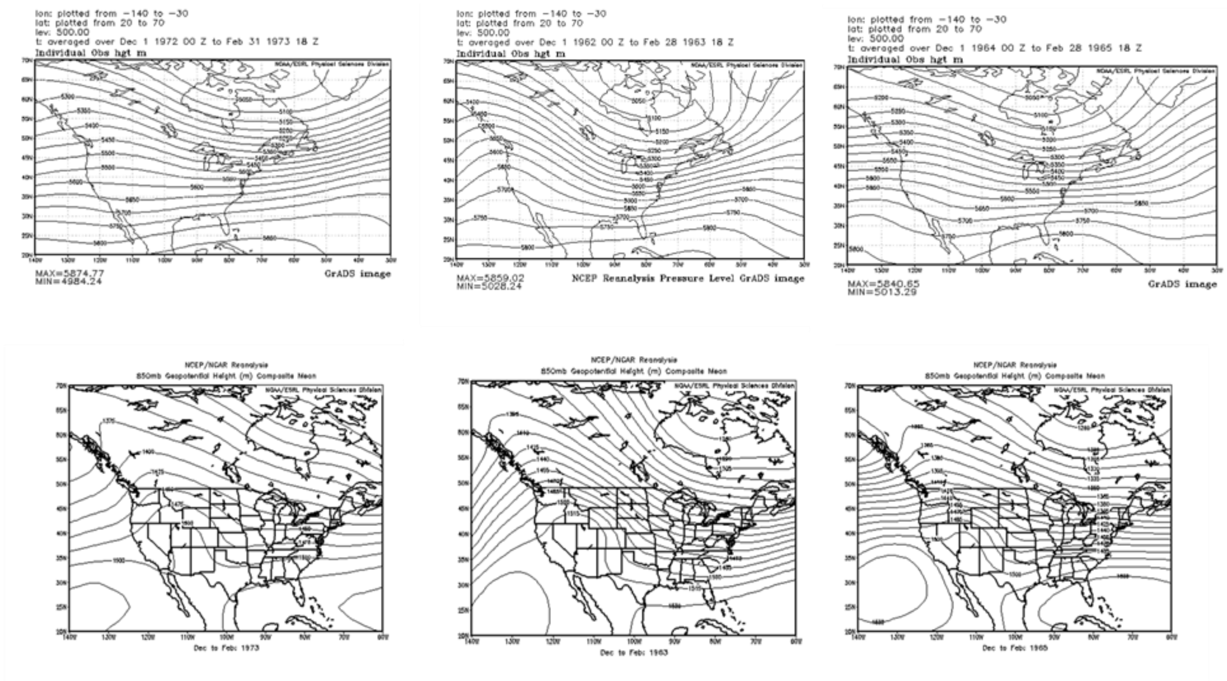

Figure 2. The 500 and 850 hPa maps (m) for LEFT: El Nino winter 1972-73 (22.9 °F dewpoint / 32.2 °F temperature / 68% RH, MIDDLE: neutral winter 1962-63 (17.2 °F dewpoint / 29.2 °F / 62% RH, and RIGHT: La Nina winter 1964-65 (23.1 °F dewpoint / 32.5 °F / 70% RH).

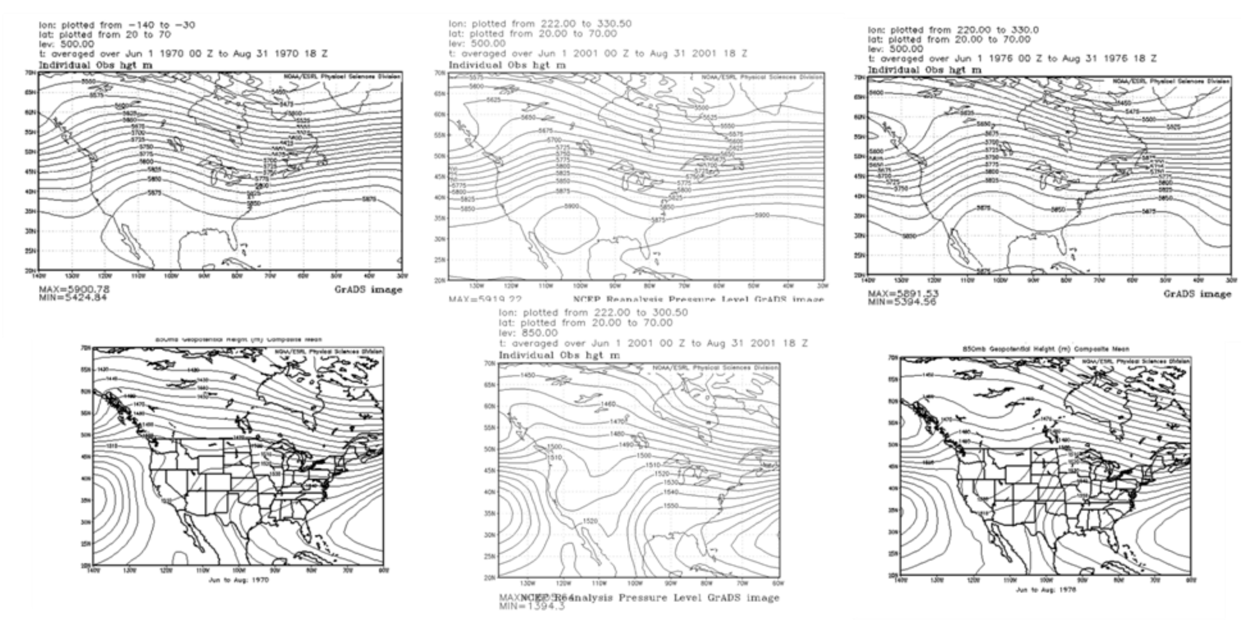

Figure 3. The 500 and 850 hPa maps (m) for LEFT: El Nino summer 1970 (62.9 °F dewpoint / 75.9 °F temperature / 65% RH, MIDDLE: neutral summer 2001 (67.0 °F dewpoint / 75.5 °F / 72% RH, and RIGHT: La Nina summer 1976 (59.3 °F dewpoint / 74.4 °F / 59% RH).

La Niña summers.

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