# JP1.5 A STUDY OF THE INTENSITY AND DURATION OF THE NORTH AMERICAN MONSOON AS A FUNCTION OF WINTER AND SPRING SNOW COVER

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## 1. INTRODUCTION

The North American Monsoon (NAM) brings heavy precipitation during the summer months to portions of Arizona, New Mexico, Colorado, Utah, Nevada, and California, and is very important for the southwestern region of the United States, as it is their primary source of water. Most of northwest Mexico is also affected. Monsoon season generally begins in July and lasts through early September.

The definition of a monsoon is a seasonal change in the direction of wind of at least 120° (Sheppard, Comrie et al. 2002). This includes all winds such as those from the mid-troposphere. As Sheppard et al. (2002) states, the NAM is considered to be a true monsoon by this definition. But according to Adams and Comrie (1997), a pronounced increase in rainfall over this area during the summer is another definition of the NAM (Adams and Comrie 1997). This study is significant in that this region of the United States is growing very quickly and so an adequate water supply is becoming more of an issue. As much as 50% of yearly precipitation falls during monsoon season and so local economies are heavily dependent on its occurrence (Lo and Clark 2002). Being able to predict these monsoonal events would allow for the region to better plan for water availability.

The NAM is known to vary quite a bit spatially and temporally, which makes it difficult to predict. The monsoon onset occurs once the westerlies retreat and the subtropical high-pressure ridge over the Colorado River Basin strengthens and advances north (Sheppard, Comrie et al. 2002). Additionally, an area of low-pressure then forms over the Lower Colorado River Basin and the northern region of the Baja of California (Adams and Comrie 1997, Sheppard, Comrie et al. 2002). This low creates a space in the atmosphere for the surges of moist air from the Gulf of California to travel north and interact with the warm desert air. Once the hot summer sun heats the ground, this interaction will lead to convection, forming thunderstorms that are sometimes even quite severe.

The onset of the NAM, determined by these atmospheric dynamics, occurs in late June over Mexico and in July over the United States. The NAM usually starts in July for the southwestern US because that is the time when the surges arrive at this region. It starts earlier in Mexico due to its proximity to the Gulf of California as the distance these surges have to travel is much shorter. Because monsoon onset occurs later with higher latitude, northern Arizona may not experience a monsoon onset until even later in July (Sheppard, Comrie et al. 2002). Figure 1 shows the dynamics necessary, specifically the gulf surge phenomenon, for the NAM to occur. In this figure, the subtropical high is shown over southern Colorado. The thermal low is visible over western Arizona. This low draws the moisture northward (shown by the dark arrows), allowing for convection to occur over the heated deserts in the southwest.

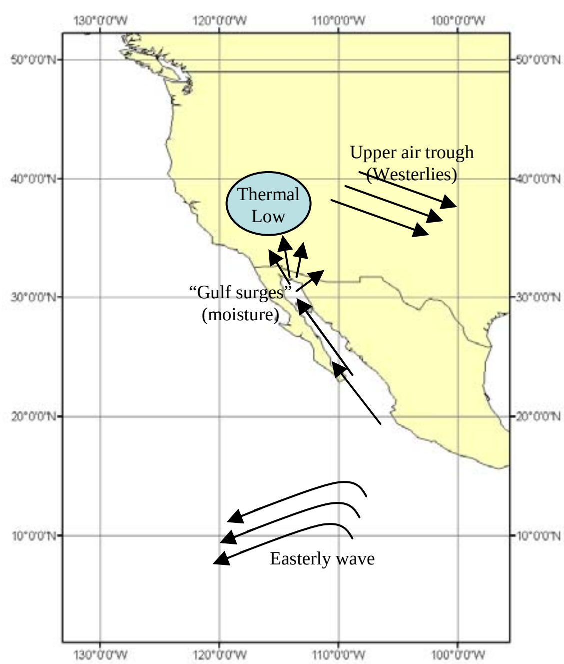


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**Figure 1. Atmospheric dynamics required for onset of NAM (adapted from Adams and Comrie 1997).**

There are many factors that can cause the intensity, onset, and duration of the NAM to vary. These factors include snow cover, soil moisture, sea surface temperatures, and many more. Previous studies have shown that there is a relationship between snowfall in the Southern Rocky Mountains region and monsoonal precipitation received in the southwestern United States. A study done by Lo and Clark (2002) showed that positive (negative) anomalies of spring snow cover leads to a weakening (strengthening) of circulations related to the monsoon causing a decreased (increased) precipitation during the monsoon season. However, this study also demonstrated that the correlation between snow and monsoonal precipitation can vary significantly over time (Lo and Clark 2002). Ellis and Hawkins (2001) demonstrated that when there is a lack of winter precipitation across the western half of the U.S., the subtropical ridge intensifies, thus making the land-sea gradient stronger. This brings in more moisture from the Gulf of California (GOC) allowing convection to occur. It is the radiative effects of snow and their influence on diabatic heating that modify the lower atmosphere (Ellis and Hawkins 2001). They found an inverse relationship between snow cover and precipitation frequency with the highest correlations occurring in eastern Arizona, and western and northern New Mexico. A study done by Gutzler and Preston (1997) proved that greater than normal snowfall led to wetter soil, thus keeping the surface of the land cooler which would decrease the amount of heating during the summer months needed for convection (Matsui, Lakshmi et al. 2003). Due to a process called land surface memory, a greater than average winter snow pack has a tendency to act as an energy sink (Lo and Clark 2002). More energy is needed to melt the snow and evaporate moisture from the soil. Thus, more energy during the following monsoon season is devoted to this process and so there is less surface heating and convection. Studying the NAM is important because if a relationship between winter snowfall and summer precipitation can be developed, and using this relationship to define the onset, intensity, and duration of the season, then monsoonal events can be better predicted. The southwestern region of the United States usually receives an average of less than 20 inches of rain a year, and so water planning is very necessary. This study examines the relationship between North American snow cover during the preceding winter and spring with the onset, intensity of precipitation, and duration of the NAM.

## 2. DATA & METHODS

### *2.1 Monsoon calendar dates*

Monsoon onset, length of monsoon season, and number of days (NDays) within the monsoon season with precipitation were obtained from Ellis and Hawkins (2001).

All monsoon calendar dates were calculated by the Phoenix Regional Office of the National Weather Service. The onset of the monsoon is considered the third day in a series in which the dewpoint temperature in Phoenix is measured at least 12.8ºC (55ºF) or higher. This does not represent the entire area studied because only Phoenix dewpoint temperatures are used, but this is the only system used to define an official onset. The ending date of the monsoon season is designated by the National Weather Service based upon local knowledge of the monsoon.

### *2.2 Winter and spring snow cover*

Measurements of winter and spring snow covered area for Northern America were obtained from the Rutgers University Global Snow Lab database (http://climate.rutgers.edu/snowcover). The data is available at a 1° x 1° resolution. It was produced from daily surface data observations at both the National Weather Service and the Meteorological Service of Canada. The years considered in this study are 1967 through 2001.

In addition to considering mean snow covered area for the entire year, snow cover values were also calculated for winter and spring for comparison between the two. Winter values consist of totals for the months of December through February. Spring values consist of totals for the months March and April. These months were chosen because the amounts of snow covered area were similar between the two seasons.

### *2.3 Monsoon precipitation*

Daily gridded meteorological data were provided by the National Surface Water Modeling Group at the University of Washington (Hamlet A.F., Lettenmaier D.P., 2005). A total of 283 grid cells in the states of Arizona and New Mexico were used to generate daily precipitation values (mm/day) for the Colorado River Basin at a resolution of 1/8⁰. This data is for the years 1967 to 2001.

## 3. RESULTS

### *3.1 Climatology of monsoon onset, termination, and length of season*

An average onset and season length were defined based on the monsoon data (1967-2001). (Table 1)

"NDays" stands for the number of days within the monsoon period where precipitation was observed.

| | Onset | End of Season | Length | NDays |
|---|---|---|---|---|
| **Mean** | 185 (Jul 4) | 261 (Sept 18) | 77 | 59 |
| **Median** | 185 (Jul 4) | 262 (Sept 19) | 77 | 58 |
| **Minimum** | 156 (Jun 5) | 230 (Aug 18) | 33 | 27 |
| **Maximum** | 206 (Jul 25) | 283 (Oct | 125 | 87 |
| **Standard deviation** | 9.4 | 14.0 | 18.5 | 14.3 |

**Table 1. Climatology of monsoon onset, termination, and length of season (1967-2001).**

By plotting the onset, length, and "NDays" on a time scale, it is clear that these dates do fluctuate between years. By comparing these dates to snow cover totals or monsoon precipitation, it is possible to find that an association between the two may exist. Figures 2 though 4 show the data series before any correlations are applied.

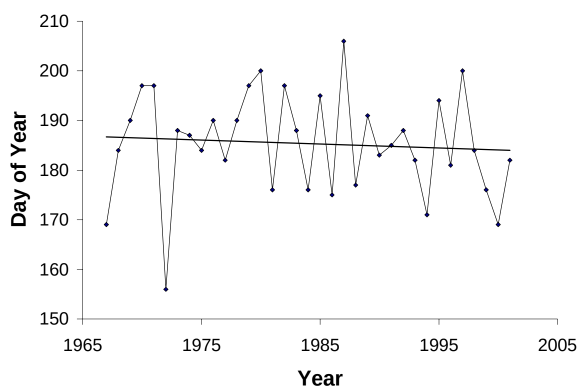


**Figure 2. Monsoon onset (day of year) from 1967 to 2001.**

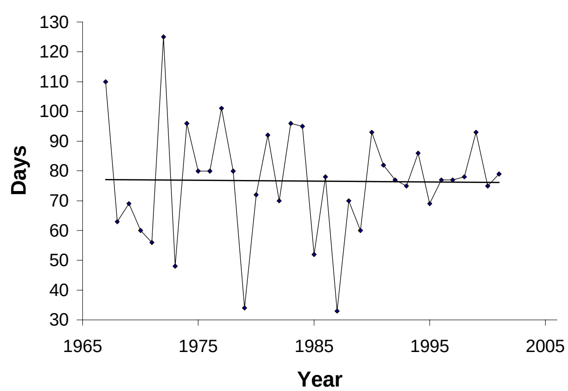


**Figure 3. Fluctuation of the length in monsoon season.**

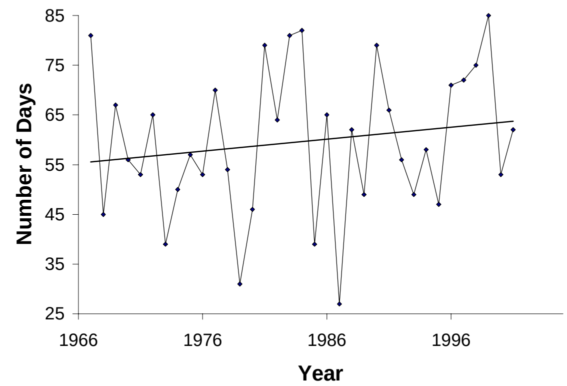


**Figure 4. Fluctuation in NDays.**

### *3.2 Climatology of winter and spring snow cover in North America*

To define what is considered normal snowfall in North America, basic statistics were used. Table 2 shows the climatology of this snow cover. Table 3 displays the years in which the largest and smallest amounts of annual snowfall were received in North America. Table 4 divides the snow cover into winter and spring values, showing the top and bottom ten years.

| | Winter ($km^2$) | Spring ($km^2$) | Annual ($km^2$) |
|---|---|---|---|
| **Mean** | 51,185,767 | 29,213,005 | 552,747,723 |
| **Median** | 50,818,782 | 29,006,291 | 549,470,198 |
| **Minimum** | 46,640,752 | 26,193,020 | 459,370,572 |
| **Maximum** | 55,067,127 | 32,018,619 | 611,905,001 |
| **Standard deviation** | 17,431,84.5 | 1,456,525 | 27,846,177 |

**Table 2. This table shows the climatology of snow cover in North America.**

| Top 10 Years | Bottom 10 Years |
|---|---|
| 1978 | 1969 |
| 1985 | 1968 |
| 1982 | 1990 |
| 1967 | 1998 |
| 1976 | 1987 |
| 1997 | 1999 |
| 1975 | 1994 |
| 1979 | 2001 |
| 1972 | 1991 |
| 1983 | 1989 |

**Table 3. This table shows the 10 years in which most and least**

**total snowfall was received in North America.**

| Winter | | Spring | |
|---|---|---|---|
| **Top 10** | **Bottom 10** | **Top 10** | **Bottom 10** |
| 1979 | 1981 | 1975 | 1968 |
| 1978 | 1992 | 1979 | 2000 |
| 1985 | 2000 | 1982 | 1988 |
| 1993 | 1987 | 1978 | 1991 |
| 1984 | 1977 | 1974 | 1992 |
| 2001 | 1999 | 1970 | 1981 |
| 1982 | 1989 | 1971 | 1990 |
| 1986 | 1968 | 1997 | 1987 |
| 1969 | 1995 | 1985 | 1973 |
| 1971 | 1998 | 1969 | 1993 |

**Table 4. This table shows the years for which the highest and lowest amounts of snow cover occurred between the winter and spring seasons.**

After plotting the value for each year on a time-analysis chart, it is possible to see that over time, there is an increase in snow cover area in North America (Figure 5). When analyzing the snow cover at a finer time scale, such as winter months versus spring months, (Figure 6), there is a gradual decrease, but it is clear that more snow falls in the winter months.

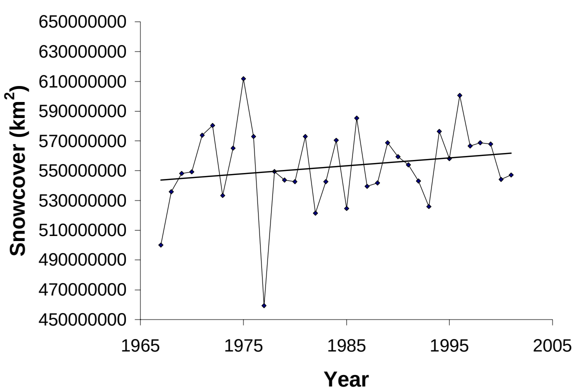


**Figure 5. This chart shows the mean annual values of snow covered area in North America.**

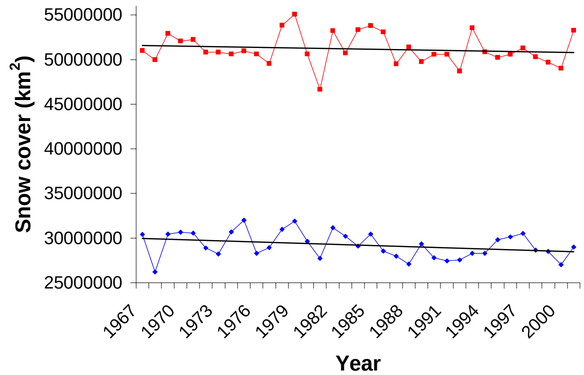


**Figure 6. Winter snow cover (red) is compared to spring snow cover (blue).**

## *3.3 Climatology of monsoon precipitation in Arizona and New Mexico*

The following table includes a list of the 10 years for which the most and least precipitation was received. Precipitation values consist of averages for each station.

| Precipitation | Top 10 Years | Precipitation | Bottom 10 Years |
|---|---|---|---|
| 212.8 | 1983 | 55.4 | 1973 |
| 181.0 | 1984 | 64.8 | 1979 |
| 181.0 | 1999 | 73.6 | 1987 |
| 177.8 | 1972 | 73.7 | 1985 |
| 175.6 | 1990 | 78.9 | 1978 |
| 174.6 | 1967 | 79.7 | 1980 |
| 141.4 | 1997 | 88.4 | 2000 |
| 136.9 | 1981 | 88.8 | 1989 |
| 136.1 | 1992 | 91.5 | 1995 |
| 134.4 | 1988 | 95.4 | 1975 |

**Table 5. This table lists the top and bottom 10 years and the precipitation received (mm/day).**

As seen in figure 7, areas near the center of the study region receive above mean amounts of monsoonal precipitation, whereas the extreme north and south regions receive less than the mean.

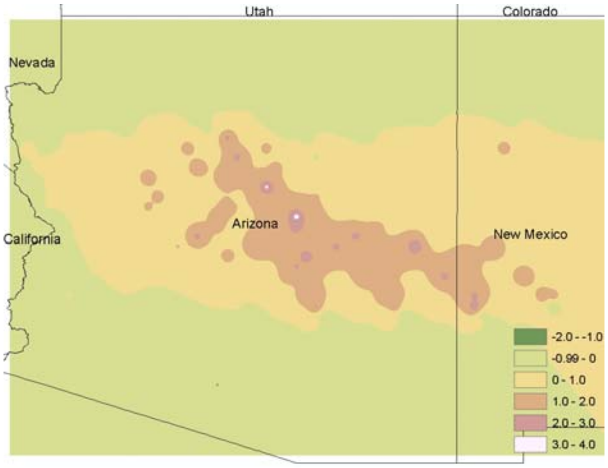


**Figure 7. This map shows the z-scores for the study region**

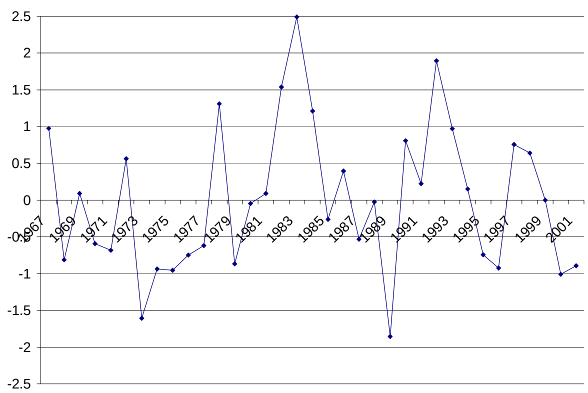

**Figure 8. This histogram displays the z-score frequency for all 283 grid points where the mean precipitation received was 7590.37 (mm/day).**

### *3.4 Relationship between winter and spring snow cover and calendar dates*

To find a relationship between snow cover and the various calendar dates given, the following correlations were found.

| | Onset | Length | NDays |
|---|---|---|---|
| **Winter Snow** | 0.213011 | -0.26619 | -0.19827 |
| **Spring Snow** | 0.388485 | -0.09099 | -0.05423 |

**Table 6. This table shows the correlation values between snow cover and the calendar dates.**

A relationship is evident between both winter and spring snow cover and the onset of the monsoon, although much stronger with the spring snow: as snow cover increases, the date of onset occurs later in the season. The stronger relationship between length of season and snow cover occurs when using winter snow cover values. As the amount of snow cover received increases, the length of the season decreases. Also, as the amount of snow cover received increases, the number of days in the monsoon season receiving precipitation decreases. It is possible that this occurs due to a shorter season length.

### *3.5 Relationship between winter and spring snow cover and monsoon precipitation*

Previous studies have shown that there is a negative correlation between snow water equivalent (SWE) and precipitation from the NAM. A study done by Lo and Clark (2002) showed that positive (negative) anomalies of spring snow cover leads to a weakening (strengthening) of circulations related to the monsoon causing a decreased (increased) precipitation during the monsoon season. A study done by Gutzler and Preston (1997) proved that greater than normal snowfall led to wetter soil, thus keeping the surface of the land cooler which would decrease the amount of heating during the summer months needed for convection (Matsui, Lakshmi et al. 2003).

In this study, it was found that various areas of the study region respond differently to the time of the year a specific amount of snow cover was received. The correlations are slightly positive with an average near zero for total snow cover compared to monsoonal precipitation. When comparing a series of months, the months of December through February (winter snow-covered area) have a wider range of correlation values, most of them being positive, while the months of March and April (spring snow-covered area) have a larger number of negative correlations than for the winter months.

The following figures, 9 and 10, show the change in correlations between the winter and spring seasons. Figure 9 shows that the center of the study region has the highest correlations, where larger snowfall relates to larger monsoonal precipitation. Also, there are regions where negative correlations exist. This shows that larger snowfall relates to less monsoonal precipitation. In Figure 10 it is clear that a shift in correlation regions occurs as spring snow cover is used. The correlations are not as large as they are for winter snow cover but the regions of negative correlations are larger and project further into the study region.

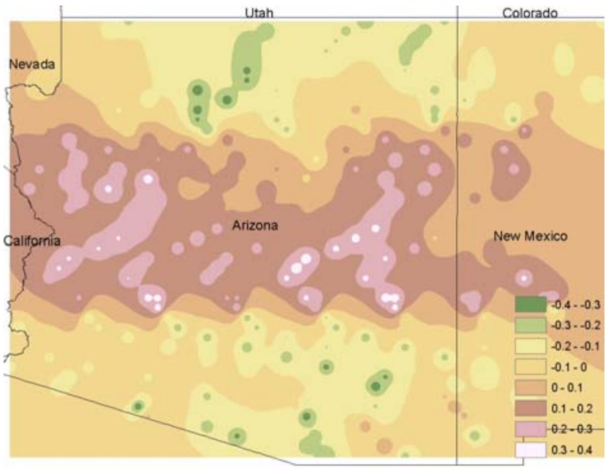


**Figure 9. Regions of correlations for the relationship between winter snowfall and monsoonal precipitation.**

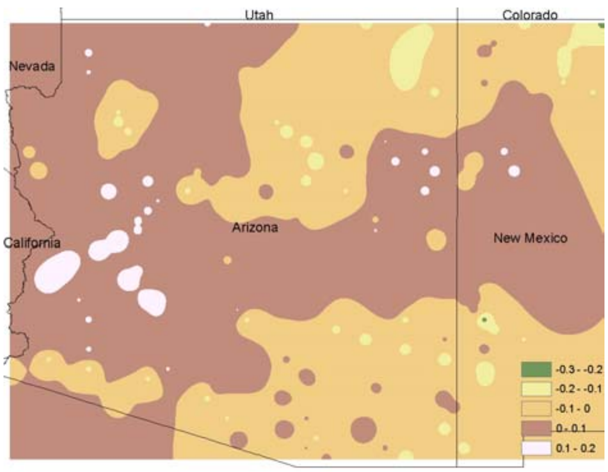


Figure 10. Regions of correlations for the relationship between spring snowfall and monsoonal precipitation.

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