Recent Trends in Northern and Southern Hemispheric Cold and Warm Pockets

Richard Grumm
National Weather Service Office, State College, Pennsylvania
and
Anne Balogh
The Pennsylvania State University

Abstract:

The climate forecast system was used to examine trends in warm and cold pools and trends in the precipitable water in both the northern and southern hemispheres from 1979-2010. The data were examined by season focusing on potential extremes in warm and cold season in both hemispheres.

The data revealed a stronger signal in 850 hPa temperatures and 500 hPa heights in the northern hemisphere. Generally, areas covered by extreme cold air; defined as the areas where the 850 hPa temperatures were equal to or less than -30C (243K); in the northern hemisphere winter are decreasing. During the warm season, the areas covered by precipitable water values equal to or greater than 60mm are increasing.

Similar but weaker 850 hPa temperature and 500 hPa height trends were found in the southern hemisphere. However, the trends in southern hemispheric precipitable water were similar to those in the northern hemisphere.

1. Introduction

The fifth assessment report (AR5) of the Intergovernmental panel on climate change (IPCC,2014) noted the potential for more extreme weather as the climate changes. The reported cited extremes in weather phenomena "*such as heat waves, droughts, floods, cyclones, wildfires*". Extreme weather would likely be in the tails of the distributions, with fewer fatalities due to cold episodes and increased fatalities due to warm episodes[1]. Diminished cold-related mortality would be and are the result of fewer cold extremes. The report also addressed the potential for increased moisture producing increased flood potential in some regions and increased drought risk in other areas. The report summarized the potential effects by regions of the globe.

A recent study by Martin (2015) showed that the extent of the Northern Hemispheric wintertime cold pool has been decreasing over the past 66 years. The study examined the area of the northern hemisphere covered by the -5 to -25C contours in 5C intervals. The data showed a slow steady downward trend with the largest impact at the lower temperature thresholds (Martin 2015: Fig1), consistent with the IPCC (2014) conclusion of fewer extreme cold episodes due to climate change.

Employing the concepts of Martin (2015) an examination of both cold pools and warm pockets was conducted. The goal was to see if the Climate Forecast System Reanalysis data version 2 (CFSR-V2) would show a signal over the past 30 years. In addition to the cold pools and warm pockets, trends in moisture were examined, using the precipitable water values. The study was conducted over both hemispheres. The methods and data are addressed in section 2 and the results are presented in section 3. A brief summary of key findings is presented in section 4.

2. Methods and Data

The climate forecast system version data (CFSV2: Saha et al. 2010) were used in this study. The data were retrieved from the NOAA National Centers for Environmental Information (NCEI). The CFSV2 data ranged from 1979 through 2010. Data from 2010 through 2016 were retrieved from the National Centers for Atmospheric Research (NCAR). Most of the images shown reflect the 30 year stable climate period used for computing means and standard deviations.

The variables, levels, and thresholds used are listed in Table 1. The analysis was conducted in both the northern and southern hemisphere and the cold (warm) and warm (cold) seasons were defined as the months of December-January-February and June-July-August in each hemisphere. The data were available at 0000, 0600, 1200 and 1800 UTC daily. No attempt was used to view any diurnal trends and to maximize the data points all 4 times were used in all monthly and seasonal computations. The Notes column in Table 1 addresses issues related to the selected

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[1] Reference page 37 of the final report showing more heat than cold related fatalities already observed.
https://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-IntegrationBrochure_FINAL.pdf

hemisphere. For example, at 500 hPa the closed 5940 m contour is an extremely rare event in the SH, therefore 5880 m as used. For comparison purposed the 5880 m contour was computed in the NH though statistically significant 5940 m areas occurred in all NH warm seasons.

Python was used to read the data using the PyGrib module and plotting was conducted using MATPLOTLIB. Numpy was used to mask out northern and southern hemispheric data respectively. Numpy array masks were the applied to mask out values greater than or equal to the specified cold or warm pool thresholds. For several variables and thresholds such precipitable water (PW) and warm season temperatures values equal to or less than the thresholds were masked out. Using the True or False condition of the masked field facilitated using greater or less than data as required.

Variable	Level	Cold Threshold	Warm Season Threshold	Notes
Temperature	850	243	293	SH 293
Temperature	850	253	298	
Temperature	850	263	273	
Temperature	850	268	268	
Height	500	5100	5880	SH
Height	500	5100	5940	NH
Height	500	5100	5880	
PW	Column	20	60	
PW	Column	50	20	

Table 1. List of variables and levels used to compute the respective cold and warm pools. Temperatures were in degrees Kelvin (K), heights in meters (m), and precipitable water was in millimeters (mm). Notes column shows thresholds used based on hemisphere

In order to account of convergence of longitude simple geometry was used to compute the area of influence of each grid point. Thus the area was a function of the latitude and longitude of the data points. The area of influence of each grid point was computed as :

$$Area = \frac{111 \, \pi \, R^2 \, |\sin(\varphi+\partial\varphi)-\sin(\varphi-\partial\varphi)| \, |(\varphi-\partial\varphi)-(\lambda+\partial\lambda)|}{360} \tag{1}$$

where ϕ is the latitude, λ is the longitude, the distance in kilometers (km) of one degree latitude is equal to approximately 111 km, and $\delta\phi$ is the chosen spacing between the grid points of the data. The main program computed the area of each available hour and day for each month for all seasons. These data were then used to compute monthly and seasonal statistics using the Numpy statistical packages. Seasonal values were plotted by year for quick interpretation.

3. Results

The results are presented by hemisphere and season showing select variables and thresholds

i. Northern Hemisphere: cold season

The crème de la crème of arctic air in North America is the -30C (243K) contour. Thus the area covered by the 243K contour (Fig. 1) was used here. The northern hemisphere 850 hPa temperatures at 243K, 500 hPa heights at 5110 m and PW greater than 20mm are shown in Figures 1-3 respectively. The 850 hPa temperatures at 253 and 263 were also examined; however the signal was strong and statistically more significant at the lower threshold. The 243K and colder 850 hPa temperature data show (Fig. 1) trend for a smaller area of the northern hemisphere covered by the extreme cold air over the past 30 years. The slope of the line and the R-squared value show a negative trend in the area and a fair correlation.

The trend in the area covered by the 5110 m contour is similar to the trend seen in the 850 hPa 243K data (Fig. 2).

The trend in the area covered by the 20mm and drier air during the northern hemisphere winter show a downward trend. The inverse image; greater than 20mm (not shown) and the area covered by the 50 mm or greater contour during the winter months (Fig. 4) had the opposite slope implying that the PW values in the northern hemisphere are increasing during the winter months and the R-squared values are statistically significant relative to those found for the 850 hPa temperatures and 500 hPa heights. Note the R-squared value was greater for the PW greater than that for the values lower than 20 mm.

ii. Northern Hemisphere: warm season

The gold standard for warm heat waves in the United States is 500 hPa heights greater than or equal to 5940m. Therefore the 5940 m contour (Fig. 5) was selected to see the impacts of climate change on larger ridges. The less aggressive 5880 m contour was also used. In addition to the 5940 m threshold, the 850 hPa 298K (Fig. 6) and 293K areas were examined along with the PW values of 50 and 60 mm (Fig. 7).

These data showed a stronger signal for areas covered by warmer temperatures and higher heights. The signal for the PW was similar in both the cold and warm seasons with a strong trend toward larger areas covered by higher PW amounts. The tendency for warmer NH summers and more humid summers was apparent in these data.

iii. Southern Hemisphere: cold season

The SH cold season signals though present were weaker than those found in the NH. The 243K 850 hPa cold pool (Fig. 8) showed a weak negative slope which was not statistically significant. The 500 hPa heights (not shown) had a similarly weak signal with a weak trend for a smaller area covered by the 5100 m contour during the winter months

The SH cold season PW showed a slightly stronger signal with a decrease in the area covered by the 20mm contour (Fig. 9) and an increase in the area covered by the 50 mm contour (Fig. 10).

iv.   Southern Hemisphere: warm season

The SH warm season 500 hPa heights greater than 5880 m (Fig. 11) and 850 hPa temperatures greater than or equal to 293K (Fig. 12) show an increase in area covered by each contour over the past 30 years. The 5940 m at 500 hPa and the 298K contour at 850 hPa are rarely present over significant areas requiring the use of lowered threshold values.

The strongest signal is in the area covered by the 60mm PW contour (Fig. 13). These data show increasing areas covered by the 60 mm contour and high R-squared value. The percent area covered by the 60 mm contour is relatively small making the small increase appear to be significant. A similar trend was observed in the area covered by the 50 mm contour (not shown) and the percentage area increase went from around 2.5% in the early 1980s to about 3.5% in the late 2000s.

4. Discussion & Summary

An analysis was conducted looking at the area covered by specific thresholds of 850 hPa temperature, 500 hPa heights and precipitable water over the intervening warm and cold seasons during 30 year period of 1980 to 2010. The analysis suggested that areas covered by lower heights at 500 hPa and lower temperatures at 850 hPa during the cold seasons are decreasing in both hemispheres. In the warm season, there was in increase in the area covered by higher 500 hPa heights and higher 850 hPa temperatures. The most consistent signal in both hemispheres was the increase in the PW.

The strongest signal appeared to be in the PW field in both hemispheres regardless of season. The trends were more significant, showing an increase in the areas covered by the both 50 and 60 mm contours in the warm season and much higher R-Squared values. Similar trends were found in the NH winter with a smaller are covered by the 20mm and lower PW contour as the overall trend was for higher PW values during the NH winter. The potential implications for higher PW might include higher humidity in some locations and an increase in heavy precipitation events as moisture is a key ingredient for precipitation events.

The data shown here relative to NH cold pools shows the same trends found by Martin (2015) with a general decrease in the area covered by the 850 hPa 243K (Fig. 1) isotherm. This implies smaller areas of deep cold air during the NH winter. Not surprisingly; due to the relationship of heights and temperatures; the 500 hPa height field showed a decrease in the area covered by the 5110 m (Fig. 2) contour. In addition to the shrinking cold season cold pools, areas covered by higher PW values show an increase over time during the NH winter months. These PW changes appear to be more significant than the changes in the temperature and height fields. Similar

trends were found in the SH with weaker signals in the 850 hPa temperatures and 500 hPa heights.

During the NH warm season (JJA), there was a signal showing in an increase in the area covered by 850 hPa temperatures in excess of 20C (293K) and 25C (298K); an increase in the areas covered by the 5880 m and 5940 m contours at 500 hPa; and an increase the area covered by the 50 mm and 60 mm PW contours. Overall, more warm air, larger ridges, and warmer air. In mid-latitudes, large ridges are known to be excellent mechanisms to transport moisture poleward which might imply, with higher PW values, more heavy rainfall events on the western flanks of these ridges. Conversely, on the eastern side of persistent ridges equatorward transport of dry air could lead to relatively dry regions.

With the exception of the SH PW increased, the southern hemisphere showed weaker overall signals relative to the NH. It was interesting to note the relative dearth of 5940 m height at 500 hPa in the SH relative to the northern hemisphere.

The current methods were applied to the CFSR data which covers a limited time period. The NCEP/NCAR data could be used to examine longer term trends covering the period of 1948-2016. These data are of coarser resolution which would expedite processing but would likely miss some of the details in the higher resolution CFSR data.

The key finds here appear to support the previous findings of Martin (2015) and the IPCC report (2014) with the significant changes occurring in the tails of the distribution. In this case, in NH it is clear that the extreme cold air, defined as areas covered by the -30C (243K) contour are decreasing which implies fewer extreme outbreaks of arctic air as the extreme cold air diminishes. Conversely the increase in the area covered by air of 20C (293K) and 25C (298K) suggest more areas may experience extreme warmth and thus warm season heat waves.

The PW data had the strongest signal indicated an increase in the moisture within the air. It is unclear if this reflects real increases in moisture or a combination of moisture increased combined with improved moisture sensing between 1979 and 2016. If the data are to be believed, the increased moisture would imply the potential some areas to see more and more intense rainfall events. Of course the distribution of these changes is not uniform over either hemisphere and despite increases of PW in both hemispheres; there are regions which, due to flow patterns, will be drier.

Thus, the data here seem in line with previous studies and the general findings of the IPCC (2014) report. Generally, the decrease in extreme cold air in both hemispheres would lead to fewer extreme cold outbreaks. The increase in extreme warm air and strong ridges would lead to an increase in warm season heat episodes and the increase in PW could lead to regionally more extreme rainfall events.

6. References

Martin, J. E., 2015: Contraction of the Northern Hemisphere, Lower-Tropospheric, Wintertime Cold Pool over the Past 66 Years. *J. Climate*, **28.** 3764-3777

Saha, Suranjana, et. al., 2010: The NCEP Climate Forecast System Reanalysis. *Bull. Amer. Meteor. Soc.*,91,8 1015-1057
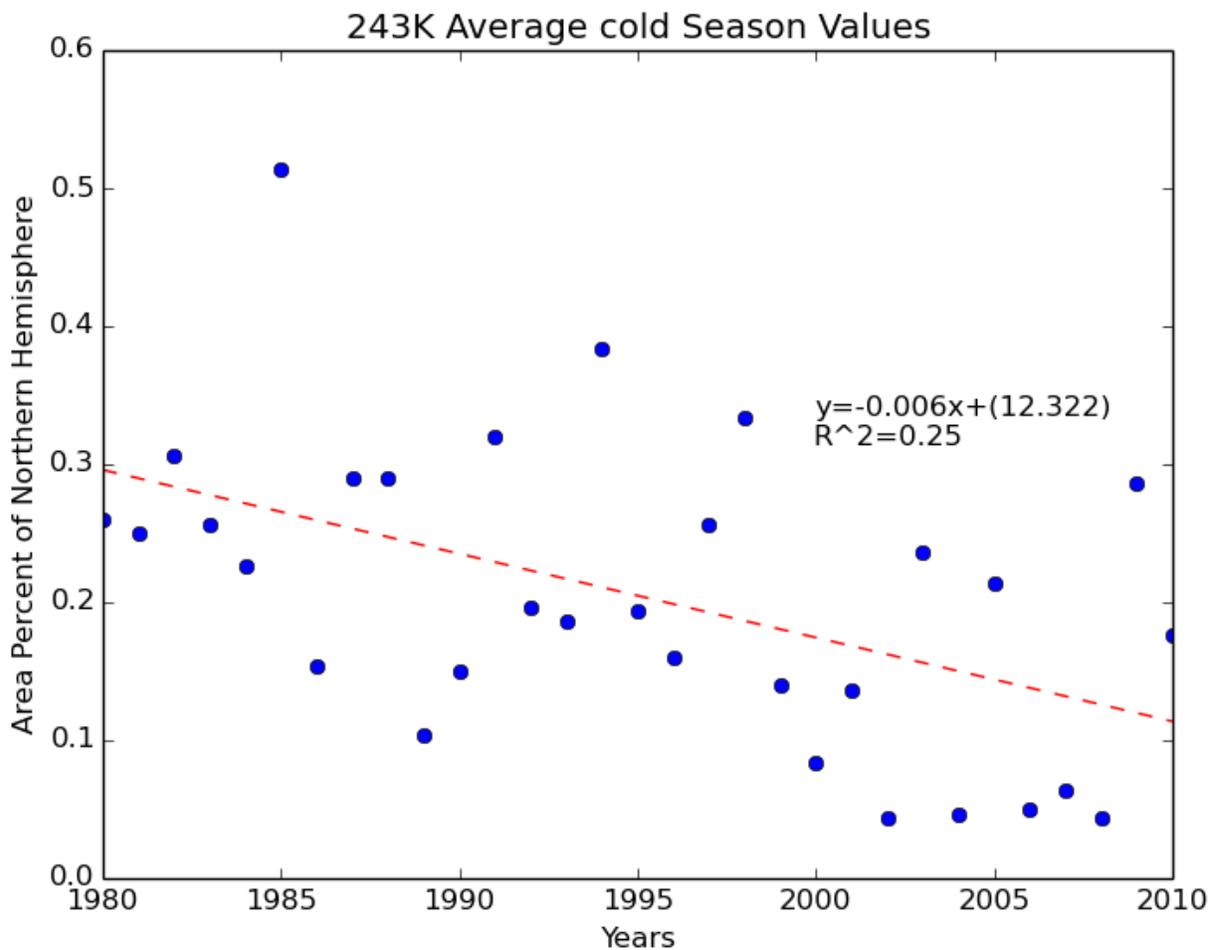

Figure 1. Northern hemisphere cold season plot of the 3-month cold seasonal mean area encompassed by the 243K (-30C) contour at 850 hPa. This represents the percent of area northern hemisphere where the values were equal to or less than 243K. Data are plotted by year. The blue dots show the seasonal value, the dashed line is the regression line; the regression equation and R-squared value are included. Return to text.
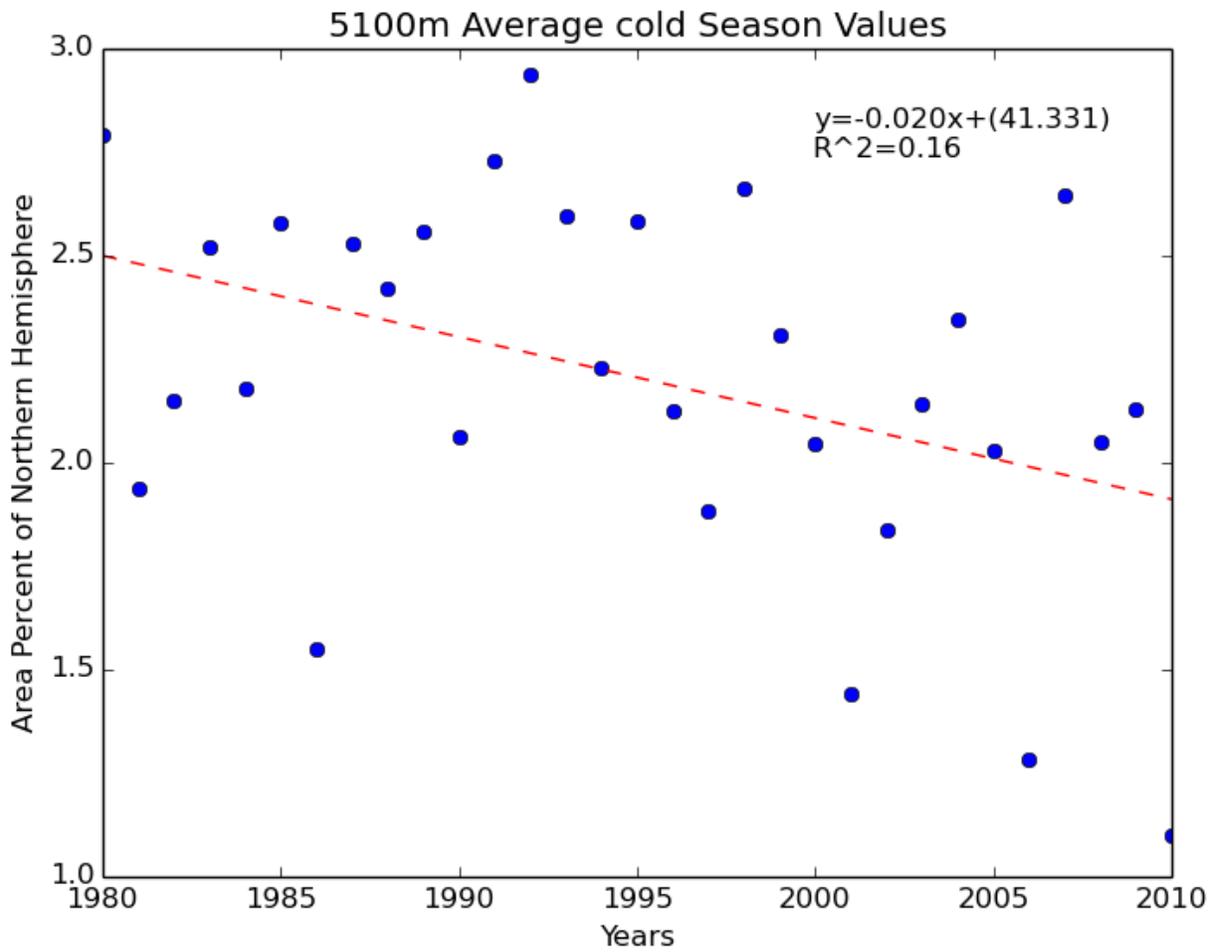
Figure 2. As in Figure 1 except for Northern hemisphere cold season areas covered by the 5100 m contour at 500 hPa. Return to text.
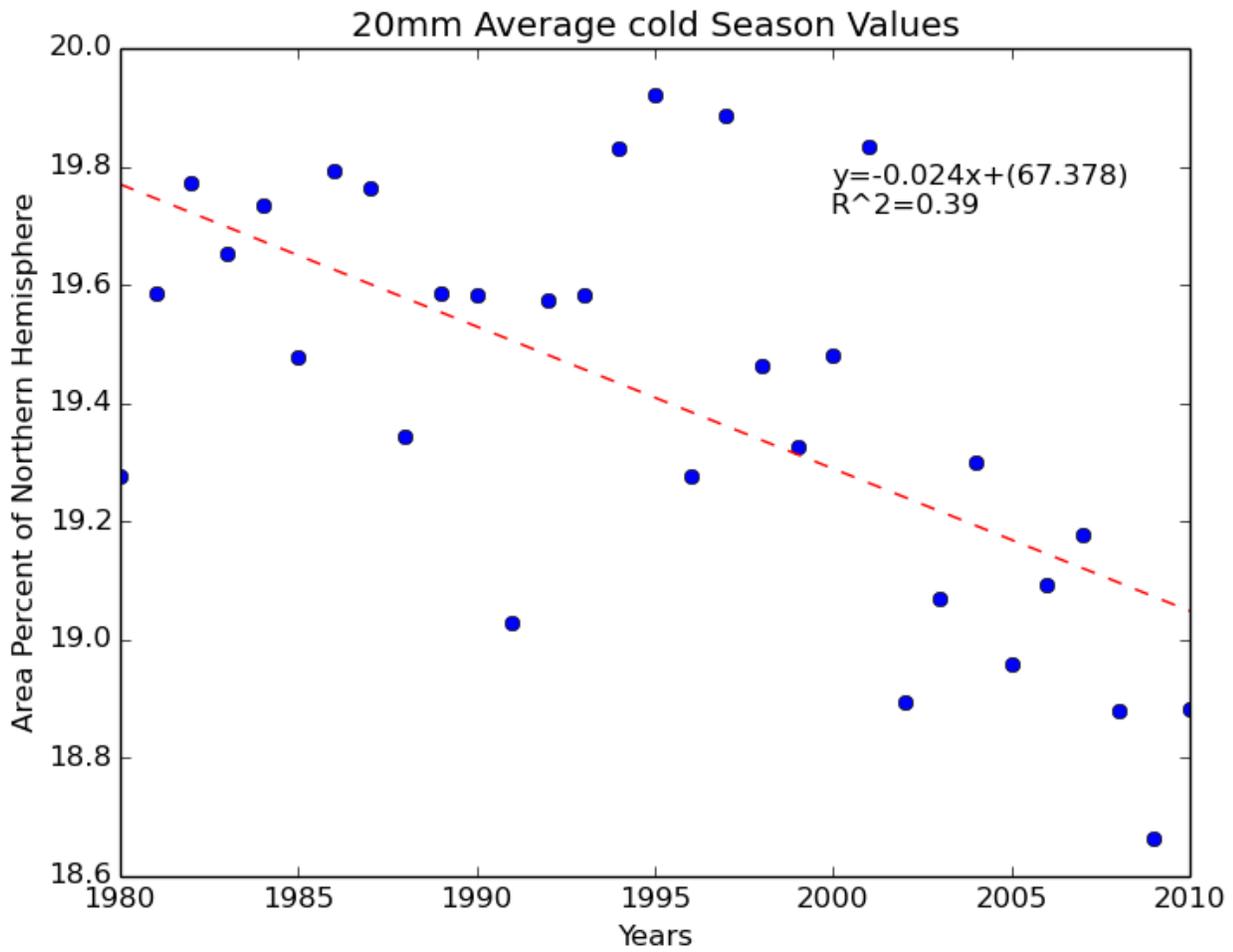
Figure 3. As in Figure 1 except for the northern hemisphere cold season area where the precipitable water values were **greater than** or equal to 20 mm. Return to text.
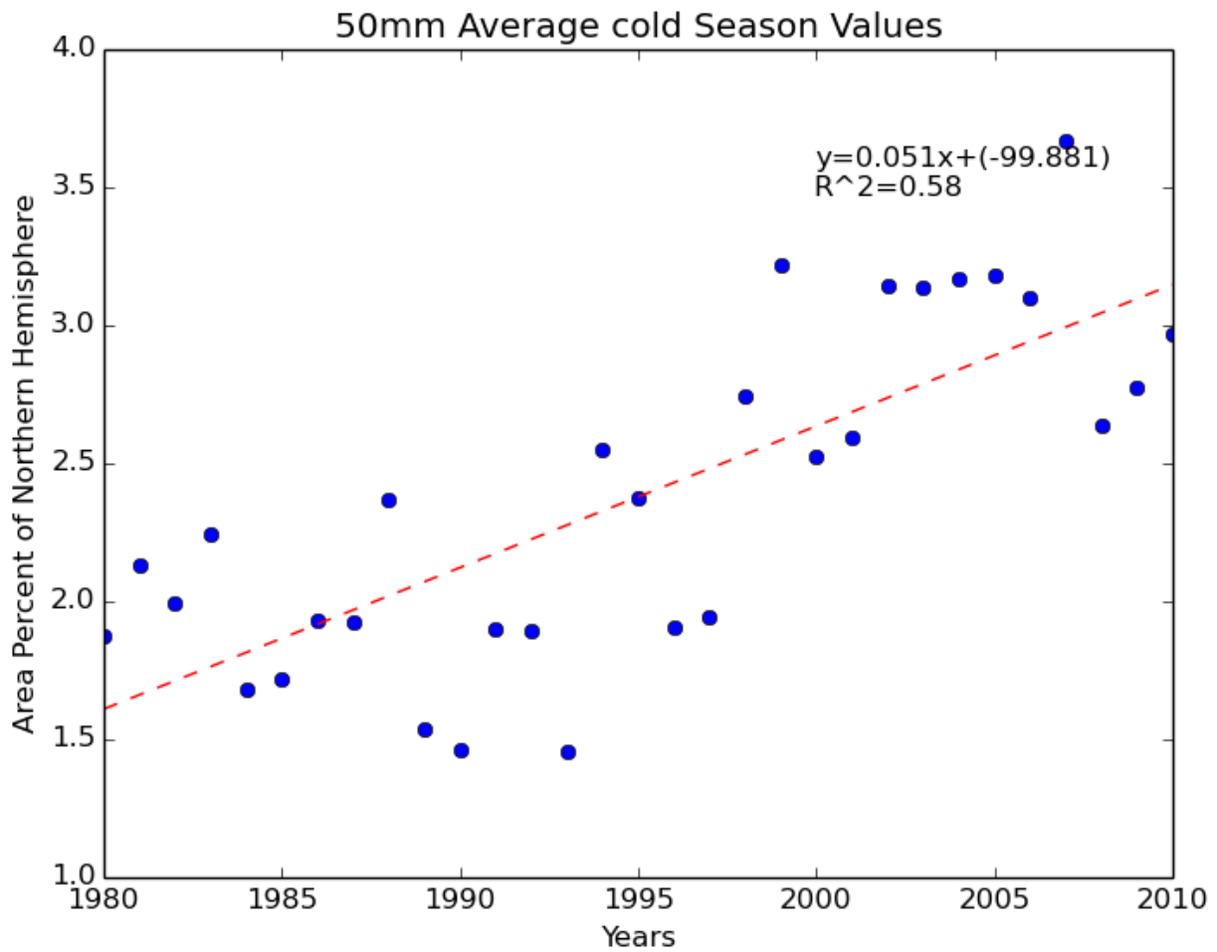
Figure 4. As in Figure 1 except for the area encompassed by the 50 mm or greater precipitable water contour. This is the inverse of the condition shown in Figure 3. Return to text.
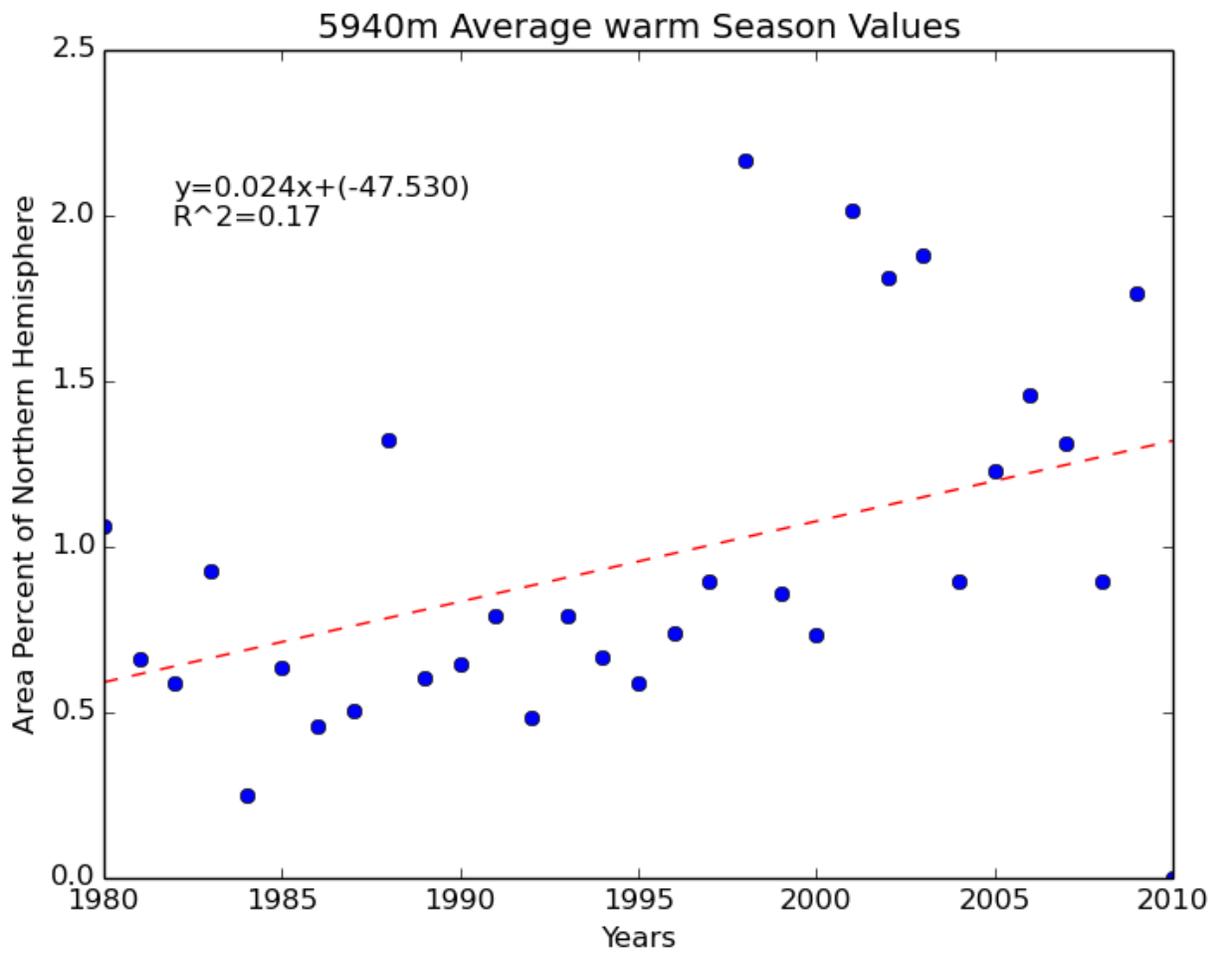
Figure 5. As in Figure 1 except northern hemisphere warm season and the area where the 500 hPa heights were equal to or greater than 5940 m. Return to text.
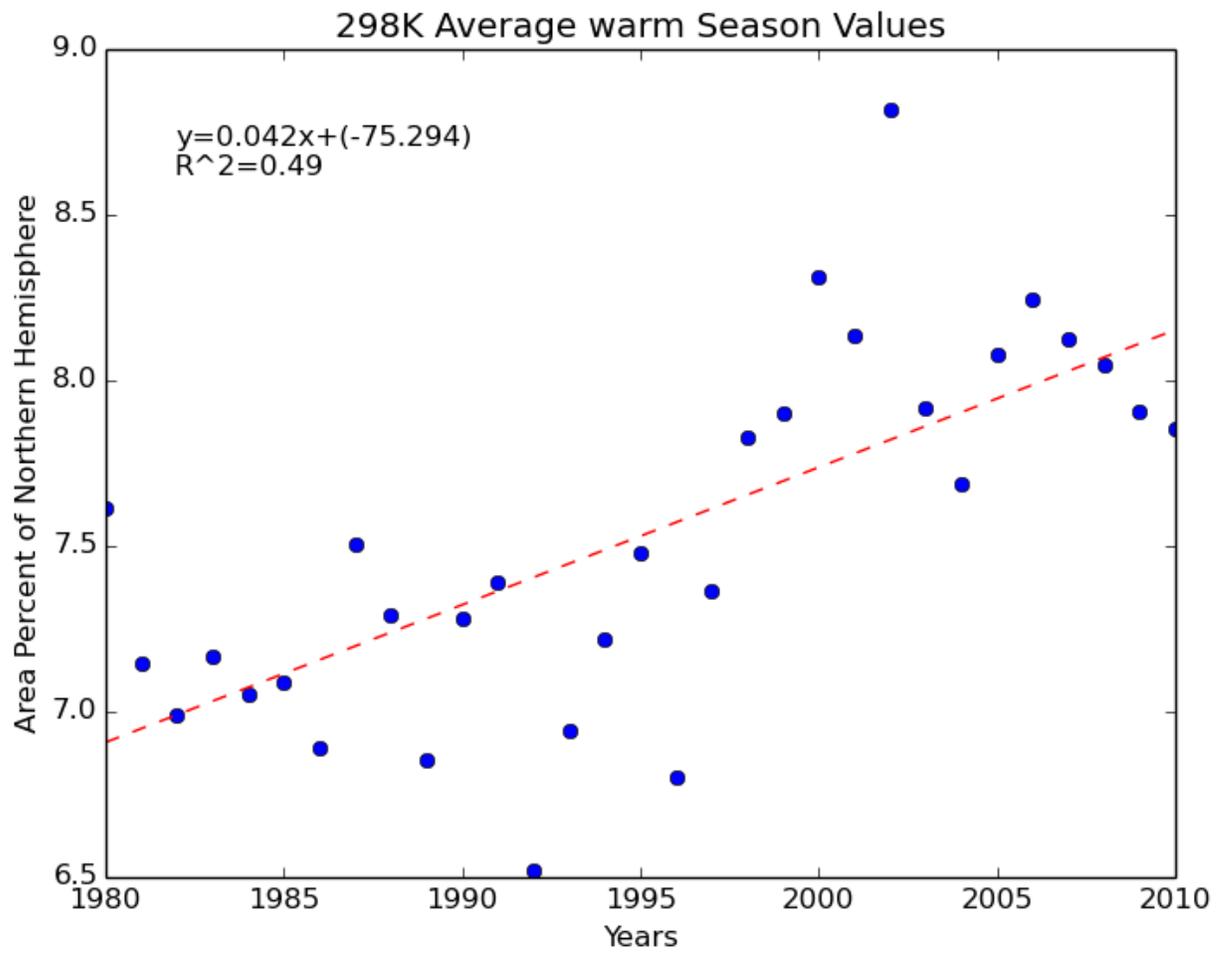
Figure 6. As in Figure 5 except northern hemisphere warm season area where the 850 hPa temperatures was greater than or equal to 298K (25C). Return to text.
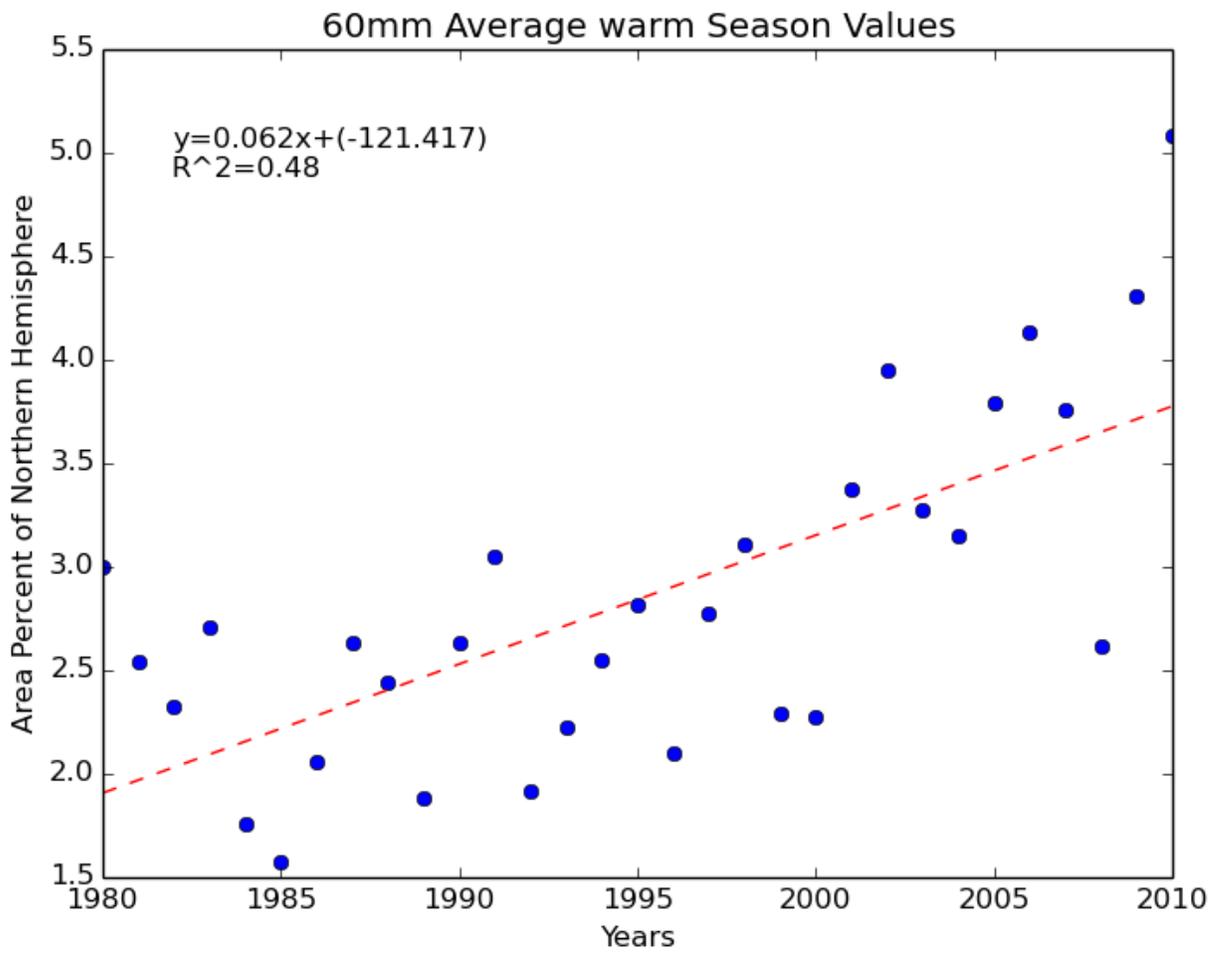
Figure 7. As in Figure 6 except area where precipitable water was greater than or equal to 60 mm. Return to text.
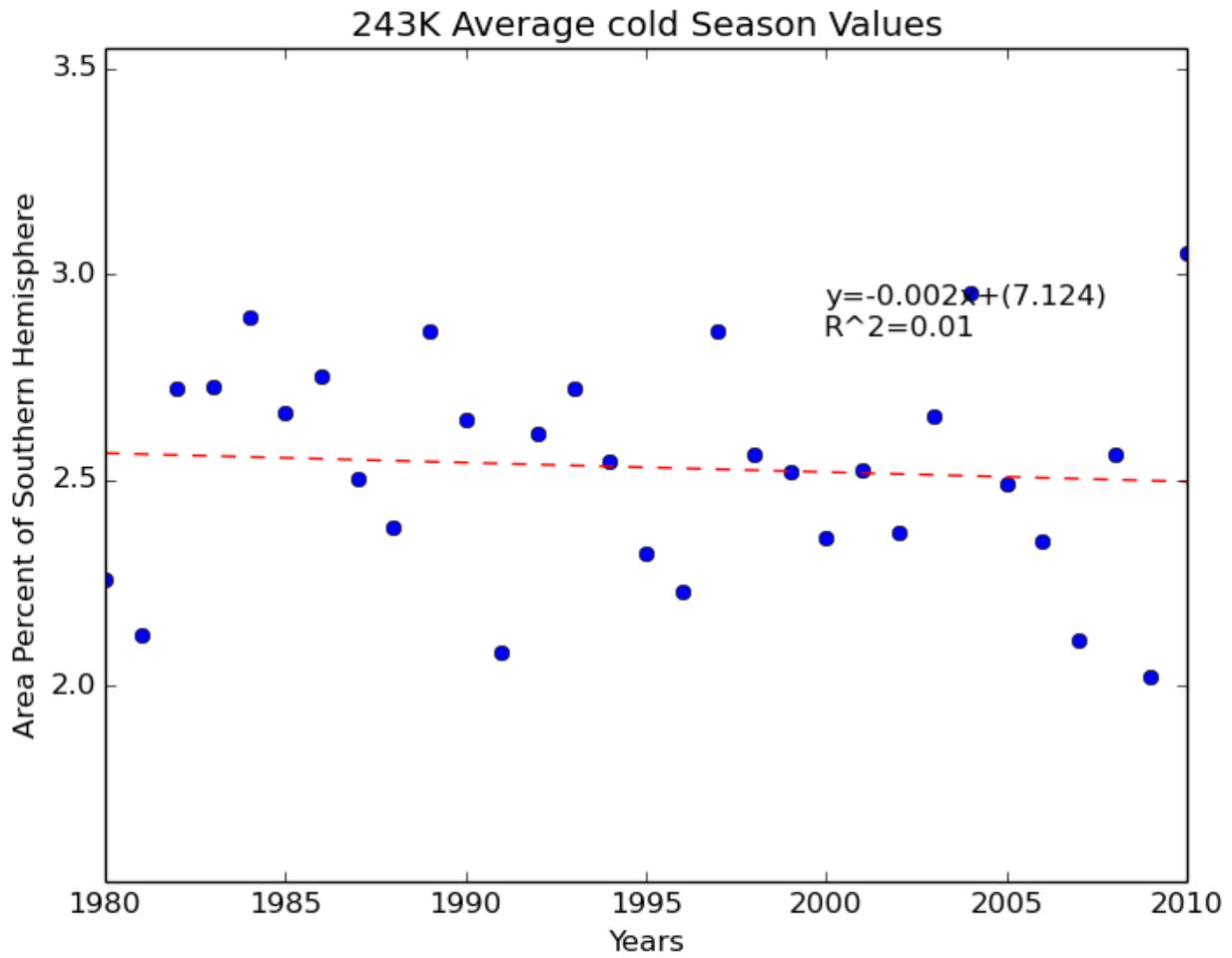
Figure 8. As in Figure 1 except for southern hemisphere cold season (JJA) percent areas where the 850 hPa temperatures were equal to or lower than 243K. Return to text.

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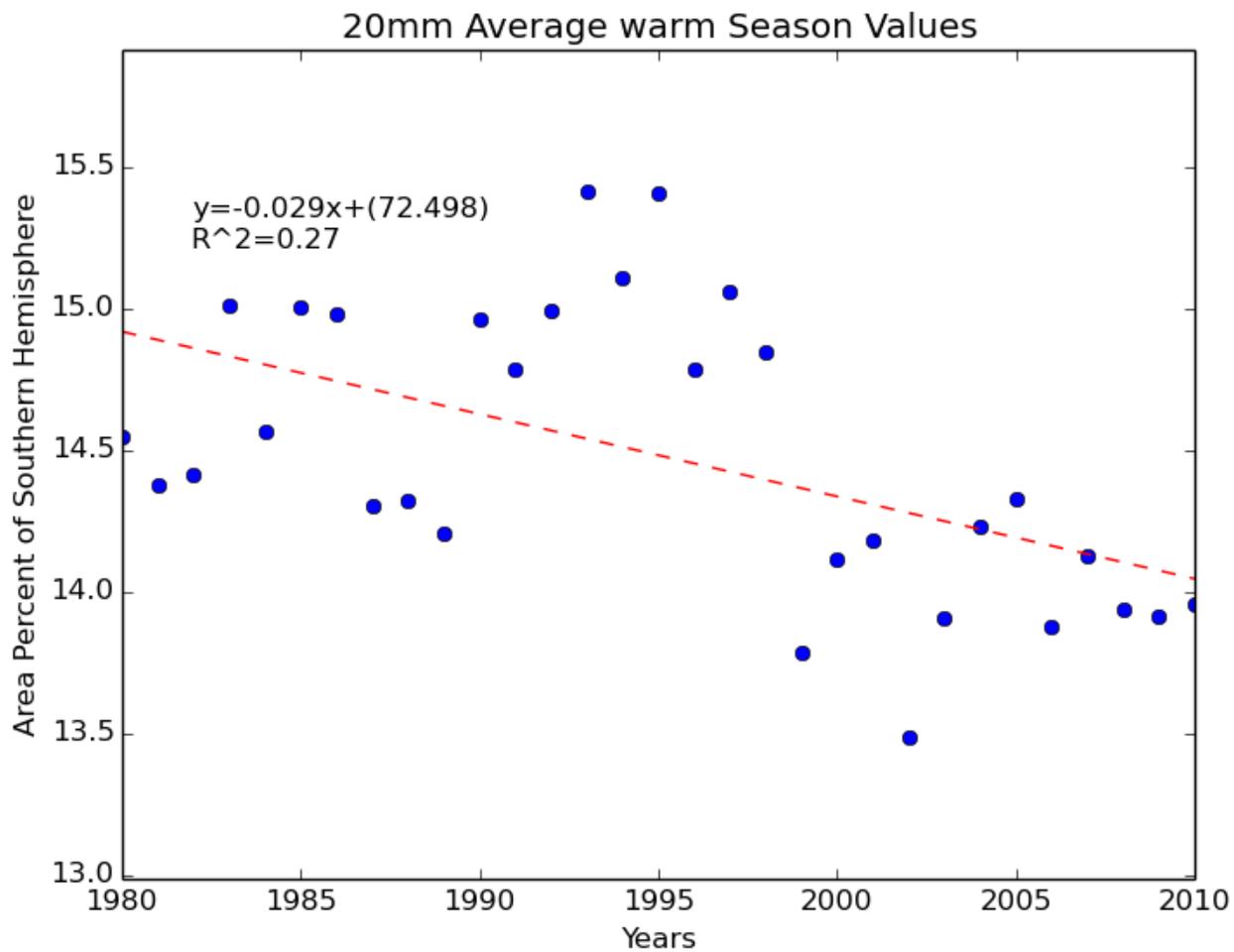
Figure 9. As in Figure 8 except the areas where the precipitable water values were 20 mm or less during the SH cold season. Return to text.
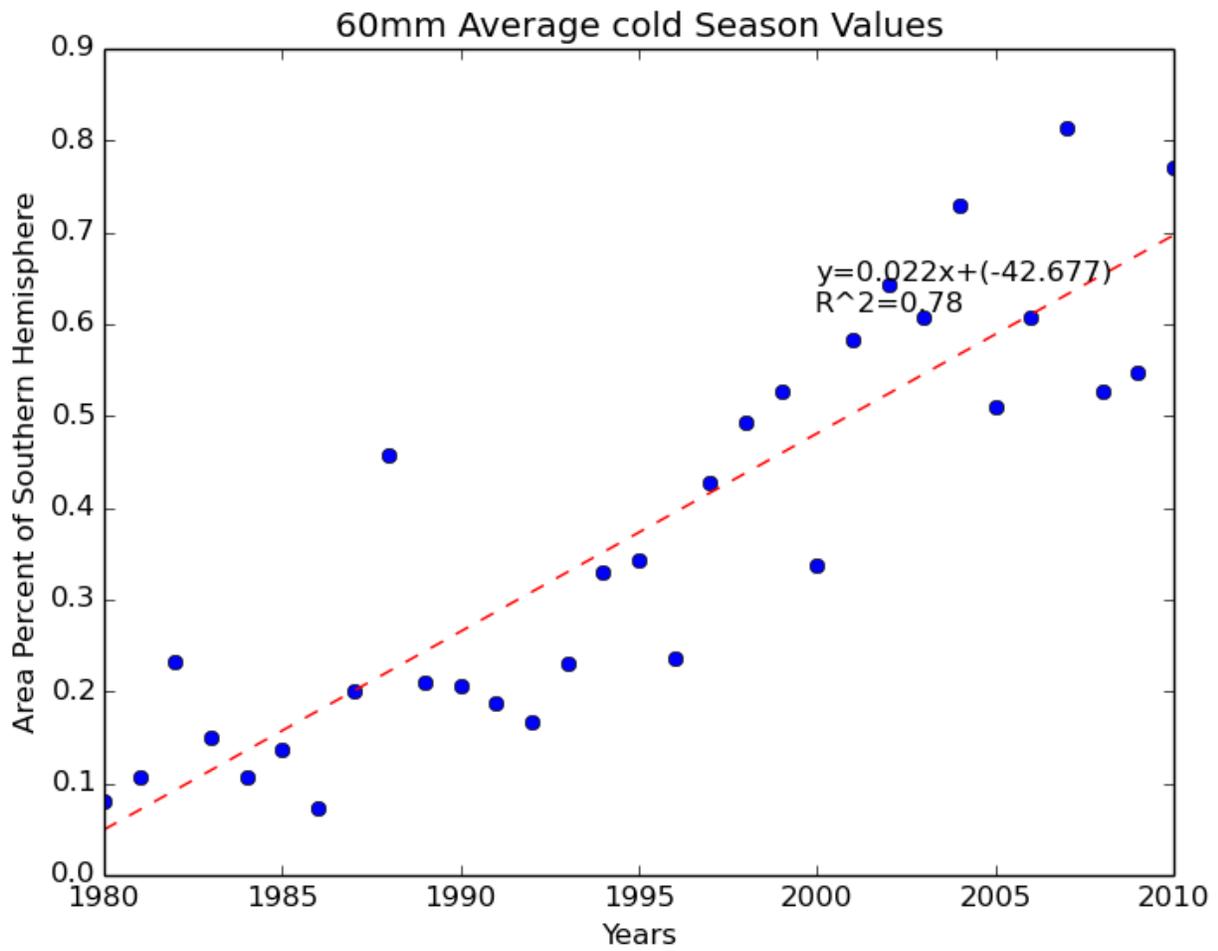
Figure 10. As in Figure 9 except for the area covered by the 60 mm contour during the southern hemisphere cold season. Return to text.
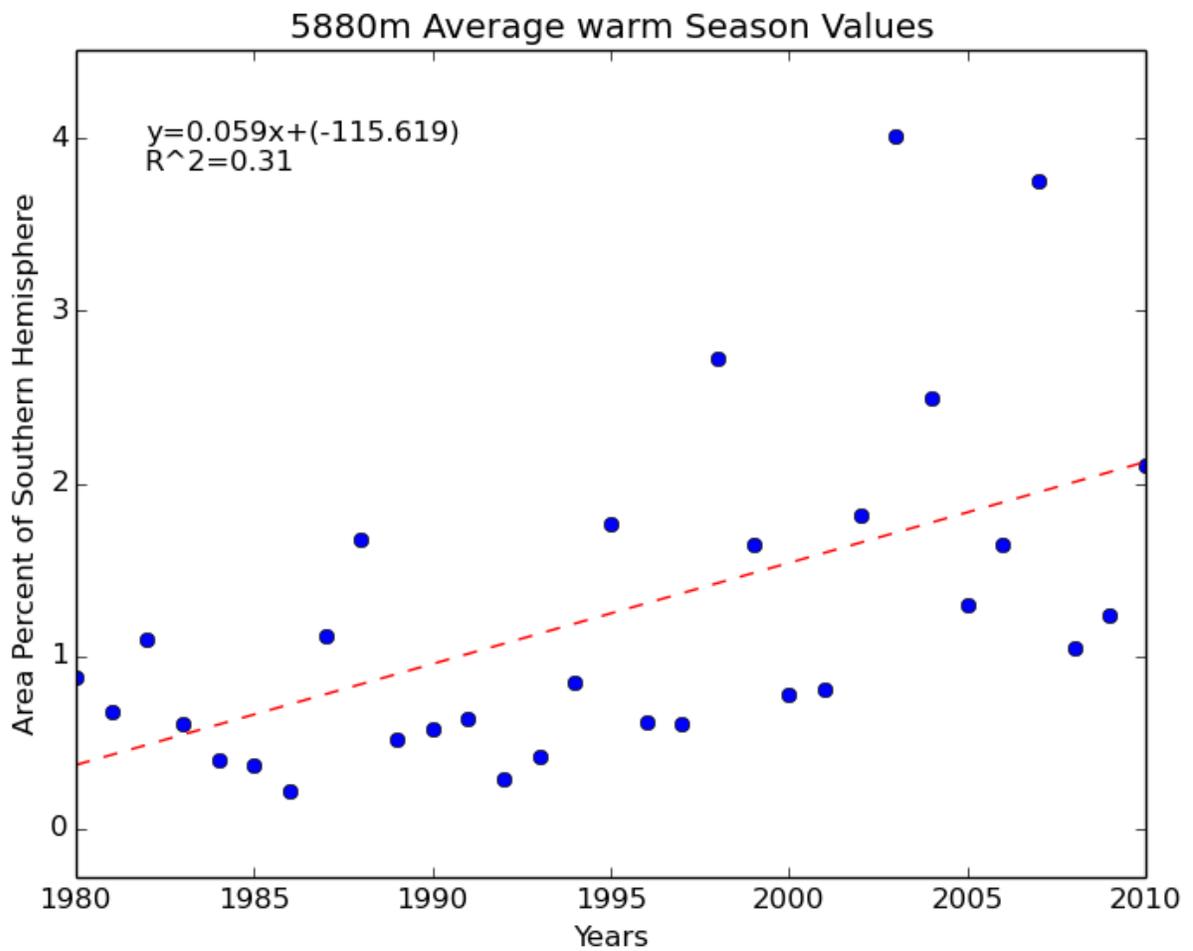
Figure 11. As in Figure 1 except for the southern hemisphere summer showing the percent area where the 500 hPa heights were equal to or greater than 5880 m. Return to text.
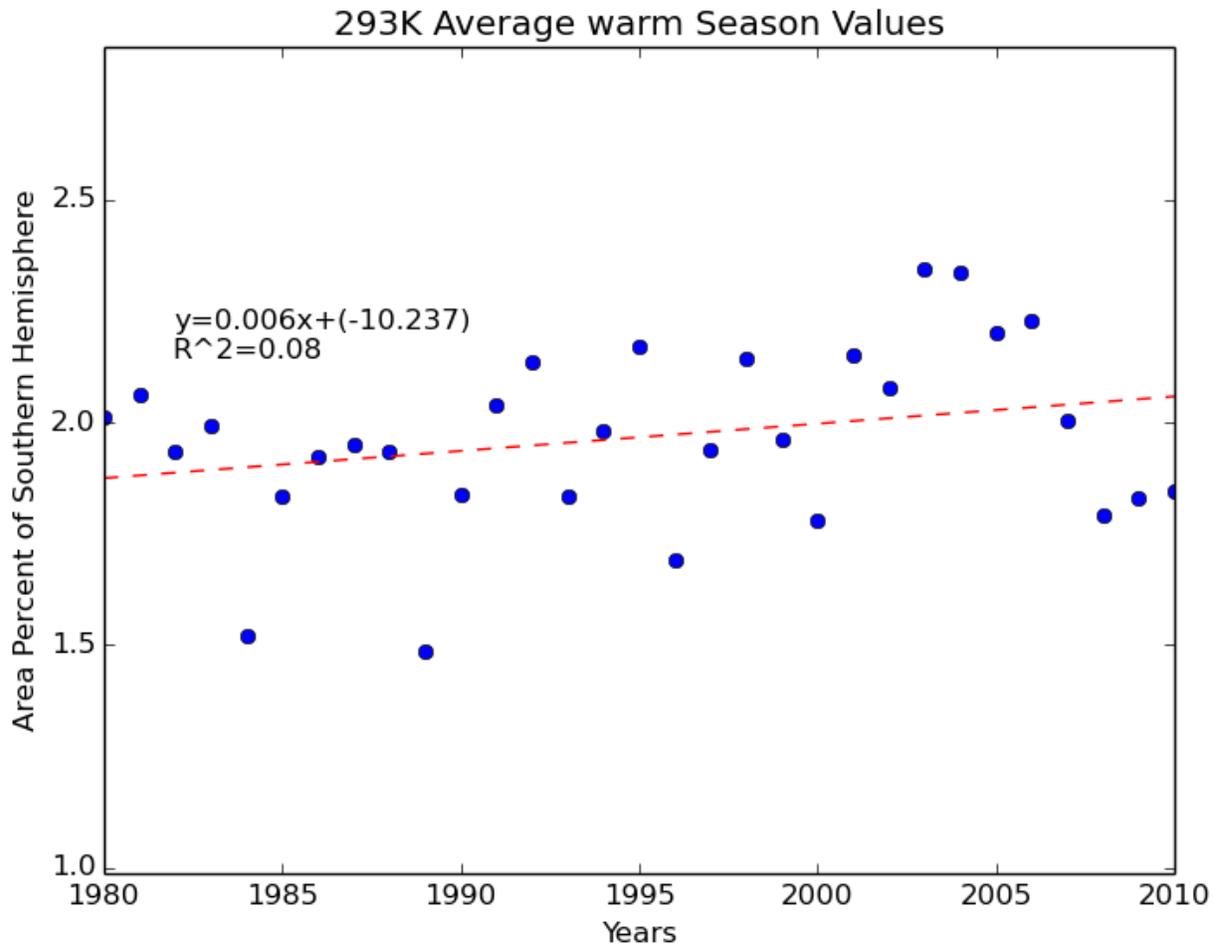
Figure 12. As in Figure 11 except for the area covered by the 293K isotherm. Return to text.

60mm Average warm Season Values
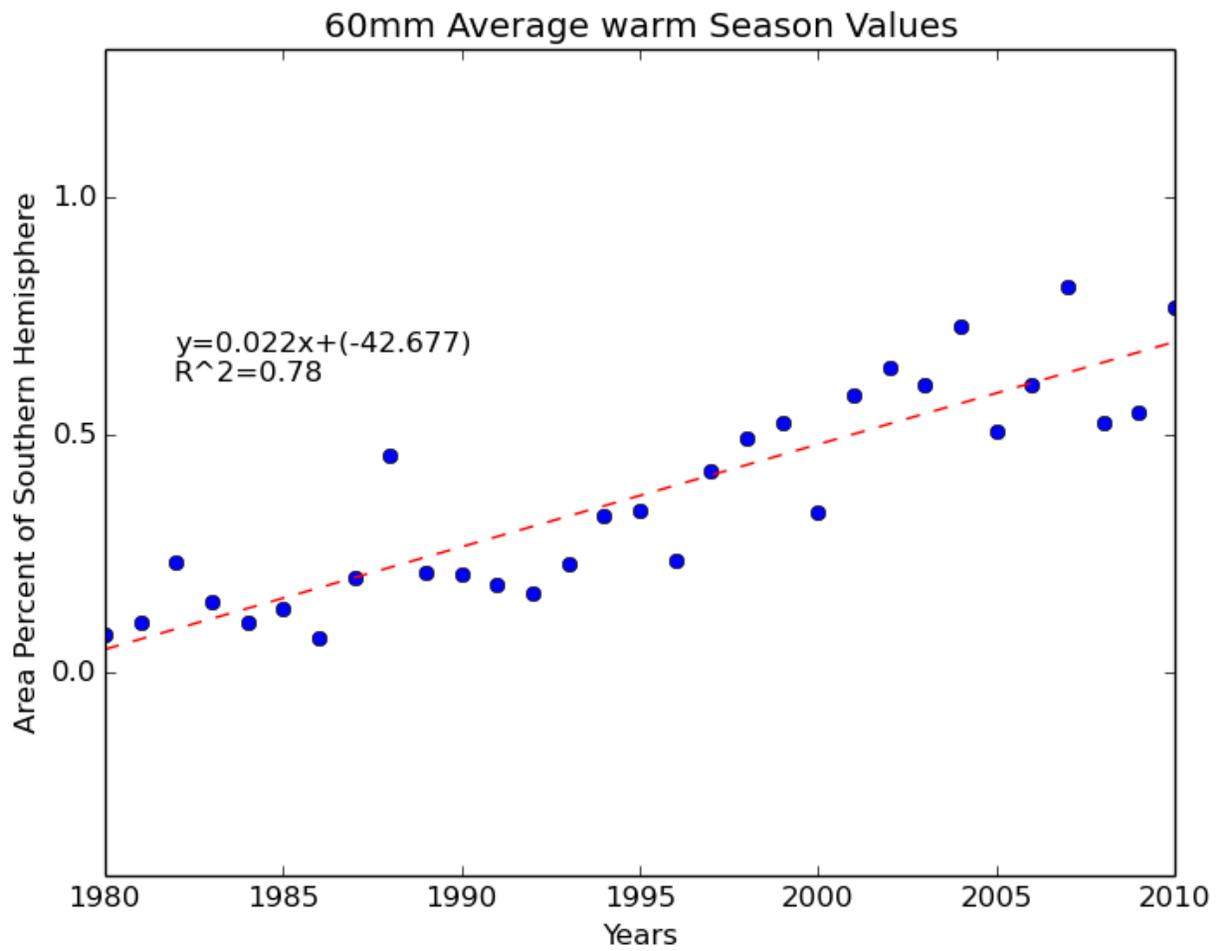
$y=0.022x+(-42.677)$
$R^2=0.78$

Figure 13. As in Figure 12 except southern hemisphere area covered by the 60 mm contour in precipitable water field. Return to text.