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MONITORING THE IMPACT OF CLIMATE CHANGE ON TEMPERATURE AND SURFACE WETNESS VALUES IN KAZAKHSTAN

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TABLE OF CONTENTS

MONITORING THE IMPACT OF CLIMATE CHANGE ON TEMPERATURE AND SURFACE WETNESS VALUES IN KAZAKHSTAN I

ACRONYMS ..... **III**

LIST OF FIGURES ..... **IV**

1. ABSTRACT **1**

2. INTRODUCTION **2**

3. METHODOLOGY AND DATA **3**

4. RESULTS **5**

CONCLUDING DISCUSSION **20**

LITERATURE CITED **22**

APPENDIX **23**

ACRONYMS

BWI	Basist Wetness Index
ERS-1 SAR	European Remote Sensing Satellite 1 Synthetic Aperture Radar
IPCC	Intergovernmental Panel on Climate Change
NOAA	National Oceanic and Atmospheric Administration
SSMI	Special Sensor Microwave Imager
USDA	United States Department of Agriculture

LIST OF FIGURES

Figure 1. Oblast map of Kazakhstan. 2

Figure 2. Almaty 5

Figure 3. East Kazakhstan 6

Figure 4. South Kazakhstan 7

Figure 5. Zhambyl 7

Figure 6. Kyzylorda 8

Figure 7. West Kazakhstan 8

Figure 8. North Kazakhstan 9

Figure 9. Significance Level 9

Figure 10. R^2 10

Figure 11. Standard Deviation 10

Figure 12. Almaty 11

Figure 13. Akmola 11

Figure 14. Aktobe 12

Figure 15. Atyrau 12

Figure 16. East Kazakhstan 13

Figure 17. Mangystau 13

Figure 18. North Kazakhstan 14

Figure 19. Pavlodar 14

Figure 20. Karagandy 15

Figure 21. Kostanay 15

Figure 22. Kyzylorda 16

Figure 23. South Kazakhstan 16

Figure 24. West Kazakhstan 17

Figure 25. Zhambyl 17

Figure 26. Significance Level 18

Figure 27. R^2 18

Figure 28. Standard Deviation 19

Figure 29. Slope 21

Figure 1a. Akmola 23

Figure 2a. Aktobe 23

Figure 3a. Atyrau 25

Figure 4a. Mangystau 24

Figure 5a. Pavlodar 25

Figure 6a. Karagandy 25

1. ABSTRACT

Understanding natural variations and trends in surface temperature and wetness in Central Asia is difficult since observations are limited. To address this problem, one may use remote sensing techniques to help capture the fluctuations. Climate change impacts can exacerbate the uncertainty in future agricultural yields to feed a growing population. Moreover, improper use of the land can promote deterioration in surface conditions, which reduce agricultural potential in growing areas, and further stresses food security.

In order to study how surface conditions are changing, the temperature and wetness products derived from the Special Sensor Microwave Imager have been employed to measure fluctuations and trends over the period 1988 to 2013. Monthly values (derived from the growing season) are averaged to represent the observed value and its inter-annual fluctuations. A series of these values for each sub-region over the 24-year record are used to derive a linear trend from a regression equation.

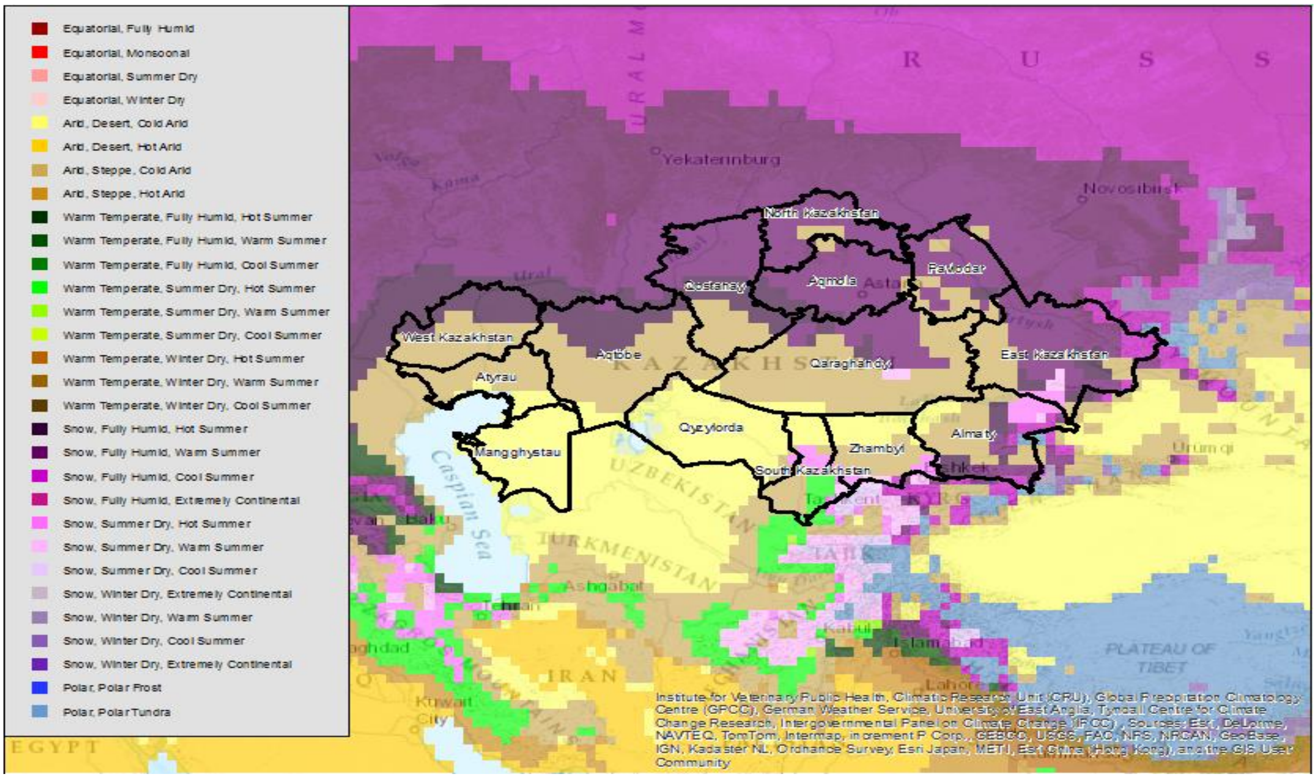
In terms of surface wetness, the trend was usually insignificant because inter-annual variability is the dominant signal. However, there are four oblasts that did have a significant slope and in all these cases the trend was positive. In other words, the surface wetness was increasing from 1988 to the present. The strongest of these positive trends occurred on the eastern edge of the country where the land rises towards the Tibetan plateau.

In terms of temperature, there were significant positive trends across the four oblasts along the northwest sector of the country. While 10 of the 14 oblasts showed insignificant positive trends at the 95% confidence level, the slopes were positive for all of the oblasts over the 23-year period (1988 and 1989 were removed from the temperature analysis).

2. INTRODUCTION

The potential impact of climate change is a significant concern in Central Asia. This extensive region of the world is landlocked and has limited atmospheric water to support the cultivation of crops except in limited areas (USDA, 2010). Fortunately, land in the northern three oblasts in Kazakhstan usually receives sufficient rainfall for the dry land farming of spring wheat. Many studies have assessed the vulnerability and exposure to changing temperature and moisture regimes in the soil (IPCC, 2014). **Climate change may be significantly impacting agricultural production as well as food security in the region** (Lioubimtseva and Henebry, 2009). In addition, many areas in Kazakhstan (particularly in the southeastern oblasts) depend on irrigation from vulnerable and variable rivers and groundwater (much of this water originates in the high mountains on the western edge of the Tibetan plateau and flows towards the Ariel Sea). The remainder of the country is primarily steppe or desert, which support grazing of animal in open scrubland. This study will investigate all of these regions of Kazakhstan in terms of variation in temperature and surface wetness in each oblast. Satellite derived products from the Special Sensor Microwave Imager (SSMI) will provide data for monitoring the temperature and upper level soil moisture for the period 1988 through 2013.

The map in Figure 1 depicts the national boundary of Kazakhstan as well as all the borders defining the oblasts inside the country. The Figure also conveys the climatological rankings throughout the country. The entire country is considered extremely continental, which implies that it has extremely cold winters, while the summers are generally hot. It can be noted that the superior agricultural land is along the northern quarter and also eastern regions of the country where Kazakhstan rises in elevation towards the Tibetan plateau. These two areas (shades of purple) are considered humid enough to support dry land agriculture. The remaining two thirds of the country (brown and tan colors) are extremely dry and agriculture can only be pursued when there is adequate irrigation water and infrastructure.



Institute for Veterinary Public Health, Climatic Research Unit (CRU), Global Precipitation Climatology Centre (GPCC), German Weather Service, University of East Anglia, Tyndall Centre for Climate Change Research, Intergovernmental Panel on Climate Change (IPCC) , Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community

Figure 1. Oblast map of Kazakhstan, and the climatic classification based on temperature and precipitation. Purple areas are the more fertile regions, tan are steppes, and light brown is desert.

3. METHODOLOGY AND DATA

In situ measurements are single point observations and may not effectively represent the surrounding area to which they are generally applied. Moreover, since precipitation and soil water holding capacity has high spatial variability in a small area, a single measurement may not represent the true distribution of soil moisture in the larger area. Therefore, remote sensing techniques have been applied to detect surface water (Aldsdorf, 2007). Considering the challenges of monitoring soil moisture directly, a simple yet robust procedure is demonstrated from the SSMI sensor, which detect passive microwave emission from the surface to monitor upper level soil moisture from satellite data (Basist, 2001). Some scientists have employed the passive microwave instruments to detect upper level soil moisture (Wagner, et al., 2007). While other approaches (Griffiths and Wooding, 1996) employ an active microwave satellite platform (ERS-1 SAR) to temporally monitor soil moisture.

The wetness observations applied in this study is noted as the Basist Wetness Index (BWI), which range from zero (representing no water detected near the surface), to a percentage of the radiating surface that is liquid water. The range is zero to 100, where 100 represents the surface as liquid water. This index is derived from a linear relationship between channel measurements (Equation 1), where a channel measurement is the value observed at a particular frequency and polarization (i.e. the SSM/I observes seven channels).

$$BWI = \Delta\varepsilon \cdot T_s = \beta_0[T_b(v_2) - T_b(v_1)] + \beta_1[T_b(v_3) - T_b(v_2)] \quad (1)$$

where the change of emissivity (Basist et al., 2001), $\Delta\varepsilon$, is empirically determined from global SSM/I measurements, T_s is surface temperature over wet or dry land, T_b is the satellite brightness temperature at a particular frequency (GHz), υ_n (n=1, 2, 3) is a frequency observed by the SSM/I instrument, β_0 and β_1 are estimated coefficients that correlate the relationship of the various channel measurements to observed surface temperature at the time of the satellite overpass. Specifically, the greater the wetness, the larger are the differences between observed surface temperatures and observed channel measurements (Basist et al., 1998).

The satellite resolution is 33 km x 33 km (hereafter noted as a satellite pixel). The satellite instrument (SSMI) provides observations in the microwave wave spectrum, which allows measurements to be made under almost all sky cover conditions. The one exception is deep convection, which is rarely an issue in Kazakhstan. As a result, there are over 50 observations inside the border in each oblast. Observations are made in the morning and evening (6 a.m. and 6 p.m.) and are averaged together each day to build a monthly observation (data point). The multiplication of these measurements means that each monthly data point is the average of thousands of measurements, which are again averaged across May through August (the most important agricultural months) into one summary value for the growing season.

These annual data points from each oblast are regressed against time in order to identify the trend as well as quantify the standard deviation of the wetness and temperature observations. Each year represents an increment on the x-axis starting in 1988 and ending in 2013 (the years 1990 and 1991 are missing, due to problems with the satellite observations during that period). On the y-axis either wetness values or temperature values are represented. The slope of the equation is a direct indication of the trend as well as a measure of the inter-annual variability.

Strict calibration has been used to seam the observations from the various satellites observations over the 24-year record into one unified data set. The wetness product has been seamed together through a global approach to remove inter-satellite and time of observation biases from the unified data set (Williams et al., 2000). In order to confirm that temperature observations from the satellite instrument do not have any significant bias or drift, they are anchored on reliable *in situ* measurements (Peterson et al., 2000).

A gridded field of maximum and minimum temperatures – derived by the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA) – was used as the anchor over the period of record (Climate Prediction Center, 2014). They provide a 0.5° grid of maximum and minimum temperature for each day from the first-order stations run by the National Weather Service over the United States and Canada. Observations centered across the latitude of 30° north to 35° north and 85° west to 100° west serve as the calibration of the satellite observations. The coincident daily satellite and the *in situ* observations within this grid box are compared and the mean offset is calculated for both the morning (minimum) and afternoon (maximum). These differences are summed over the month to calculate the monthly mean offset. These monthly values are calculated over the period of record, January 1988 through July 2014. A 12-month running spline was derived across these offsets, which serves as a high pass filter and stabilizes the relationship over the annual cycle.

The result of this process gives confidence that the satellite observations are accurately anchored on maximum and minimum observations from one of the world's most reliable station networks during the growing season.

Since the primary months of the growing season are May through August, the study of wetness and temperature trends was restricted during these four months of the year. The mean anomaly was calculated over the four months in order to remove the influence of inner monthly variations and capture the mean anomaly the period between planting and maturity. This also serves as a filter to remove inner monthly variations. Consequently the satellite observations are anchored on *in situ* measurements over four month period of each year. The trend shows anomalies are used to calculate the trend of surface wetness and temperature over a 24-year period.

4. RESULTS

Regression equations will be presented and a discussion provided for each oblast that had a significant trend. In addition, insignificant trends will be presented to demonstrate the magnitude of inter-annual variability in some oblasts. The fluctuation in wetness can be very informative in terms of the natural variability, as will help identify the probability of extreme events, which can have catastrophic impacts.

Regression equations and oblasts that are outside of the scope of this result section will be provided in an appendix. In this way the reader will have the opportunity to review all of the oblasts, in terms of the trends and variability of wetness and temperature across Kazakhstan.

Beginning with the surface wetness value in the Almaty oblast in the southeastern corner of Kazakhstan. Figure 2 demonstrates that there is a positive trend in the slope over the 25-year period of record. This regression equation indicates that the wetness values are increasing over time and that the slope is a 0.06 increase in wetness values on an annual basis (in actual measures that is additional 0.06% of the surface detected as liquid water each year. The explanatory power of this trend line is 68%, which means 68% of the annual variation in the surface wetness is identified by the slope of the model.

The model had 22 degrees of freedom, which also is true for all the subsequent models, and the equation is significant at the 0.0001 level – in other words there is less than 1 in a 10,000 chance that this slope was derived by accident (**a confidence level of 0.9999**).

It is difficult to determine the mechanism that is promoting wetness values to increase over time, however, one could surmise that as temperatures rise the atmosphere can hold additional moisture and that the mountains to the east provide a mechanism to promote increase precipitation on their windward side.

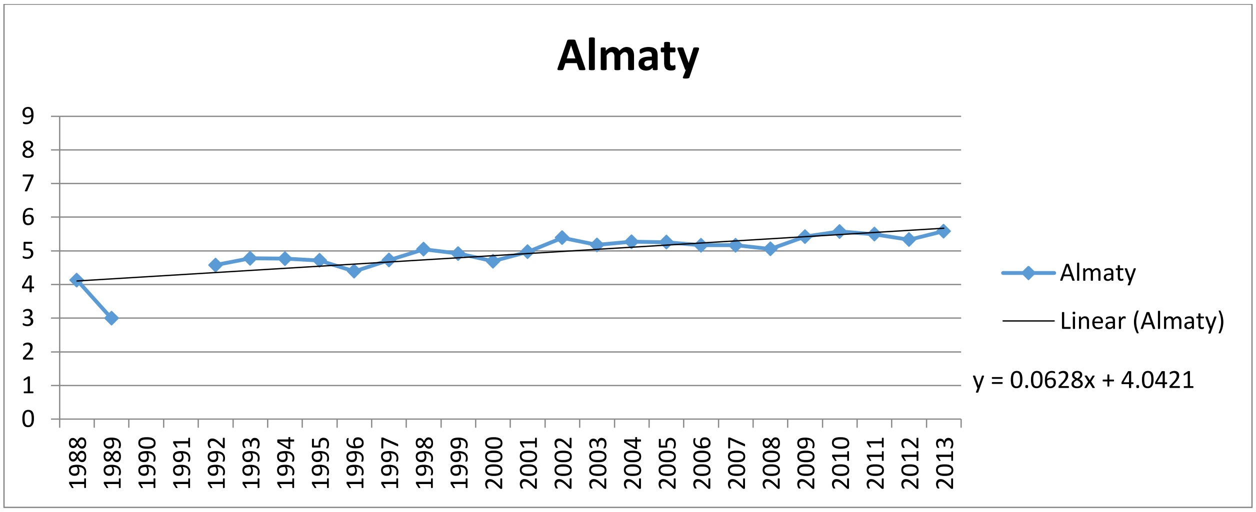


Figure 2. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Almaty oblast.

There appears to be a similar pattern of increasing wetness in East Kazakhstan. However, the slope in this oblast is not nearly as pronounced as the slope has only a 0.01 increase in the wetness value for each year of the record. Moreover, the explanatory power of this trend is 22% of the total inter-annual variability. Nonetheless, this model is significant at the 0.98 confidence level. Eastern Kazakhstan is just north of the

Almaty oblast and, most likely, the same physical processes that are promoting increased precipitation are likely affecting the eastern oblasts. The mountains are much smaller on the eastern side of these oblasts so it is not surprising that the mountains capacity to promote precipitation is significantly reduced and that the increase in precipitation associated with additional water vapor in the air would be diminished. The magnitude of localized surface wetness is conveyed in the wetness value. Almaty has wetness values between 4 and 5, whereas Eastern Kazakhstan has values near 2, which means the surface is much drier in Eastern Kazakhstan.

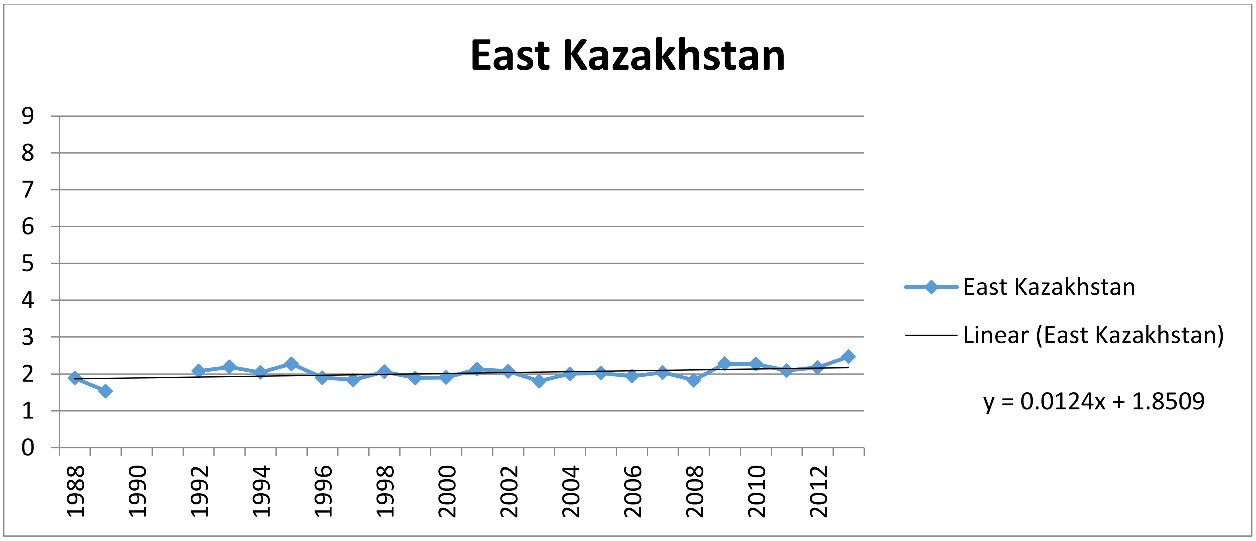


Figure 3. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the East Kazakhstan oblast.

The oblast of South Kazakhstan has a positive slope and is significant at the 0.97 confidence level (Figure 4). Southern Kazakhstan is very dry and is generally known as a scrubland with some limited grazing in small areas of irrigated agriculture. The low wetness value (generally below one) represents the dryness near the surface of the soil. The slope is about is about 0.02, and the explanatory power the model is 19%. The wettest years in this oblasts occurred in 2002 and 2003, and the driest year occurred in 1989, which was also the driest year in the previous two oblasts that were discussed above.

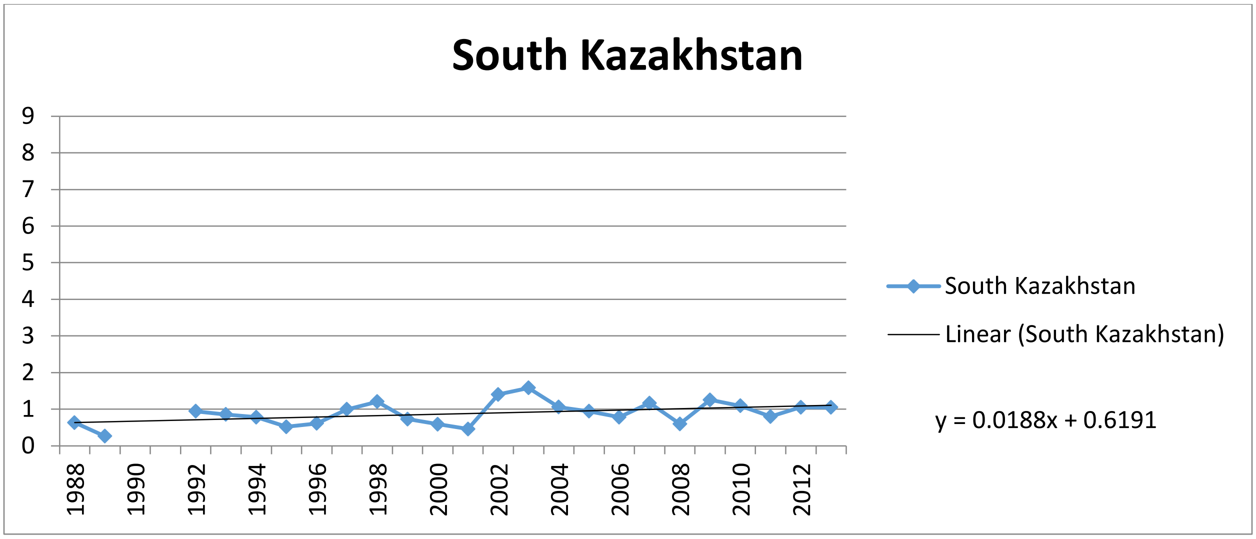


Figure 4. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the South Kazakhstan oblast.

The oblast of Zhambyl (Figure 5) also had a slight positive slope in the regression equation, which means there was a small increase in wetness over the period of record. The model was significant at the 0.96 confidence level. It also had its wettest year in 2002 and 2003 and its driest year in 1989. This oblast is also in a very dry region of Kazakhstan as represented by the low wetness values, which generally range around a value of one.

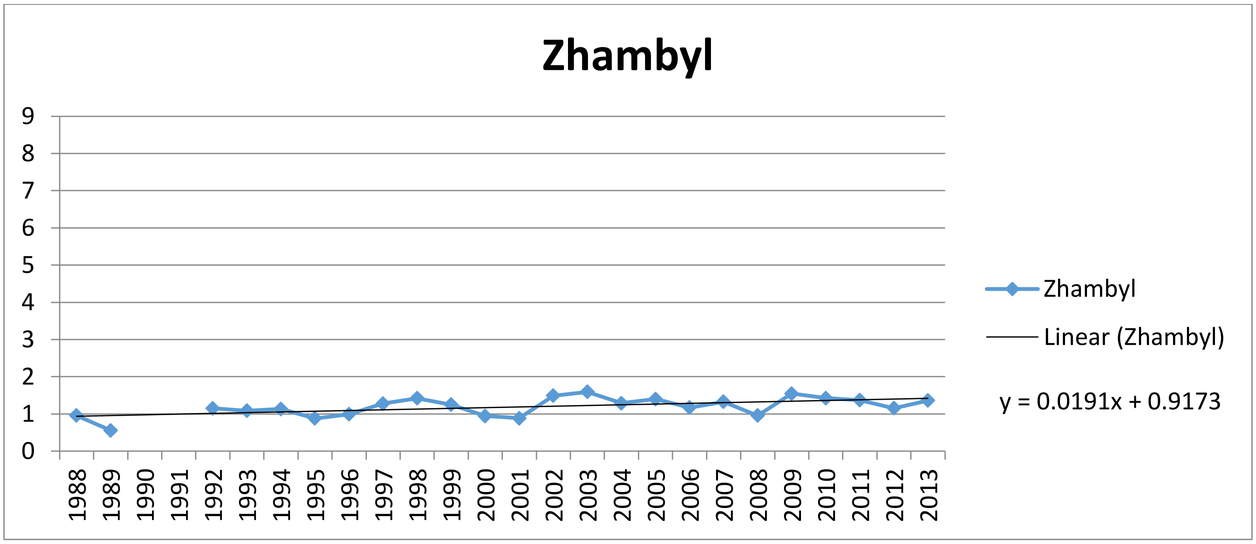


Figure 5. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Almaty oblast.

The oblast of Kyzlorda (Figure 6) had a significant increase of surface wetness at the 0.90 confidince level. The trend is generally small, although it does rise by 0.01 per year. The region is very dry and this increase in upper level soil does not have a considerable influence on the potential to increase crop rain fed crops.

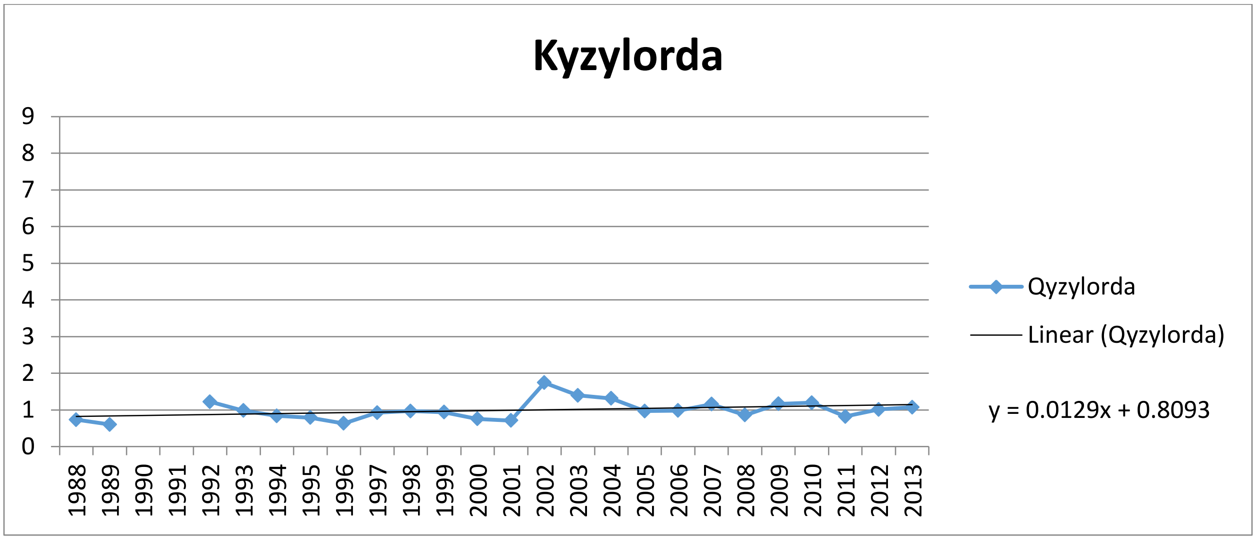


Figure 6. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Kyzylorda oblast.

Figure 7 (below) covers Western Kazakhstan, which shows that this oblast did not have a significant trend over the period of record. Nonetheless, the oblast in Figure 7 is presented as an indication of a negative trend. The slope is -0.02. However, the explanatory power the model is only 6%. One reason this model's trend is insignificant could be the large fluctuation in wetness from year-to-year. For example, there was a wet period in 2002 and 2003 followed by a long dry period and then a substantial increase around 2011. This oblast is also located in a very dry region of central Asia and is generally slightly wetter than southern Kazakhstan.

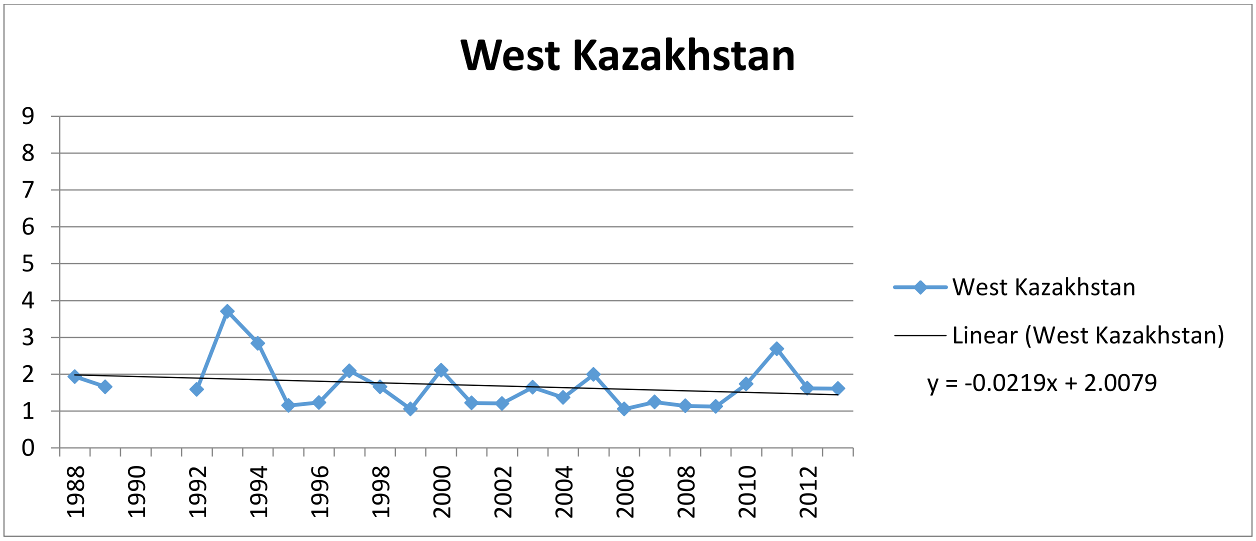


Figure 7. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the West Kazakhstan oblast.

The final oblast for in this section is North Kazakhstan (Figure 8). The regression equation for this oblast is also not significant. Since this plot is used to demonstrate the dominance of inter-annual variability, no trend was superimposed in the plot. This oblast is included for two reasons. First, it is located in the most important wheat producing area in central Asia. Second, the inter-annual variability is extremely pronounced.

One can note some very wet years around 1993 through 1995 and some subsequent dry years at the end of the century. During the last seven years there is been a tremendous amount of variability which has directly impacted wheat yields in Central Asia. The driest year of record was 2010 followed by a much wetter period. As a consequence, this fluctuation in wetness has a direct relationship to food security across the region.

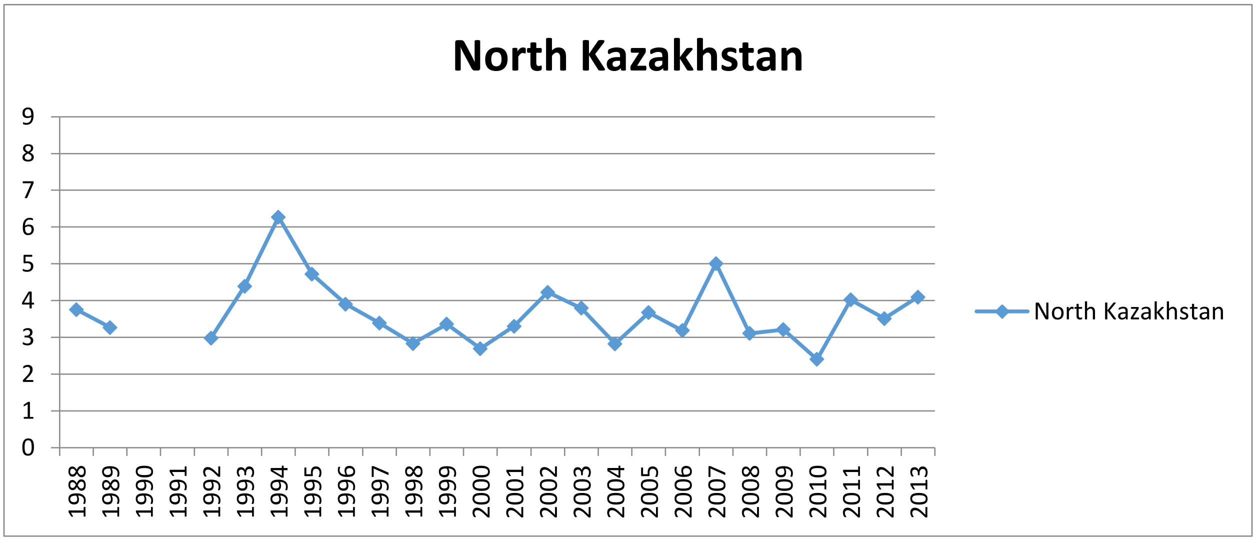


Figure 8. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the North Kazakhstan oblast.

Only four oblasts have significant trends in near surface moisture at the 95% confidence level and one additional oblast had a significant trend at the 90% confidence level (Figure 9). All four these trends were positive, indicating that rainfall has increased during the summer season. The strongest trends occurred in Almaty, while the weakest of the significant trends was in Kyzylorda. The remaining oblasts had inconclusive findings regarding a significant change in soil moisture over the 24-year period of record.

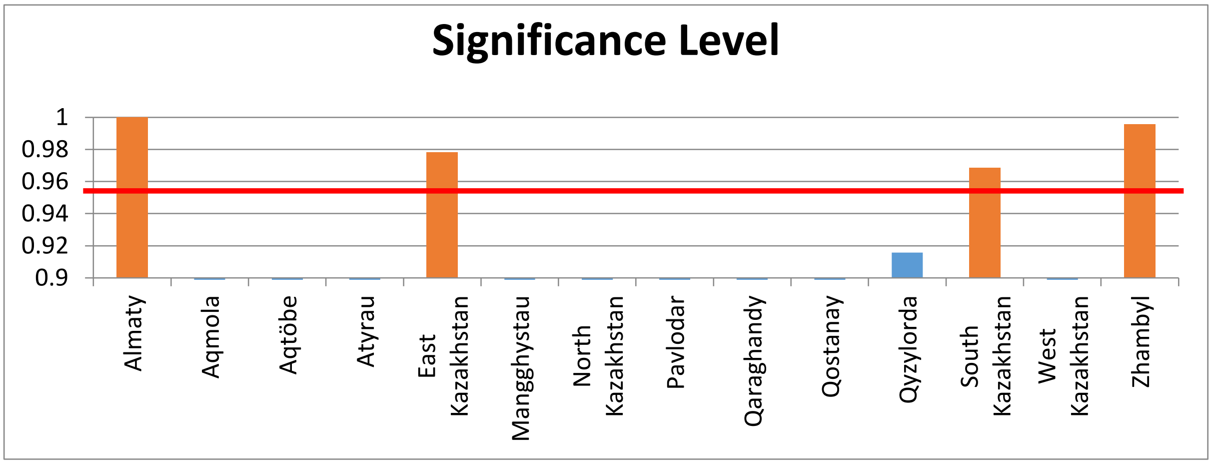


Figure 9. Plot shows the oblasts that had positive trends above a 95% confidence interval, above the red line. Below line is the oblast that was significant at the 90% level.

The largest R-square (explanatory power) of the trend line occurred in Almaty, where the model explained nearly 68% of the variability in surface wetness (Figure 10). Zhambyl had the next highest R-squared at around 30%. The linear trends over the majority of the oblasts generally explained less than 20% of the total variability in surface wetness over the period of record.

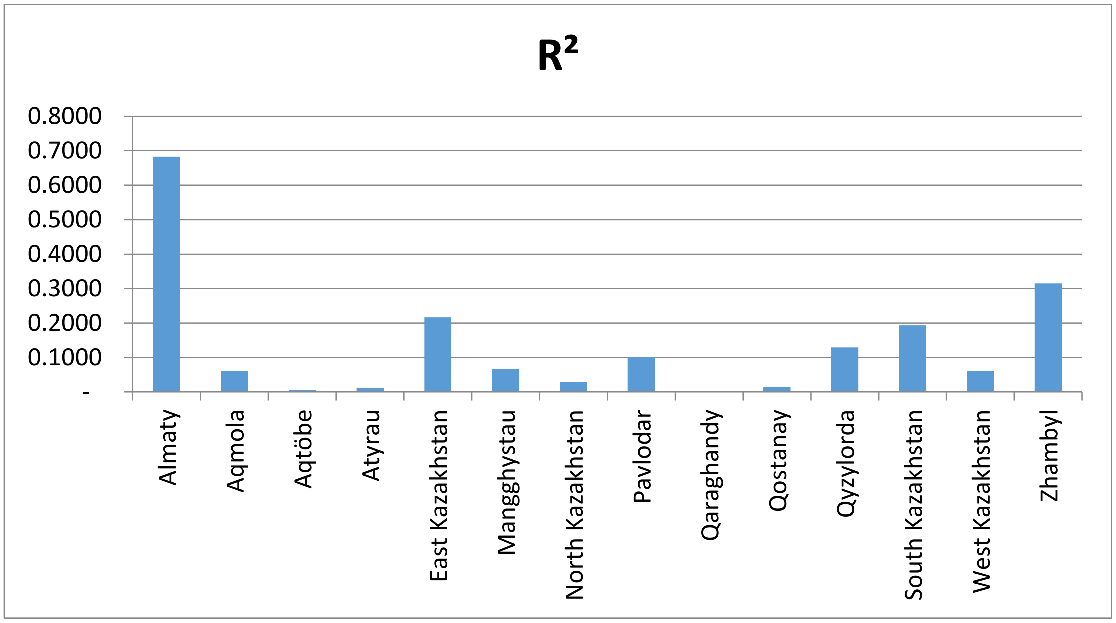


Figure 10. Explanatory power of the trend line, relative to the total variability between the years.

Standard deviation (Figure 11) was generally quite large, since inter annual fluctuations are generally the largest signals. The largest standard deviation occurred in northern Kazakhstan. **This finding indicates there is a tremendous amount of year-to-year uncertainty in the availability of soil moisture for the production of spring wheat. Northern Kazakhstan (North Kazakhstan, Akmola, and Kostanay) generally has the highest production in the country. Their variability in soil moisture demonstrates instability in spring wheat production to feed communities across Central Asia**.

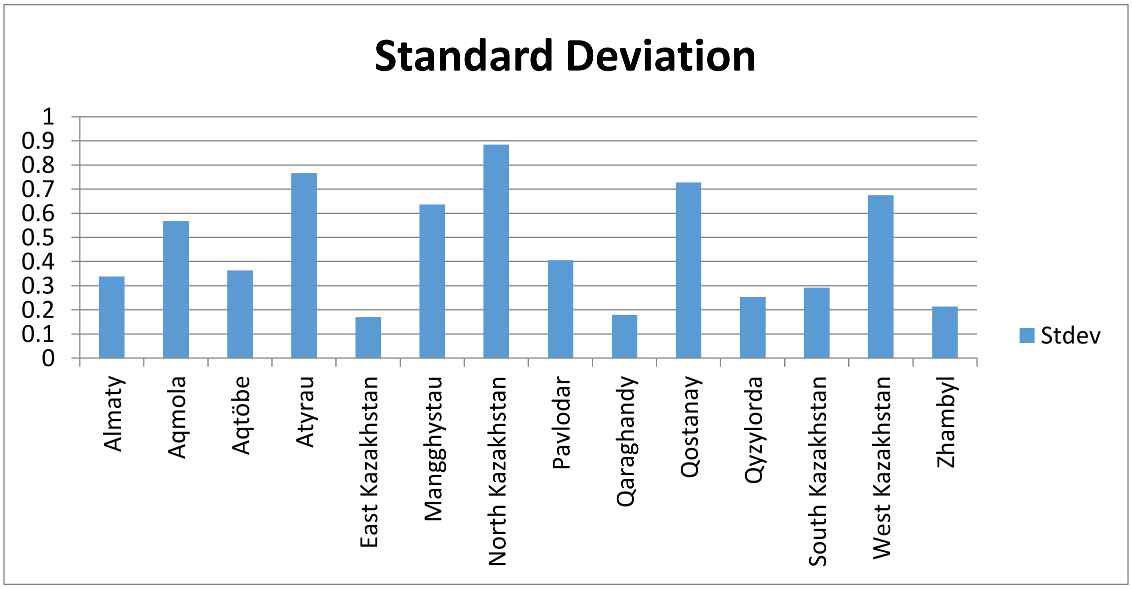


Figure 11. The standard deviation among the years in each oblasts.

In the next section, the trend in temperature in each oblast of Kazakhstan is analyzed. The following time series began in 1992. There was uncertainty regarding the time of observations and bias derived for the period 1998 and 1989. Also, data from 1990 and 1991 are missing.

The first oblast analyzed is Almaty. It has a positive trend of 0.037°C per year showing that over the 23-year period (1992-2014) there is a 0.8°C increase in temperature during the active growing season. The linear model explains 2% of the variability of temperature over the period of record. The trend has an f-score of 0.42 and 21 degrees of freedom (this same degrees of freedom applies to the all the following model results). The slope (trend) of warming is not significant at the 95% confidence level. These findings show that the inter-annual variability is by far the dominant signal, although **a slight positive temperature trend is evident over the period of record across the Almaty oblast**.

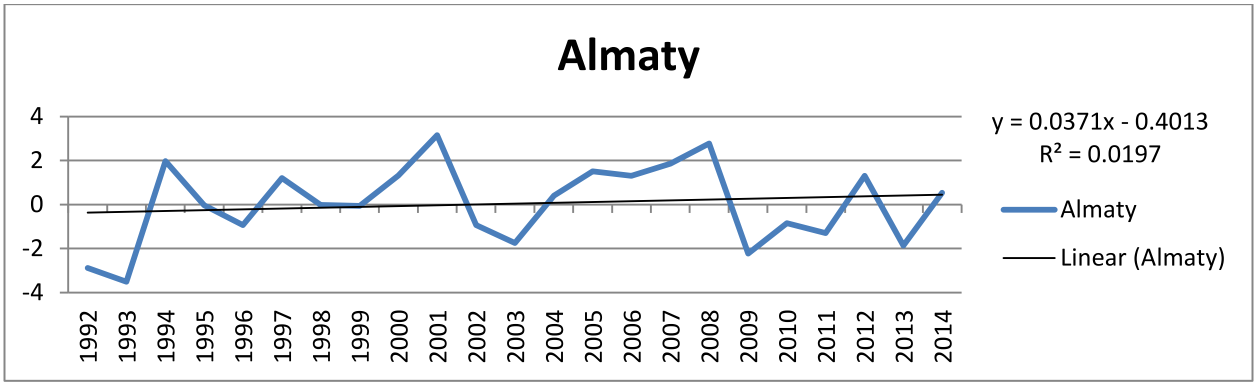


Figure 12. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Almaty oblast.

The next oblast is Akmola. Figure 12 shows this oblast has a positive slope of 0.146°C per year, or about 3°C over the 23-year record. This linear model explains 12% of the variability in temperature over the period of record. The f-score 2.87, which shows the trend is not significant at the 95% confidence level as inter-annual variability dominates the signal.

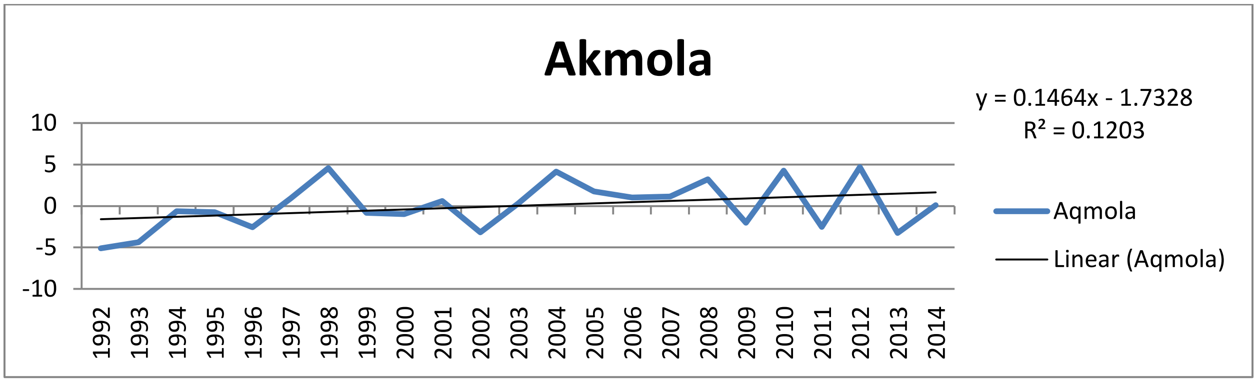


Figure 13. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Akmola oblast.

The third oblast analyzed is Aqtobe (Figure 13). It has a positive trend of 0.234°C per year, or 5^0C over the 23 year time series. The slope explains 29% of the inter-annual variability of temperature over the period of record. The f-score 8.63 shows that the trend is significant at the 95% (actually at the 99%) confidence level. **This means there is a very clear warming signal since 1992**.

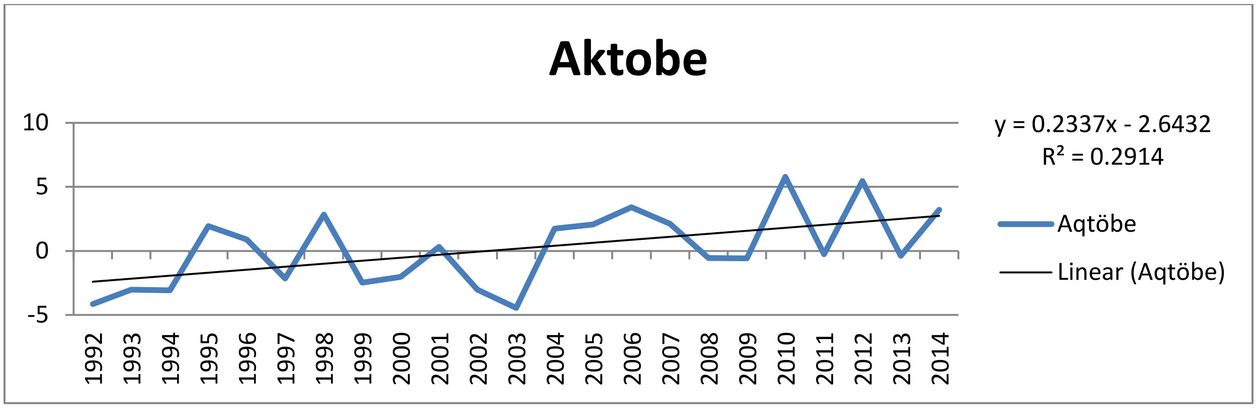


Figure 14. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Aqtobe oblast.

The fourth oblast analyzed is Atyrau (Figure 14). It has a positive trend of 0.287°C per year, or 6^0C over the 23-year time series. The slope explains 23% of the inter-annual variability of temperature over the period of record. The f-score 8.44 shows that the trend is significant at the 95% (actually at the 99%) confidence level. **There is a clear warming since 1992 in Atyrau and Aktobe to the east**.

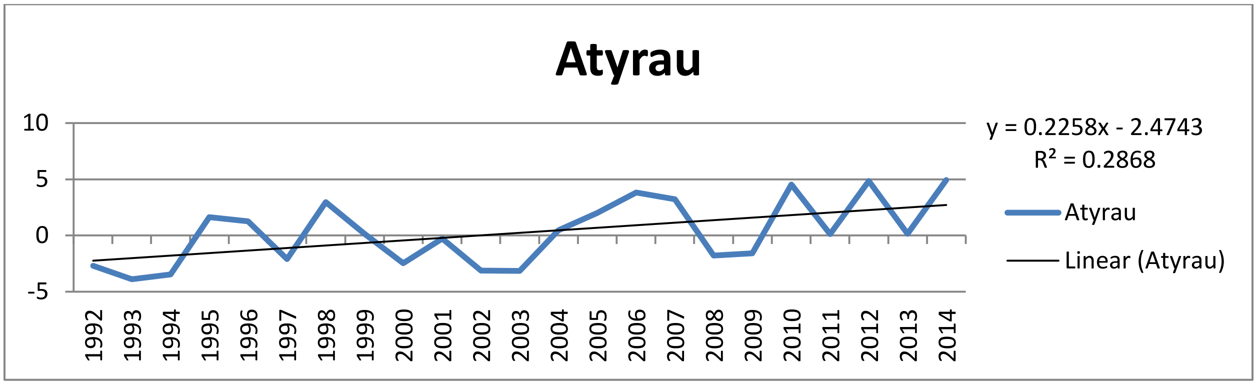


Figure 15. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Atyrau oblast.

The fifth oblast analyzed is East Kazakhstan (Figure 15). It has a positive trend of 0.003°C per year, or 0.07^0C over the 23-years. The f-score is 0.002 and the slope explains less than 1% of the inter-annual variability in temperature over the period of record. Therefore the trend is not significant at the 95% confidence level. **These findings indicate that there is not an increase of temperature over the period of record in the East Kazakhstan**.

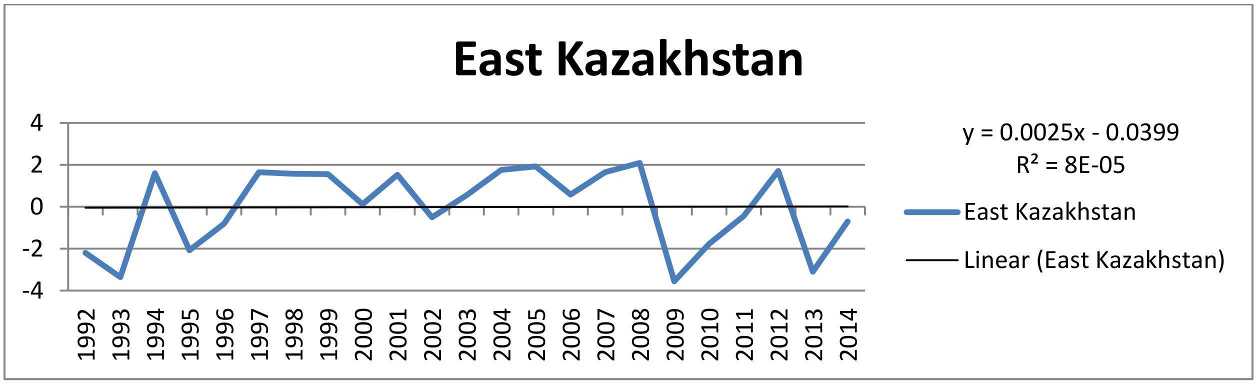


Figure 16. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the East Kazakhstan oblast.

The sixth oblast analyzed is Mangystau (Figure 16). It has a positive trend of 0.076°C per year, or 1.6^{0}C over the 23 years. The slope explains 6% of the inter-annual variability in temperature over the period of record. The f-score is 1.41 which means the trend is not significant at the 95% confidence level. **These findings conclude that there is not a significant increase of temperature in Mangystau**.

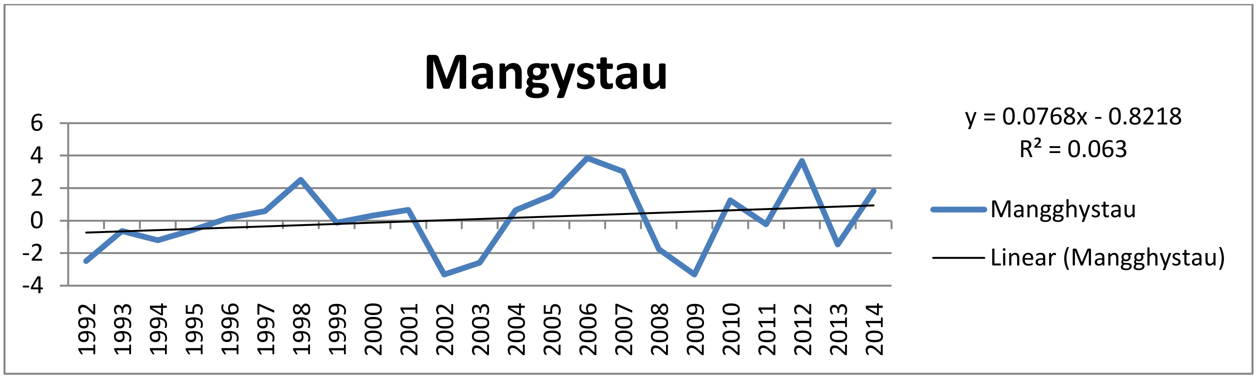


Figure 17. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Mangystau oblast.

The seventh oblast analyzed is North Kazakhstan (Figure 17). It has a positive trend of 0.105°C per year, or 2.3^{0}C over the 23 years. The slope explains 7% of the inter-annual variability in temperature over the period of record. The f-score is 1.59 and shows that the trend is not significant at the 95% confidence level. **These findings conclude that there is no significant increase of temperature in North Kazakhstan**.

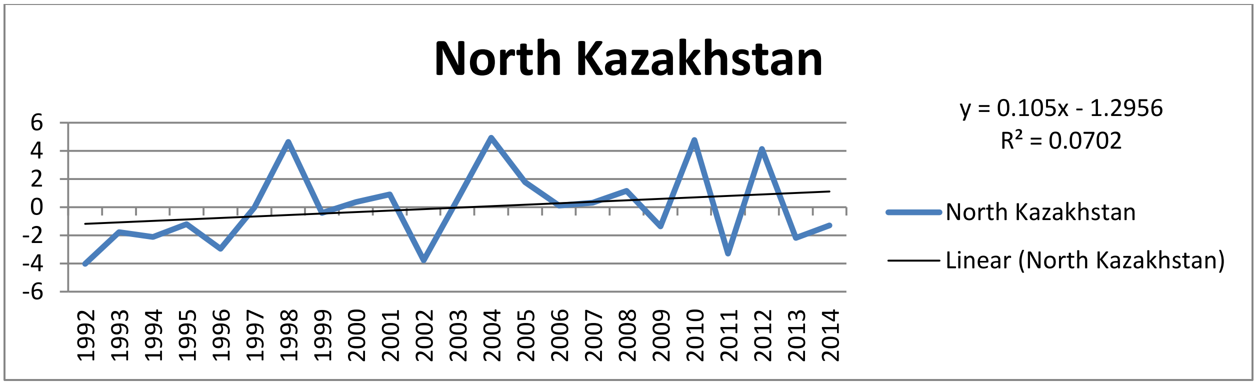


Figure 18. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the North Kazakhstan oblast.

The eight oblast analyzed is Pavlodar (Figure 18). It has a significant positive trend of 0.112°C per year, or 2.5^{0}C over the 23 years. The slope explains 9% of the inter-annual variability in temperature over the period of record. The f-score is 2.03, which means the trend is not significant at the 95% confidence level. **These findings conclude that there is no significant increase of temperature in North Kazakhstan**.

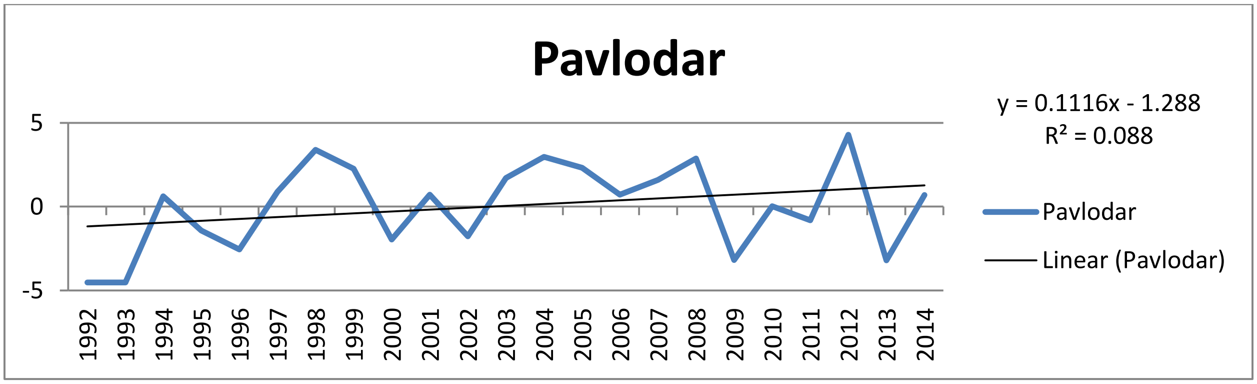


Figure 19. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Pavlodar oblast.

The ninth oblast analyzed is Karagandy (Figure 19). It has a positive trend of 0.062°C per year, 1.4^{0}C over the 23 years. The slope explains 5% of the inter-annual variability in temperature over the period of record. The f-score is 1.04, which means the trend is not significant at the 95% confidence level. **These findings conclude that there is a no significant increase of temperature in Karagandy**.

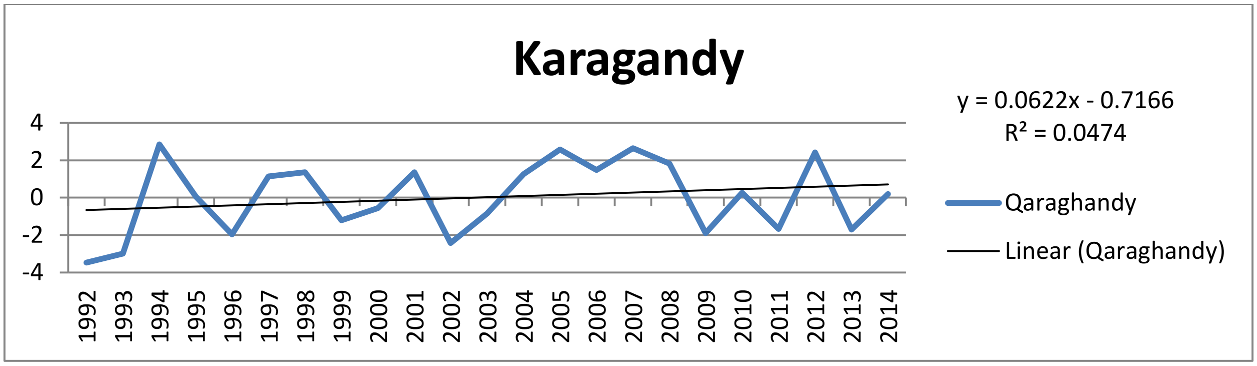


Figure 20. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Karagandy oblast.

The tenth oblast analyzed is Kostanay (Figure 20). It has a positive trend of 0.21°C per year, or 4.8^{0}C during the previous 23 years. The slope explains 20% of the inter-annual variability in temperature over the period of record. The f-score is 5.31, which means the trend is significant at the 95% confidence level. **These findings conclude that there is a significant increase of temperature in Kostanay and also neighboring oblasts to the west, Aqtobe and Atyrau**.

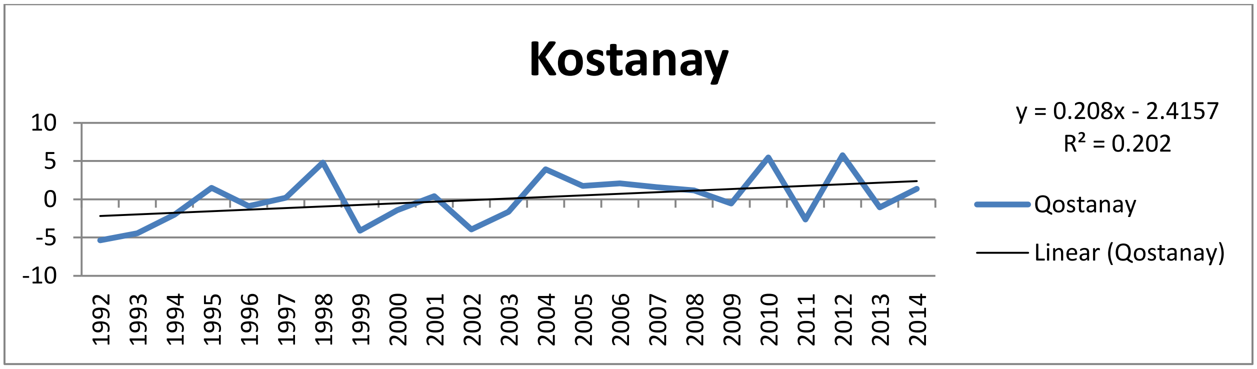


Figure 21. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Kostanay oblast.

The eleventh oblast analyzed is Kyzylorda (Figure 21). It has a positive trend of 0.065°C per year, 0.15^{0}C during the 23-year period. The slope explains 7% of the inter-annual variability in temperature over the period of record. The f-score is 1.45, which means the trend is not significant at the 95% confidence level. **These findings conclude that there is a not a significant increase of temperature in Kyzylorda**.

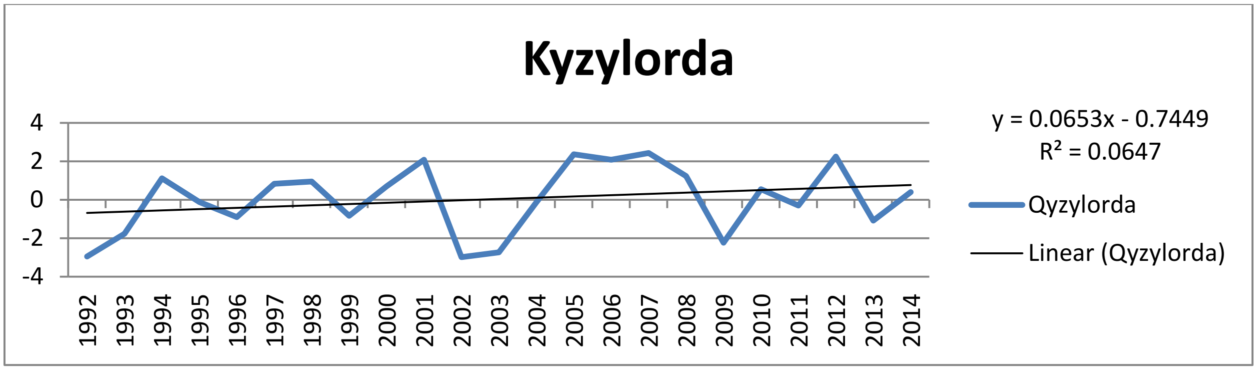


Figure 22. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Kyzylorda oblast.

The twelfth oblast analyzed is South Kazakhstan (Figure 22). It has a positive trend of 0.002°C per year, or 0.050C over the 23-year period. The slope explains less than 1% of the inter-annual variability in temperature over the period of record. The f-score 0.04 is not significant at the 95% confidence level. **These findings indicate that there is not a significant increase of temperature in South Kazakhstan**.

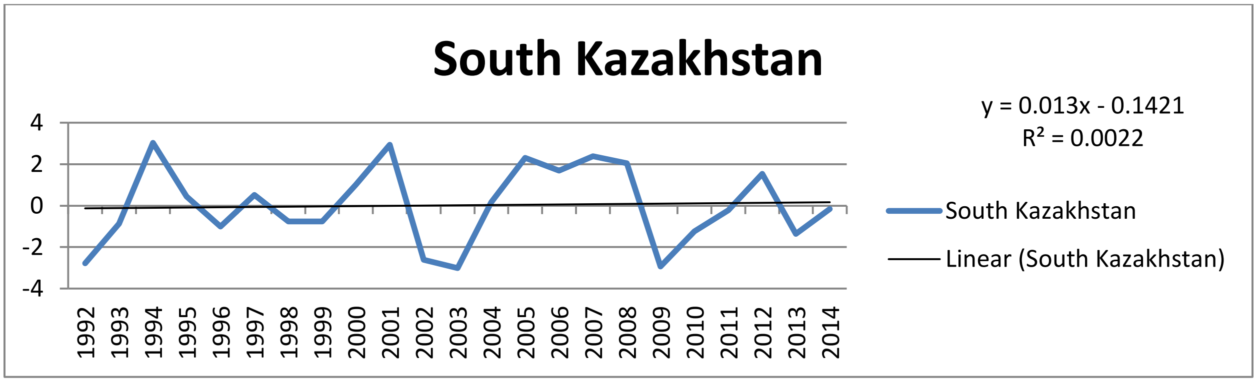


Figure 23. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the South Kazakhstan oblast.

The thirteenth oblast analyzed is West Kazakhstan (Figure 23). It has a positive trend of 0.338°C per year, over 7^0C over the 23-year period. The slope explains 41% of the inter-annual variability in temperature over the period of record. The f-score is 14.8, which means the trend is significant at the 99% confidence level. These findings conclude that there is a significant increase of temperature in West Kazakhstan. **The trend is highest in this oblast and becomes less pronounced further to the east (although there remains a significant trend) in Atyrau, Aqtobe, and Kostanay**.

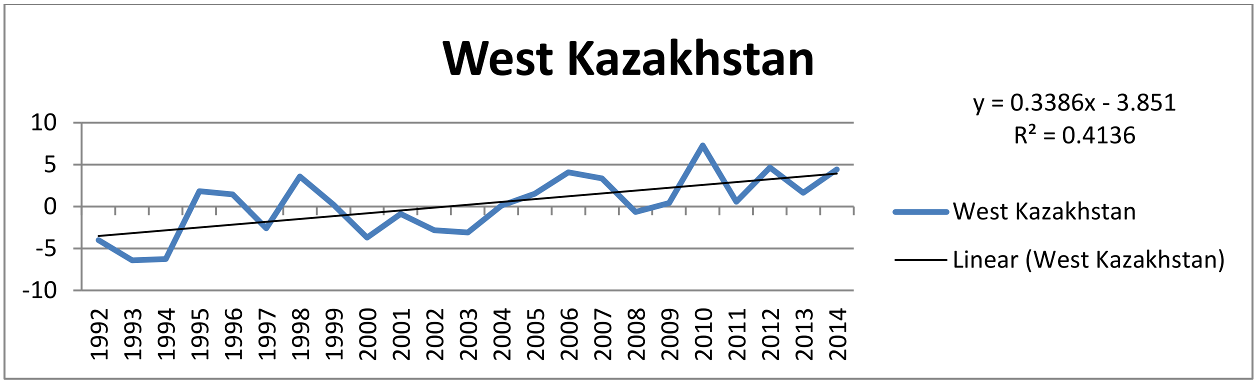


Figure 24. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the West Kazakhstan oblast.

The fourteenth oblast analyzed is Zhambyl. It has a positive trend of 0.005°C per year, or 0.13^{0}C over the 23-year period. The slope explains less than 1% of the inter-annual variability in temperature over the period of record. The f-score is 0.01 is not significant at the 95% confidence level. **These findings conclude there is not a significant temperature increase in Zhambyl**.

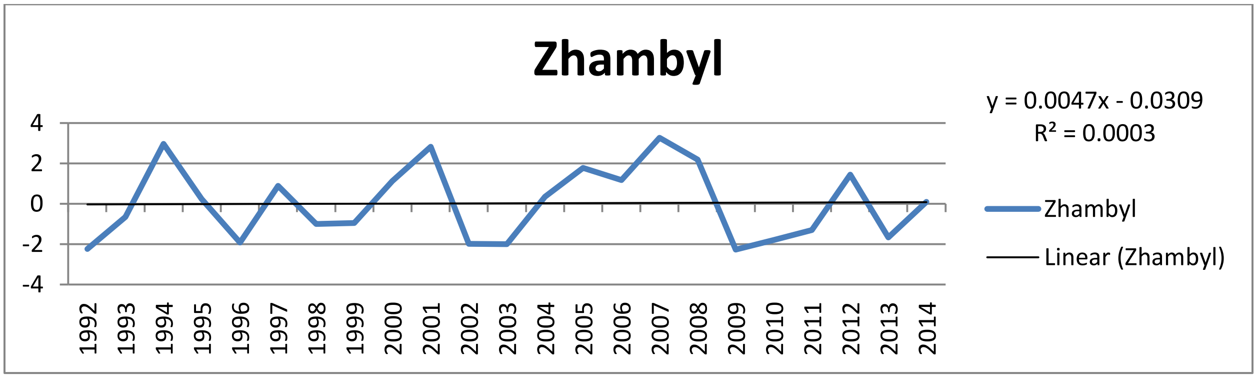


Figure 25. Inter-annual variability of surface temperature during the warm season is represent by the blue line across the period of record, and the black line is the linear trend of the regression. The equation is displayed on the right side of the figure. This data is from the Zhambyl oblast.

The investigation of temperatures across Kazakhstan shows that 4 of the 14 oblasts (Aqtobe, Atyrau, Kostanay, and West Kazakhstan) in this study had a significant warming trend. Three of the slopes are significant at the 0.99 confidence level, while Kostanay had a slope significant at the 0.95 confidence level.

All four of these oblasts are located in the northwestern sector of the country, which demonstrates a clear spatial structure, and promotes confidence that the models are detecting a pattern in significant warming trends over the last 23 years.

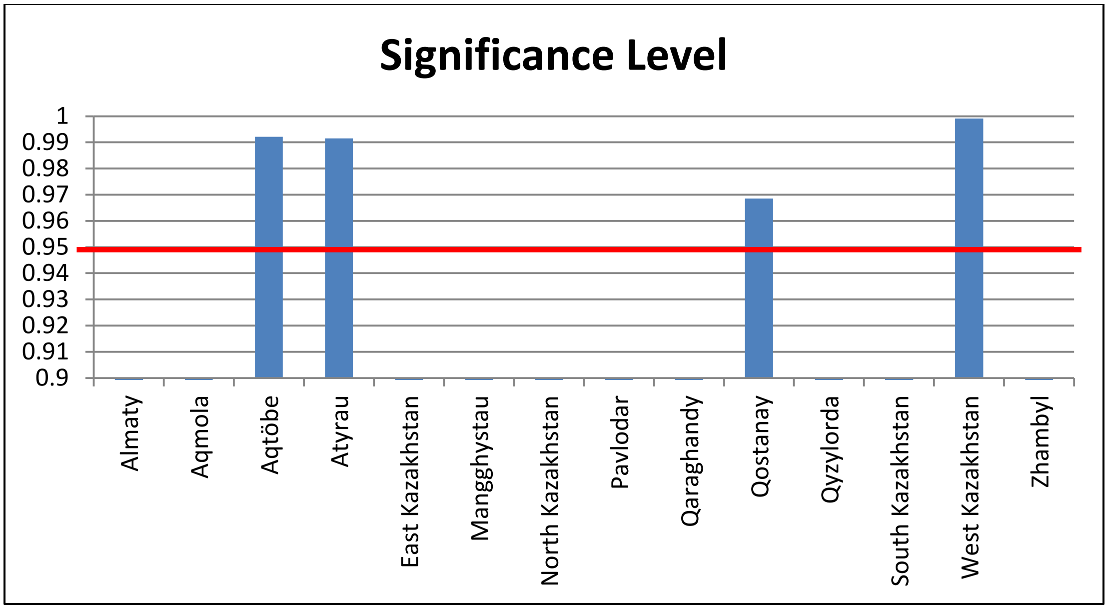


Figure 26. Plot shows the oblasts that had positive trends above a 95% confidence interval, above the red line. Below line is the oblast that was significant at the 90% level.

The slope of the trend (rise in the temperature) was able to explain at least 20% of the inter-annual variability in the statistically significant models (Figure 26). The warming trend over Western Kazakhstan explained 41% of the variability over the period of record. Also the slope in temperature across Aqtobe and Atyrau were able to explain 28% of the variability. The trend in Kostanay was able to explain about 20% of the variability. It is clear that inter-annual variability continues to dominate the total signal in temperature fluctuations.

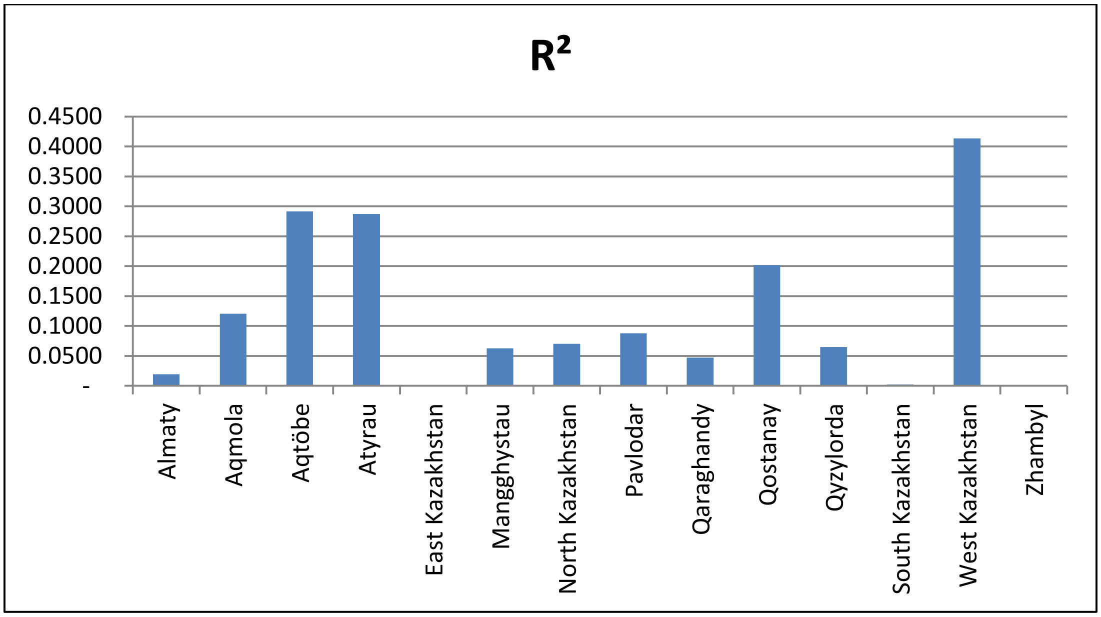


Figure 27. Explanatory power of the trend line, relative to the total variability between the years.

The standard deviation was generally greater than 2°C per year (Figure 27). The largest standard deviation was over Western Kazakhstan with over 3.5° Celsius per year. The lowest standard deviation occurred over Kyzylorda at 1.7°C.

These values indicate that there is a large inter-annual variability in temperature, which tend to dominate any observed trend. The oblasts with the significant warming trend also tend to have the largest standard deviation across Kazakhstan.

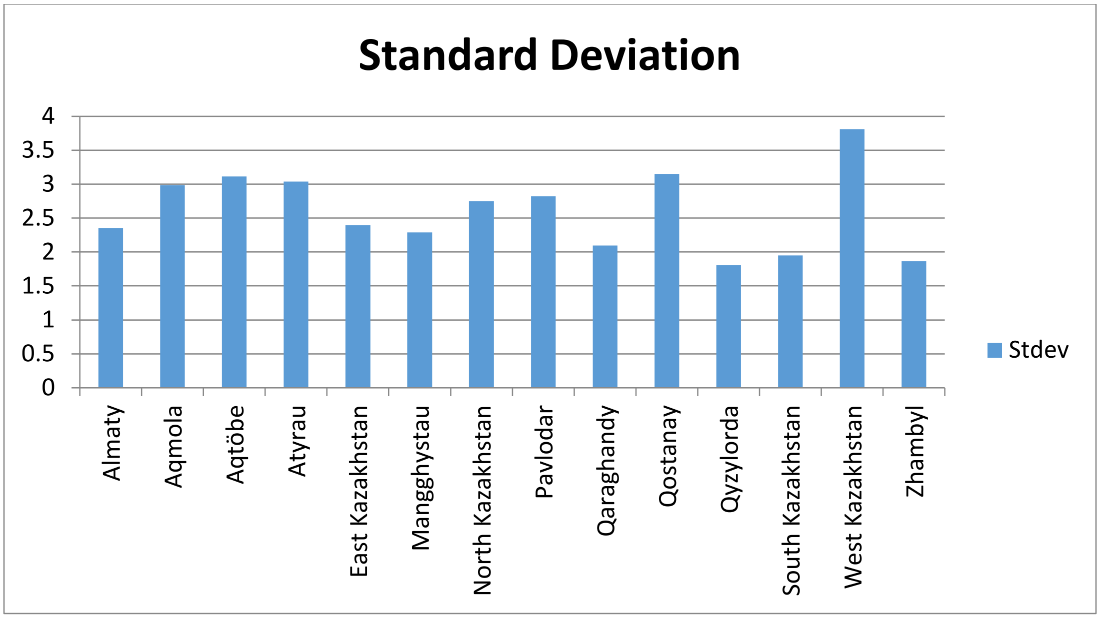


Figure 28. The standard deviation among the years in each oblast.

CONCLUDING DISCUSSION

It is important to understand trends in land/surface conditions Kazakhstan and how agriculture might be impacted. Food security and climate resilience are essential for national well-being (Vörösmarty et al., 2000). In order to achieve such an understanding of conditions over such a vast area as Kazakhstan – an area nearly the size of Western Europe – remote sensing techniques must be relied upon. Therefore, data is applied from the Special Sensor Microwave Imager to detect land surface temperature and wetness since 1988. These two products are excellent indicators of the growing conditions, as well as predictors of likely yields.

Much of Kazakhstan is extremely dry and extensive agriculture can only be performed in the northern three oblasts as well as along the eastern edge of the country that abuts the Tibetan plateau. **Most climate models indicate Central Asia will be adversely impacted in terms of reduced soil moisture and additional heat. These impacts will add stress to societies in Central Asia by adversely impacting food supplies.**

Wheat is central to economic and geo-political cooperation across central Asia (Weinthal, 2002). The primary goal of the study was to create a methodology to measure both natural variability and the factors of climate change in the region. Detecting and sharing trends and shifts in the variability of climate will assist policymakers to plan for securing food in the event of scarcity. This information will also allow stakeholders and policy makers to work together to build strategies for climate resilience.

In terms of surface wetness, inter-annual variability was the dominant signal. For each oblast a regression equation was calculated over the period of record. Then, a confidence level of 0.95 is used to determine which of these trends were significant.

Four of 14 oblasts had significant trends in surface wetness and each of these trends was positive. The strongest positive trend occurred in Almaty, which is on the southeastern corner of Kazakhstan and abuts the Tibetan plateau. To the north, the East Kazakhstan oblast also had a significant trend – though the slope was not nearly as large as the slope calculated in Almaty.

An explanation of these positive trends is associated with a likely increase atmospheric water vapor and the orthographic influences of the mountains. This combination would allow the topography to force additional moisture from the atmosphere, which could lead to increased precipitation in these regions.

These findings agree with the projections of the IPCC (2014). The increased surface wetness in northern Kazakhstan is relatively small compared to expectations and the inter-annual variability dominate any observed trend.

Zhymbal and South Kazakhstan oblasts in southern Kazakhstan also displayed positive and significant trends in surface wetness. These oblasts shared similar slopes and a comparable statistical confident slightly above the 95% level. Both of these areas are extremely dry and promote little opportunity for agriculture or even widespread grazing. Nonetheless it is interesting to note that soil moisture is rising slightly. In contrast, across the remaining oblasts of Kazakhstan, the inter-annual variability by far dominates the signal and no significant trends were identified.

Kostanay, Aktobe, Atyrau, and West Kazakhstan oblasts had significant, positive trends in near surface temperature during the growing season. These trends were generally around two degrees Celsius per decade. **West Kazakhstan was the exception with nearly 3.5^{0}C increase per decade** (Figure 28). All four of the oblasts are contiguous in the northwest section of the country, which promotes confidence that a clear signal with spatial structure. The warming trend is evident further to the north and east, across the remainder of the wheat production region. However, inter-annual variability is also quite strong, which promotes uncertainty about a trend.

It's important to note that 10 of the 14 oblasts had positive slopes (Figure 29). Though the findings were insignificant in terms of a temperature trend, the findings align with the IPCC (2014), which associates warmer temperatures throughout the region. From our analysis, Almaty is the only oblast where climate change may have a significant benefit to the agricultural potential since it has experienced a substantial increase in wetness, and maintains relatively stable temperatures.

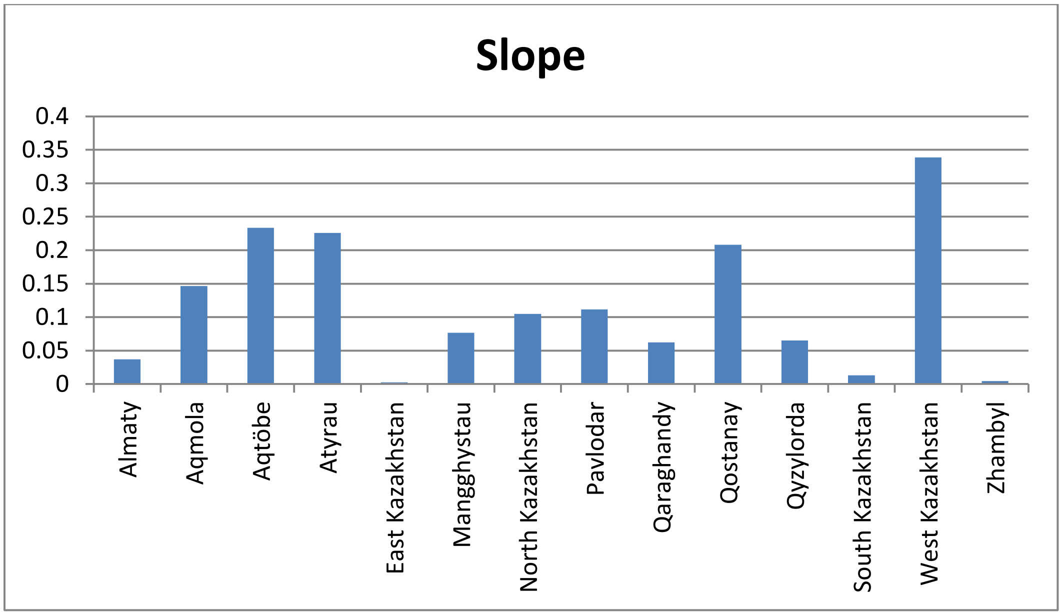


Figure 29. The observed slope (annual change) of temperature over the period of record.

There is a concern that variability could be increasing in the northern three oblasts of Kazakhstan, making the region more vulnerable to drought. Recently (2012) this region had a major deficit of soil moisture with increased temperatures, which led towards drought. In future work, it would be ideal to explore temporal changes in temperature and soil moisture over the period of record. Cursory analysis indicates that the standard deviation is increasing over the latter years. **These large swings in temperature and wetness are most evident in the last 5 to 10 years of the satellite record**. An extensive analysis over changes in standard deviation during the 25-year record would provide valuable insight into the food security in Central Asia.

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APPENDIX

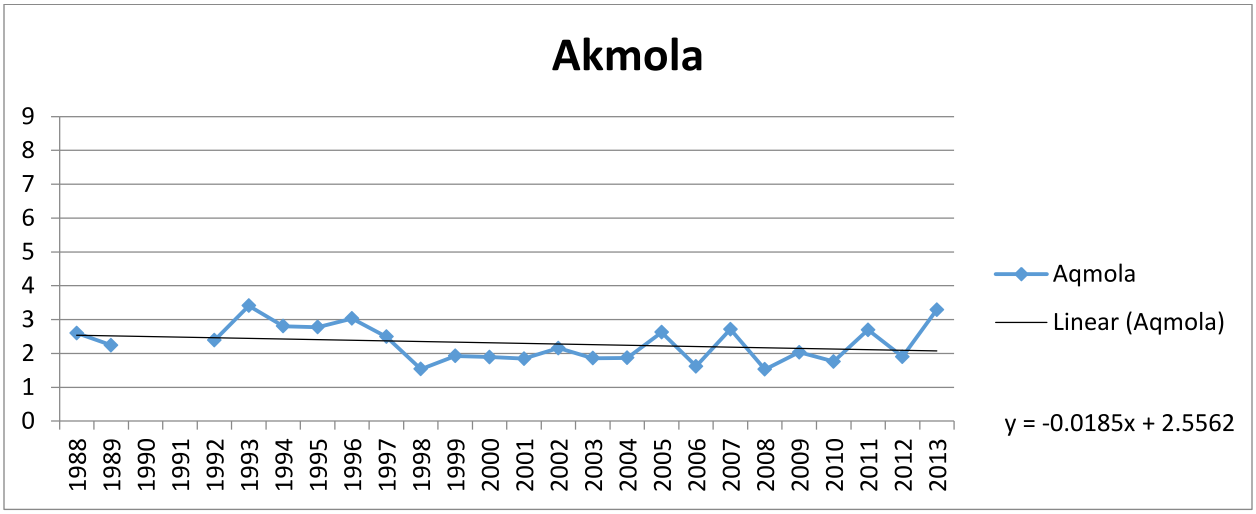

Figure 1a. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Akmola oblast.

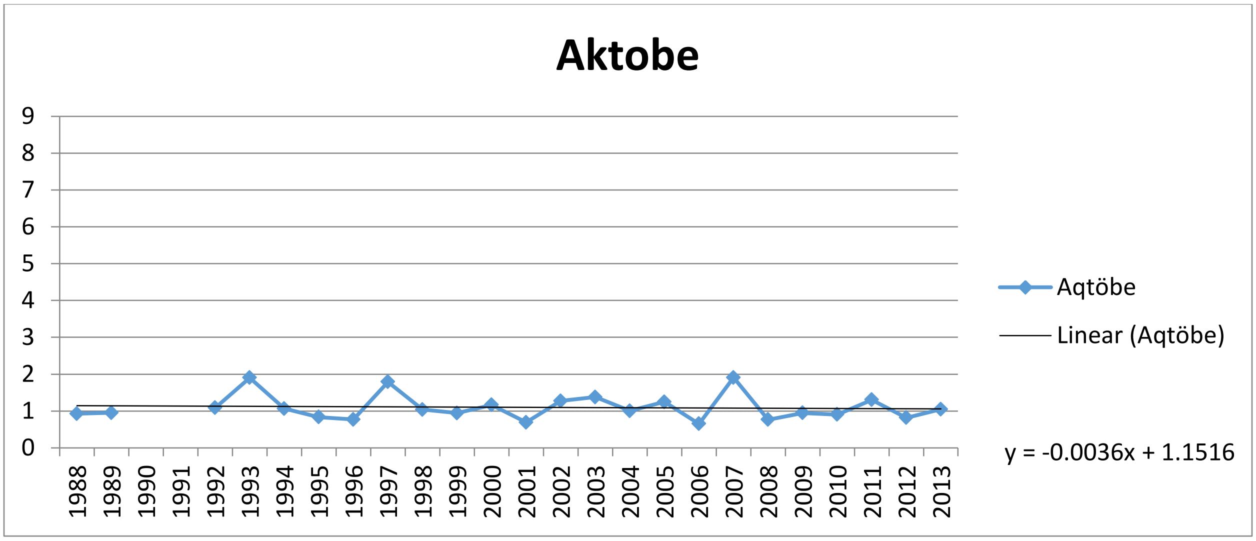

Figure 2a. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Aktobe oblast.

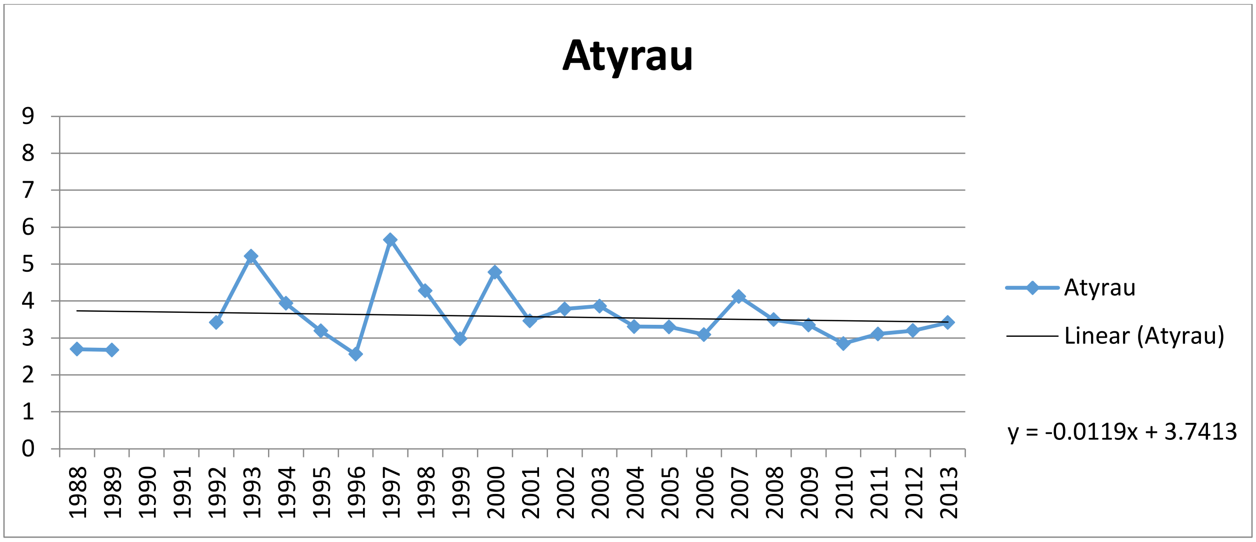

Figure 3a. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Atyrau oblast.

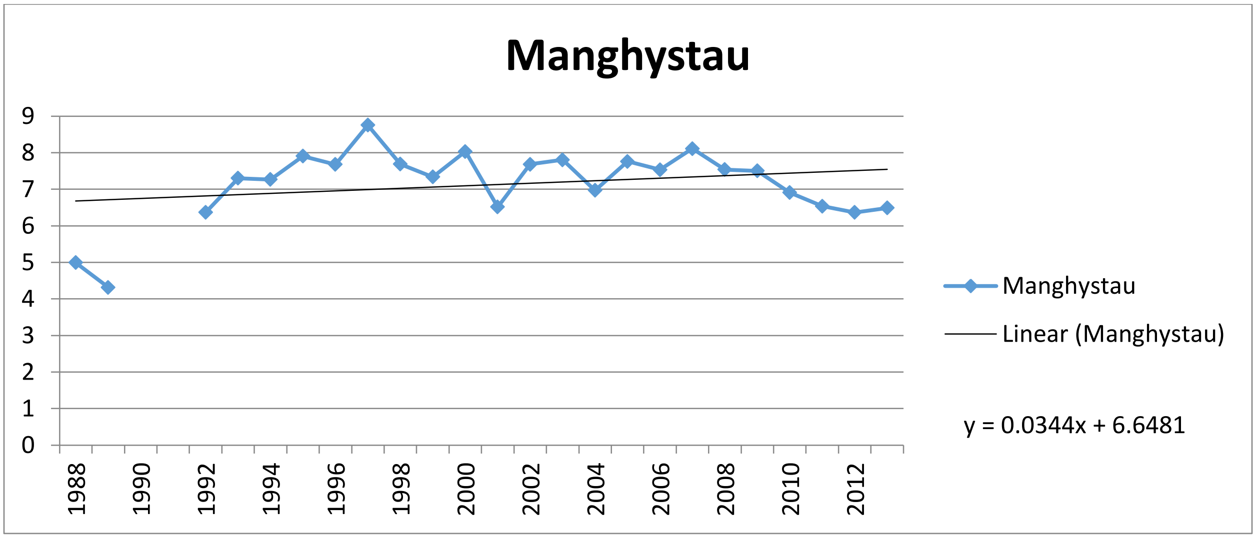

Figure 4a. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Mangystau oblast.

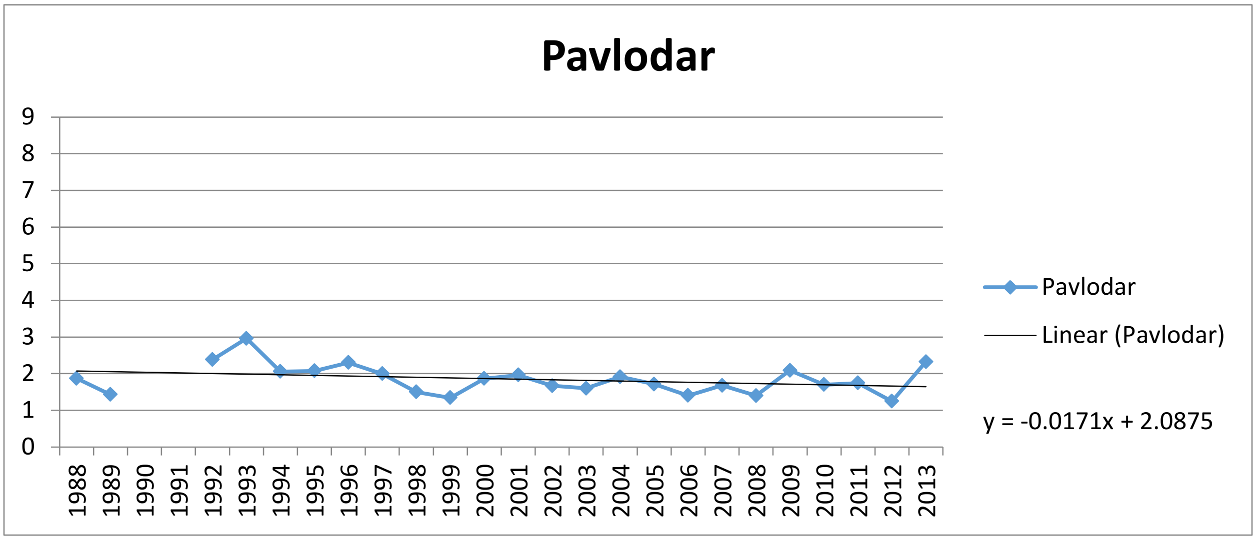

Figure 5a. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Pavlodar oblast.

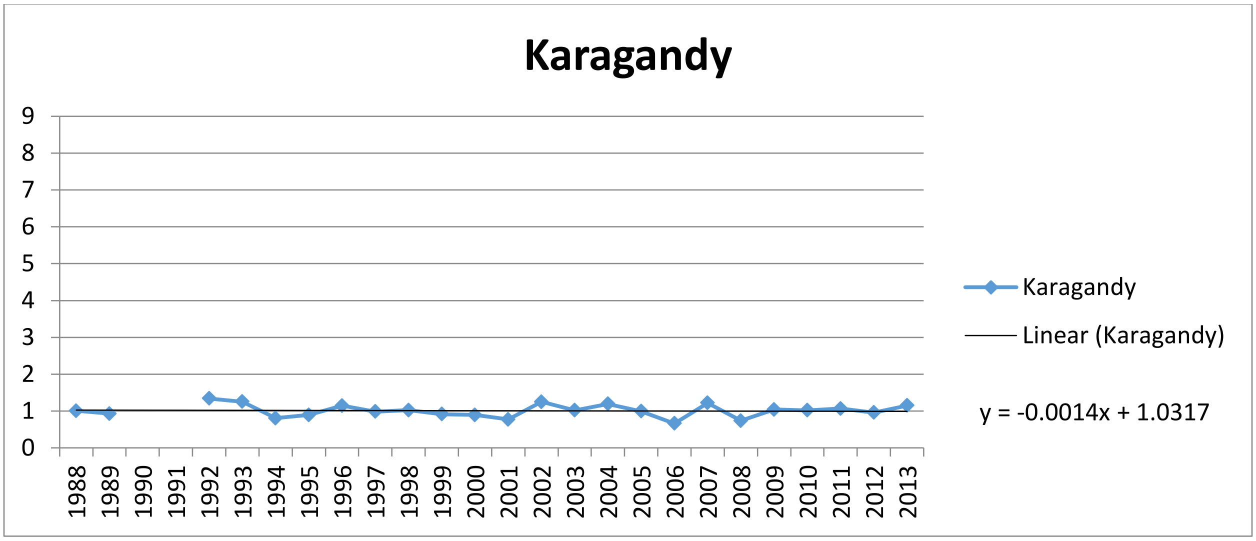

Figure 6a. The inter-annual variability of surface wetness during the warm season are represented by the blue dots and line. The linear trend of the regression line is represented in black and the equation is displayed towards the lower right corner of the figure. This data is from the Qarahnady oblast.

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