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Capstone Project

A Comparison of ERA-40 and NOAA Climate Data over Kazakhstan.

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Introduction.

Changes in weather patterns over the entire planet or particular regions over a prolonged period of time is known as climate change. Climate change and its consequences is one of the most serious issues people face in the 21st century.

People have collected climate data for the last 150 years in order to discern trends in climate. The fact that climate change is happening is undisputed.

For interpretation and modeling of climate change there is a wide range of datasets containing observations of different climate parameters, such as temperature, precipitation, humidity, evaporation, soil moisture, cloud cover, etc. Climate dataset interpretation and modeling is an essential tool that can be used by policymakers for analyzing climate change, climate trends, and the consequences of climate change. Therefore, the use of reliable datasets describing the spatial and temporal changes of climate variables provides better information with which to cope with climate variability.

Science.

This project is to compare meteorological observations of The European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis (ERA-40) and NOAA (National Oceanic and Atmospheric Administration) global precipitation and temperature anomaly datasets, and to draw conclusions from ERA-40 and NOAA graphed climate datasets.

ERA-40 is a second-generation reanalysis produced by ECMWF for the period September 1957 August 2002 (Uppala et.al 2005). ERA-40 is a climate model output utilizing data assimilation procedures, and has a resolution 2.5 degree. ERA-40 has more than 50 different climate data parameters that were collected for the period 1957 to 2002. This project includes the two most common climate parameters: temperature and precipitation (temperature at 2 meters above the ground and large-scale precipitation). The ERA-40 data can be obtained from the following website: http://apps.ecmwf.int/datasets/data/era40-moda/levtype=sfc/. ERA-40 assimilates and reanalyzes data and uses climate-modeling procedures to provide climate output information, involving climate modeling.

NOAA temperature anomaly is a monthly 5-degree gridded temperature anomaly data of the NOAA National Climatic Data Center data for the period January 1880 to January 2016. This data is available on the NOAA NCDC website: http://www.ncdc.noaa.gov/temp-and-precip/global-maps/. NOAA precipitation anomaly is a 2.5-degree gridded precipitation anomaly data for the period of 1901-2009 produced by NOAA Global Precipitation Climatology Center (GPCC). The NOAA anomaly dataset, which includes observational data from ground stations blended with satellite data[1].

1. The NOAA Global Precipitation Climatology Center (GPCC) monthly precipitation anomaly data is a blended gridded data of satellite and ground stations with different resolutions (0.5, 1, and 2.5). "The data were reconstructed by the method of spectral optimal gridding for precipitation version 1.0 (SOGP 1.0) by using EOFs generated by the 2.5 monthly GPCP data and regression on the 2.5-degree gridded land station data of GPCC". Data is available on Dr. Samuel Shen's website as a .csv file http://shen.sdsu.edu/press.html.

Objective.

The goal of the project to compare air temperature and precipitation of modeled ERA-40 and NOAA anomaly observational datasets for the time period of 1958-2001, in order to compare the datasets to interpret climate trends for that particular time period. And based on the results of that comparison to recommend policy that can be applied to agriculture (the spring wheat production) by the relevant public authorities of Kazakhstan.

Data.

The inputs are:

1. The ERA-40 monthly temperature at 2 meters above the ground 1958-2001 produced by ECMWF. Format: netCDF file. 2.5-degree resolution.
2. The ERA-40 monthly large-scale precipitation 1958-2001 produced by ECMWF. Format: netCDF file. 2.5-degree resolution.
3. Monthly temperature anomaly data 1880-2016 produced by the NOAA National Climatic Data Center. Format: Excel document. 5-degree resolution.
4. Monthly precipitation anomaly data 1901-2009 produced by NOAA Global Precipitation Climatology Center (GPCC). Format: .csv file/Excel document. 2.5-degree resolution.
5. Historical monthly mean temperature and monthly mean precipitation data 1958-2001 produced by the Climate Research Unit of the University of East Anglia. Format: Excel documents.

My Procedure.

1. Obtain the ERA-40 climate data: temperature at 2 meters above the ground and large –scale precipitation.
2. Convert ERA-40’s netCDF files into a readable format – Excel.
3. Extract from the global temperature and precipitation data products latitude longitude grid boxes over Kazakhstan from all 4 datasets.
4. Extract particular time period of interest from NOAA temperature and precipitation datasets from 1958 to 2001.
5. For both the NOAA anomaly and ERA-40 datasets calculated the average values for whole territory of the country for each month from January to December for the period of 1958-2001 by taking the mean value of all points on a gridded map over Kazakhstan.
6. Obtain annual mean values of precipitation and temperature for the period 1958-2001.

7. Plot the charts of both datasets with annual values for the period of 1958-2001 in order to compare them.

8. Plot 12 separate comparative graphs for every single month from January to December.

9. Obtain mean precipitation and temperature datasets from the Climate research Unit (the World Bank Climate Change Knowledge Portal). Extracted the same time periods of 1958-2001.

10. Write analysis of climate trends of the NOAA and ERA-40 datasets.

11. Based on the results, write a possible solution or recommendation regarding agriculture (the spring wheat production).

Temperature.

From both the ERA-40 and NOAA datasets there is a comparison of the period 1958-2001 (43 years) due to the limited period of ERA-40 data coverage. Both ERA-40 and NOAA datasets have monthly average values. NOAA and ERA-40 temperature anomaly have a 5-degree and 2.5-degree resolution respectively.

For comparison I took 14 grid boxes over the territory of Kazakhstan. Latitude: from 42.5 to 52.5 North and longitude: from 47.5 to 82.5 East. Resolution: 5 degrees for both datasets. Thus, on a gridded map over Kazakhstan the ERA-40 and NOAA temperature anomaly have 24 data points. Both datasets are in a good agreement (Figure 1.1).

January.

There is a good correlation between two datasets. However, ERA-40 tends to overestimate the values. The trend line of both datasets is slightly increased (*Figure 2.1*).

February.

The distribution of NOAA values for the period 1958-2001 has a good agreement with the ERA-40 values, but ERA-40 still slightly overestimates temperature. Both clearly show increasing temperature over the time (*Figure 2.2*).

March and April.

The results show a good agreement. For March the ERA-40 and NOAA trend lines are slightly upward (*Figure 2.3*).

May and June.

The ERA-40 data overestimates temperature values. The trend lines show a slight trend increase of mean temperature over the time period (*Figure 2.4*).

July.

The ERA-40 data approaches more closely to the NOAA values than in May and June. However, it tends to overestimate the temperature values (*Figure 2.5*).

August.

The ERA-40 data overestimates the temperature values compared to NOAA ground data (*Figure 2.6*).

September and December.

Both datasets are nearly similar for these two months. The ERA-40 trend line suggests that the increase of temperature values is not as great as NOAA's trend line suggests (*Figure 2.7*).

October and November.

The Era-40 has good agreement with NOAA temperature anomaly dataset. The graph in November shows nearly flat mean temperature over the time period (*Figure 2.8*).

Annual.

Overall, both datasets are similar, and show a clean trend of increasing temperature over Kazakhstan over time (*Figure 2.9*).

Precipitation.

From both the ERA-40 and NOAA monthly precipitation anomaly datasets there is a comparison of the period 1958-2001 (43 years). The ERA-40 and NOAA are gridded datasets. Both have 2.5-degree resolution. However, the grid points in both datasets have a slightly different geographical location with different latitude and longitude. For this reason, for comparison I took only the grid points located within the area of Kazakhstan: 54 points for NOAA precipitation anomaly and 56 data points for ERA-40 precipitation (*Figure 1.2*).

January.

The Era-40 has biases showing increasing precipitation in 1962, 1968, 1975, 1978, 1989, 1993, 1999, while for the same years NOAA precipitation anomaly values show the opposite. In 1967 the ERA-40 shows a decline in precipitation while NOAA shows a slightly increasing precipitation. Both trend lines increase slightly (*Figure 2.10*).

February.

The Era-40 values show increasing precipitation in 1961, 1971, 1973, and 1976. NOAA Precipitation values for the same years have opposite trend line direction. There is an increase of precipitation in 1985 in the ERA-40 dataset in comparison with a slight increase in NOAA dataset. Overall both datasets match for the rest of the years. Both trend lines have a smooth, slightly upward direction (*Figure 2.11*).

March.

The ERA-40 dataset has overestimated precipitation values in 1984 and underestimated in 1960-1962, 1970, 1978, and 2001. Overall, both datasets in a good agreement. Both trend lines show reduction of precipitation this month for the period of 1958-2001 (*Figure 2.12*).

April.

April has more biases between two datasets. There are sharp changes in the ERA-40 precipitation while the NOAA precipitation datasets are smoother and do not show surges until 1985. The ERA-40 has underestimated values in 1960-1963, 1967-1966, 1977, 1983, 1986 and overestimated in 1958, 1964, 1973-1974, 1978-1981. The trend lines are almost equal with a slight slope down, showing a trend of decreasing precipitation (*Figure 2.13*).

May.

The ERA-40 underestimates the values in 1961-1968, 1974-1977, 1997, and overestimates in 1981. Overall, for the period of 1978-2001 both datasets conform with each other, except in 1997, where the ERA-40 shows a rapid increase of precipitation. The trend lines, however, have different direction. The NOAA trend line is almost flat with a smooth slope down. The Era-40 trend line shows a significant increase in precipitation over the time period (*Figure 2.14*).

June.

The ERA-40 dataset has more biases than the NOAA dataset and shows significant overestimation in 1978, 1984, 1999 and underestimation in 1965. In general, both datasets have good agreement with each other. The ERA-40 trend line shows increasing precipitation, while NOAA dataset has a smooth decrease (*Figure 2.15*).

July.

The Era-40 dataset has a significant underestimation from 1961 to 1967, 1970-1971, 1974-1976, 1984, 1988, and 1991. Also, the ERA-40 has much higher precipitation value estimates in 1960, 1968, and 1999.

Overall, the ERA-40 data shows an increasing trend line over the time period, while NOAA's trend line is decreasing (*Figure 2.16*).

August.

The ERA-40 dataset has a number of both exaggerated and reduced values compare to NOAA precipitation values. Both datasets have a good correlation in 1983-1992. The trend lines of both datasets have a slight slope - downward for NOAA and upward for ERA-40 (*Figure 2.17*).

September.

NOAA anomaly dataset has a smooth distribution compare to the ERA-40 dataset. The ERA-40 has overestimated values for the whole time period of 1958-2001, showing significant biases in 1965, 1973, 1981, 1982, and 1996. The Era-40 and NOAA both have upward trend lines (*Figure 2.18*).

October.

Both datasets have good correlation overall except for a few years where the ERA-40 has a significant exaggeration in 1969, 1976, 1979, and 1985. NOAA's precipitation trend line is relatively flat. The ERA-40 trend line is slightly downward (*Figure 2.19*).

November.

From 1963 to 1990 the ERA-40 has overestimated precipitation values with much higher values in1963, 1965, 1978, 1980, and 1984. Both trend lines have a slight upward direction (*Figure 2.20*).

December.

Overall, both datasets have a good correlation. However, the ERA-40 has a number of values which are overestimated or underestimated over the time period of 1958-2001. The trend lines have opposite directions – increasing for the ERA-40 and decreasing for NOAA (*Figure 2.21*).

Annual mean.

The results of the ERA-40 and NOAA anomaly precipitation values distribution of all January months for 1958-2001 time period shown on the graph have different trends. ERA-40 for this particular time period shows that precipitation has been increasing, the NOAA precipitation anomaly dataset has a decrease. Era-40 has relatively overestimated precipitation values over the time period (*Figure 2.22*).

The ERA-40 data has fewer biases in seasonal comparison with NOAA observational data but it is less accurate in capturing annual precipitation values (Tong et. al. 2014). Thus, the results suggest that for annual precipitation data ERA-40 reanalysis is not a well-modeled dataset of ECMWF.

Results.

Regarding temperature: from comparing the results shown in the 13 comparative graphs between the ERA-40 temperature and NOAA-NCDC temperature anomalies it seems reasonable to conclude that overall both datasets match and have similar differences of values depending on the month or season.

Both ERA-40 and NOAA datasets match on graphs in winter months December, January, February, and in March, April with increasing minor differences. However, ERA-40 has more biases in May and June. Both datasets match in September but ERA-40 overestimates the data in the months of October and November.

Regarding precipitation: the results of the comparison of the ERA-40 precipitation and NOAA precipitation anomaly show less agreement with each other than the temperature data comparison. ERA-40 data shows that over the time precipitation is slightly increasing. However, NOAA dataset suggests that the trend line was decreasing.

Analyzing linear regressions of both datasets it is clear that for ERA-40 and for NOAA datasets R-squared (the goodness of fit) values are low with a range between 0.001 and 0.1 for ERA-40 and 0.0001 and 0.07 for NOAA anomaly.

Since the NOAA anomaly datasets are using observational data derived from actual ground stations, its climate projections are assumed more reliable. Despite the fact that the temperature data of both the ERA-40 and NOAA datasets correlate, the ERA-40 precipitation dataset is more biased and has the trend line showing an increase of precipitation over time. Therefore, to verify the direction of the precipitation trend line I obtained additional climate datasets derived from observational temperature and precipitation data over Kazakhstan from 1958 to 2001 produced by the Climate

Research Unit of the University of East Anglia. This suggests that over the time period mean temperature had increased for about +0.8 degree Celsius. Along with rising mean temperature, the trend line of mean precipitation shows a slight decrease over the time (*Figure 3*). This data is available at: http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisRegion=Asia&ThisCCode=KAZ.

Policy.

Climate change has a range of negative effects on countries and populations. Long-term climate observation shows an increasing trend of surface temperature and a slight decrease of precipitation over the territory of Kazakhstan. 90% of the country is arid zone with a low water availability, typical to Central Asian countries (Sarsenbekov et. al., 2016). Most of the country experiences increasing aridity of climate. In addition, the territory of Kazakhstan has an unevenly distributed water system. Due to the distance from the ocean, continental climate prevails in the country with hot summers and cold winters.

The climate scenario for the future shows likely water availability, land degradation, and lower yields in Central Asian countries (IPCC, 2007). In order to deal with the consequences of climate change on susceptible agriculture, a policy of necessary measures are needed to reduce environmental impacts, such as water deficiency, lack of precipitation, warmer summers with extreme heat, etc. Along with climate change, there is a lack of specific methods in agribusiness to deal with climate change, taking into consideration climate instability.

To date, due to the closing of the ground stations in the country in the 1980s and following collapse of the Soviet Union in 1991, the long-term soil moisture data for Kazakhstan was not published and used (Robock et.al. 2001). However, projected climate trends in the country are likely to affect agriculture. Both increasing temperature and a slight decrease in precipitation over time period are likely to affect soil moisture conditions in the future, which in turn affects grain production. Reduction of grain crop puts at risk not only Kazakhstan but also those countries that import Kazakh wheat.

Grain production is the mainstay of agriculture in the country. Kazakhstan is one of the biggest producers of wheat, which plays an important role for the economy. Almost all regions of the country are involved in wheat production (*Figures 4.1, 4.2*). Kazakhstan produces about 13-14 million tons of wheat per year. Spring wheat is 75% of the total harvest (Per the Agency of Statistics of the Republic of Kazakhstan, 2016).

Drip irrigation, which reduces water consumption by 60%, might be a reasonable solution for grain farming. Using the experience of foreign countries, Kazakhstan might adapt this relatively new method of irrigation to increase a spring wheat crop production and decrease consumption of already scarce water resources.

1. Drip irrigation is profitable from the economic point of view. The drip irrigation system supplies water where is needed and as much as needed. The system requires less fertilizers, electricity, fuel, and water itself due to direct soil moistening.

2. Controlled water delivery is needed in case of a shortage of rain. More arid southern and western parts of Kazakhstan are likely to have less precipitation in future (Lioubimtseva et al. 2009). Thus, southern and western parts of the country will have higher need for drip irrigation systems, while the rain-fed wheat of northern Kazakhstan will get more precipitation, due to climate projections suggesting the increase of precipitation in northern and mountainous eastern parts of Kazakhstan.

3. Compared to conventional irrigation, with drip irrigation water is not lost due to evaporation. Water is supplied directly to the ground surface.

4. Since drip irrigation water supplies only the ground surface, the stalks of grain stay dry, which prevents the spread of diseases.

5. Due to the direct drip irrigation, the soil around stays dry, which means less favorable conditions for weeds.

6. Installation of drip irrigation does not require a complex structure. The plastic pipe network can be modified for the required fields. It is not permanent and can be removed when needed.

7. Drip irrigation contributes to better yields due to maintenance of stable soil moisture.

8. The system can use either surface or ground water sources.

Along with these benefits, there are some drawbacks.

1. Drip irrigation requires professional maintenance for installation/dismantling and constant monitoring (Planting in May and harvesting in August).

2. The system might need a frequent filter replacement depending on type of water coming through it. Particles and salt might clog the drip emitters.

3. The price of a drip irrigation system is one of the drawbacks, which varies between $1000 and 3000 per hectare; yet it is a single large investment followed by a further relatively minimal cost of repairs and maintenance.

4. The system can be used only for spring wheat due to very low temperatures in winter in most parts of Kazakhstan, which could damage the system due to freezing.

A pumping station is required for water extraction from the source (surface or ground water), filter, piping system, and emitters, fertilizer tank for adding chemical or natural substances to water (*Figure 5*).

Conclusion. Taking into account historical climate observation or modeled climate datasets we can apply the most reliable data to create a specific policy or set of recommendations for a particular region or country in order to mitigate, or adapt to climate change and its detrimental consequences for the environment and human populations.

References.

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Lioubimtseva, Elena, and Geoffrey M. Henebry. "Climate and environmental change in arid Central Asia: Impacts, vulnerability, and adaptations." *Journal of Arid Environments* 73.11 (2009): 963-977.

http://shen.sdsu.edu/press.html

http://sdwebx.worldbank.org/climateportal/

http://apps.ecmwf.int/datasets/data/era40-moda/levtype=sfc/

Appendix.

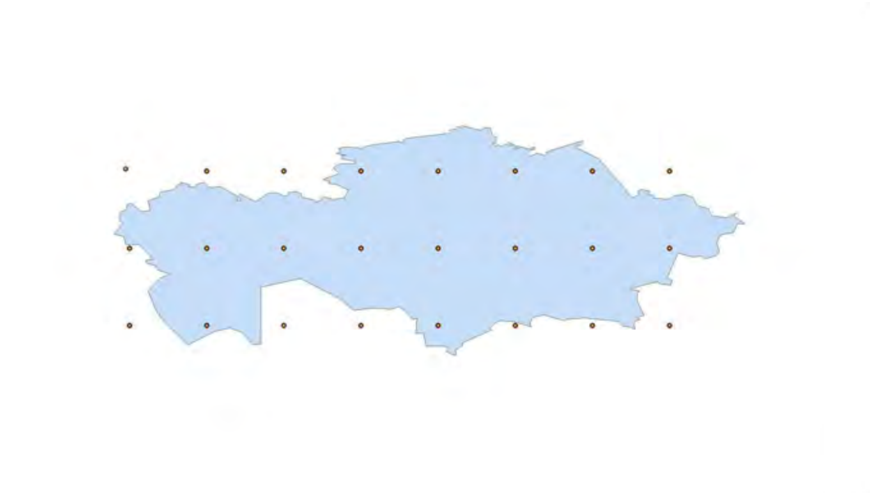


Figure 1.1 The ERA-40 and NOAA anomaly grid points.

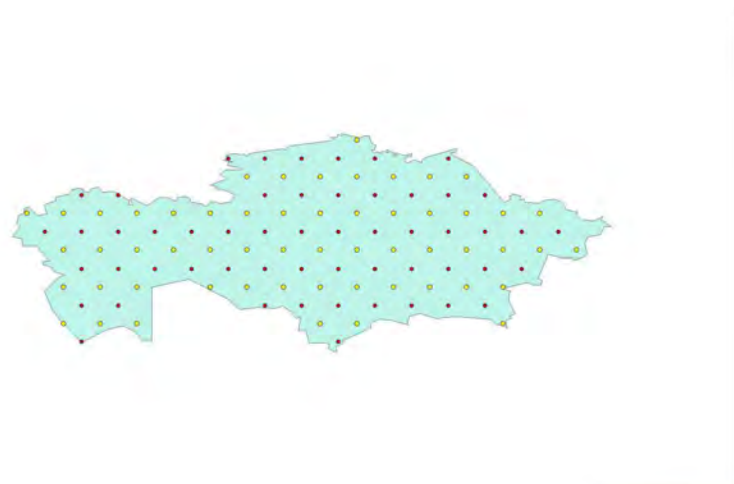
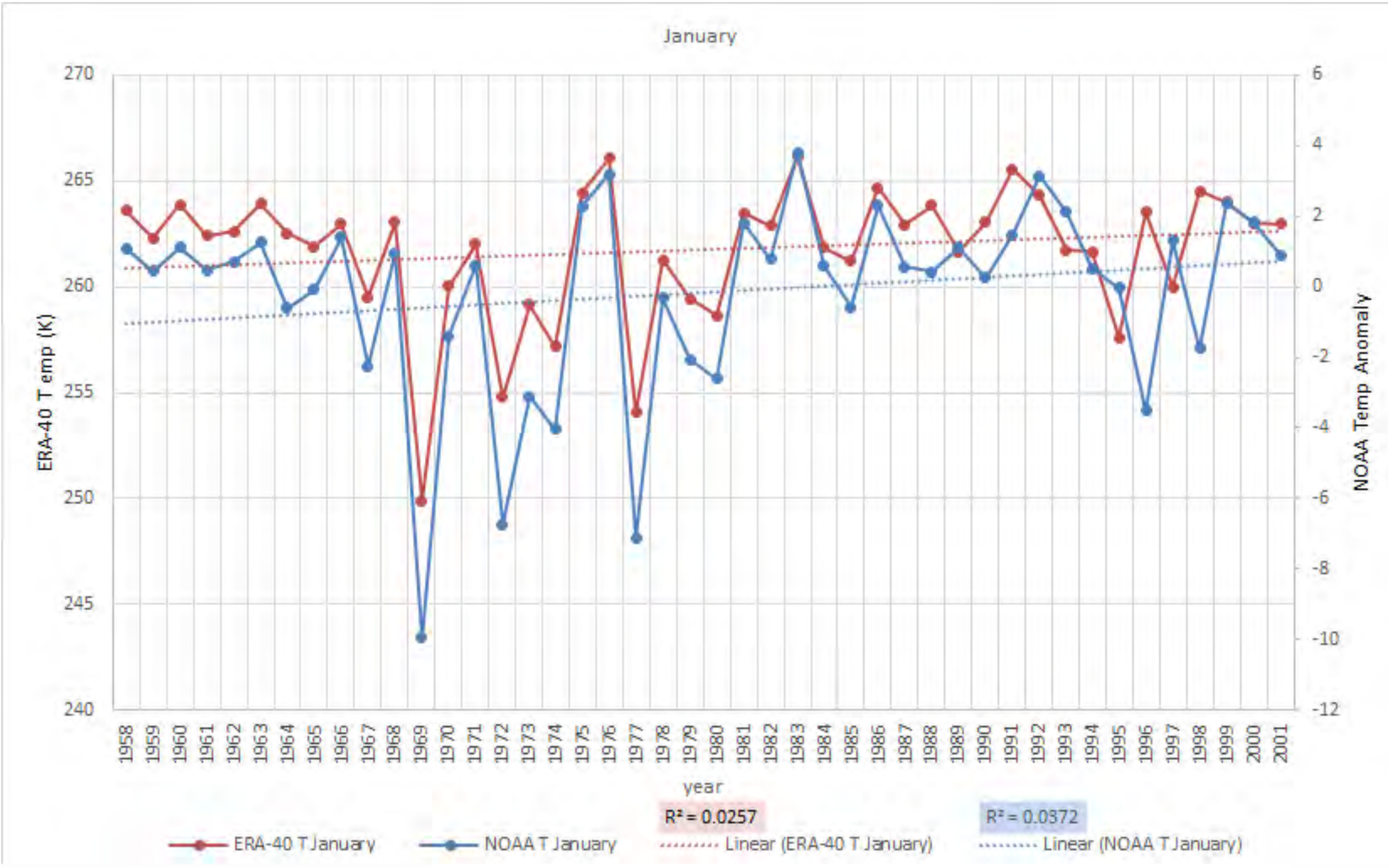


Figure 1.2 The ERA-40 grid points (yellow); The NOAA anomaly grid points (red).



January
270
265
260
255
250
245
240
6
4
2
0
-2
-4
-6
-8
-10
-12
ERA-40 T emp (K)
NOAA Temp Anomaly
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
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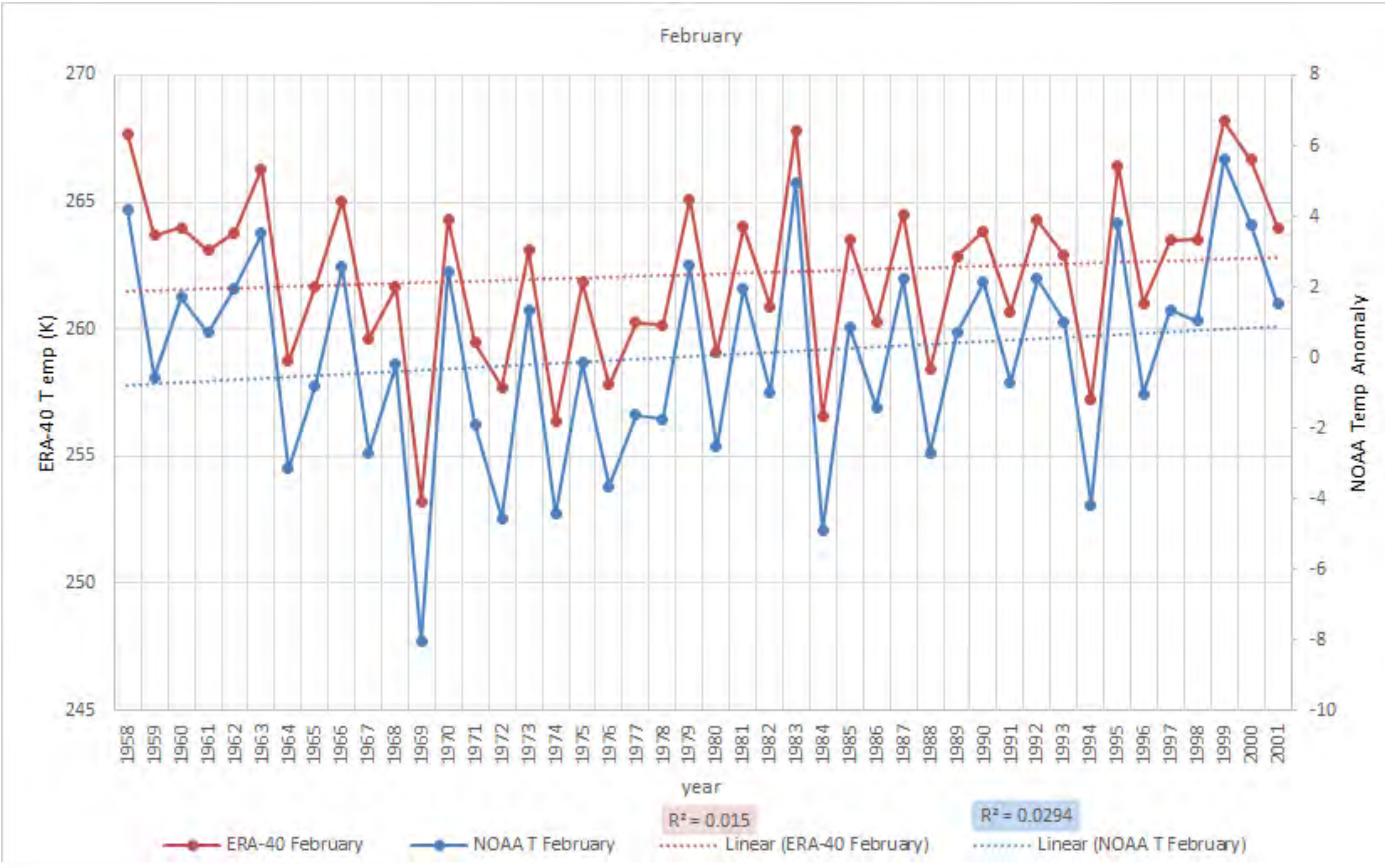
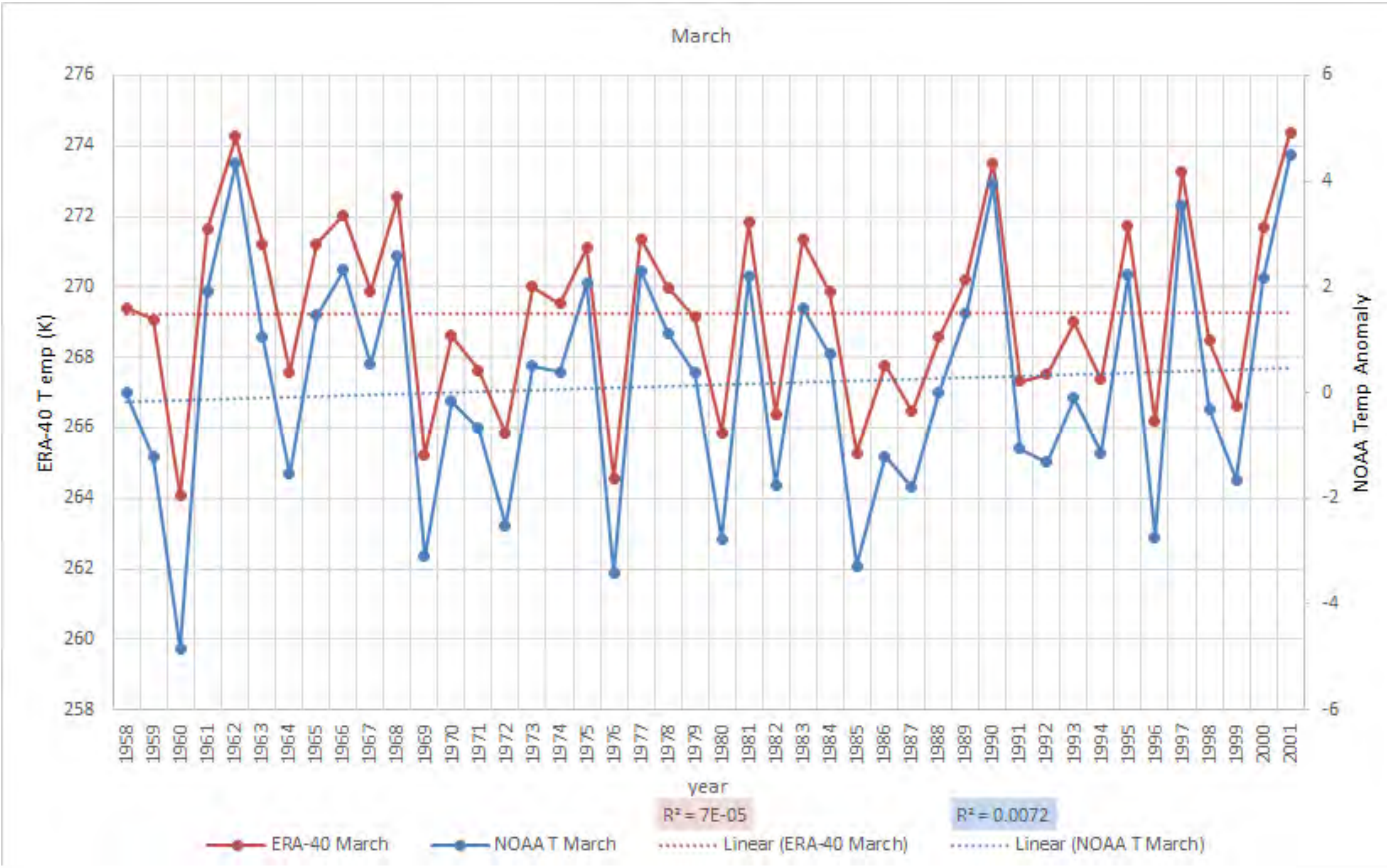
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
year
R² = 0.0257
R² = 0.0372
ERA-40 T January
NOAA T January
Linear (ERA-40 T January)
Linear (NOAA T January)

Figure 2.1

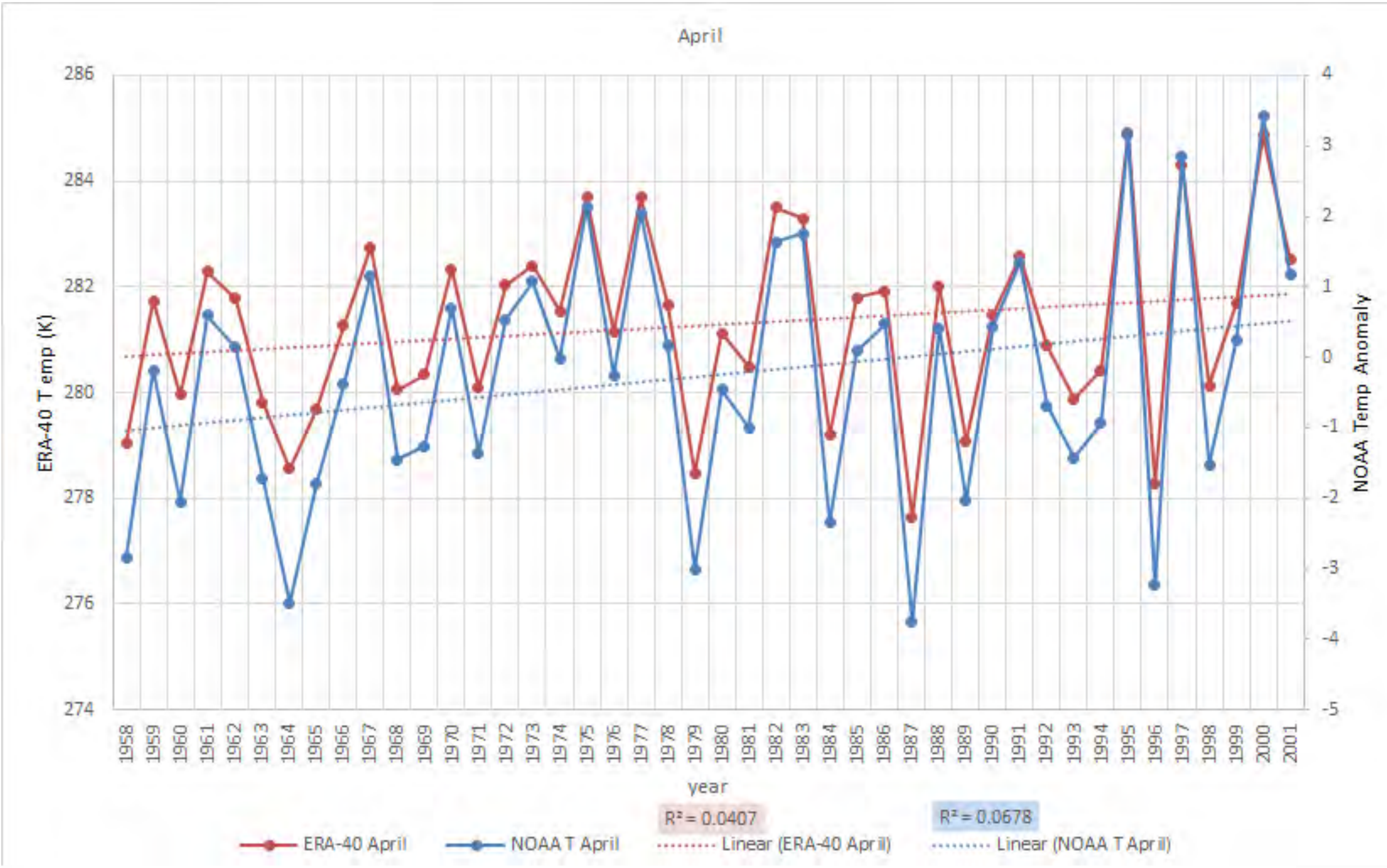


February
270
265
260
255
250
245
8
6
4
2
0
-2
-4
-6
-8
-10
ERA-40 T emp (K)
NOAA Temp Anomaly
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
year
R² = 0.015
R² = 0.0294
ERA-40 February
NOAA T February
Linear (ERA-40 February)
Linear (NOAA T February)

Figure 2.2

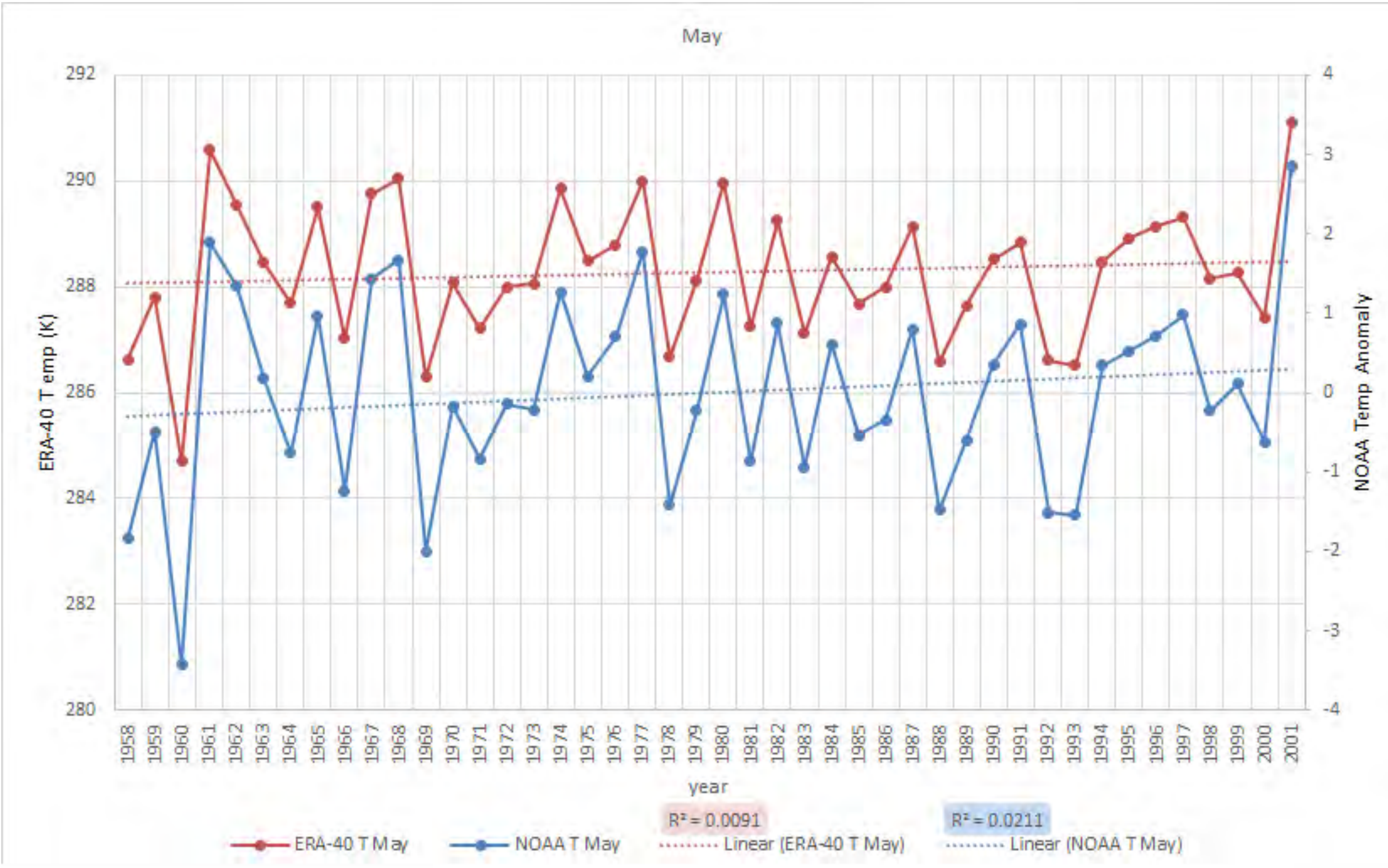


March
ERA-40 T emp (K)
NOAA Temp Anomaly
year
R² = 7E-05
R² = 0.0072
ERA-40 March
NOAA T March
Linear (ERA-40 March)
Linear (NOAA T March)



April
ERA-40 T emp (K)
NOAA Temp Anomaly
year
R² = 0.0407
R² = 0.0678
ERA-40 April
NOAA T April
Linear (ERA-40 April)
Linear (NOAA T April)

Figure 2.3


May
ERA-40 T emp (K)
NOAA Temp Anomaly
year
R² = 0.0091
R² = 0.0211
ERA-40 T May
NOAA T May
Linear (ERA-40 T May)
Linear (NOAA T May)

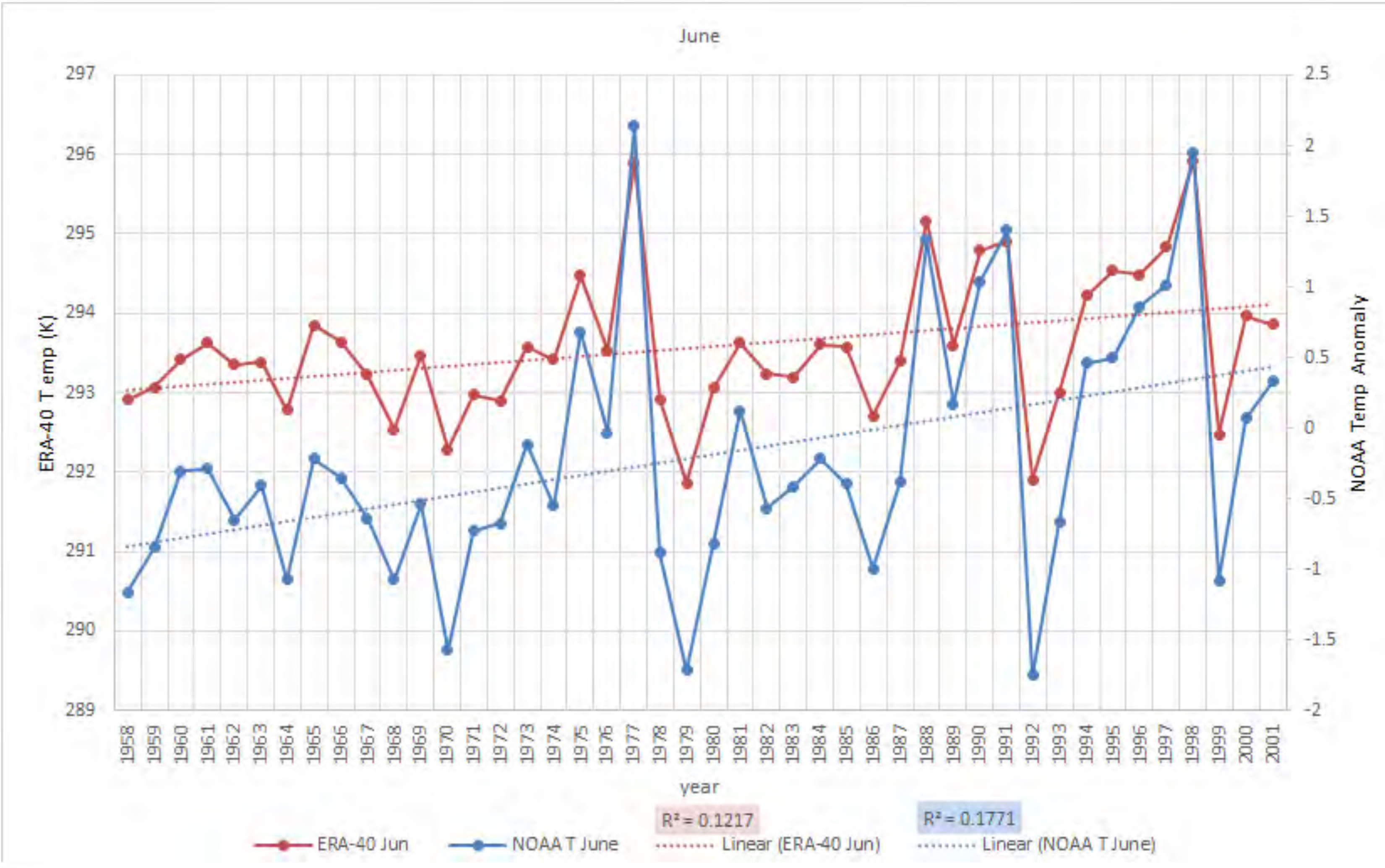
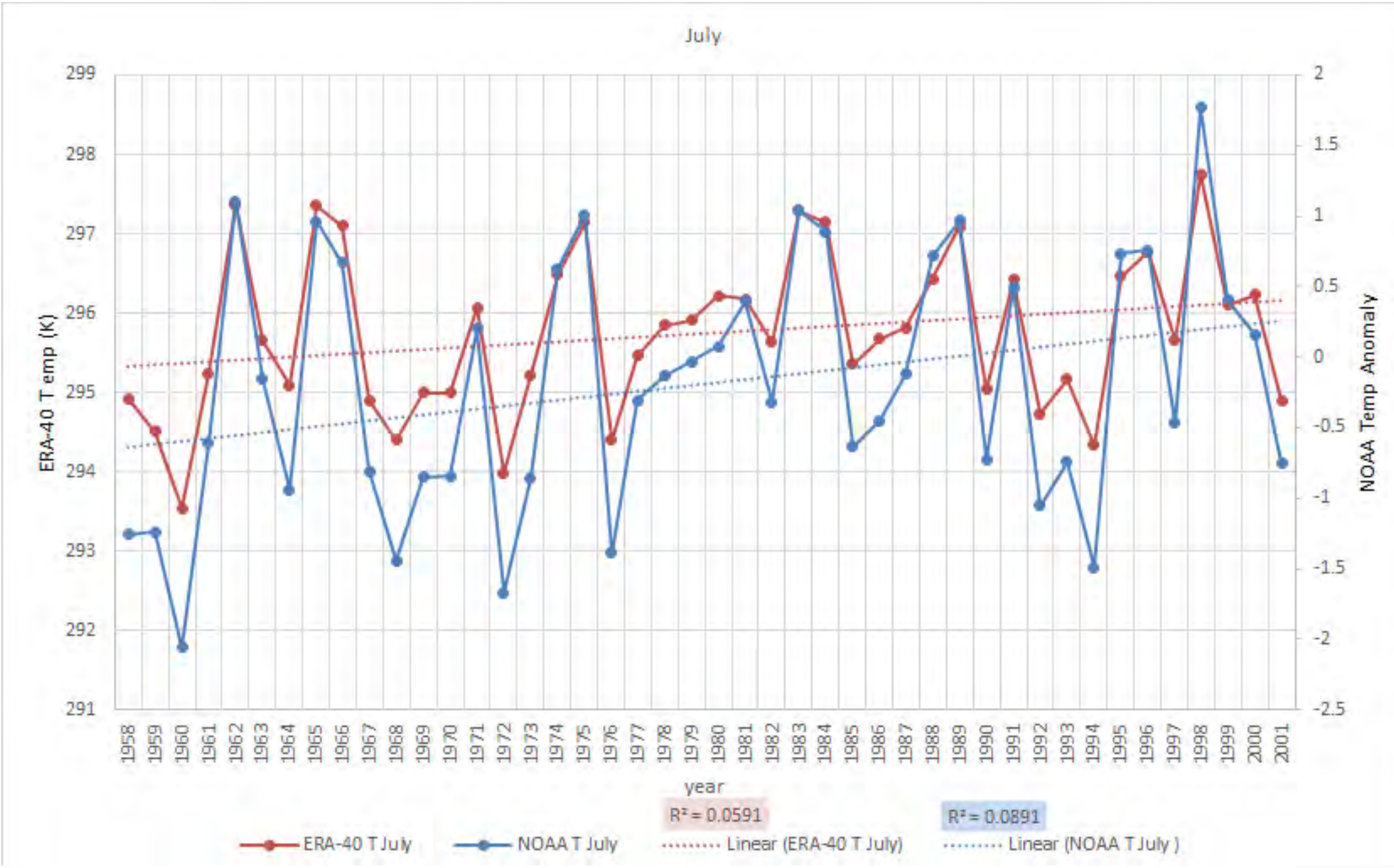
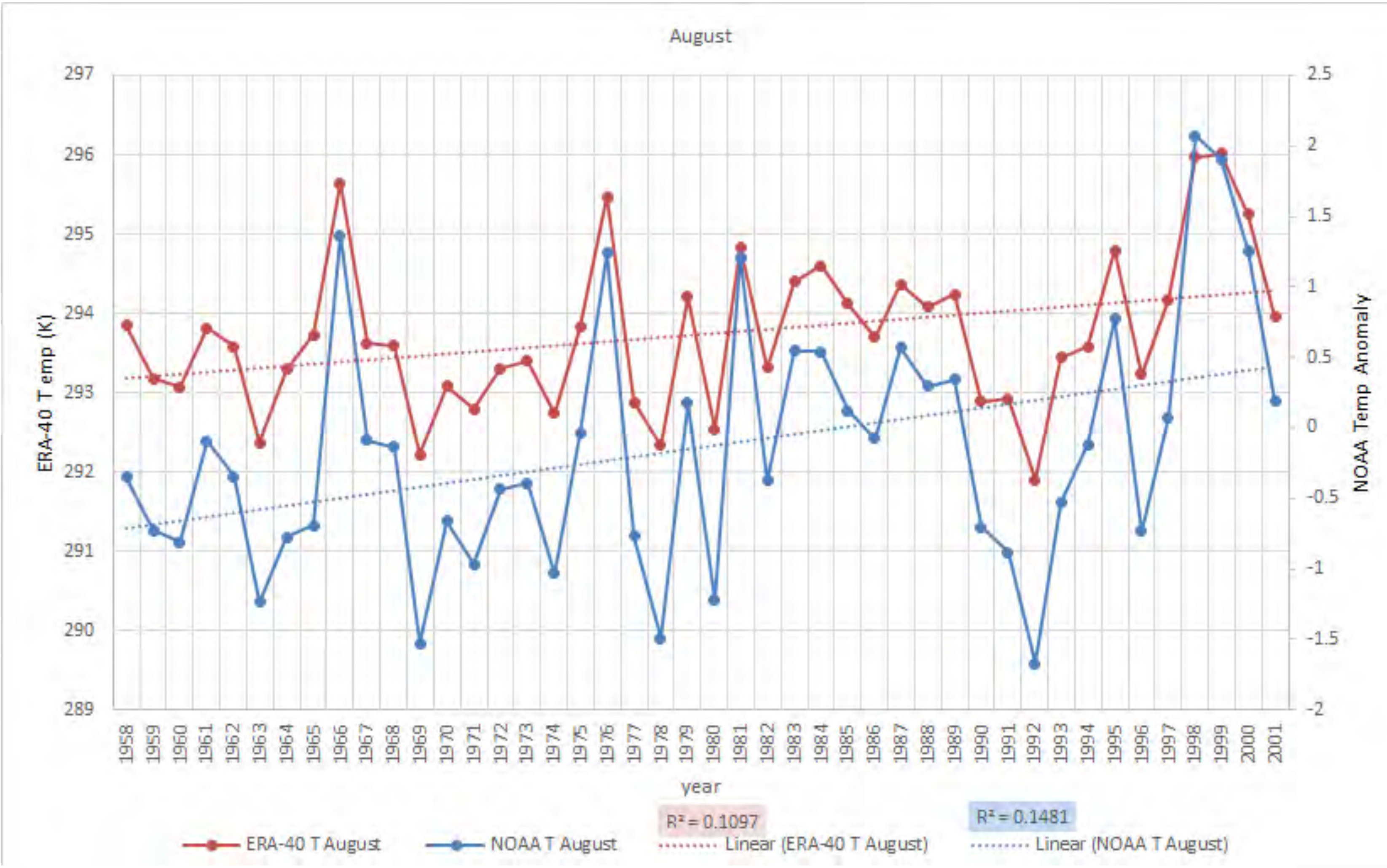

June
ERA-40 T emp (K)
NOAA Temp Anomaly
297
296
295
294
293
292
291
290
289
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
year
R² = 0.1217
R² = 0.1771
ERA-40 Jun
NOAA T June
Linear (ERA-40 Jun)
Linear (NOAA T June)

Figure 2.4



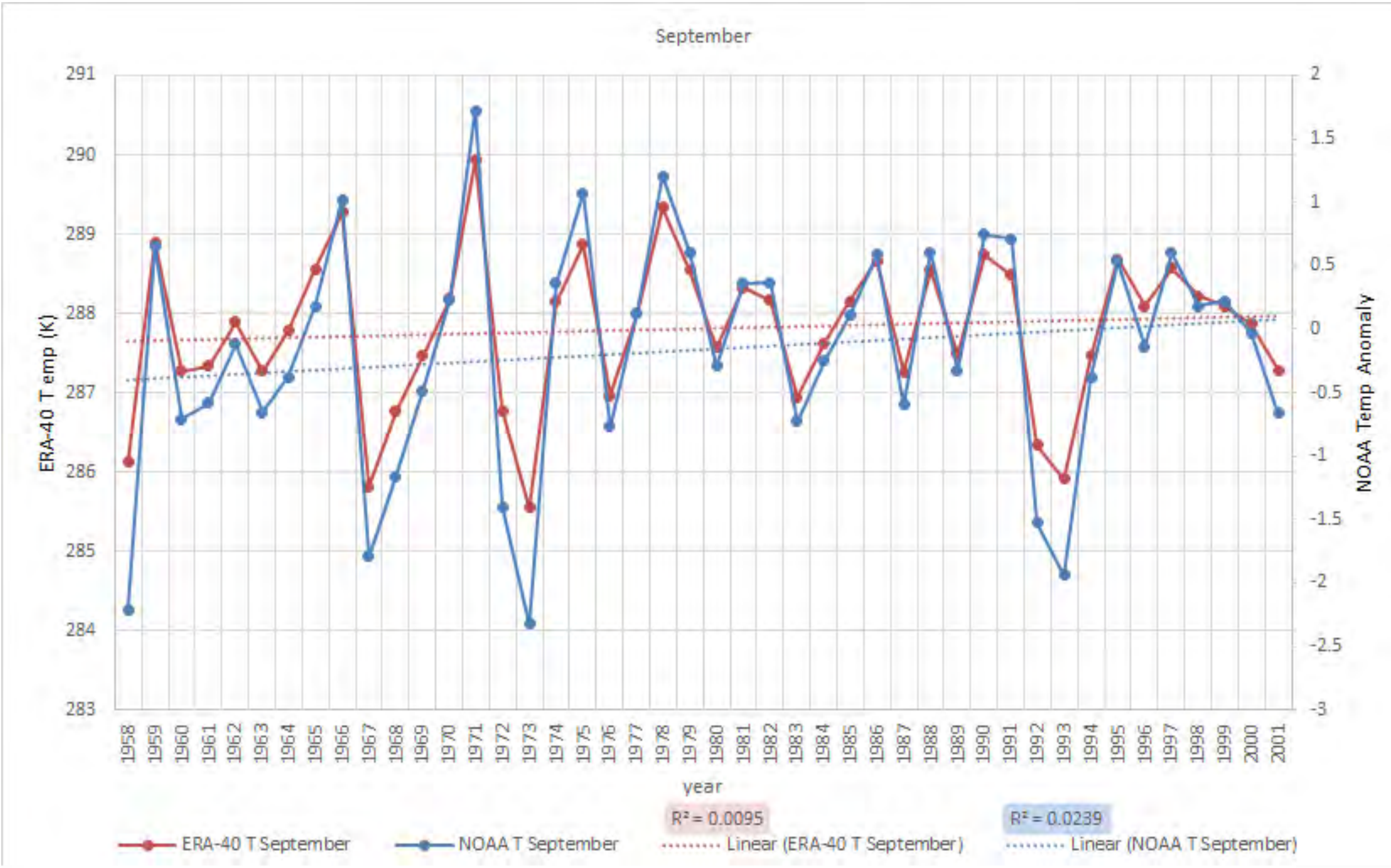
July
ERA-40 T emp (K)
NOAA Temp Anomaly
year
R² = 0.0591
R² = 0.0891
ERA-40 T July
NOAA T July
Linear (ERA-40 T July)
Linear (NOAA T July)

Figure 2.5



August
ERA-40 T emp (K)
NOAA Temp Anomaly
year
R² = 0.1097
R² = 0.1481
ERA-40 T August
NOAA T August
Linear (ERA-40 T August)
Linear (NOAA T August)

Figure 2.6



September
291
290
289
288
287
286
285
284
283
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
ERA-40 T emp (K)
NOAA Temp Anomaly
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
year
R² = 0.0095
R² = 0.0239
ERA-40 T September
NOAA T September
Linear (ERA-40 T September)
Linear (NOAA T September)

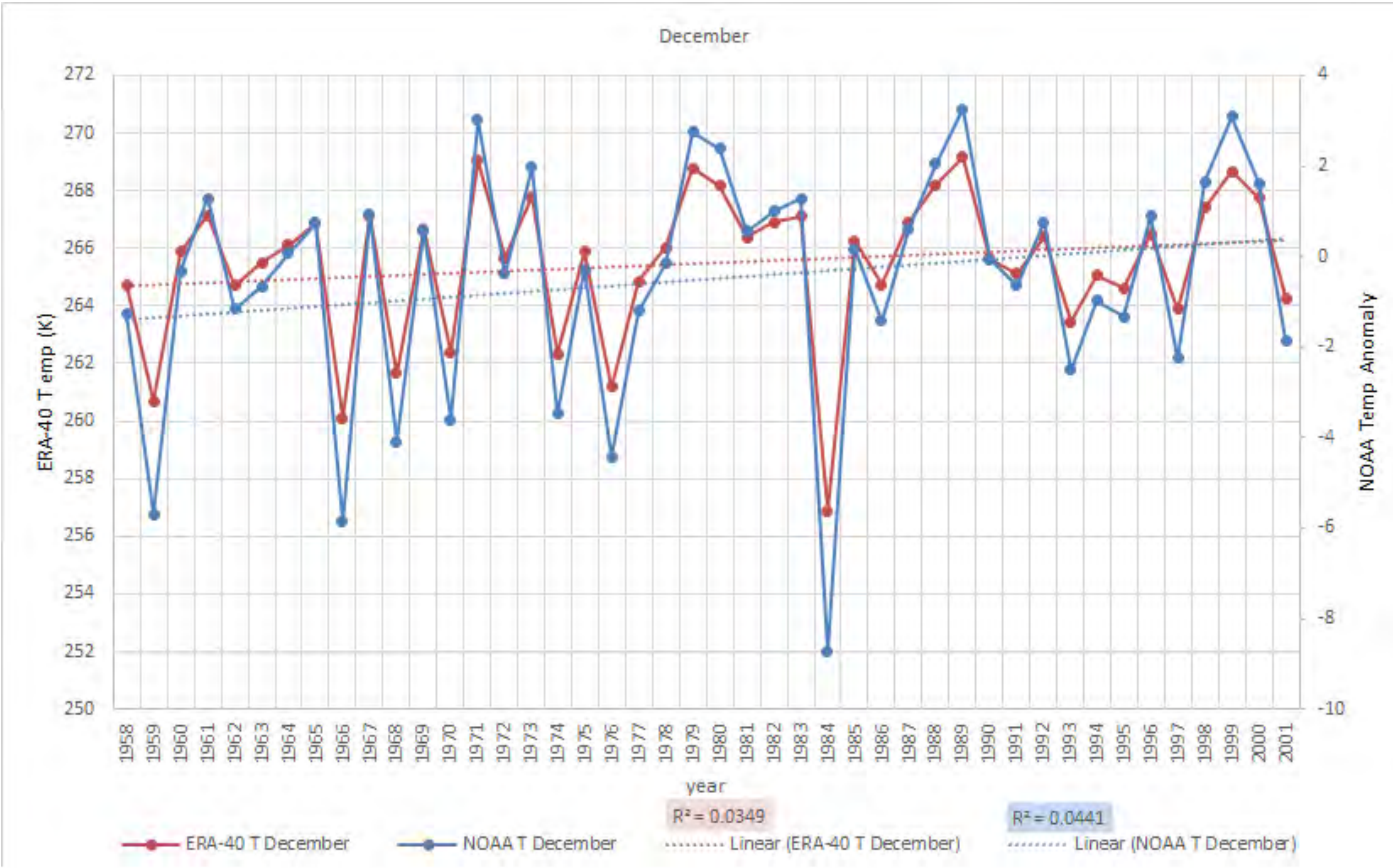
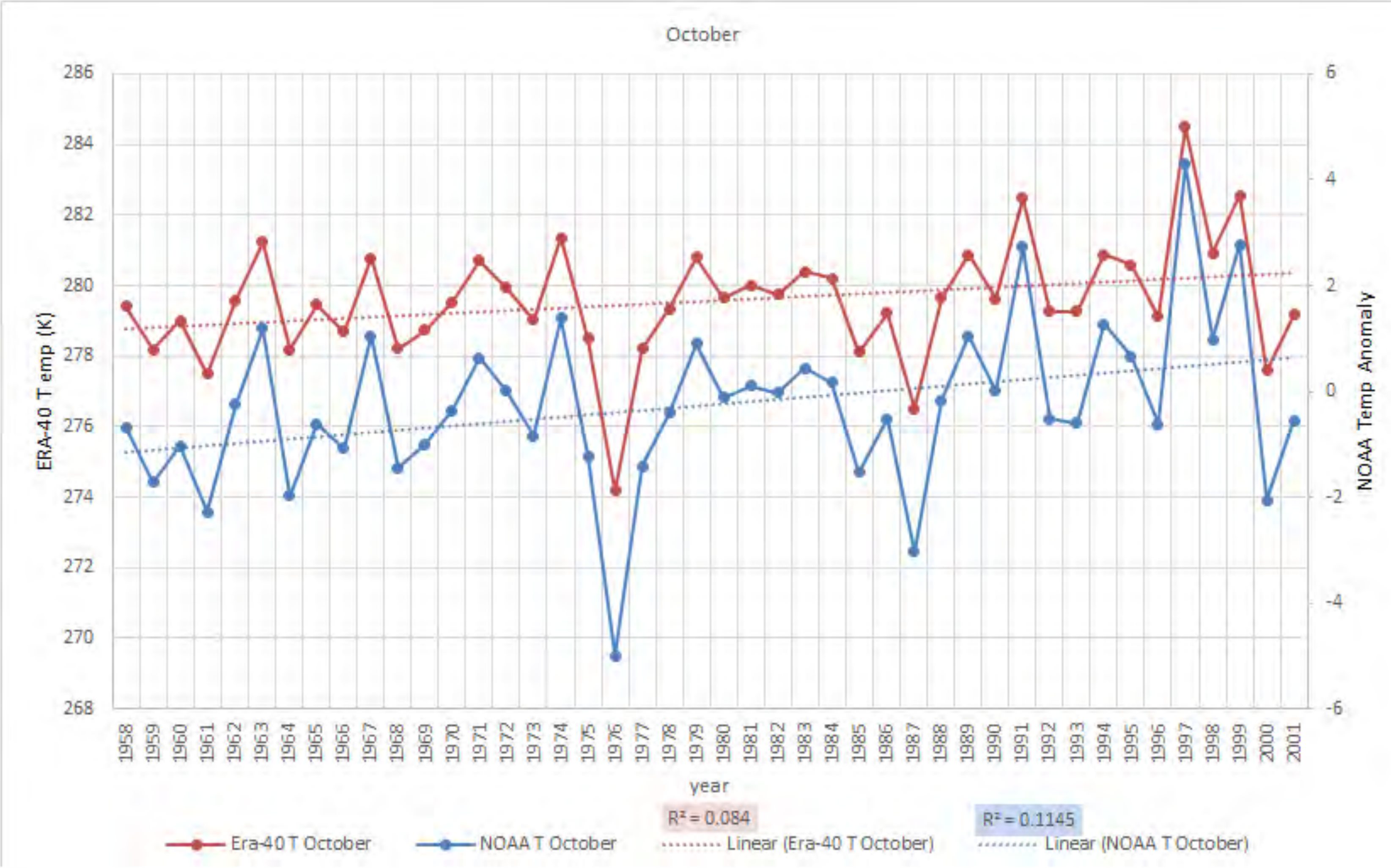
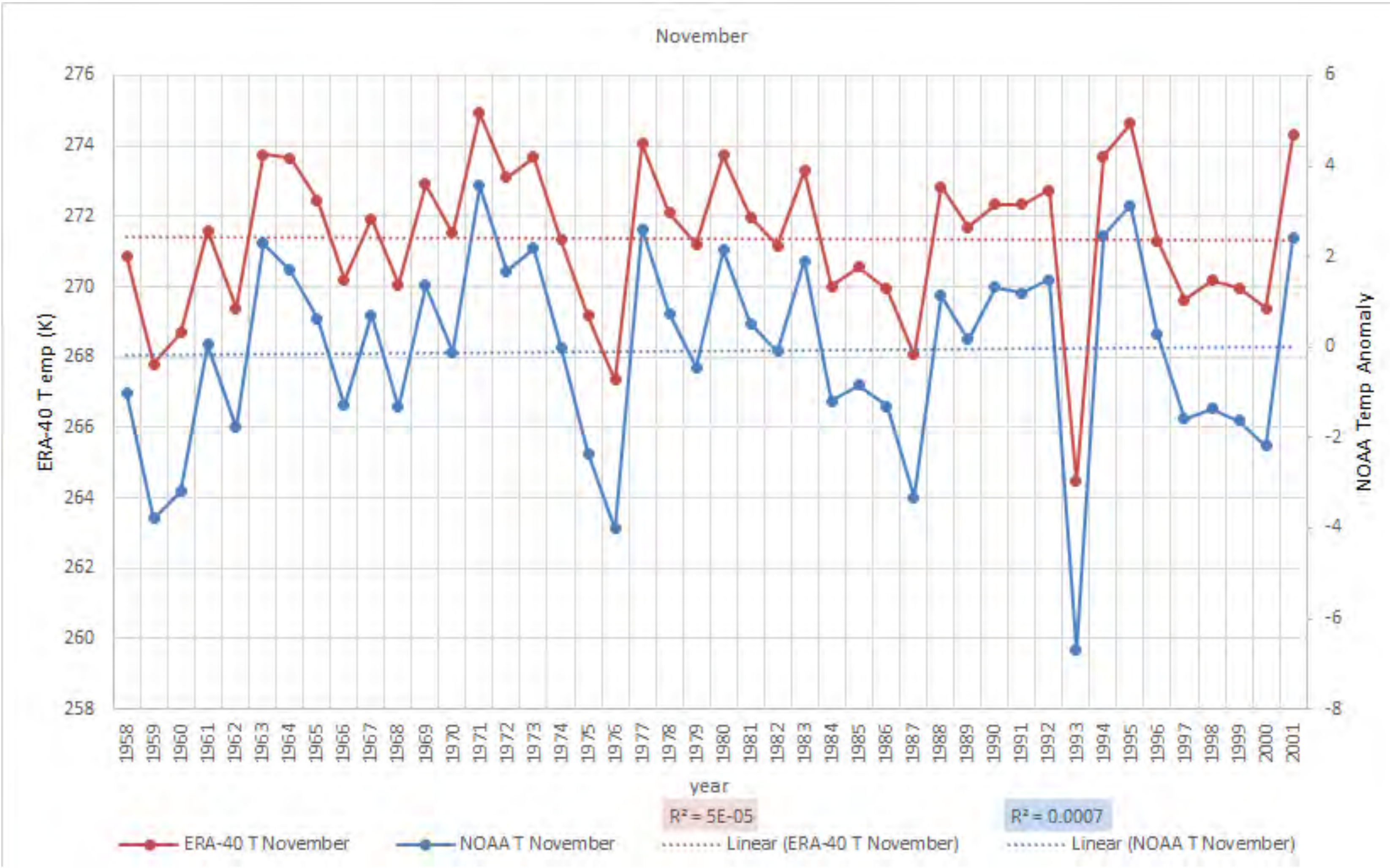

December
ERA-40 T emp (K)
NOAA Temp Anomaly
year
R² = 0.0349
R² = 0.0441
ERA-40 T December
NOAA T December
Linear (ERA-40 T December)
Linear (NOAA T December)

Figure 2.7



October
ERA-40 T emp (K)
NOAA Temp Anomaly
year
R² = 0.084
R² = 0.1145
Era-40 T October
NOAA T October
Linear (Era-40 T October)
Linear (NOAA T October)



November
276
274
272
270
268
266
264
262
260
258
ERA-40 T emp (K)
6
4
2
0
-2
-4
-6
-8
NOAA Temp Anomaly
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
year
R² = 5E-05
R² = 0.0007
ERA-40 T November
NOAA T November
Linear (ERA-40 T November)
Linear (NOAA T November)

Figure 2.8

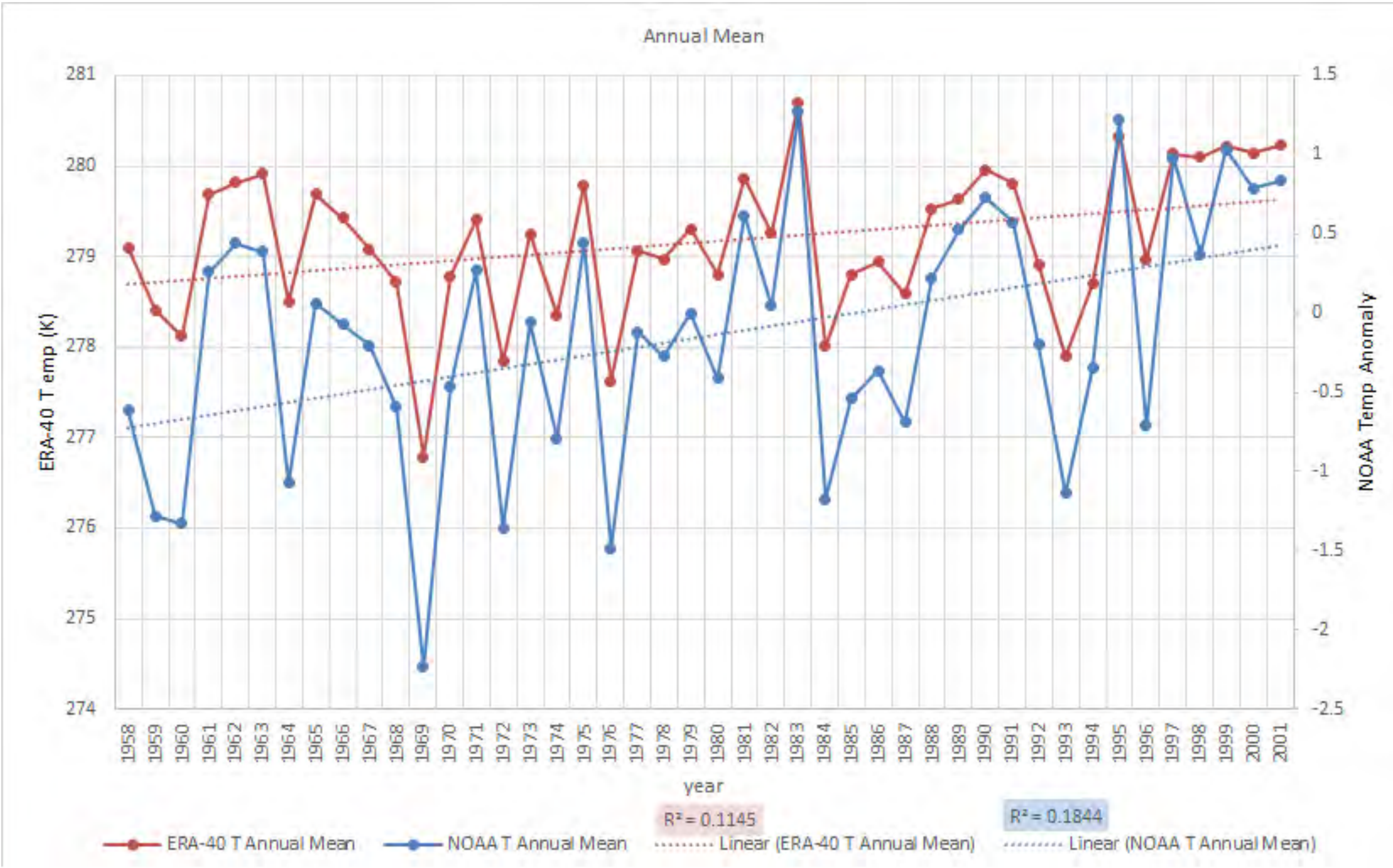

Annual Mean
ERA-40 T emp (K)
NOAA Temp Anomaly
281
280
279
278
277
276
275
274
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
year
R² = 0.1145
R² = 0.1844
ERA-40 T Annual Mean
NOAA T Annual Mean
Linear (ERA-40 T Annual Mean)
Linear (NOAA T Annual Mean)

Figure 2.9

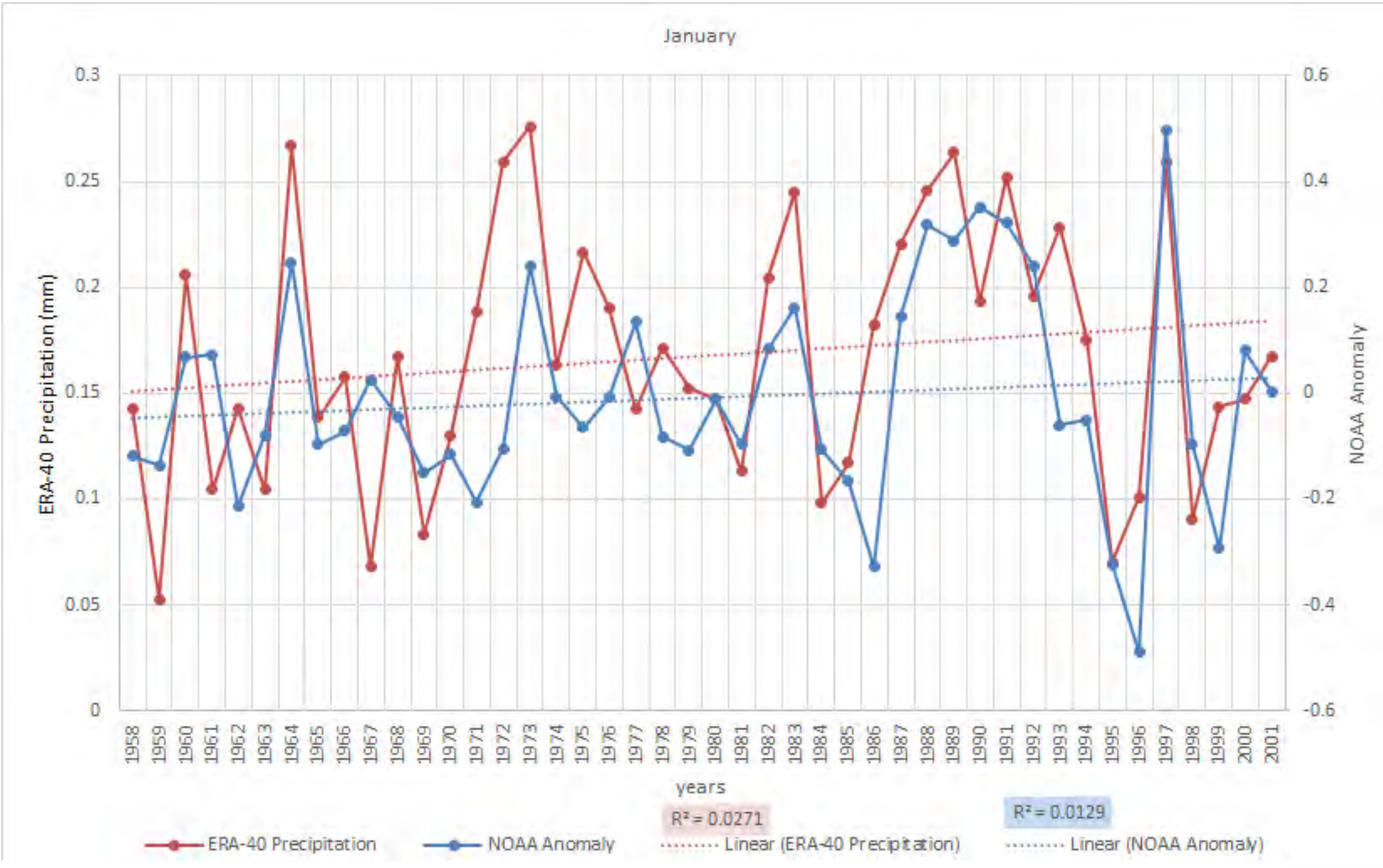

January
0.3
0.25
0.2
0.15
0.1
0.05
0
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
ERA-40 Precipitation (mm)
NOAA Anomaly
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
years
R² = 0.0271
R² = 0.0129
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.10

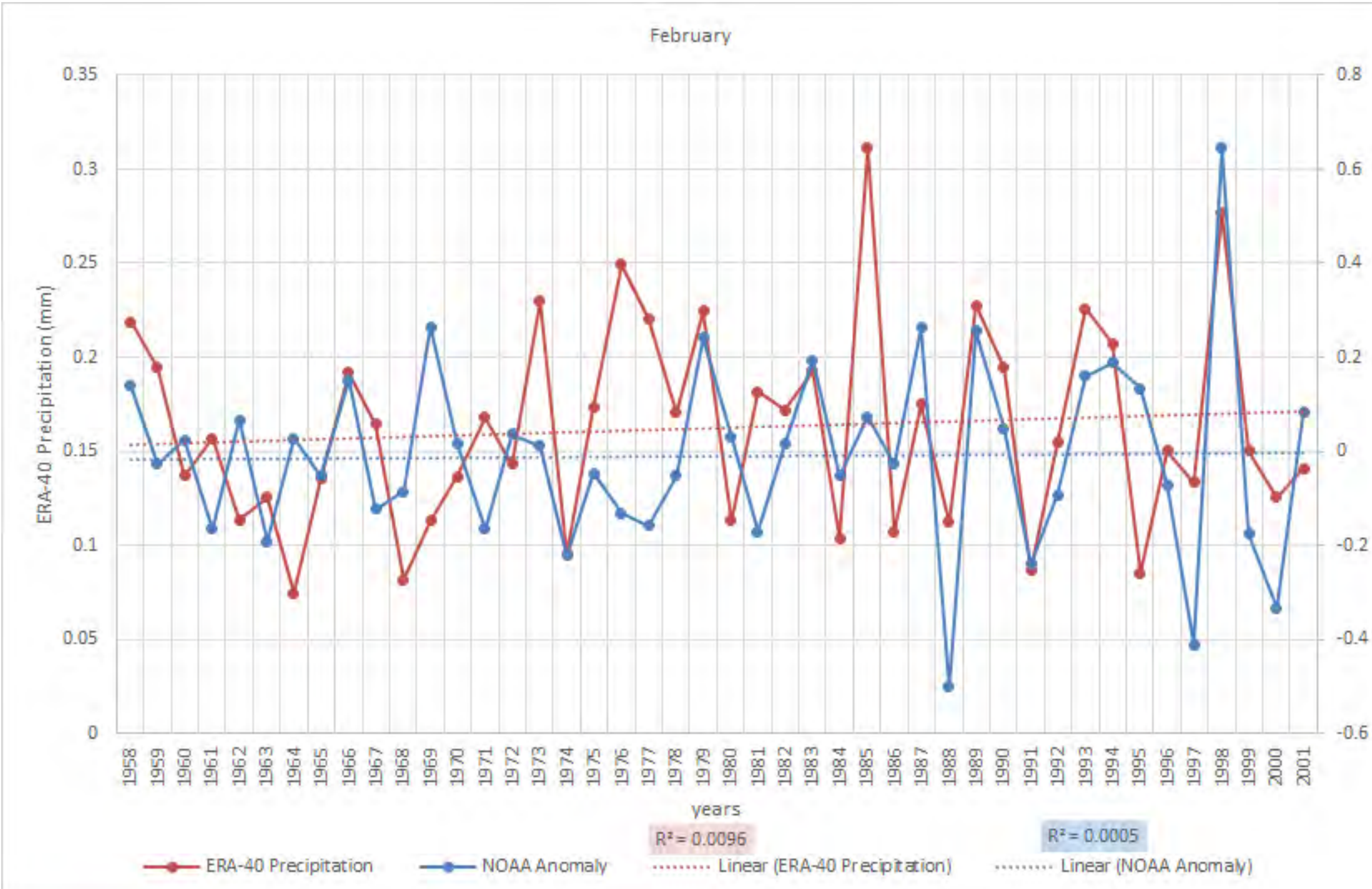

February
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
ERA-40 Precipitation (mm)
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.0096
R² = 0.0005
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.11

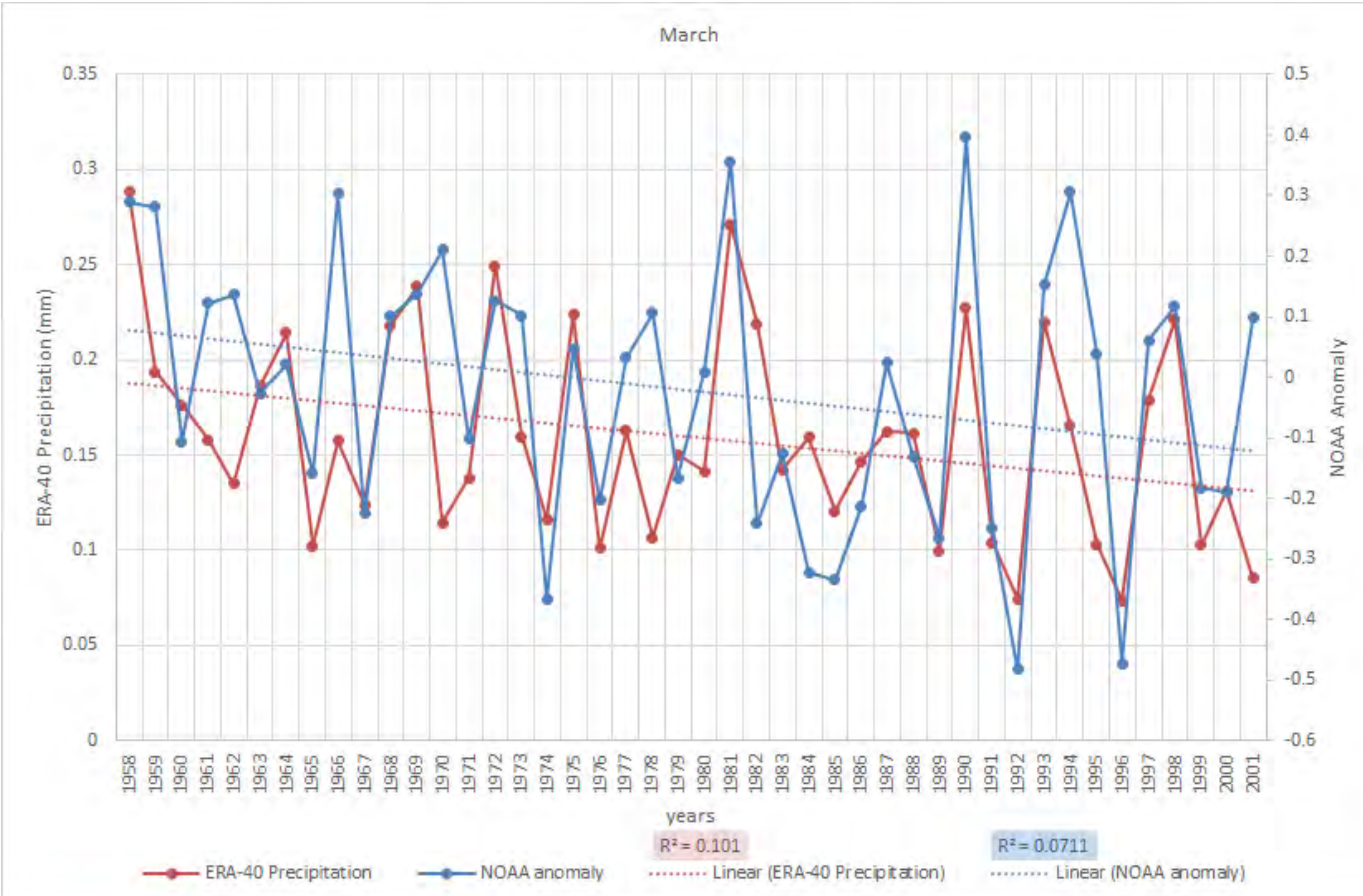

March
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
ERA-40 Precipitation (mm)
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
NOAA Anomaly
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.101
R² = 0.0711
ERA-40 Precipitation
NOAA anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA anomaly)

Figure 2.12

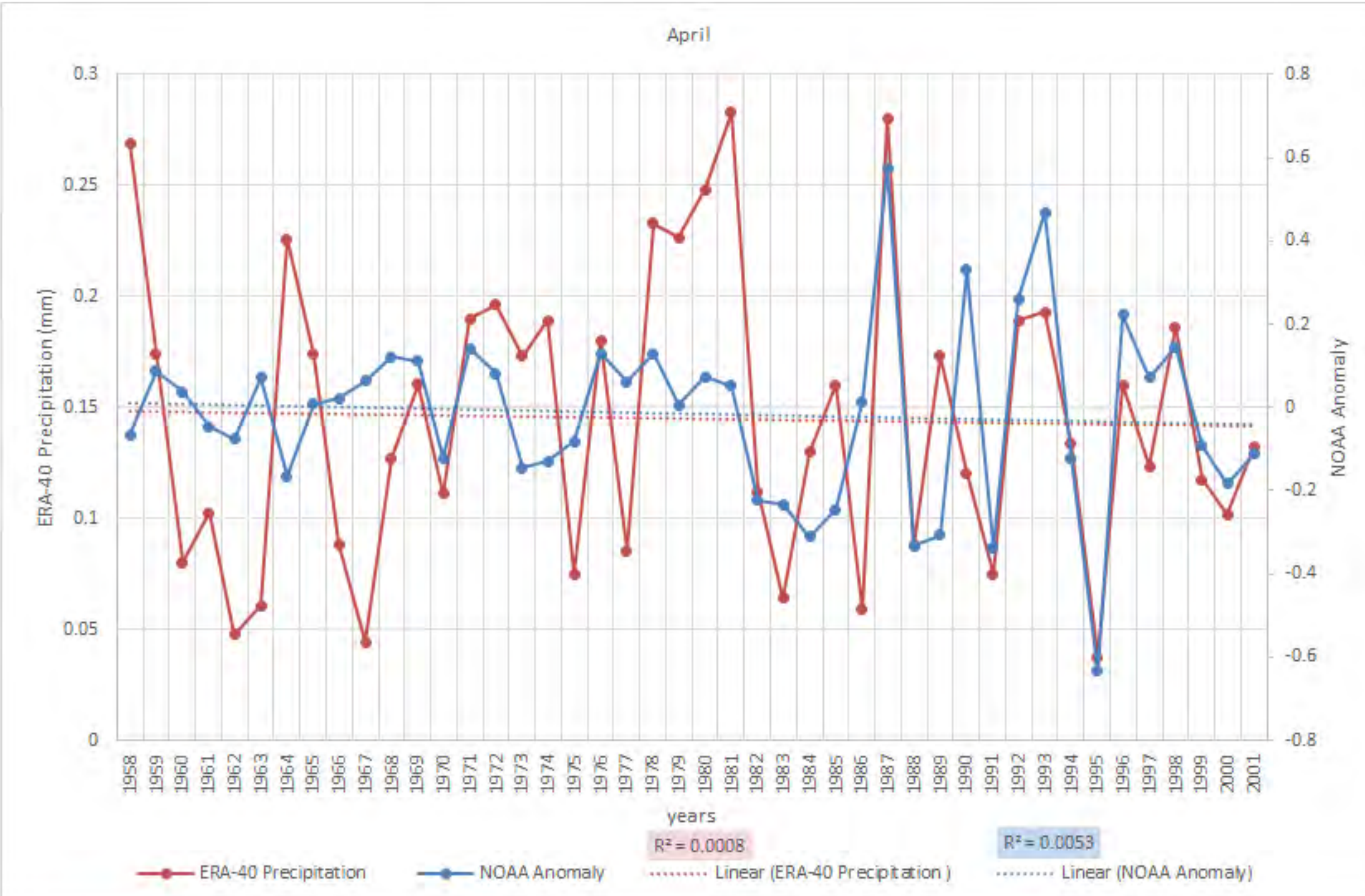

April
0.3
0.25
0.2
0.15
0.1
0.05
0
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
ERA-40 Precipitation (mm)
NOAA Anomaly
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.0008
R² = 0.0053
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.13

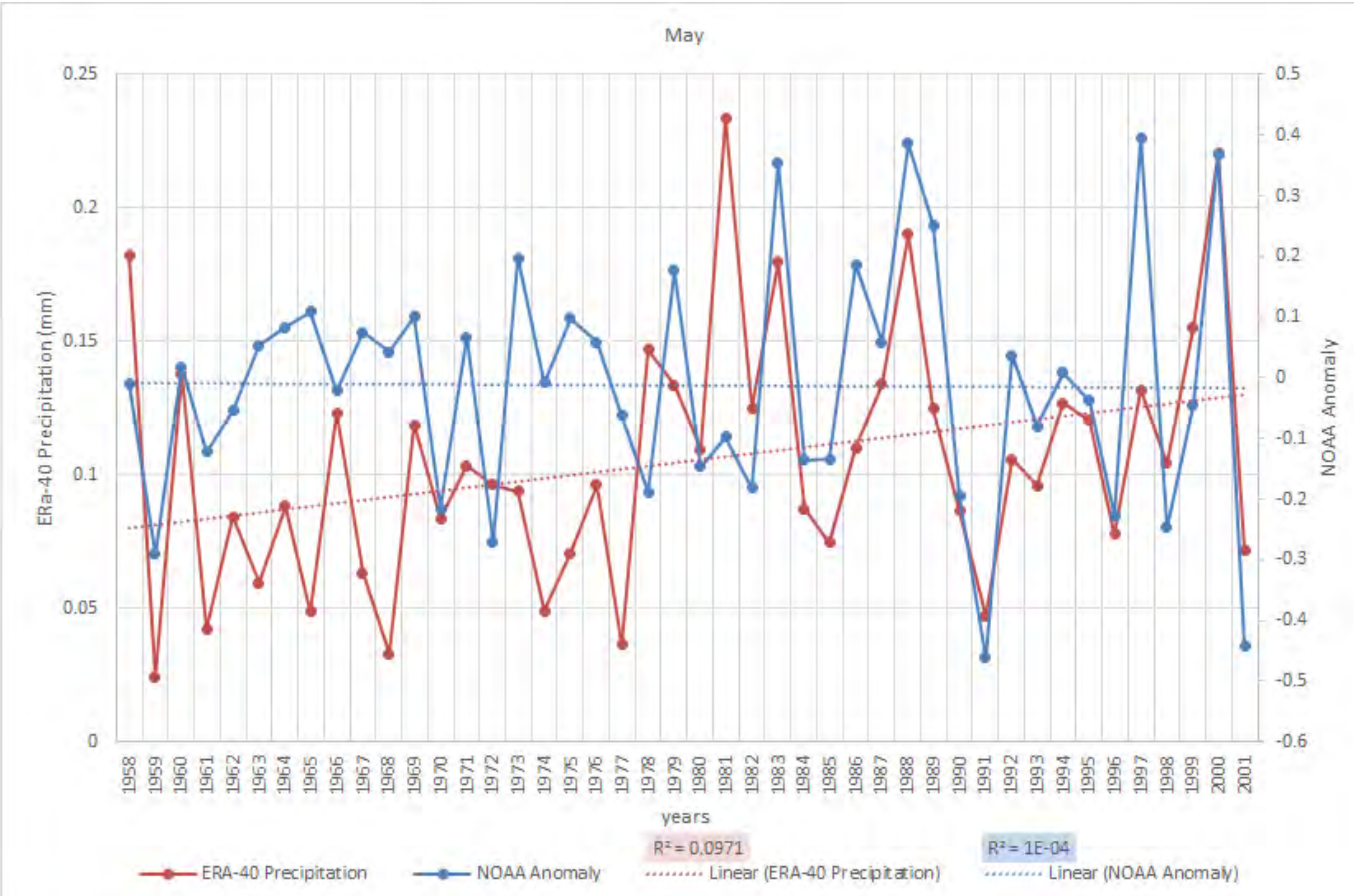
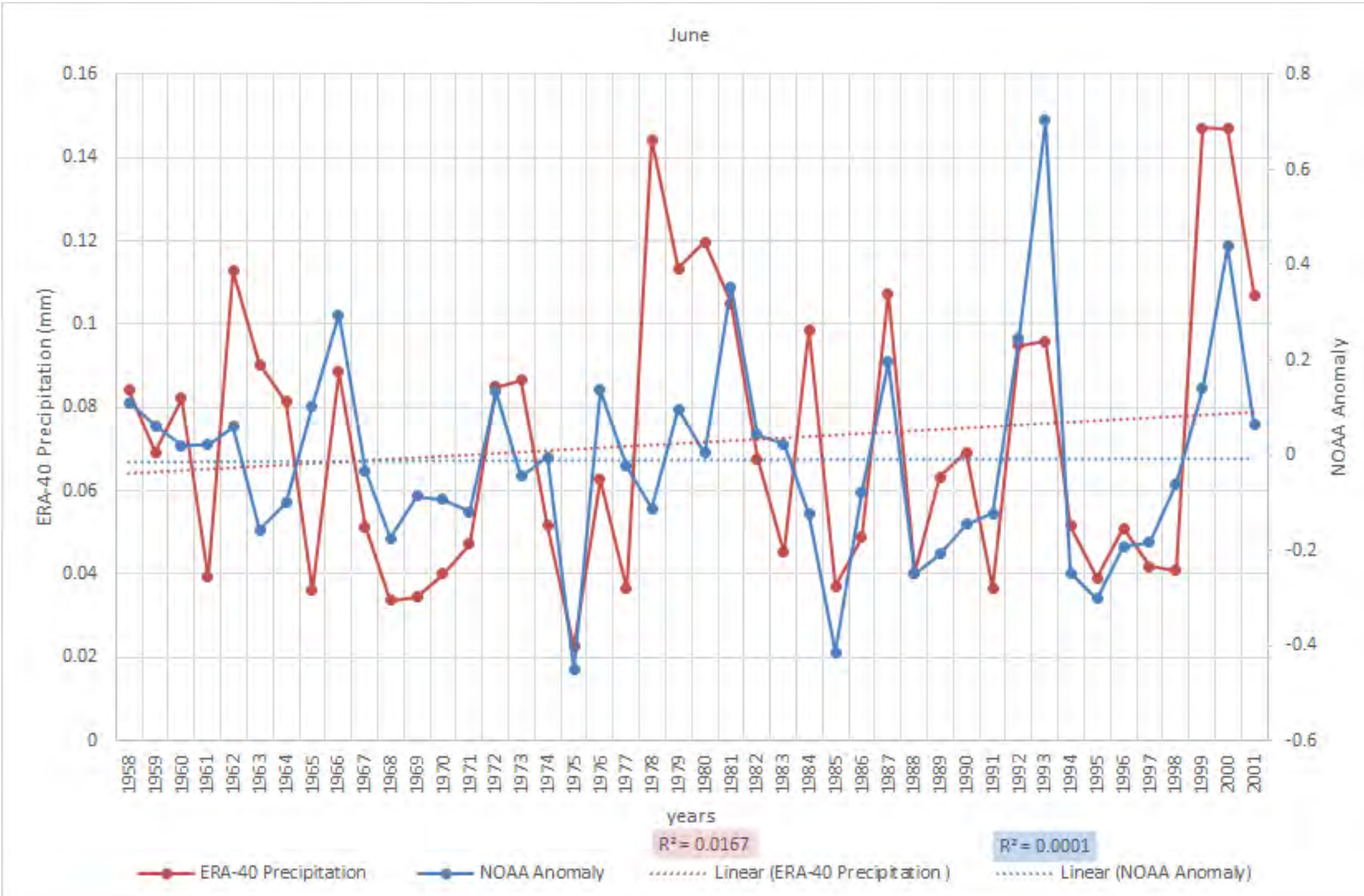

May
ERa-40 Precipitation (mm)
NOAA Anomaly
years
R² = 0.0971
R² = 1E-04
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.14



June
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ERA-40 Precipitation (mm)
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
NOAA Anomaly
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
years
R² = 0.0167
R² = 0.0001
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.15

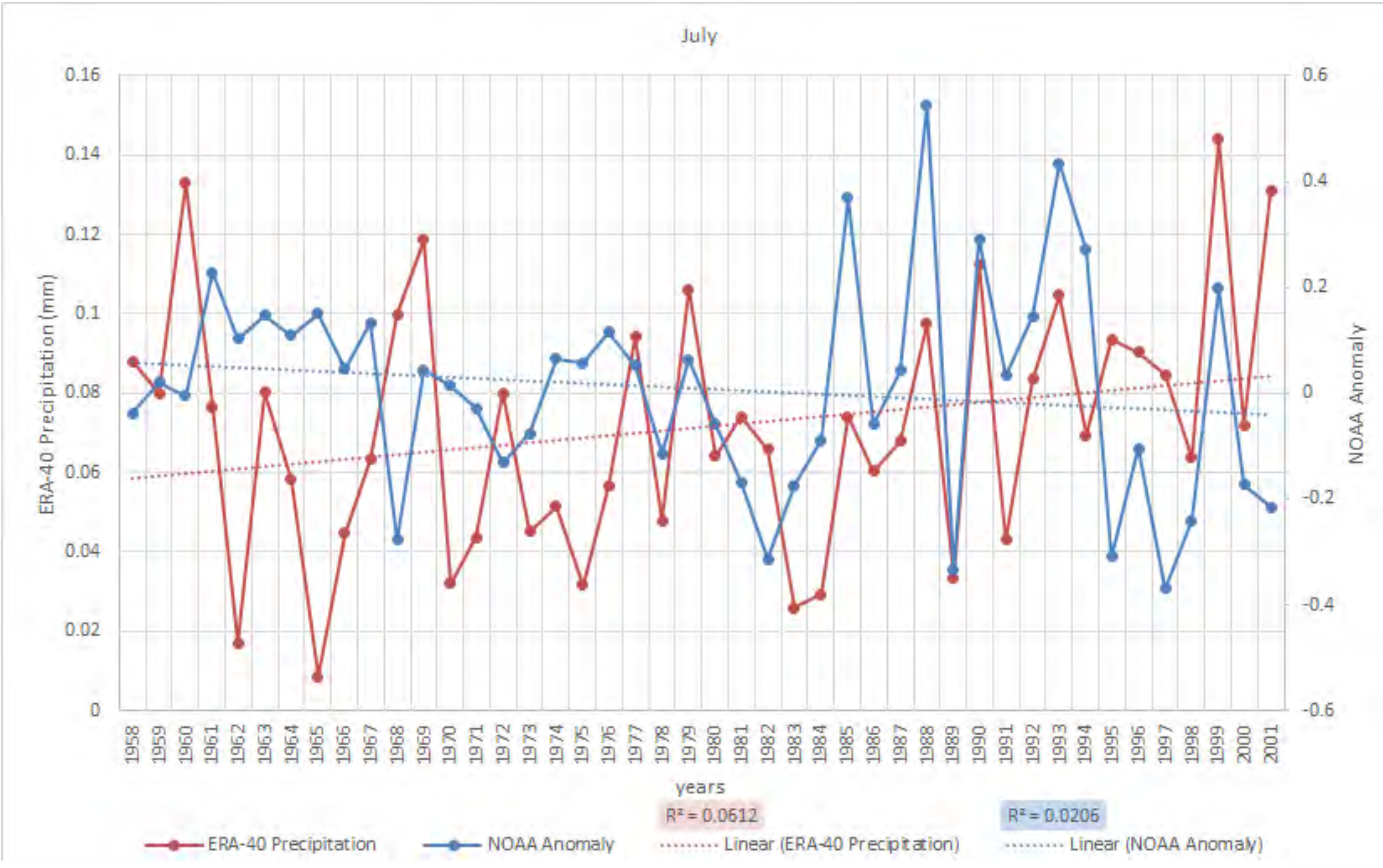
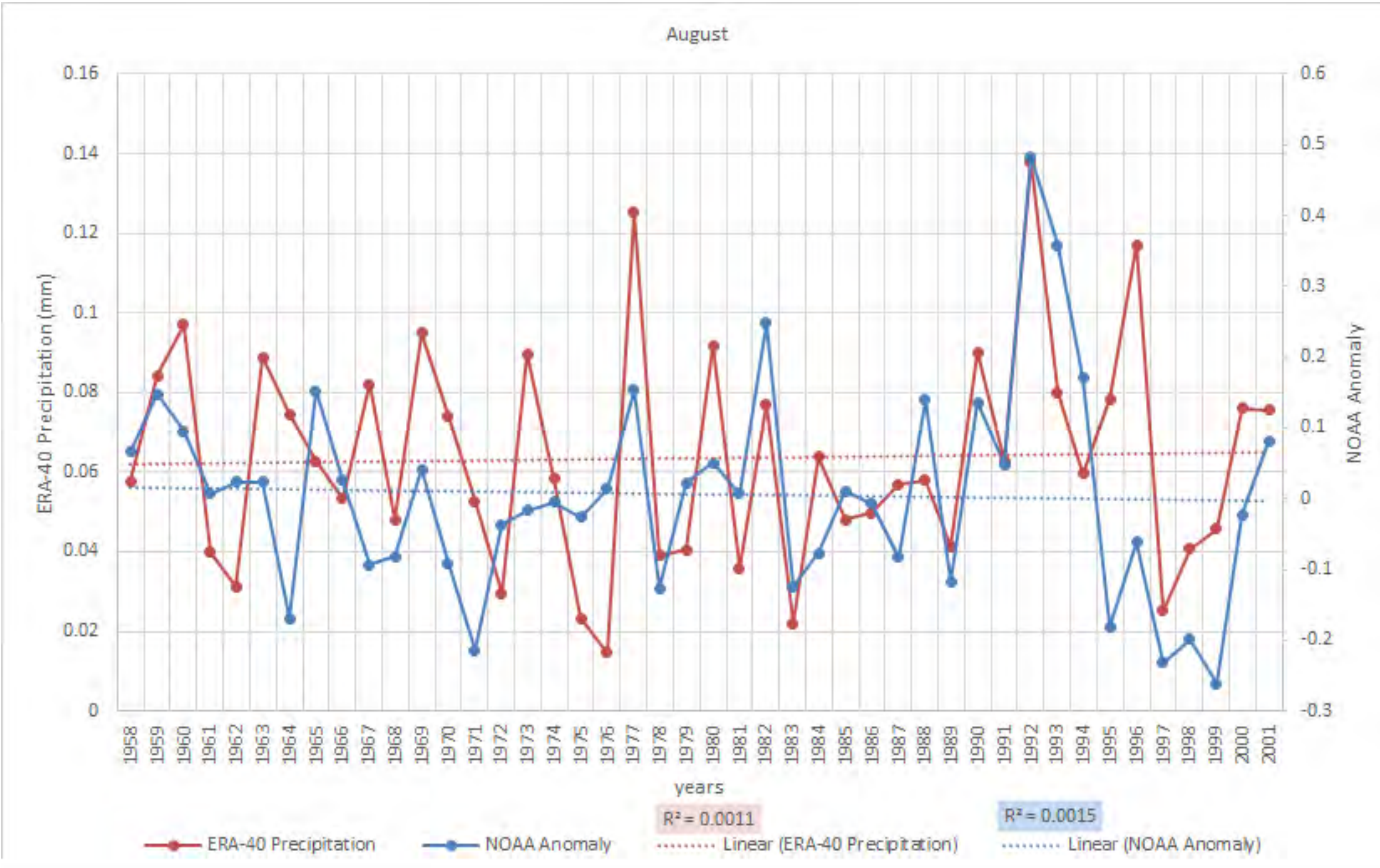
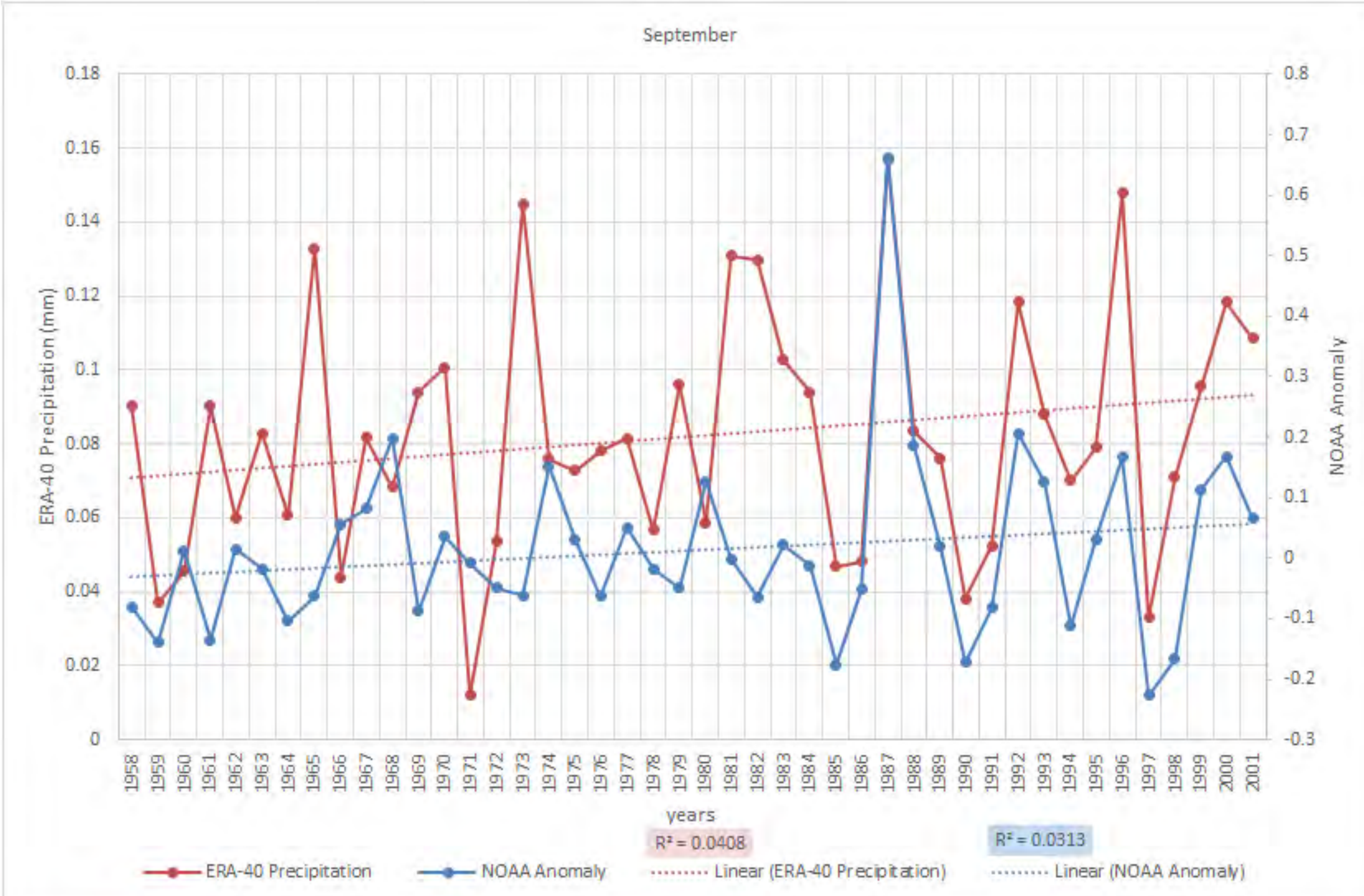

July
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
ERA-40 Precipitation (mm)
NOAA Anomaly
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
years
R² = 0.0612
R² = 0.0206
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.16



August
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
ERA-40 Precipitation (mm)
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
NOAA Anomaly
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
years
R² = 0.0011
R² = 0.0015
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.17



September
ERA-40 Precipitation (mm)
NOAA Anomaly
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.0408
R² = 0.0313
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.18

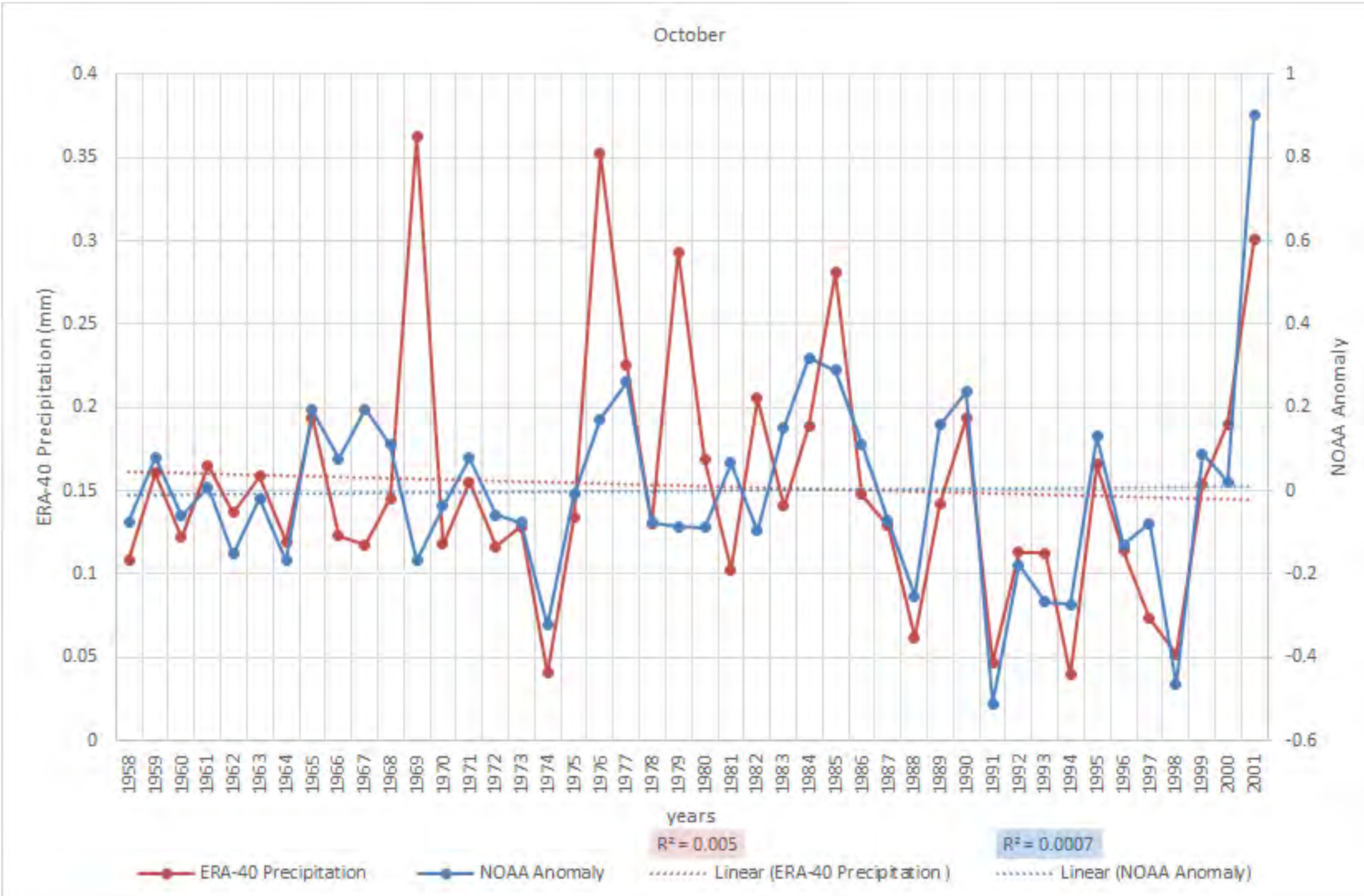
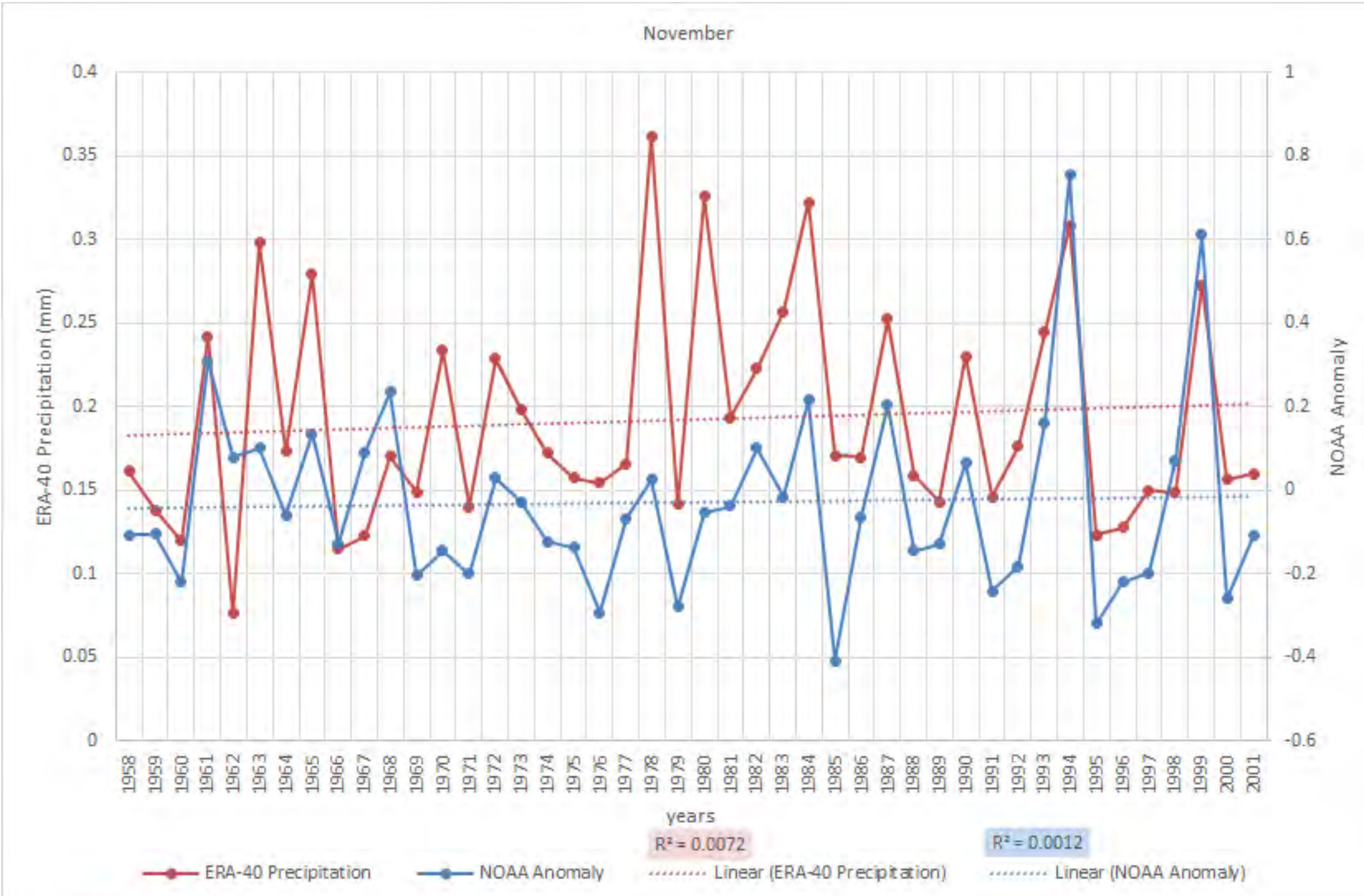

October
ERA-40 Precipitation (mm)
NOAA Anomaly
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.005
R² = 0.0007
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.19



November
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
ERA-40 Precipitation (mm)
NOAA Anomaly
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.0072
R² = 0.0012
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.20

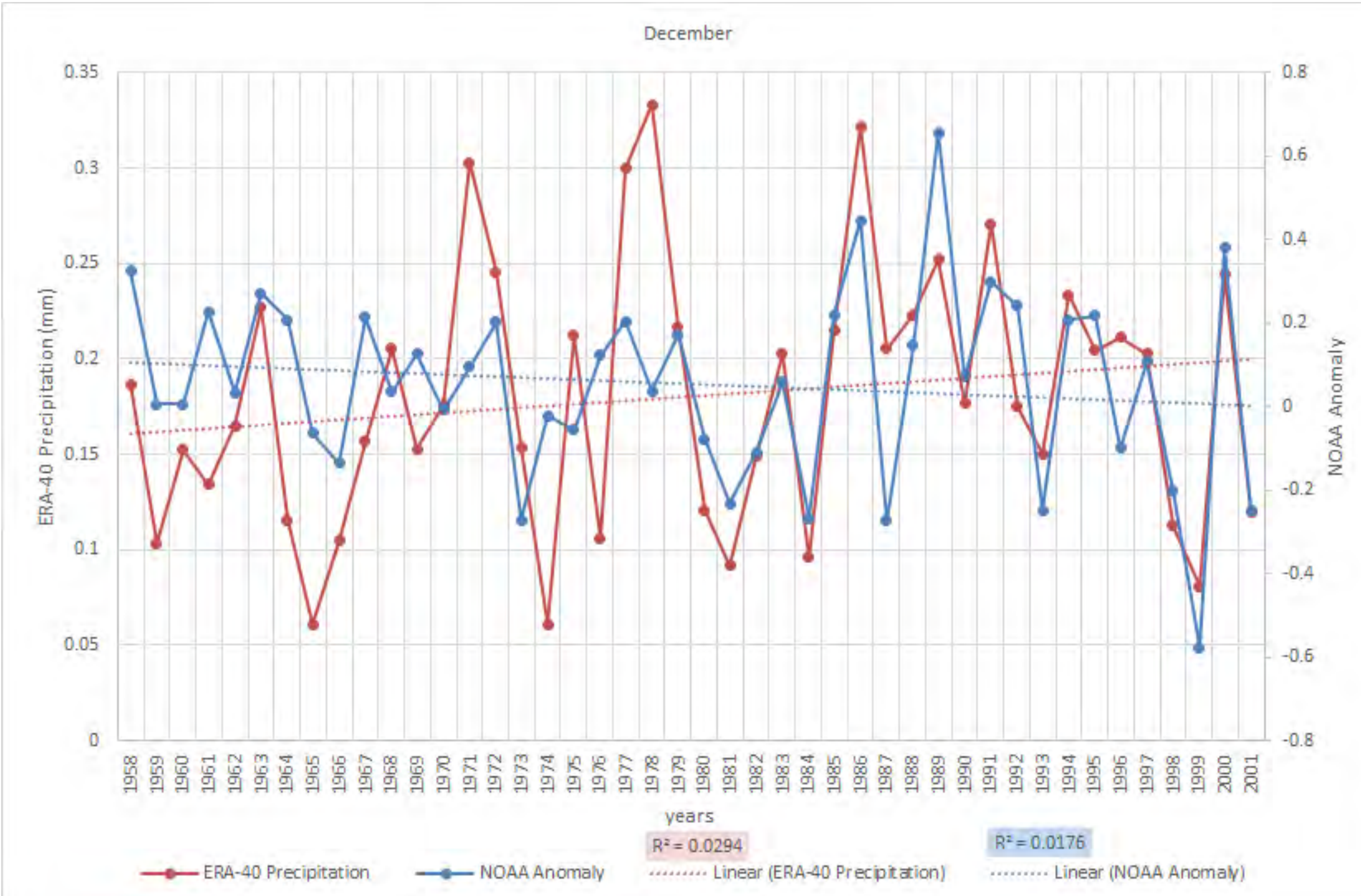

December
ERA-40 Precipitation (mm)
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
NOAA Anomaly
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.0294
R² = 0.0176
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.21

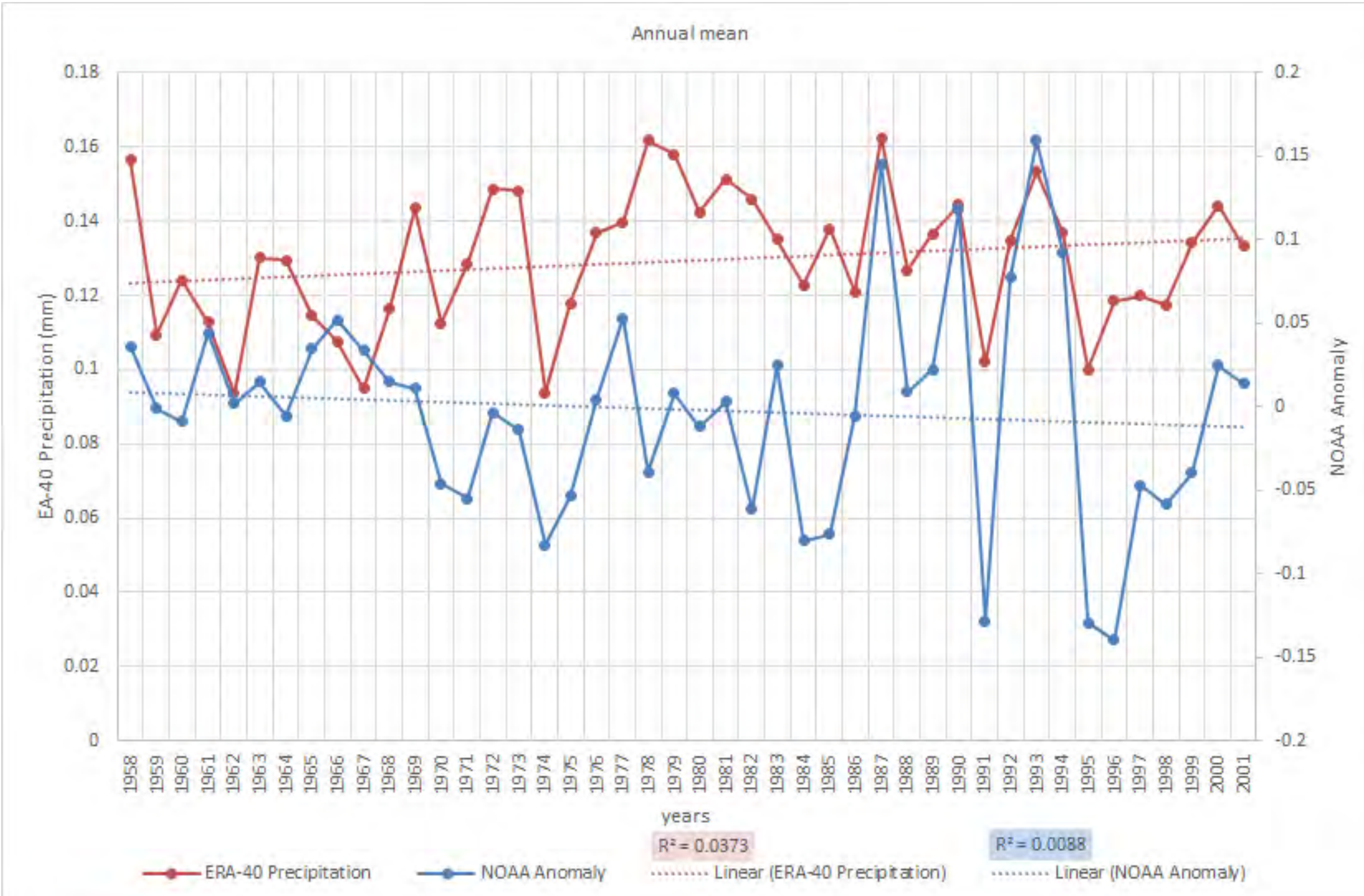
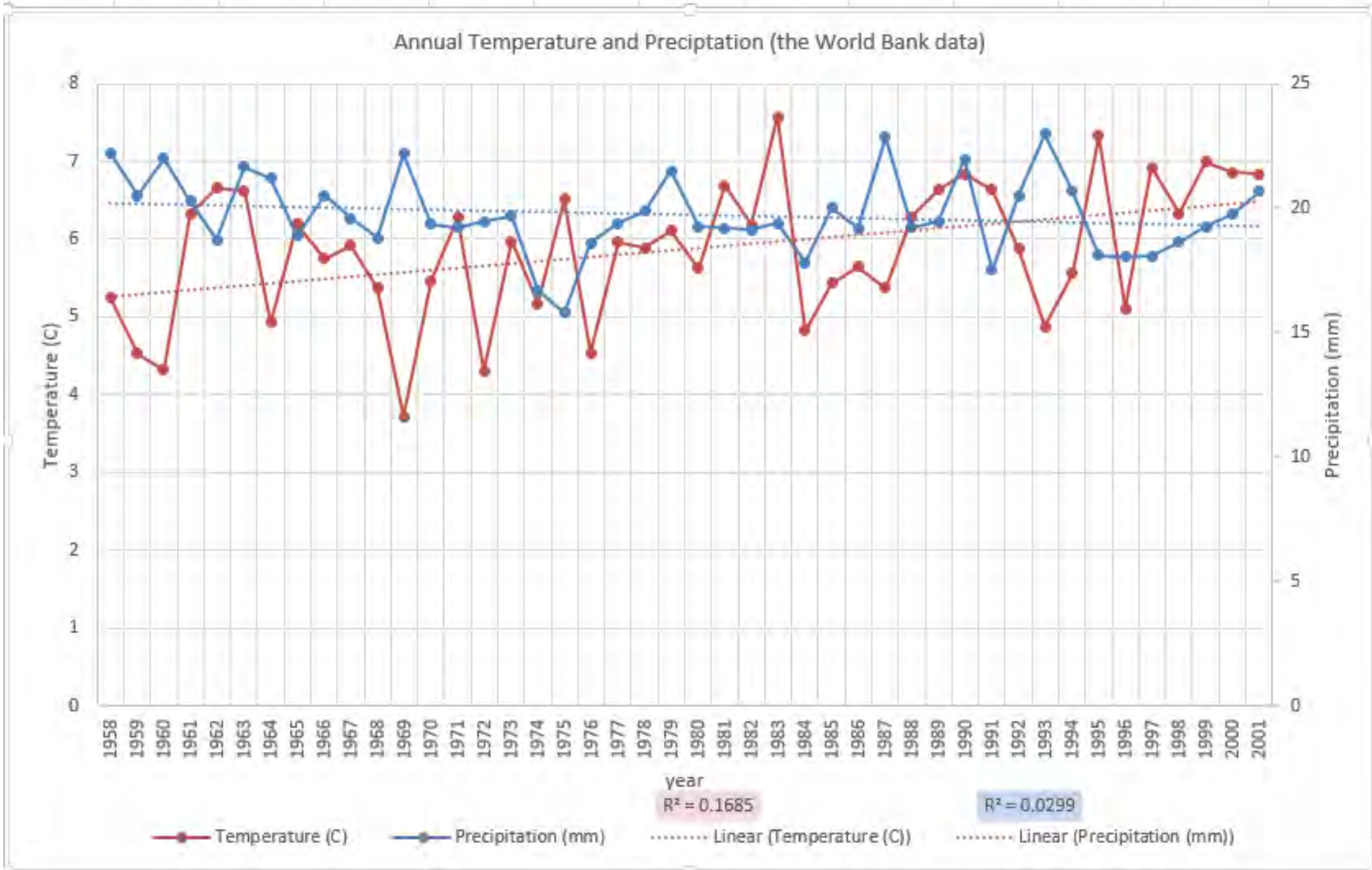

Annual mean
EA-40 Precipitation (mm)
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
NOAA Anomaly
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
1958 1959 1960 1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001
years
R² = 0.0373
R² = 0.0088
ERA-40 Precipitation
NOAA Anomaly
Linear (ERA-40 Precipitation)
Linear (NOAA Anomaly)

Figure 2.22



Annual Temperature and Preciptation (the World Bank data)
Temperature (C)
Precipitation (mm)
year
R² = 0.1685
R² = 0.0299
Temperature (C)
Precipitation (mm)
Linear (Temperature (C))
Linear (Precipitation (mm))

Figure 3.

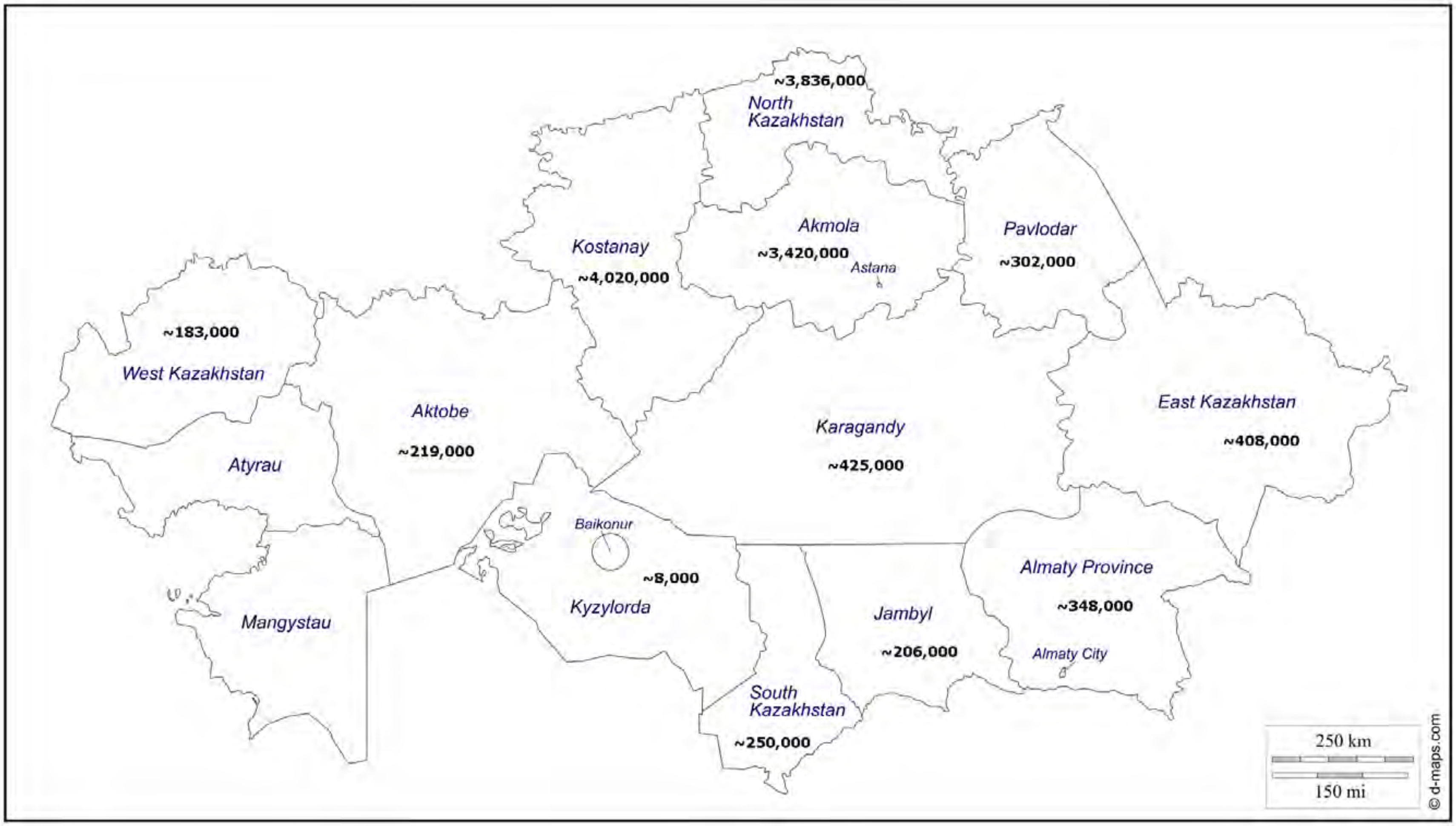


Figure 4.1 Annual Wheat Crop (tons).

The Agency of statistics of the Republic of Kazakhstan, 2016.

www.d-maps.com

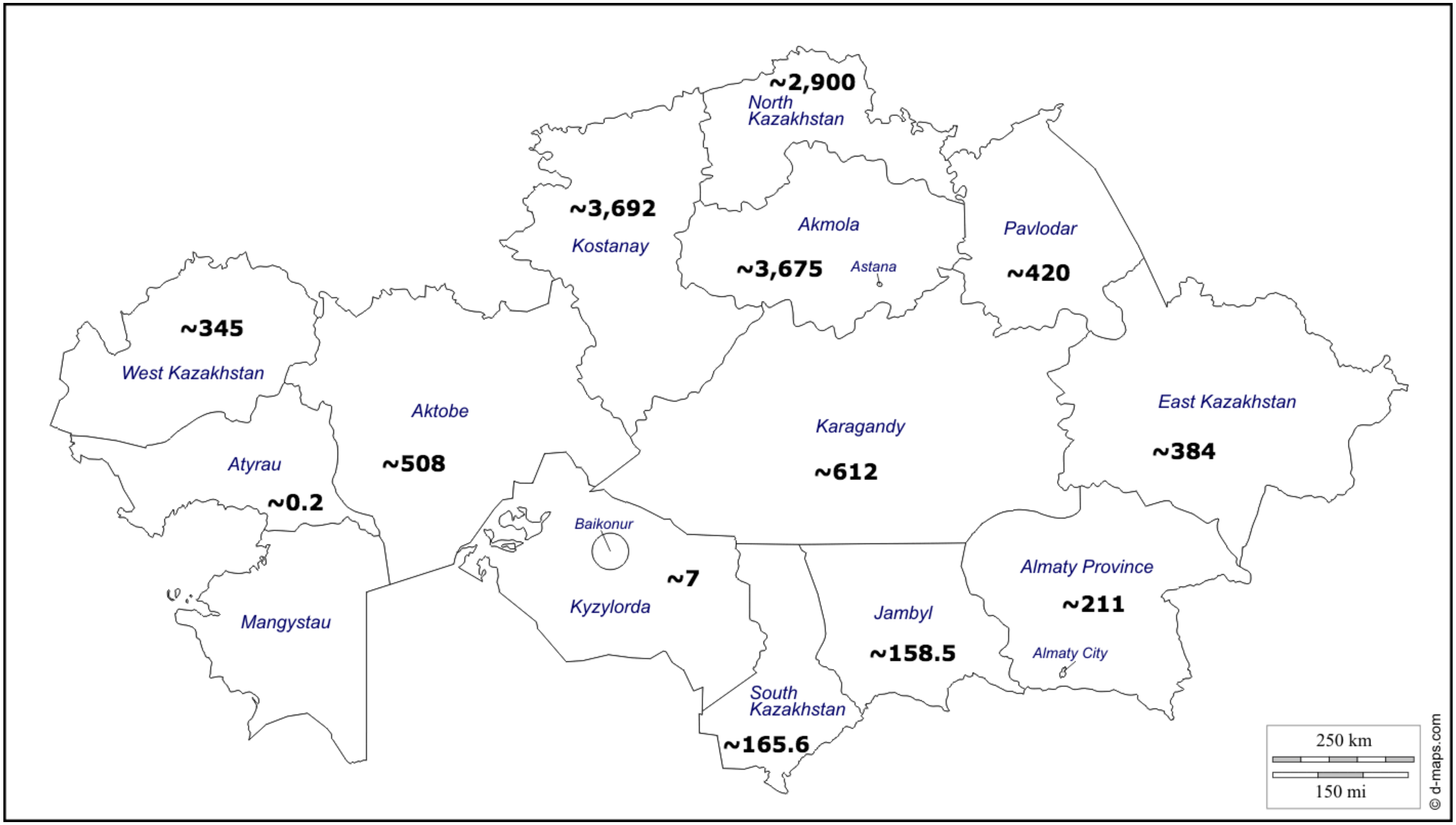


Figure 4.2 Annual Wheat Area (thousands of Hectares).

The Agency of statistics of the Republic of Kazakhstan, 2016.

www.d-maps.com

Figure 5. A drip irrigation pipes