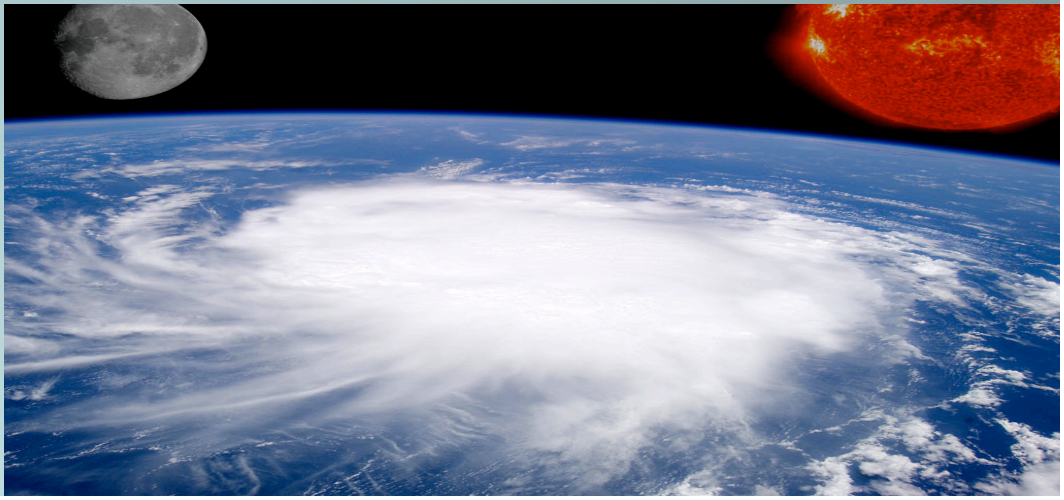
Climate Change over Past and Recent Solar Minima

By Chris Maloney

Mentors: Tom Woods, Odele Coddington, Peter Pilewskie, Andrew Kren



The Focus

- Sun is a major driver of our climate
- Recent low solar minimum spanning 2007-2009
- Did this minimum have an affect over North America's climate?

  - (Lockwood, Harrison, Woollings, & Solanki, 2010,Environ Res. Lett., 5) found a correlation between solar minima and cooler winters in Europe
- Use a Linear Regression model

  - Comprised of four components which have major effects on temperature: Total Solar Irradiance (TSI), El Niño-Southern Oscillation (ENSO), Volcanic Aerosols, and Anthropogenic (mankind's impact)

  - Linear Regression tells us how much impact each of these components has on surface temperature

- Similar study conducted by (Lean, & Rind, 2008,GRL,35)

- Each map shows the impact on temperature around the globe from the specific components

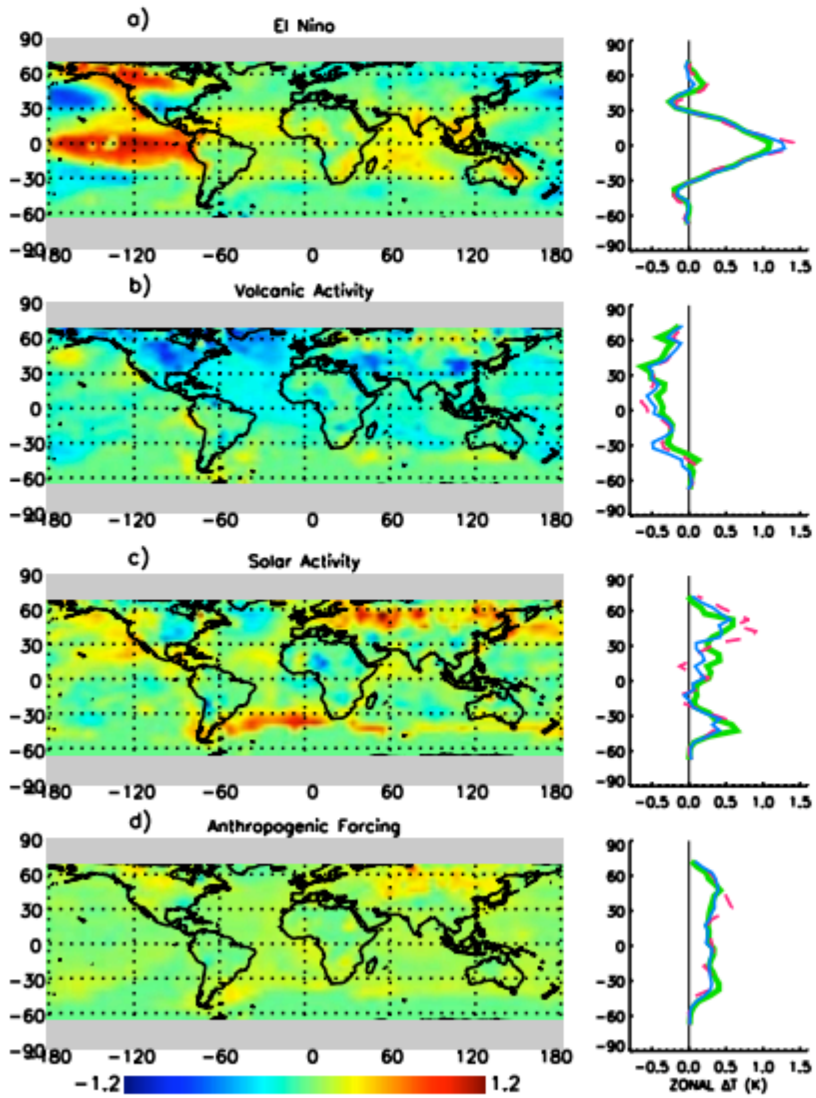
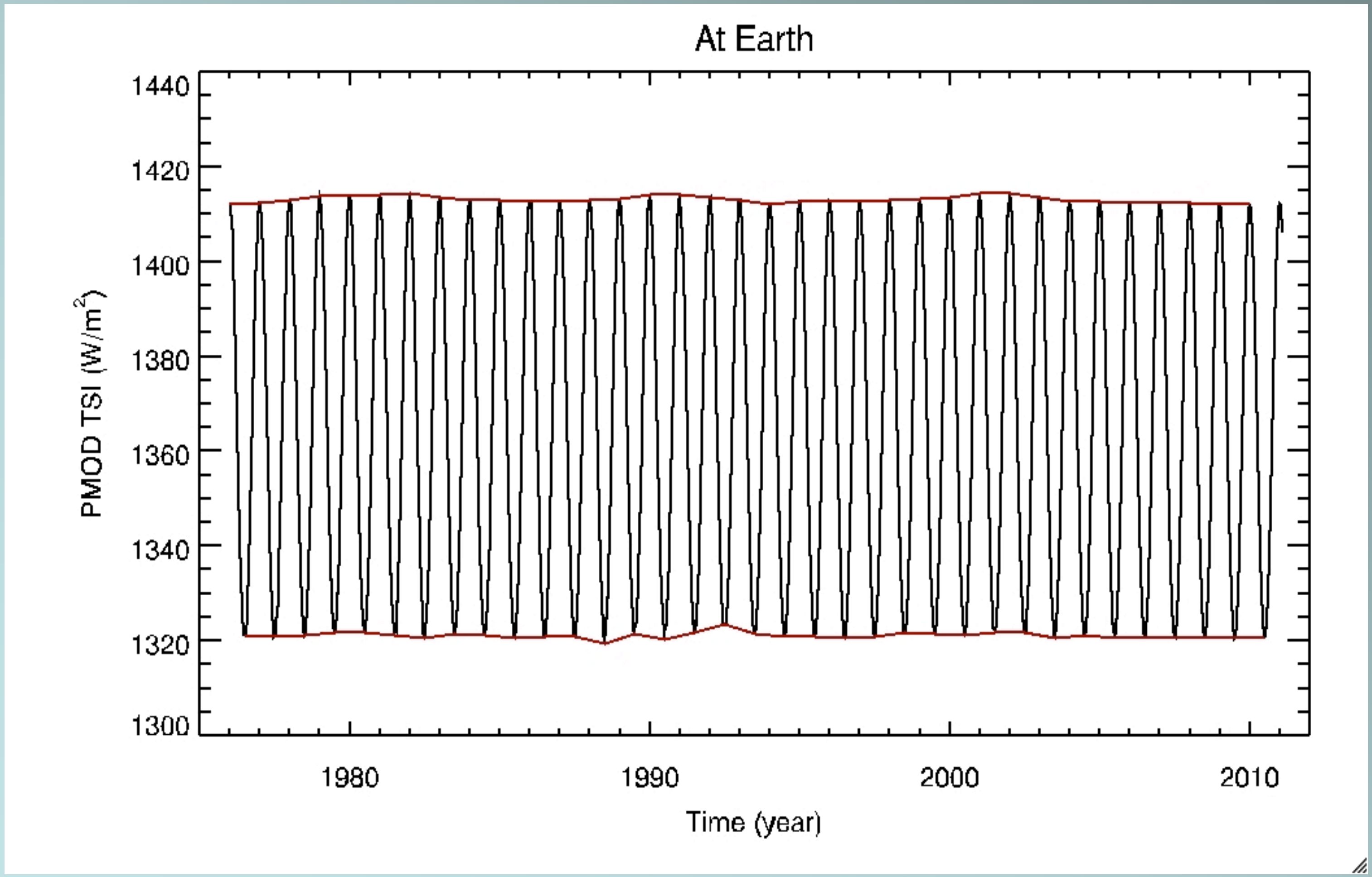


Figure 3. (left) Compared are geographical response patterns, each normalized to a 0.1 K global temperature change, due to ENSO, volcanic, solar and anthropogenic influences, derived from the monthly historical surface temperature records (1889–2006). (right) Also shown are zonal means of the geographical responses from the regression of data in three different epochs. The thick (green) curve is for the entire period from 1889 to 2006, the thin (blue) curve is for the NCEP period from 1960 to 2006 and the dashed (pink) curve is for the satellite era from 1980 to 2006.

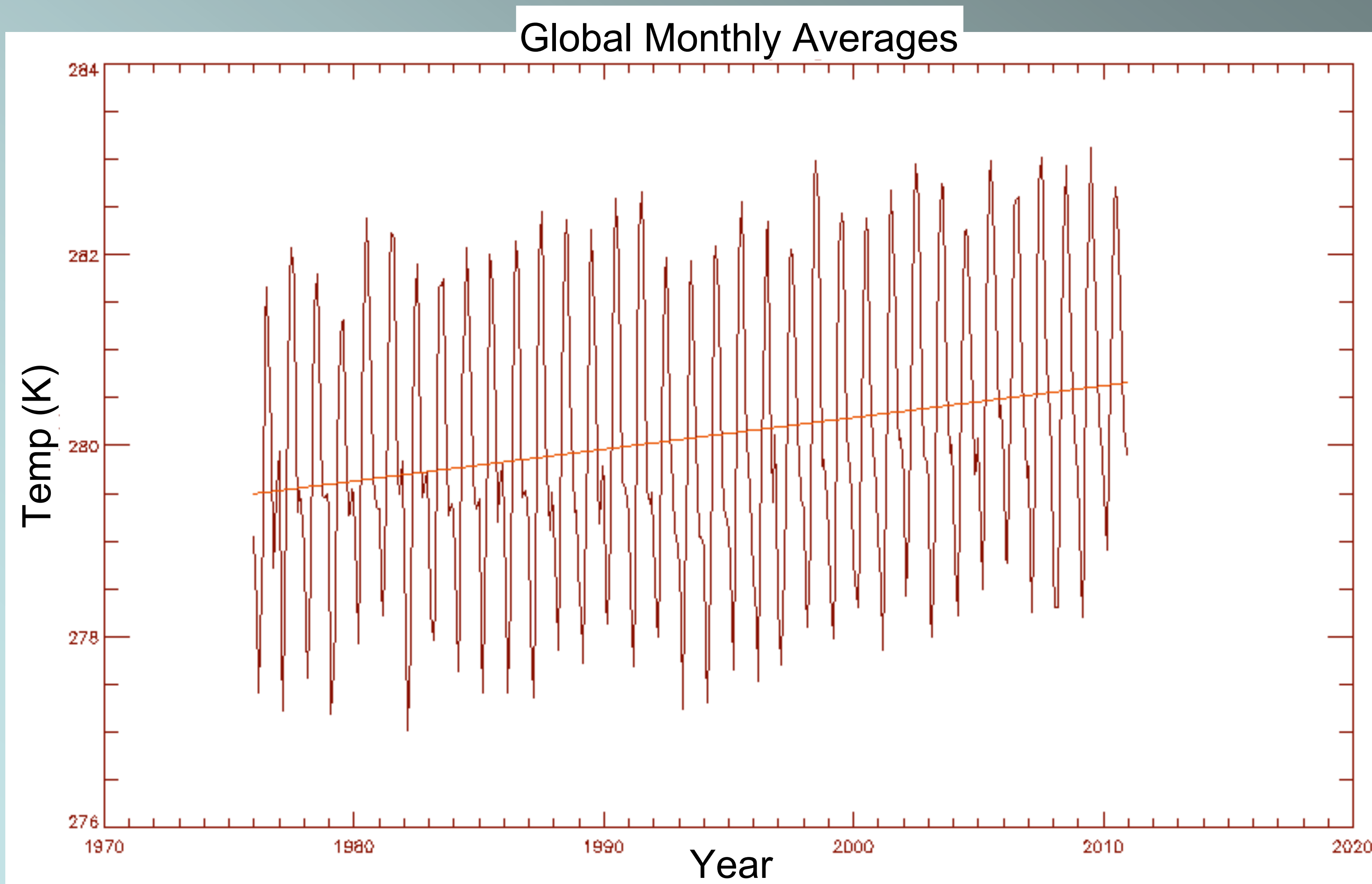
Earth's Orbit Impacts TSI

- The total solar irradiance reaching Earth is dominated by a annual cycle due to Earth's elliptical orbit and its distribution is affected by Earth's axis of rotation
- Focus on individual seasons is critical to our analysis in order to see long term solar variations



Monthly Temperature values

- Annual variability dominates temperature as well



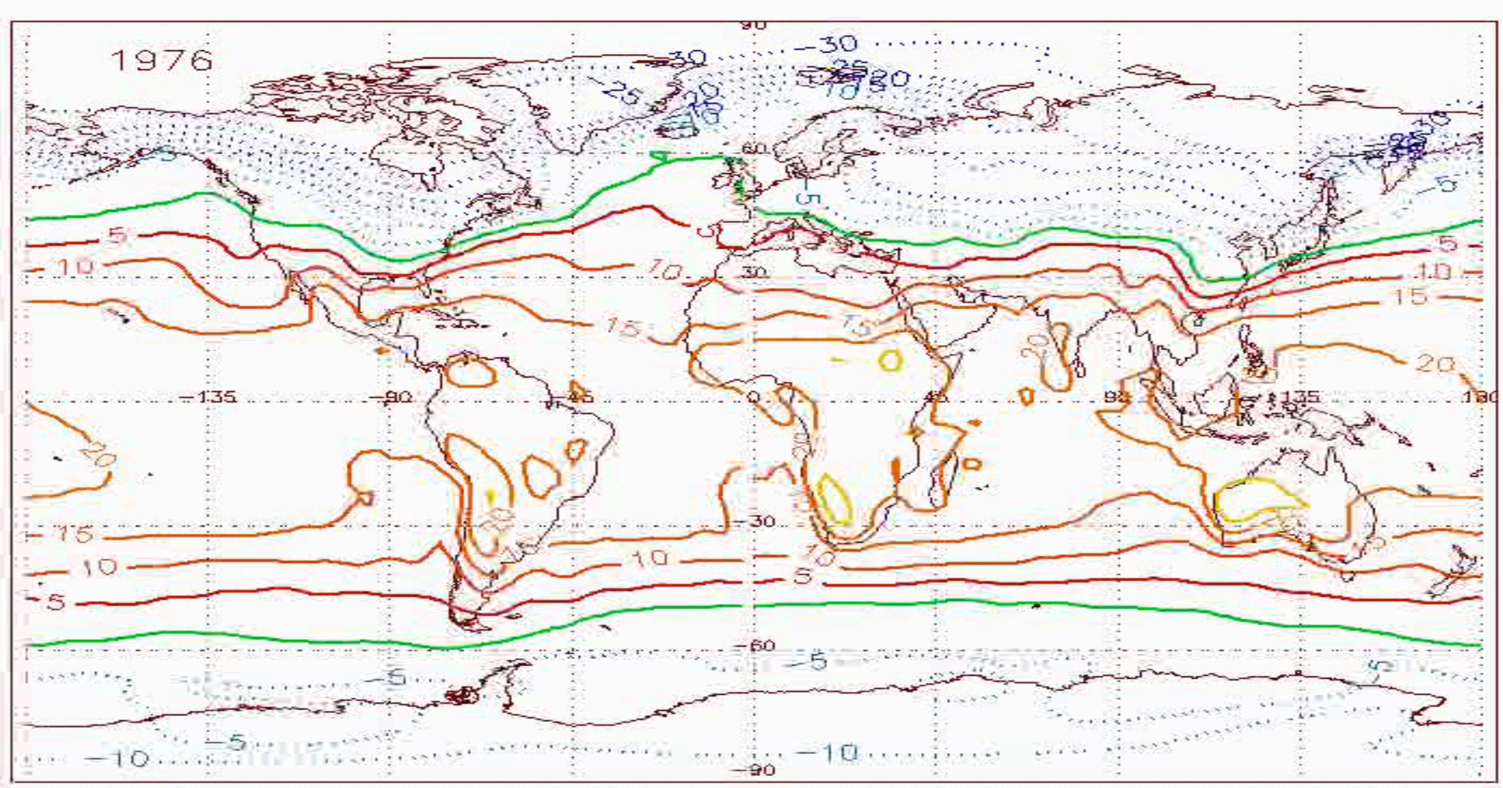
What we expect to find

- Looking for very small temperature changes between past solar minima and this recent solar minimum from our linear regression
  a) Temp = A + B*time + C*[Esol-Emin]+ D*[ENSO data] + V*[Volcanic data]
  b) approximately 0.1 degree differences between this recent low solar min (2007-2009) and the past solar min in 1996
- By understanding one forcing component on our atmosphere, we can then better understand how we humans affect our atmosphere

Dec_Jan_Feb

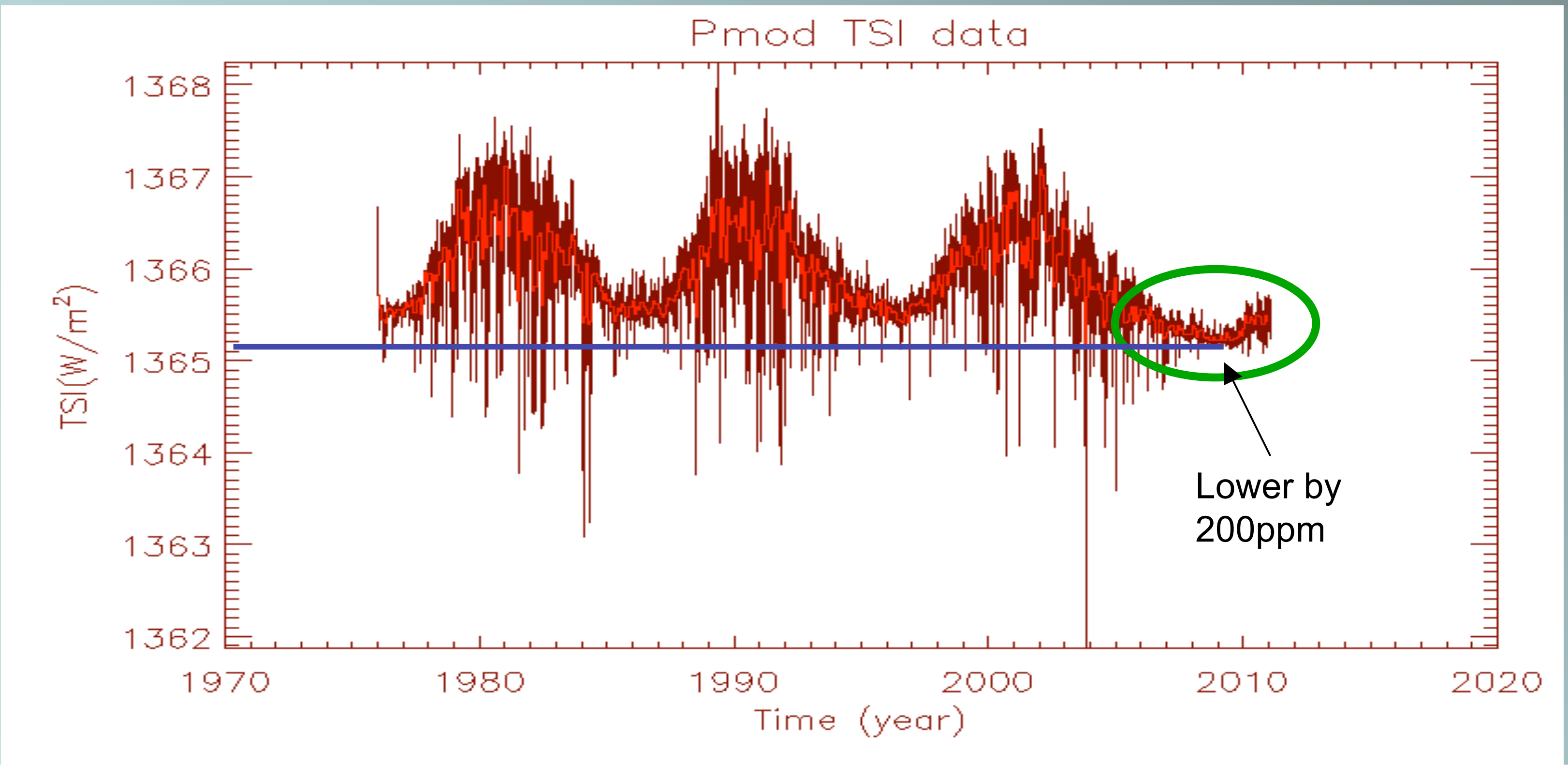
0 – avg temp (degrees K)

Above	Below
5	-5
10	-10
15	-15
20	-20
25	-25
	-30



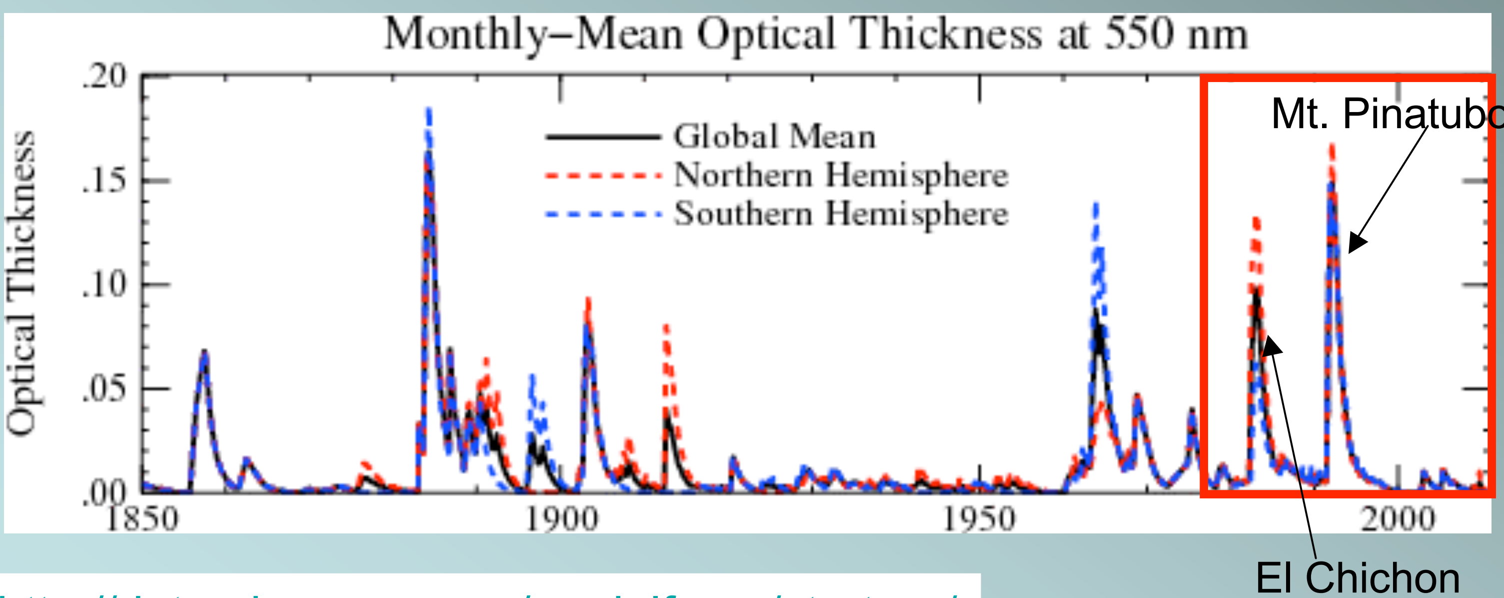
Total Solar Irradiance

- Variability on the daily period to 11 year cycles
- Used the Physikalisch-Meteorologisches Observatorium Davos (PMOD) composite time series and aligned it with the TIM data



Volcanic Aerosols

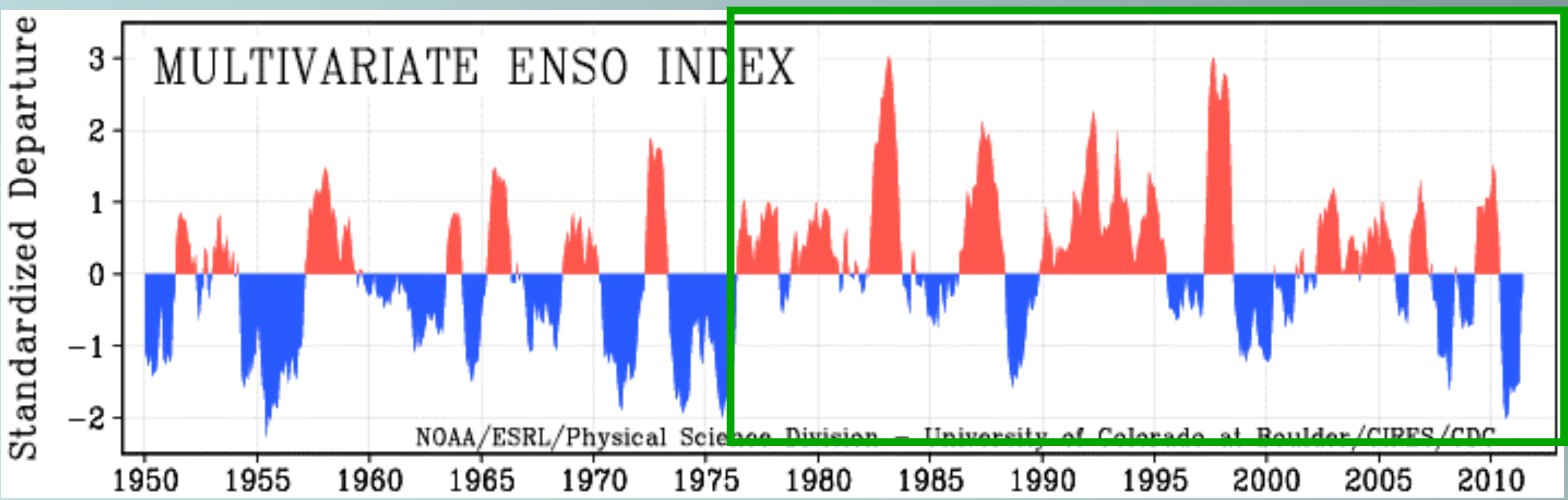
- Comprised of the dust and gasses from volcanic eruptions
- *Should* have a cooling effect
  a) optical thickness is the extinction of light
  b) aerosols block incoming light from the sun in the stratosphere
- Very sporadic effects



http://data.giss.nasa.gov/modelforce/strataer/

El Niño-Southern Oscillation

- A quasi-periodic climate pattern
  - a) occurs roughly every 2-5 years in Pacific Ocean
  - b) large body of warm water
- Comes in two forms :El Niño (warming) and La Niña (cooling)
- Results in large deviations from climatic norms



http://www.esrl.noaa.gov/psd/enso/mei/#ref_wt1

Anthropogenic

- The human impact on our climate
  - a) greenhouse gases
  - b) tropospheric aerosols
  - c) albedo components

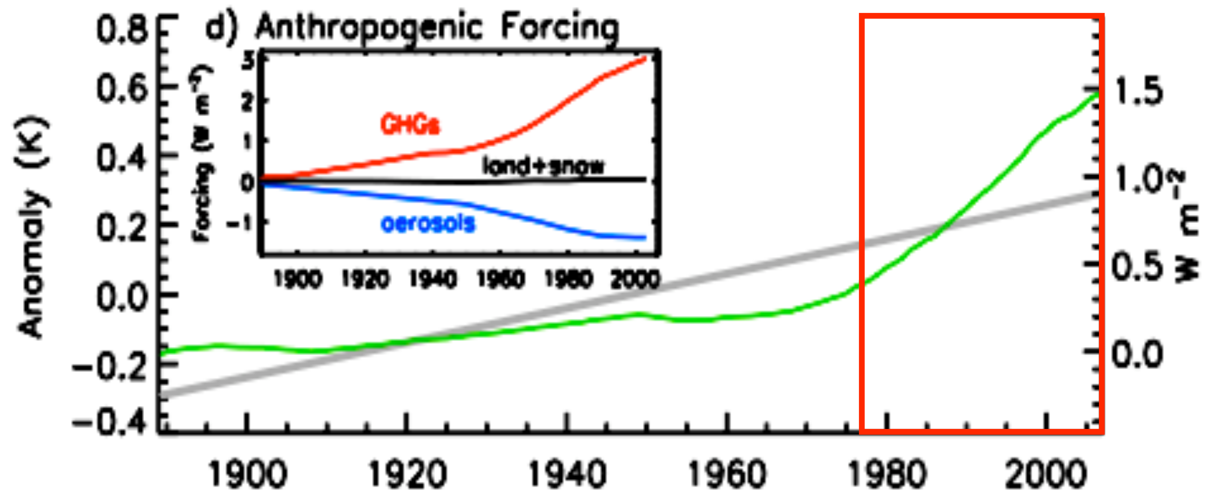
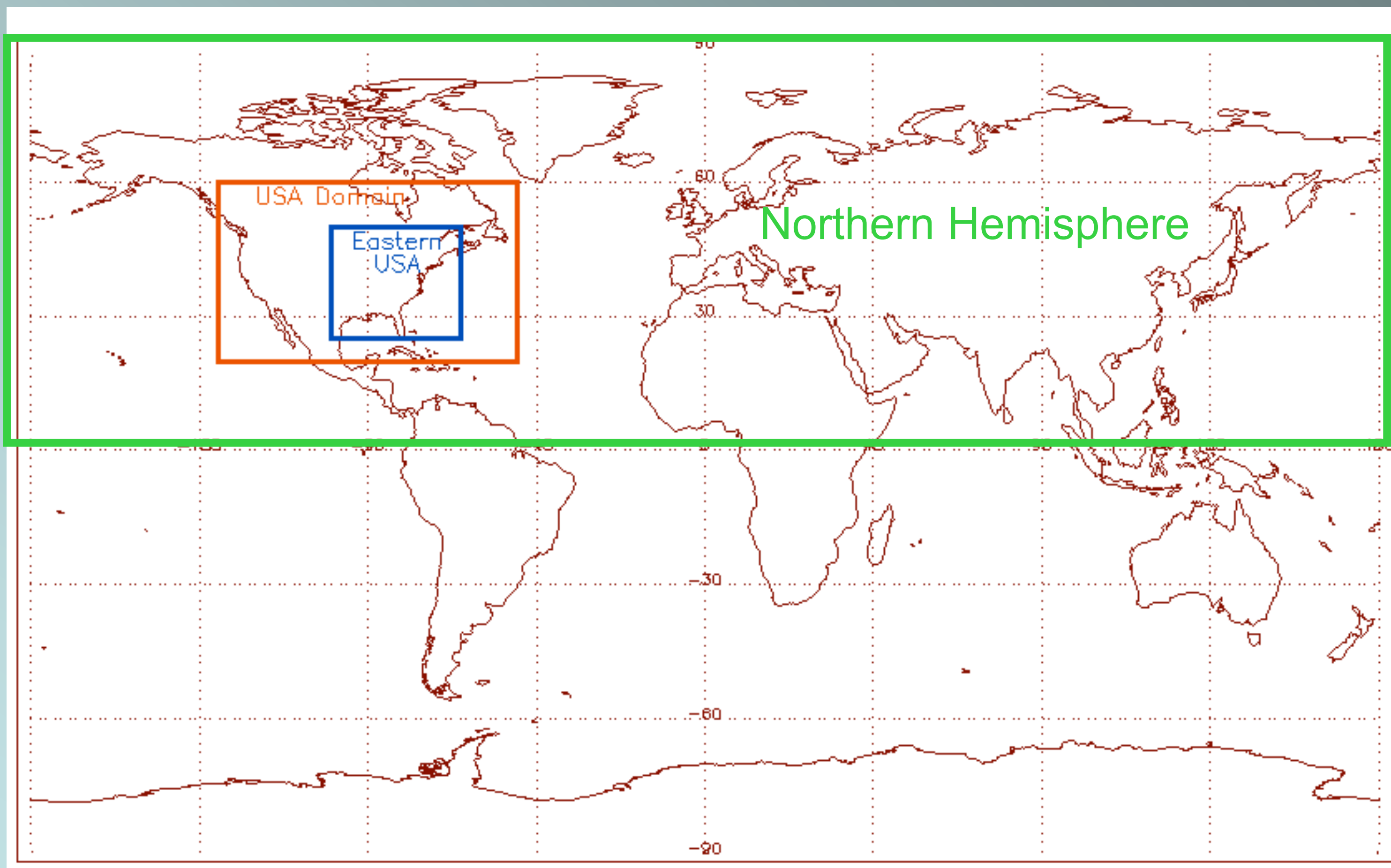
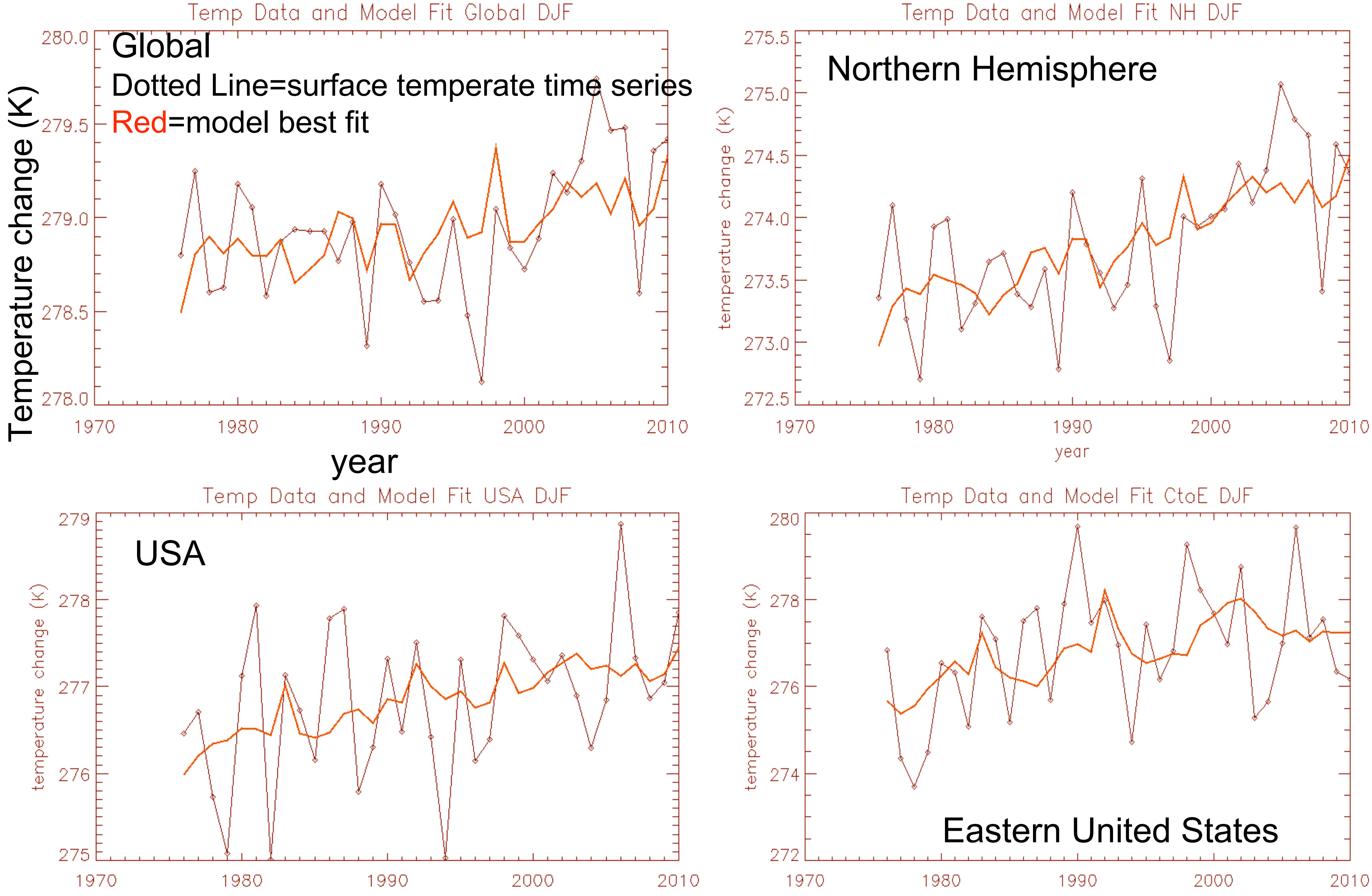


Figure 2. Reconstructions of the contributions to monthly mean global surface temperatures by individual natural and anthropogenic influences (at appropriate lags) are shown. The right hand ordinates give the native scales of each influence and the left hand ordinates give the corresponding temperature change determined from the multiple regression analysis. The grey lines are trends for the whole interval. The inset in Figure 2d shows the individual greenhouse gases, tropospheric aerosols and the land surface plus snow albedo components that combine to give the net anthropogenic forcing.

Our Domains of Interest

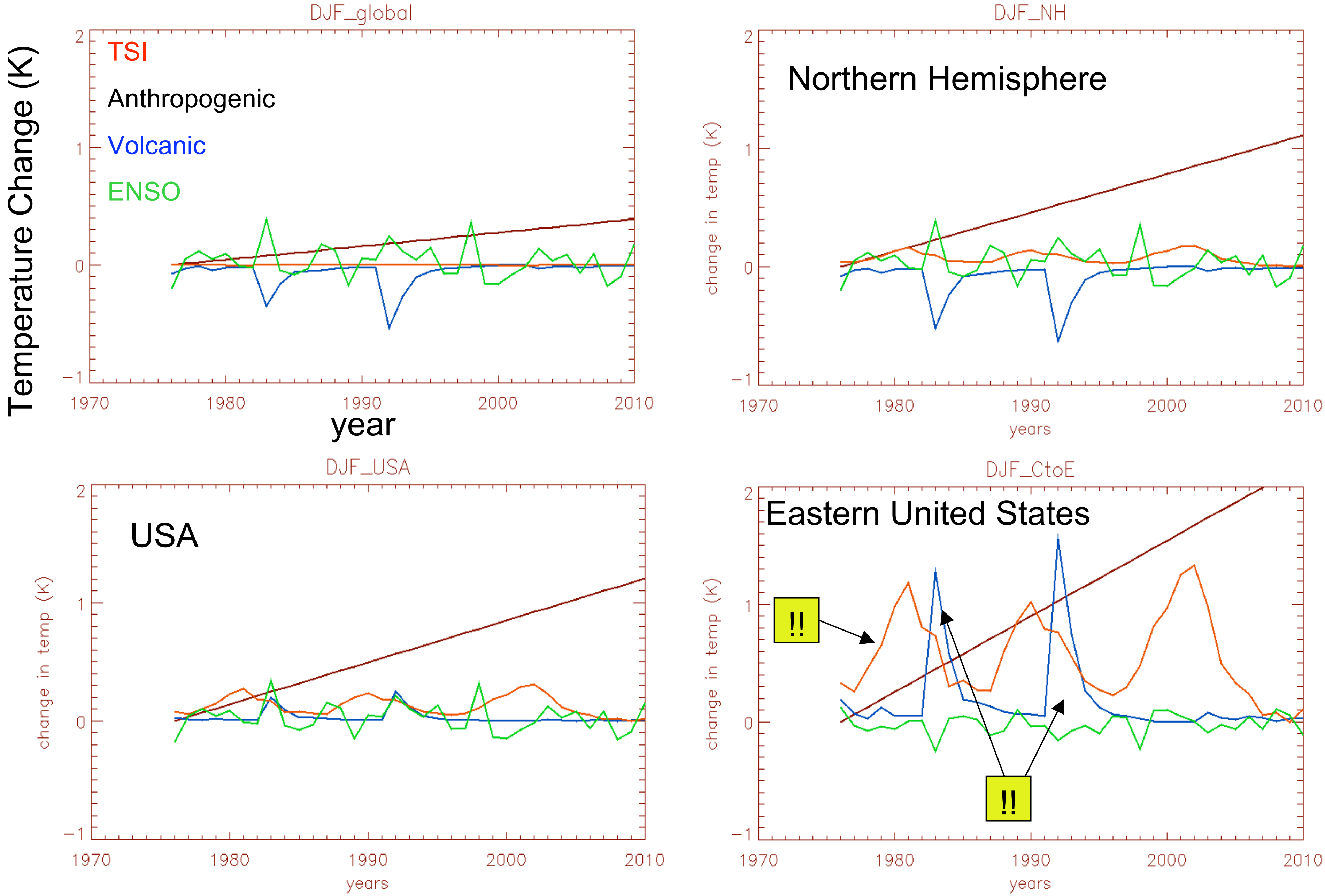


Model fit for Winter Season (DJF) as a function of domain size



Model fit worsens as domain size decreases.

Regression for winter season as a function of domain size



Quick Summary of the other seasons

- June-July-Aug had the best overall correlation
- Each season exhibited same issues as domain size decreased
    a) March-Apr-May and Sept-Oct-Nov both had some very radical results
- All of the other seasons had a higher correlation than Dec-Jan-Feb months

The Numbers

Temp = A + B*time + C*[Esol-Emin]+ D*[ENSO data] + V*[Volcanic data]

Global

	Coefficients				
	Anthro	Volcanic	TSI	ENSO	mcorrelation
DJF	0.011	-3.7	-0.0029	0.14	0.53
MAM	0.037	-3.8	0.11	0.11	0.84
JJA	0.034	-3.8	0.17	-0.02	0.86
SON	0.041	-2.5	0.066	-0.0011	0.92
Annual	0.031	-3.6	0.081	0.042	0.85

Annual Error: 13% 48% 126% 156%

Northern Hemisphere

	Coefficients				
	Anthro	Volcanic	TSI	ENSO	mcorrelation
DJF	0.033	-4	0.11	0.14	0.65
MAM	0.044	-3.3	0.19	0.11	0.85
JJA	0.025	-2	0.12	0.005	0.83
SON	0.056	-2.3	-0.078	-0.014	0.89
Annual	0.039	-3.3	0.072	0.049	0.87

12% 53% 165% 156%

USA

	Coefficients				
	Anthro	Volcanic	TSI	ENSO	mcorrelation
DJF	0.036	1.6	0.19	0.12	0.42
MAM	0.0018	-5.3	-0.026	0.17	0.29
JJA	0.018	-4.2	0.16	-0.0076	0.66
SON	0.035	-4.6	0.26	0.0082	0.68
Annual	0.022	-4.2	0.12	0.12	0.6

Annual Error: 30% 60% 147% 91%

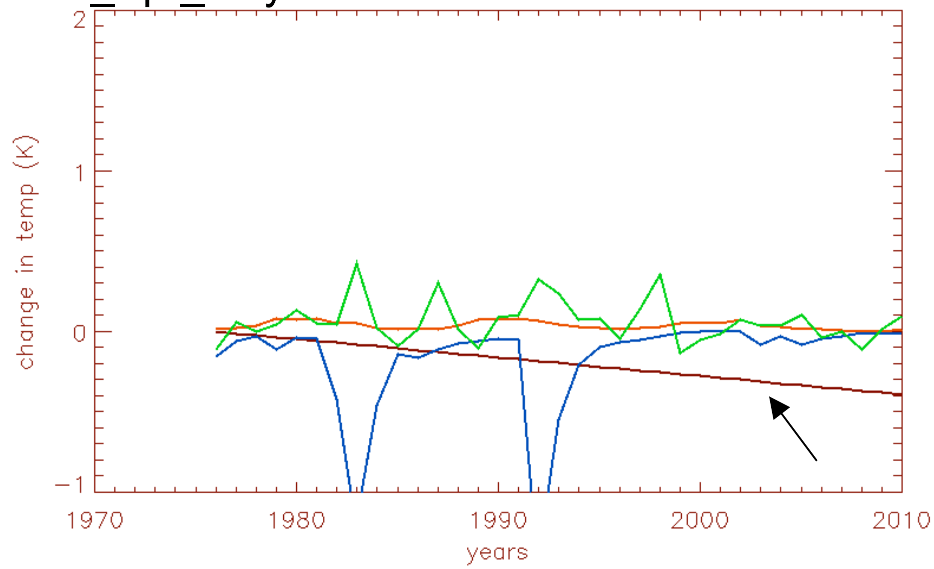
Central to Eastern United States

	Coefficients				
	Anthro	Volcanic	TSI	ENSO	mcorrelation
DJF	0.064	9.8	0.8	-0.088	0.48
MAM	-0.012	-9.8	0.057	0.15	0.39
JJA	0.012	-5.3	0.28	-0.061	0.47
SON	0.39	-2.9	0.33	-0.94	0.65
Annual	0.028	-3.3	0.4	0.1	0.55

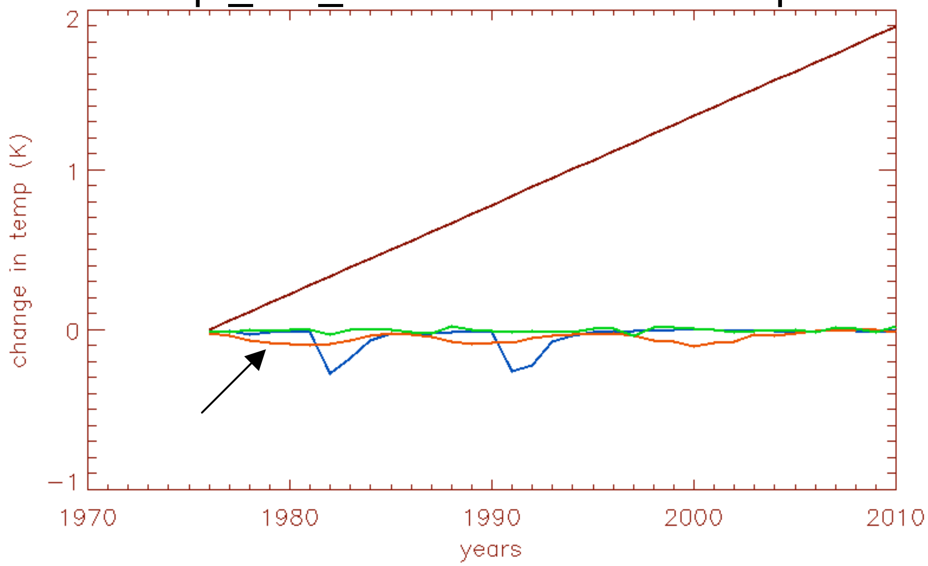
31% 99% 56% 135%

The Horror!!

March_Apr_May in Central to Eastern United States



Sept_Oct_Nov in Northern Hemisphere



Correlation = 0.39

Correlation= 0.89

•Linear Regression may be an inadequate method for smaller regions

•As the domain of interest shrinks in geographic size our correlation decreases

- Increase of variability in both temperature and dynamics in smaller regions
- Oceans act as large bodies of constant warm temperatures and thus reduce the amount of temperature variability

Individual Correlation Values of Components

Global

	Ftest	Correlation Values			ENSO
	Ftest	Anthro	Volc	TSI	ENSO
DJF	2.93	0.37	-0.21	-0.081	0.237
MAM	18	0.81	-0.28	-0.22	-0.011
JJA	21.8	0.82	-0.43	-0.28	-0.28
SON	40.6	0.91	-0.37	-0.38	-0.29
Annual	20	0.83	-0.4	-0.26	-0.23

Northern Hemisphere

	Ftest	Correlation Values			ENSO
	Ftest	Anthro	Volc	TSI	ENSO
DJF	5.38	0.59	-0.26	-0.039	0.084
MAM	19.7	0.12	0.61	0.67	0.71
JJA	16.2	0.8	-0.4	-0.27	-0.21
SON	28.4	0.88	-0.35	-0.44	-0.28
Annual	23.4	0.85	-0.4	-0.29	-0.22

USA

	Ftest	Correlation Values			ENSO
	Ftest	Anthro	Volc	TSI	ENSO
DJF	1.62	0.37	0.037	0.017	0.14
MAM	0.7	0.099	-0.19	-0.05	0.068
JJA	5.78	0.55	-0.49	-0.14	-0.25
SON	6.45	0.62	-0.39	-0.17	-0.25
Annual	4.17	0.54	-0.33	-0.13	-0.076

Central to Eastern United States

	Ftest	Correlation Values			ENSO
	Ftest	Anthro	Volc	TSI	ENSO
DJF	2.21	0.35	0.12	0.17	0.011
MAM	1.31	-0.089	-0.3	0.046	-0.06
JJA	2.12	0.26	-0.39	0.033	-0.27
SON	5.56	0.59	-0.31	-0.11	-0.35
Annual	3.29	0.46	-0.22	0.066	-0.57

What did I really find?

- Climate is an extremely complex system of our planet
- Anthropogenic forcing dominates the model fits
- Volcanic forcing is second strongest
- Solar and ENSO are smaller and less obvious contributions to climate change
- Linear regression fairly accurate for global and large regions but is unable to produce highly correlated results in smaller domains

Results for Solar Minima

- This analysis suggests during the 2007-2009 solar minimum, surface temperatures were lower in 2009 than in the1996 minimum

  a) Global scale change ranged from:

  -0.046 to 0 K

  b) Northern Hemisphere change ranged from:

  -0.051 to 0.021* K

- To compare to (Lockwood, Harrison, Woollings, & Solanki, 2010, Environ Res. Lett., 5) I also did a regression over Europe

  a) Overall season temperature changes between Europe and Central to Eastern United states were comparable:

  Europe range: -0.22 to -0.015 K

  Central to Eastern US: -0.2 to -0.051 K

  b) Lockwood et. al (2010) concluded that there is a correlation between solar minima and cooler winters in Europe

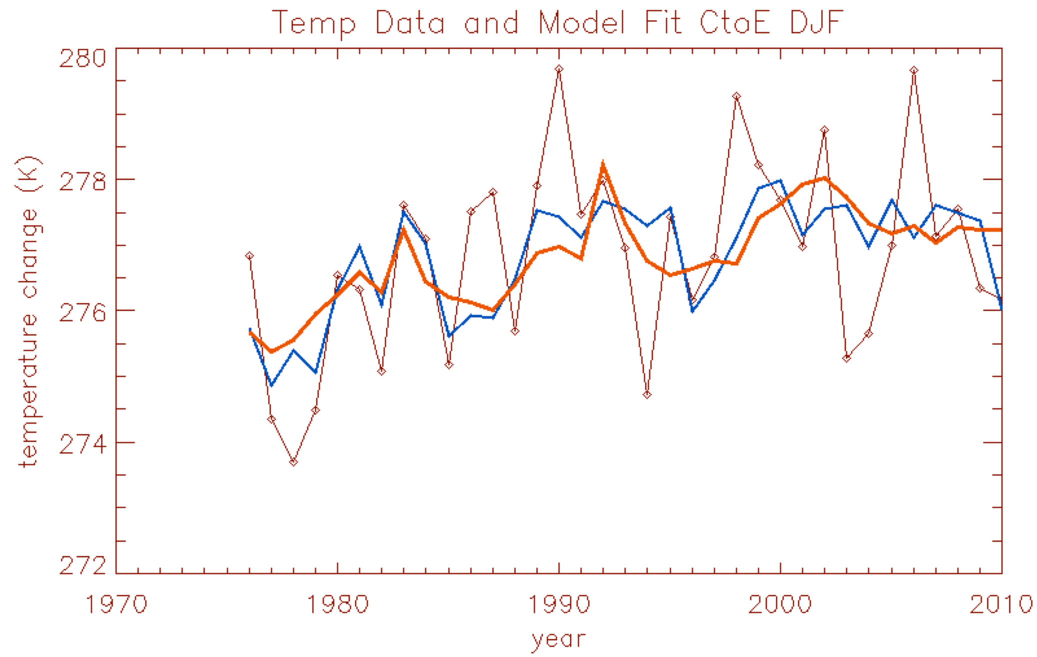
  - Their correlation values ranged from 0.2-0.25

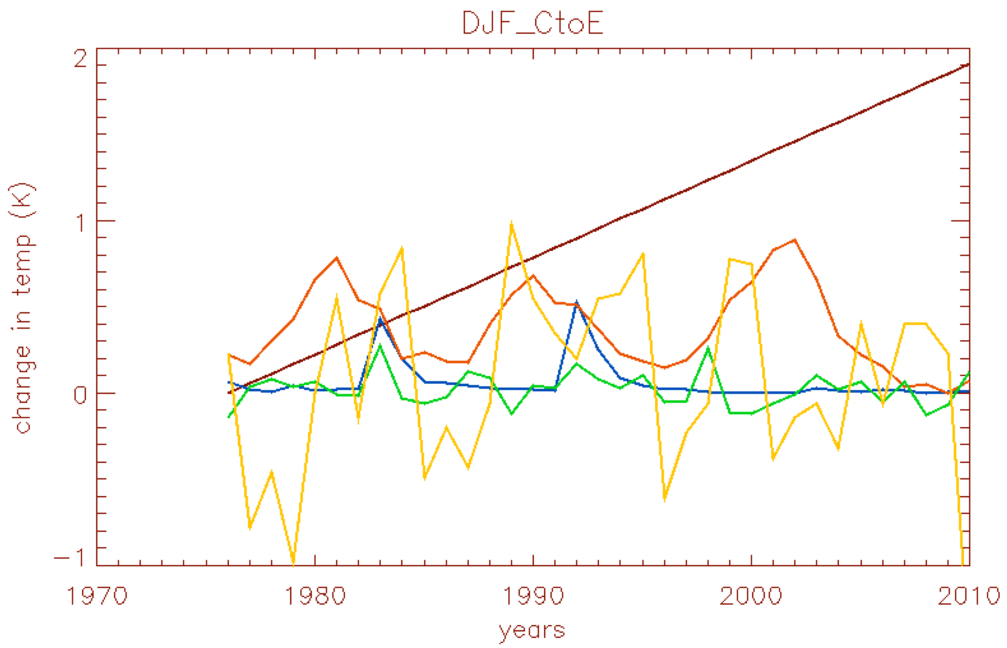
Future paths

- Regions have specific dynamics that can be included into the regression model
- Appears to be a quasi two year cycle which dominates temperature variations.

  a) North Atlantic Oscillation (NAO) or Quasi Biannual Oscillations (QBO) in the stratosphere are two possibilities
- Slower oscillating components from the oceans, which are too long for my time period

- Adding a NAO component did increase correlation from 0.48 to 0.59
- In the graph to the right, our model including NAO (in blue) has a better fit than the previous model (in red) that does not include NAO





- The figure to the left shows the corresponding regression plot
- Note the impact of NAO (in yellow)

NAO correlation = 0.44

Anthropogenic correlation = 0.35

References

- Lean, J, & Rind, D. (2008). How natural and anthropogenic influences alter global and regional surface temperatures: 1889 to 2006. *Geophysical Research Letters*, *35*. Retrieved from http://www.agu.org/pubs/crossref/2008/2008GL034864.shtml doi: 10.1029/2008GL034864
- Lockwood, M, Harrison, R G, Woollings, T, & Solanki, S K. (2010). Are cold winters in europe associated with low solar activity?. *Environmental Research Letters*, *5*. Retrieved from IOPscience.iop.org doi: 10.1088/1748-9326/5/2/024001
- Temperature data, ENSO and Volcanic Aerosol figures obtained from the following NOAA and NASA websites:

  ENSO: www.esrl.noaa.gov/psd/enso/mei/

  Volcanic Aerosol: http://data.giss.nasa.gov/modelforce/strataer/

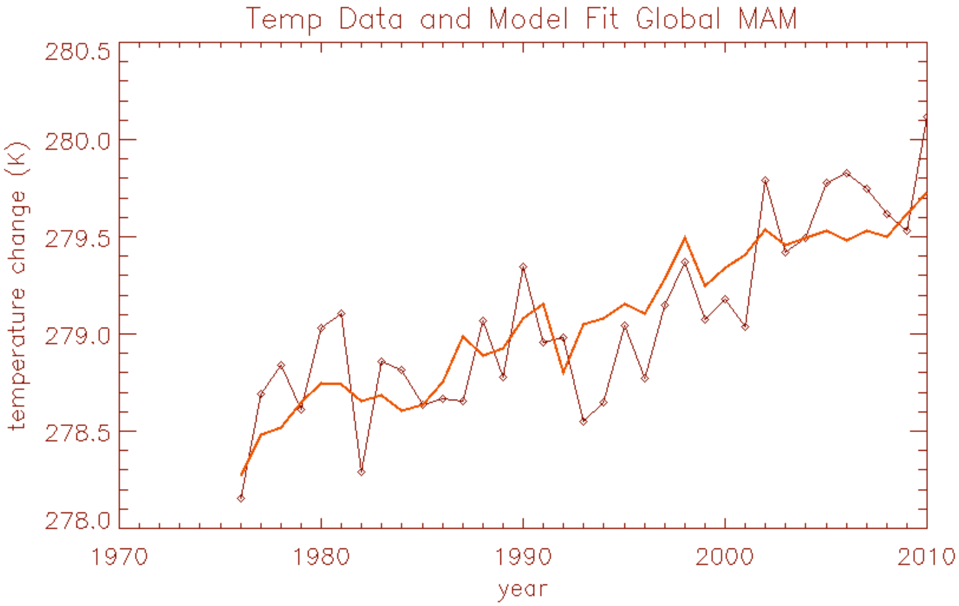
  Temperature data downloaded from here: ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis/

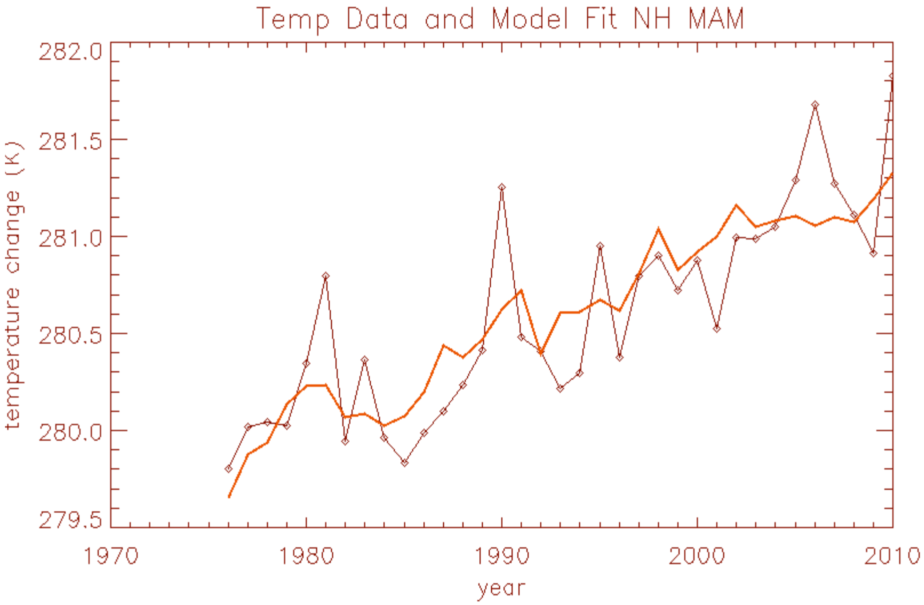
  Information on reanalysis data can be found here: http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html

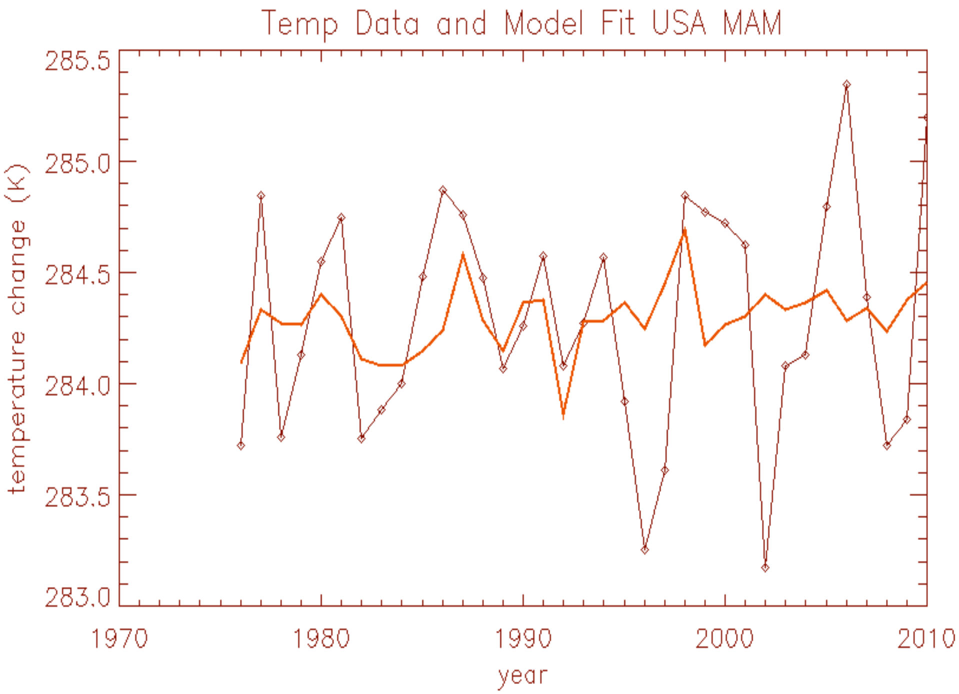
Any Questions?

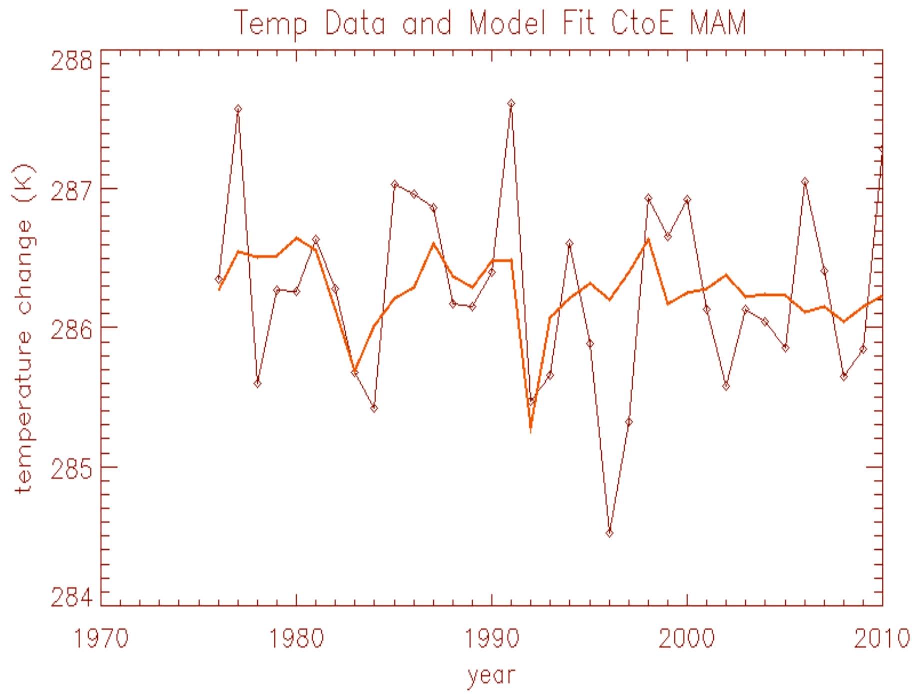
Extra Slides

Spring Season: March-Apr-May

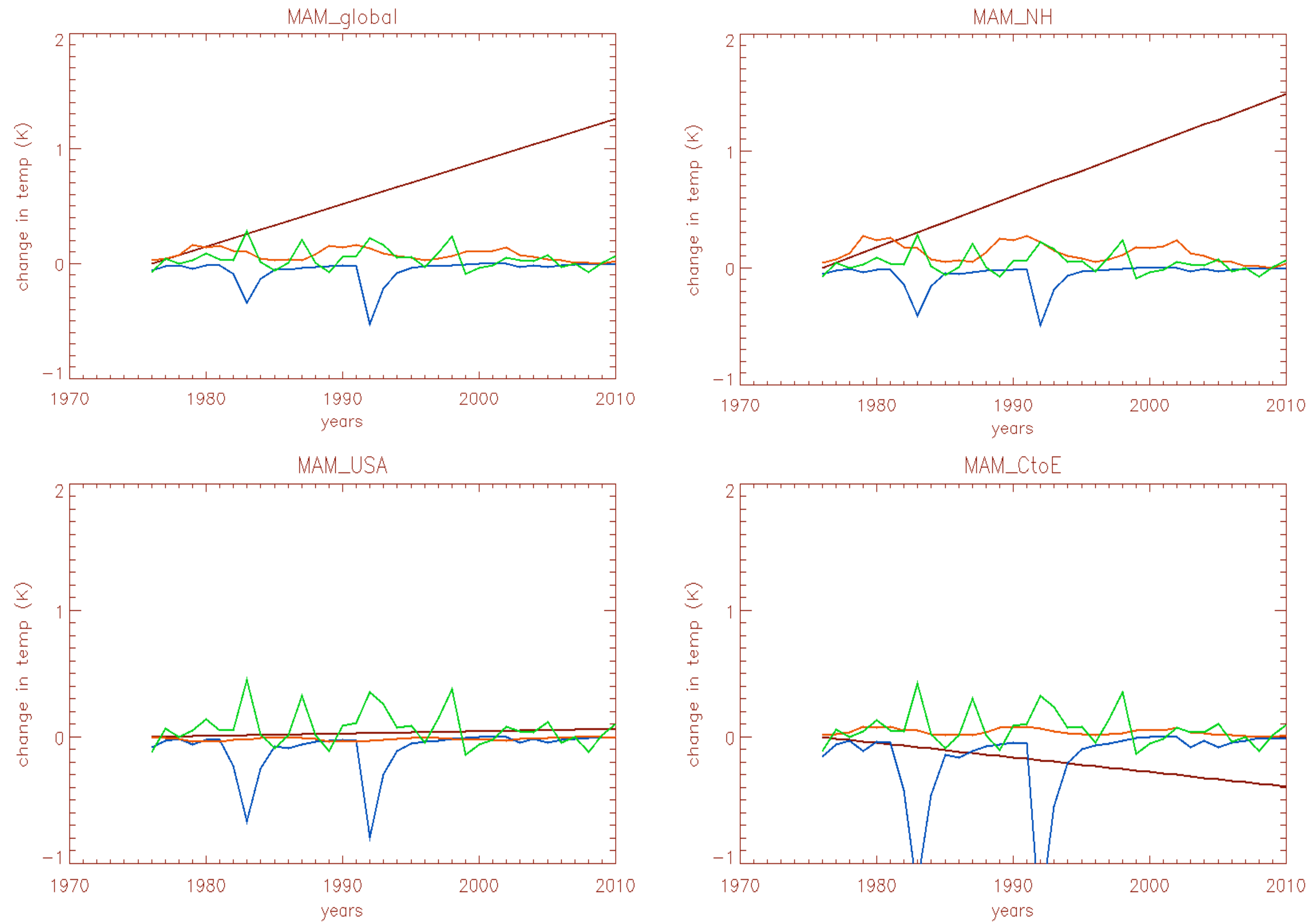




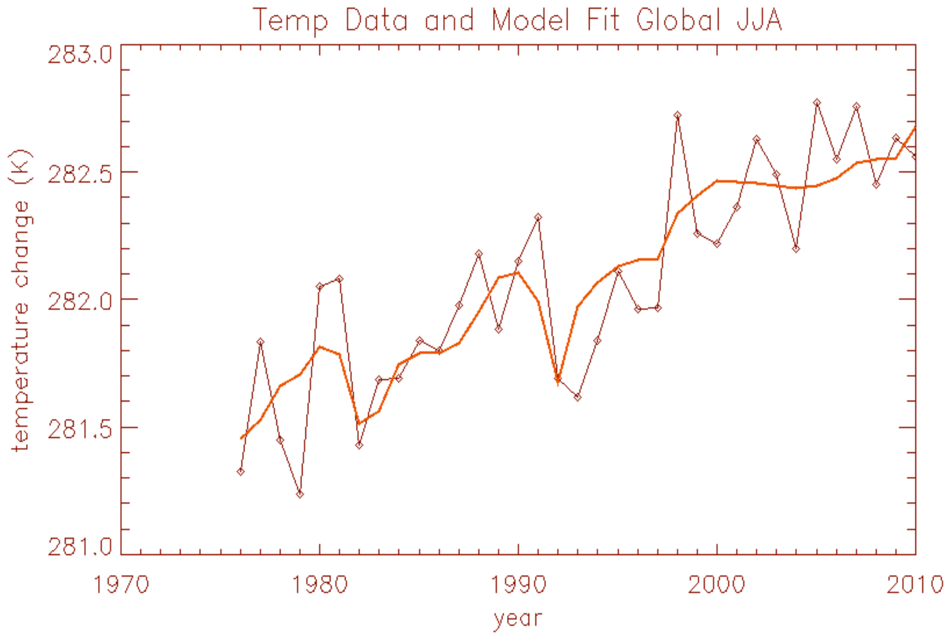


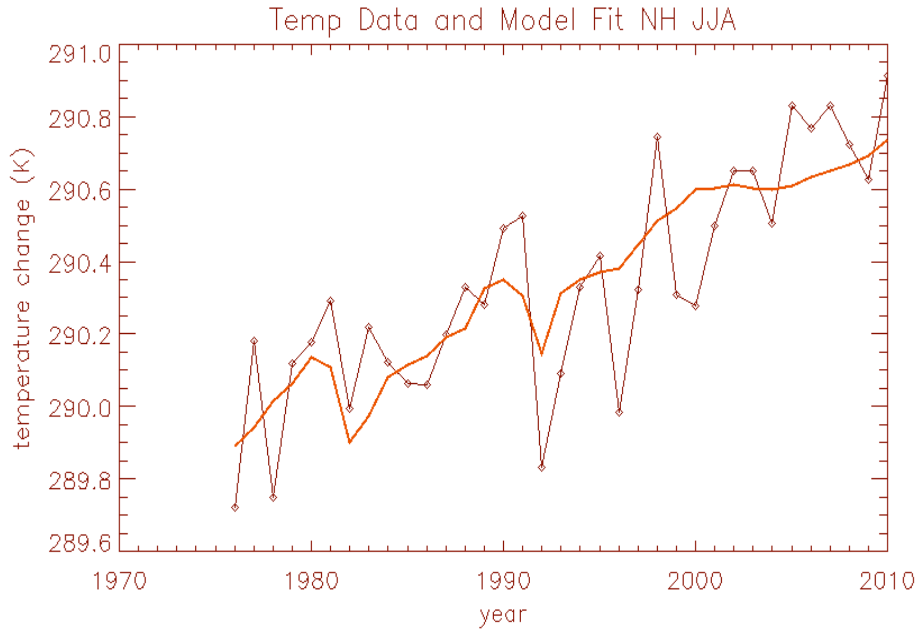


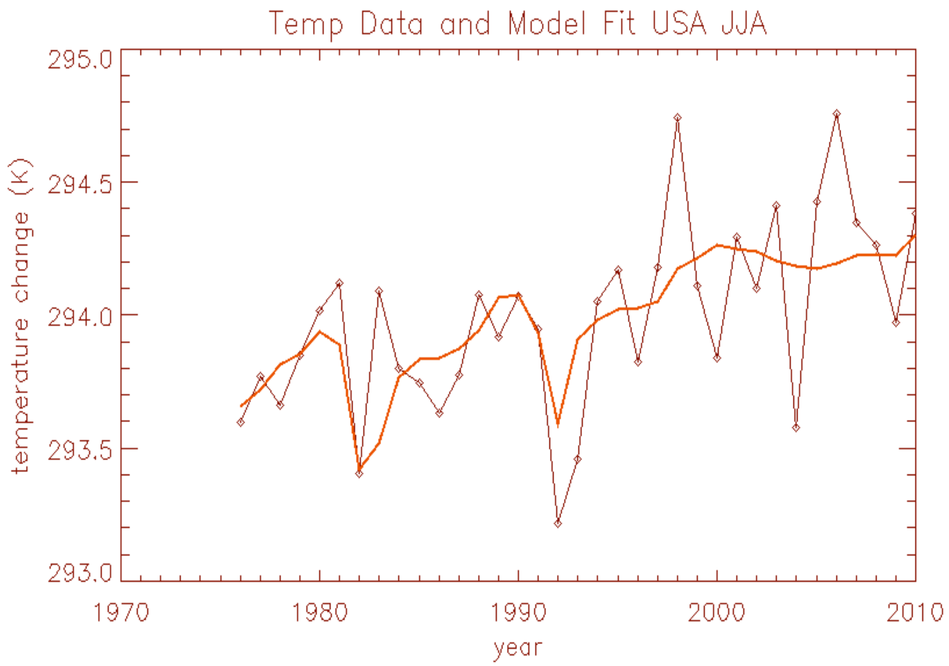
Spring Season Regression

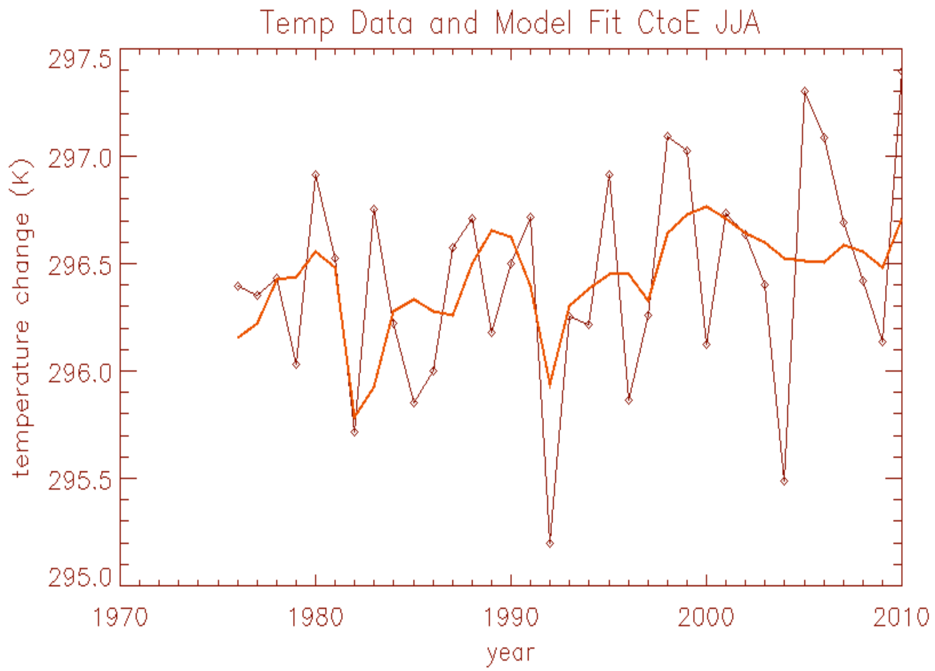


Summer Season: June-July-Aug

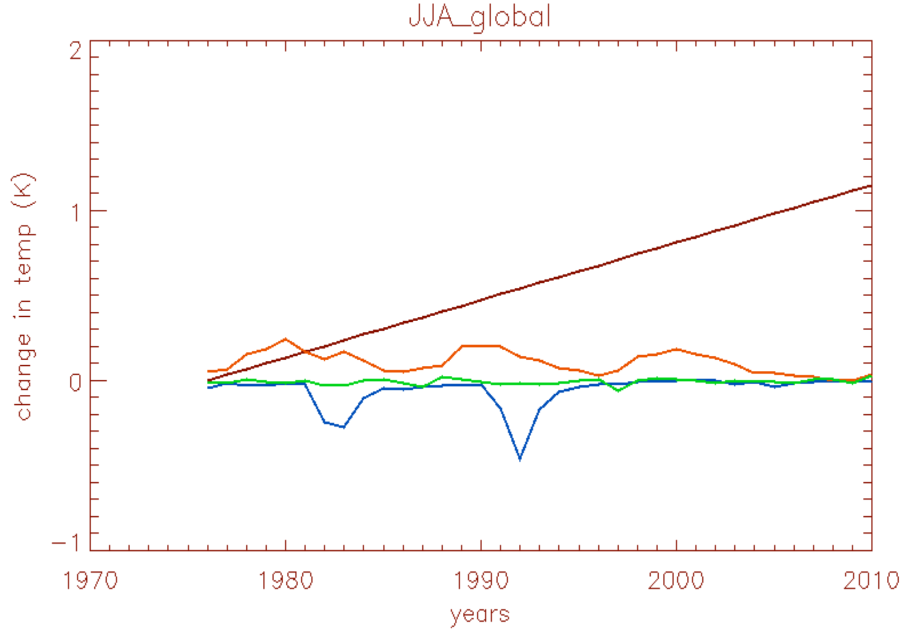


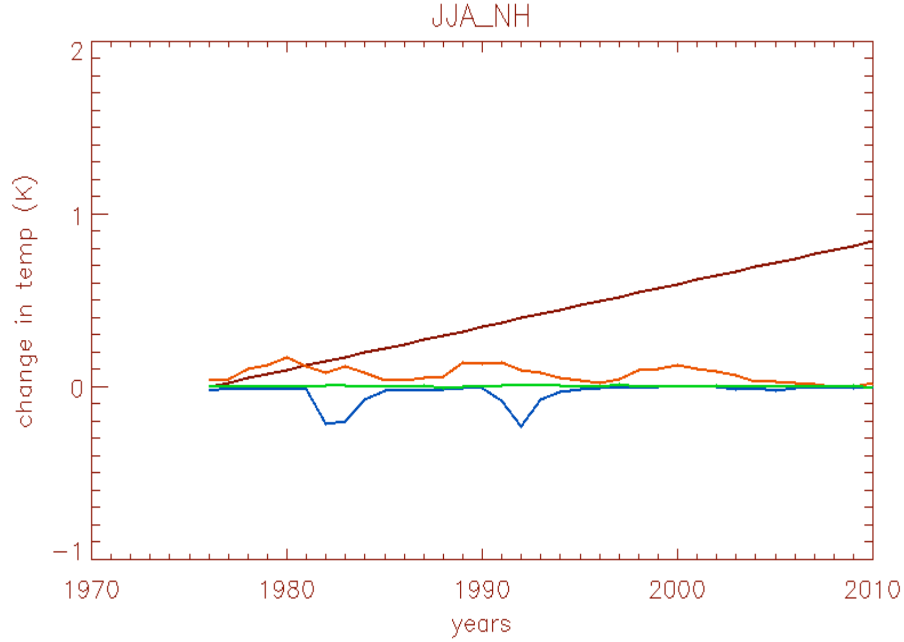


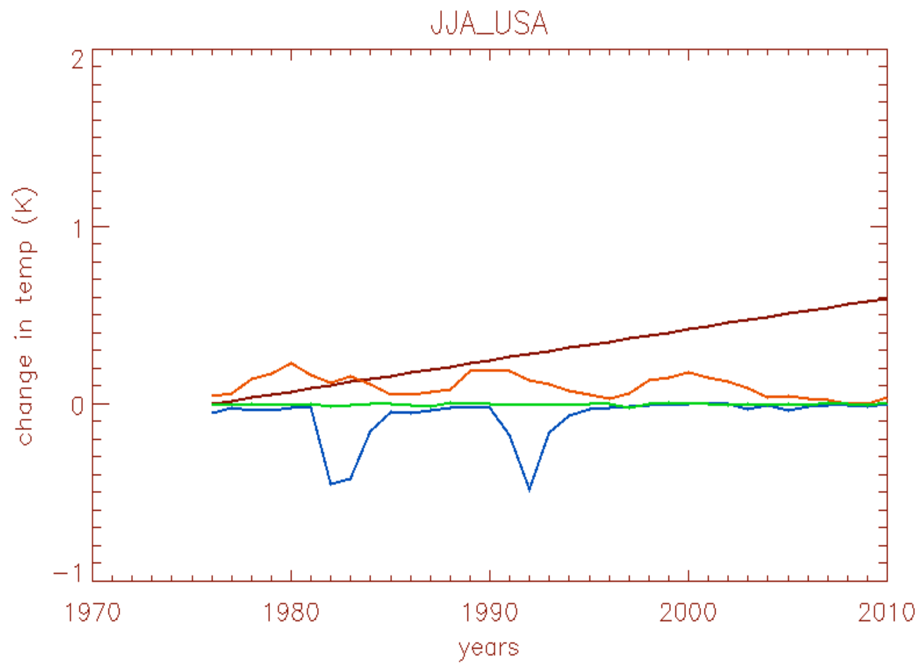


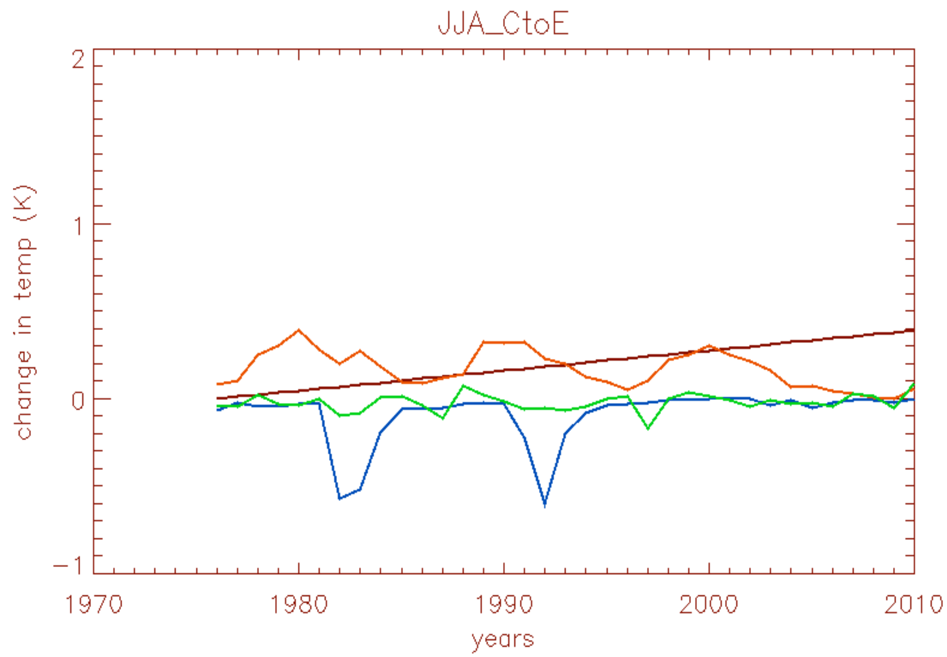


Summer Months Regression

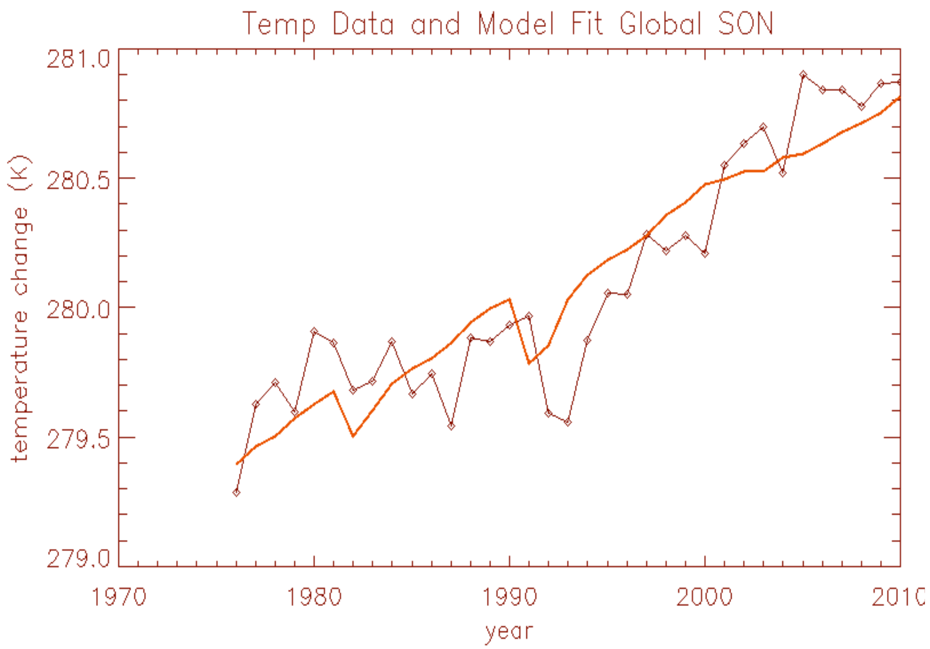


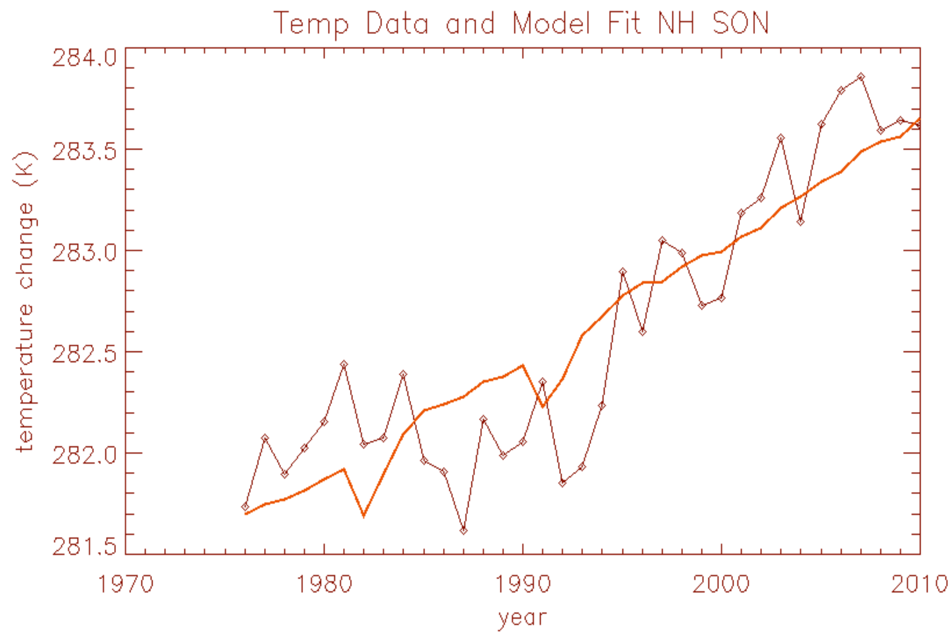


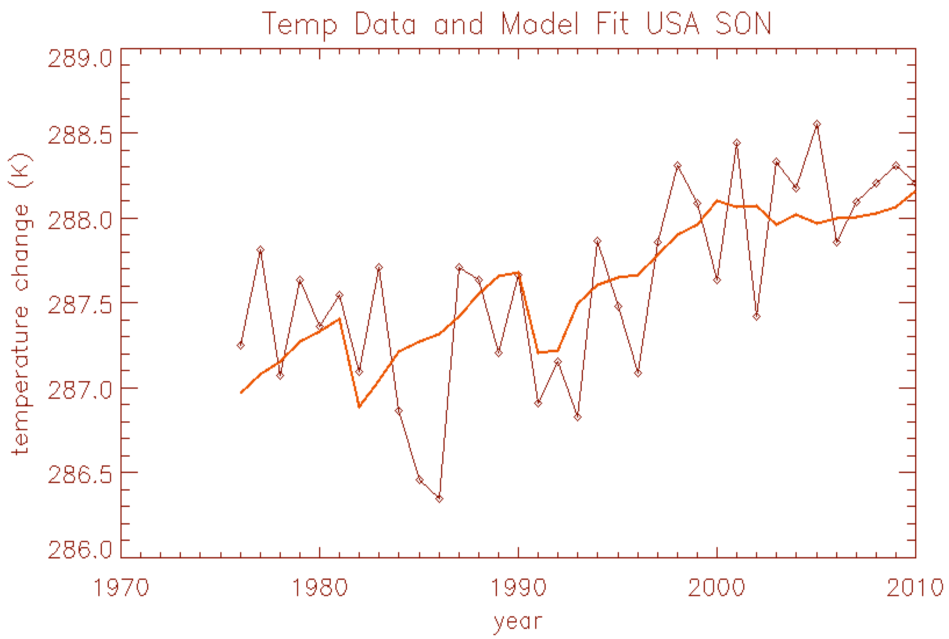


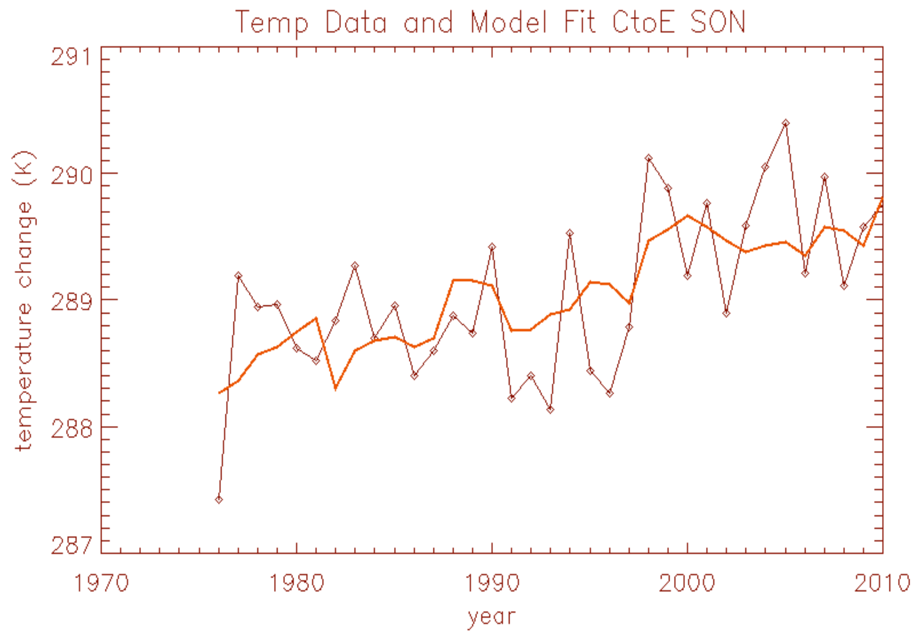


Fall Season: Sept-Oct-Nov

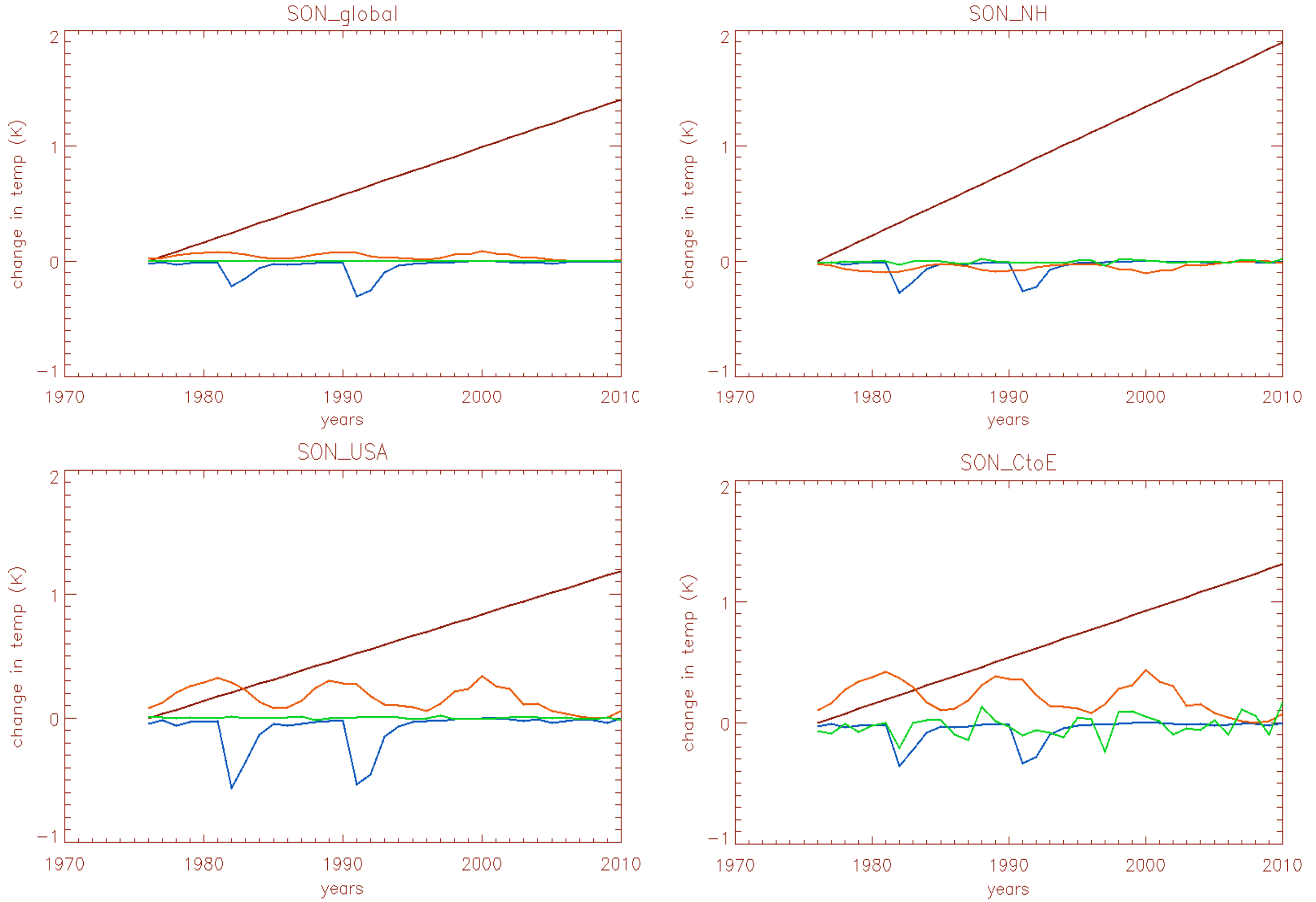




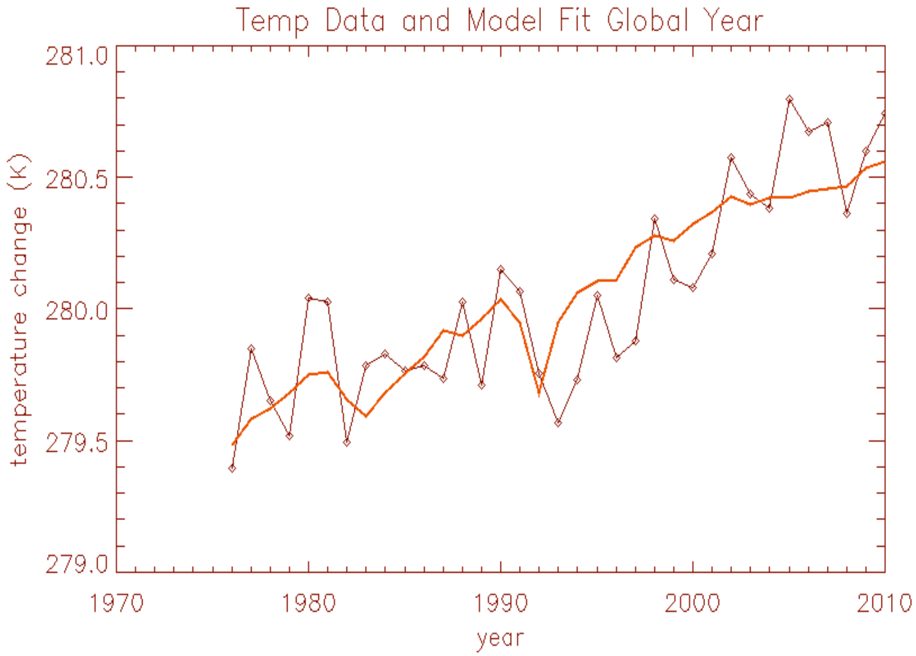


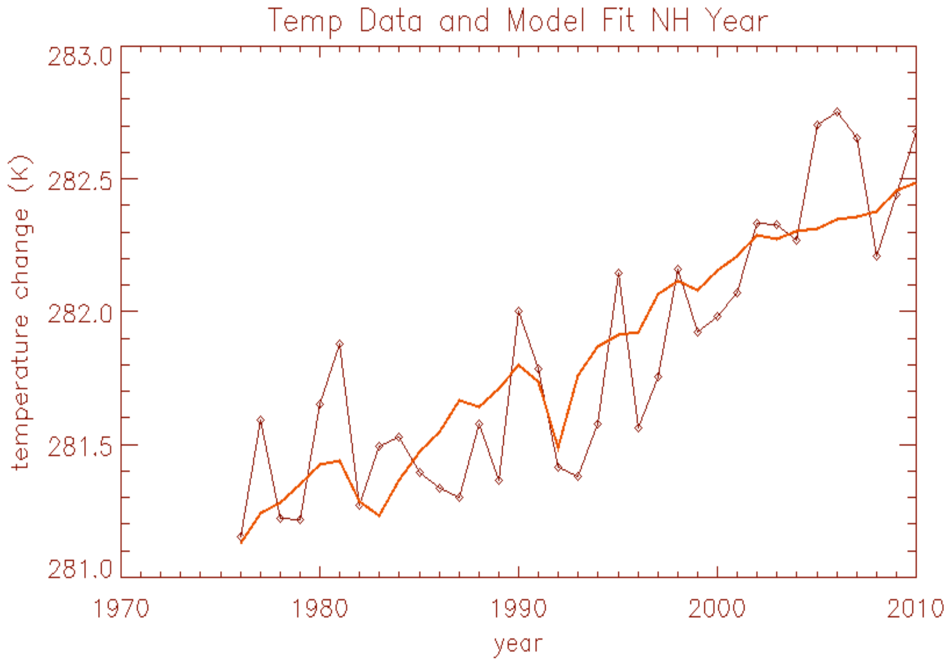


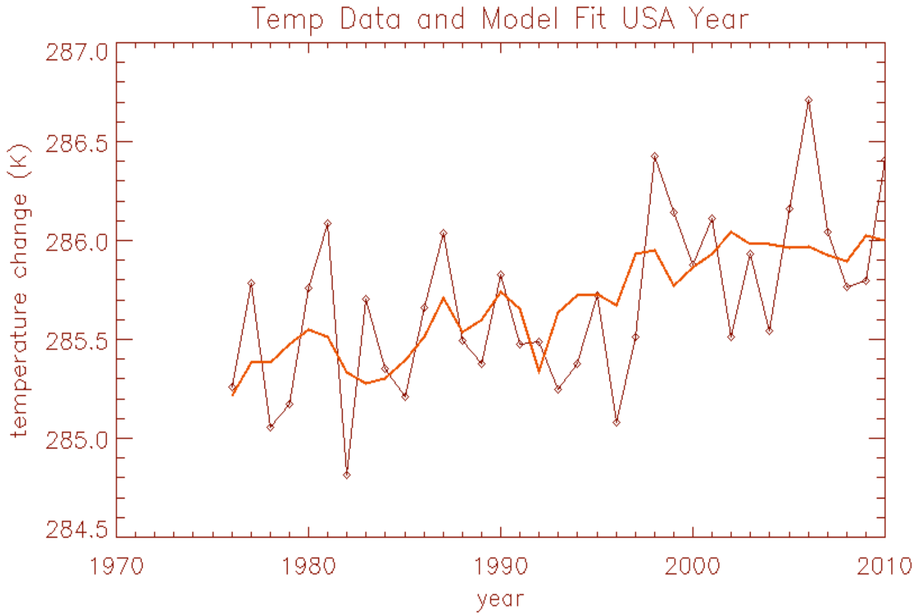
Fall Season Regression

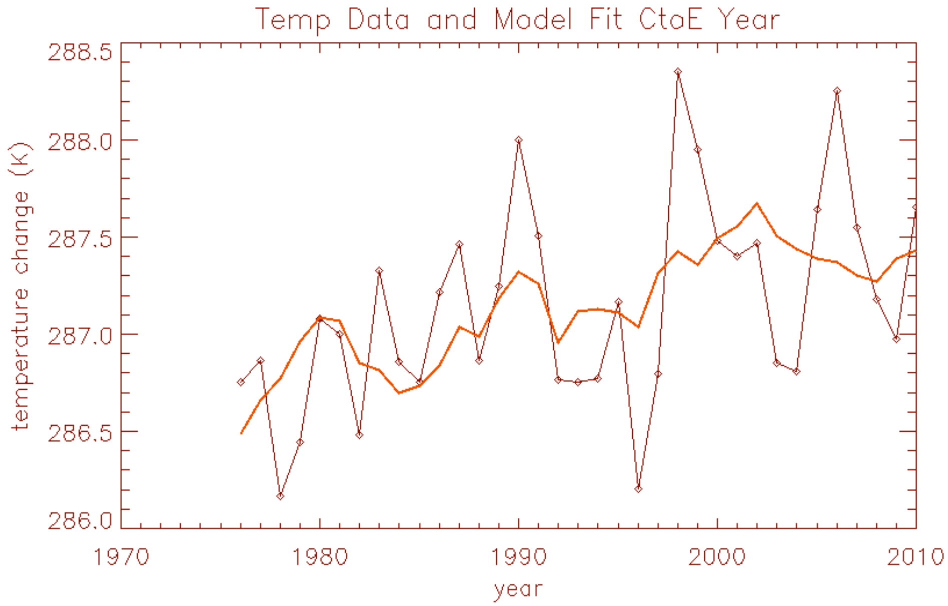


Model for Annual Temp data

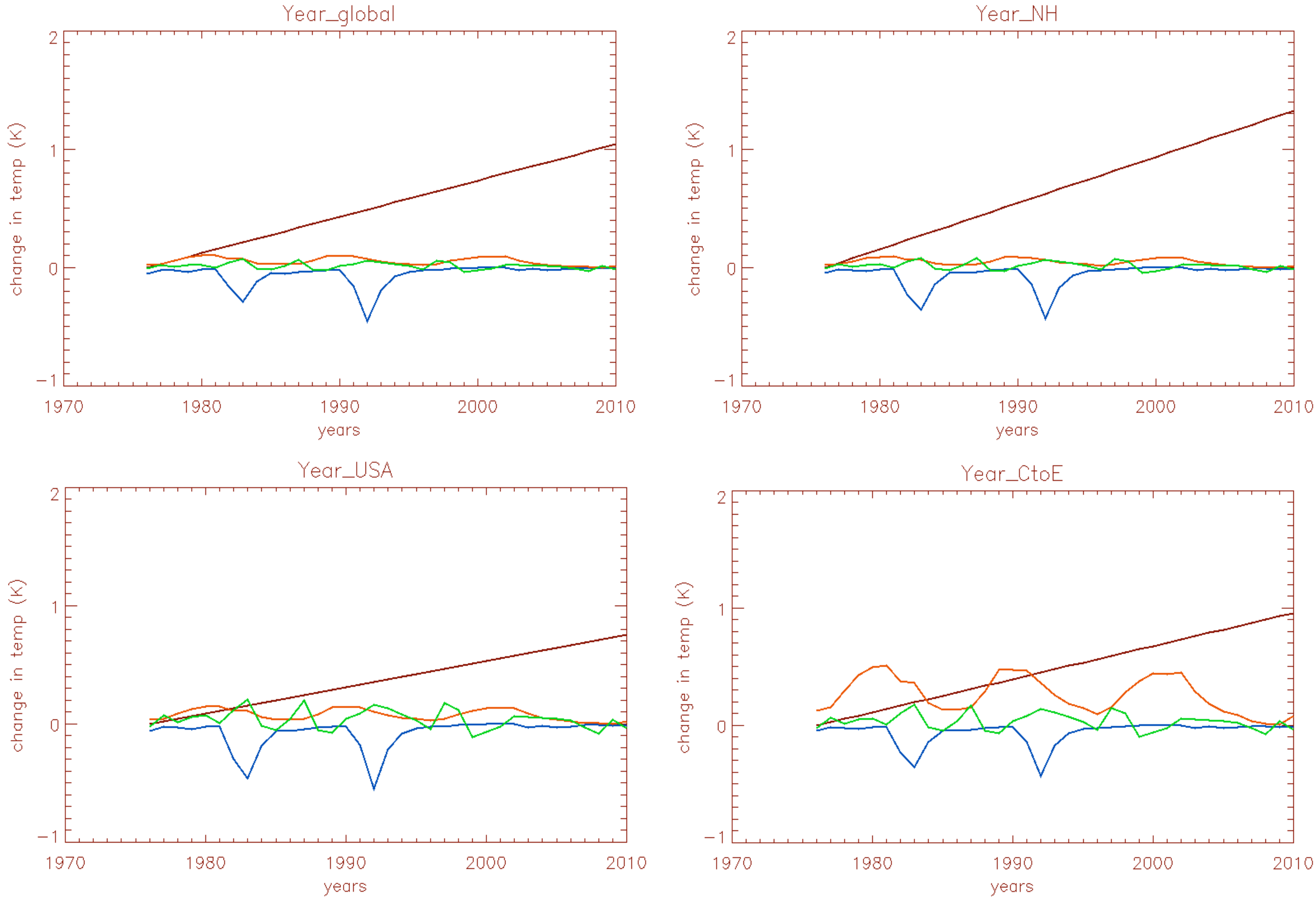




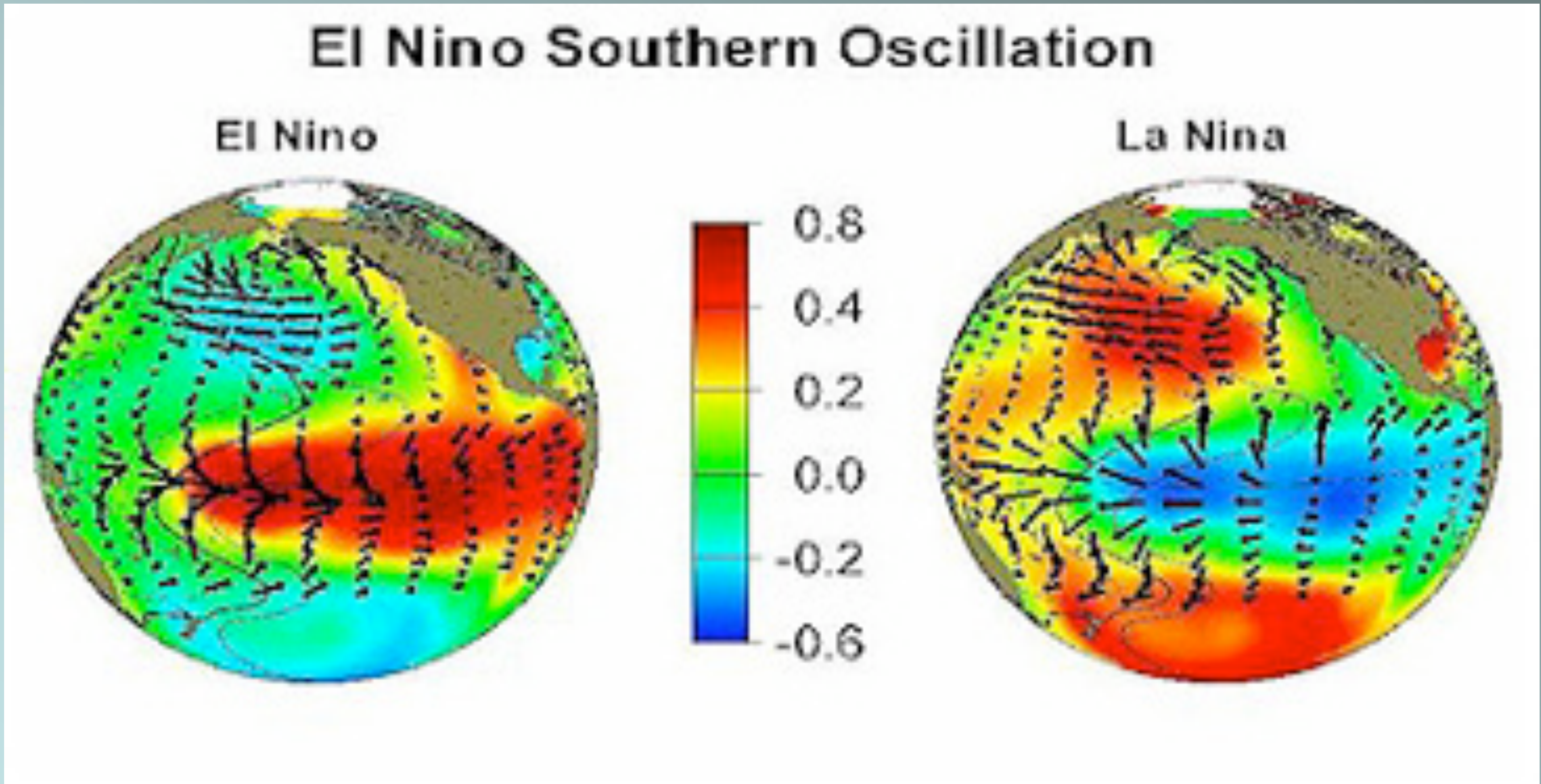




Annual Regression

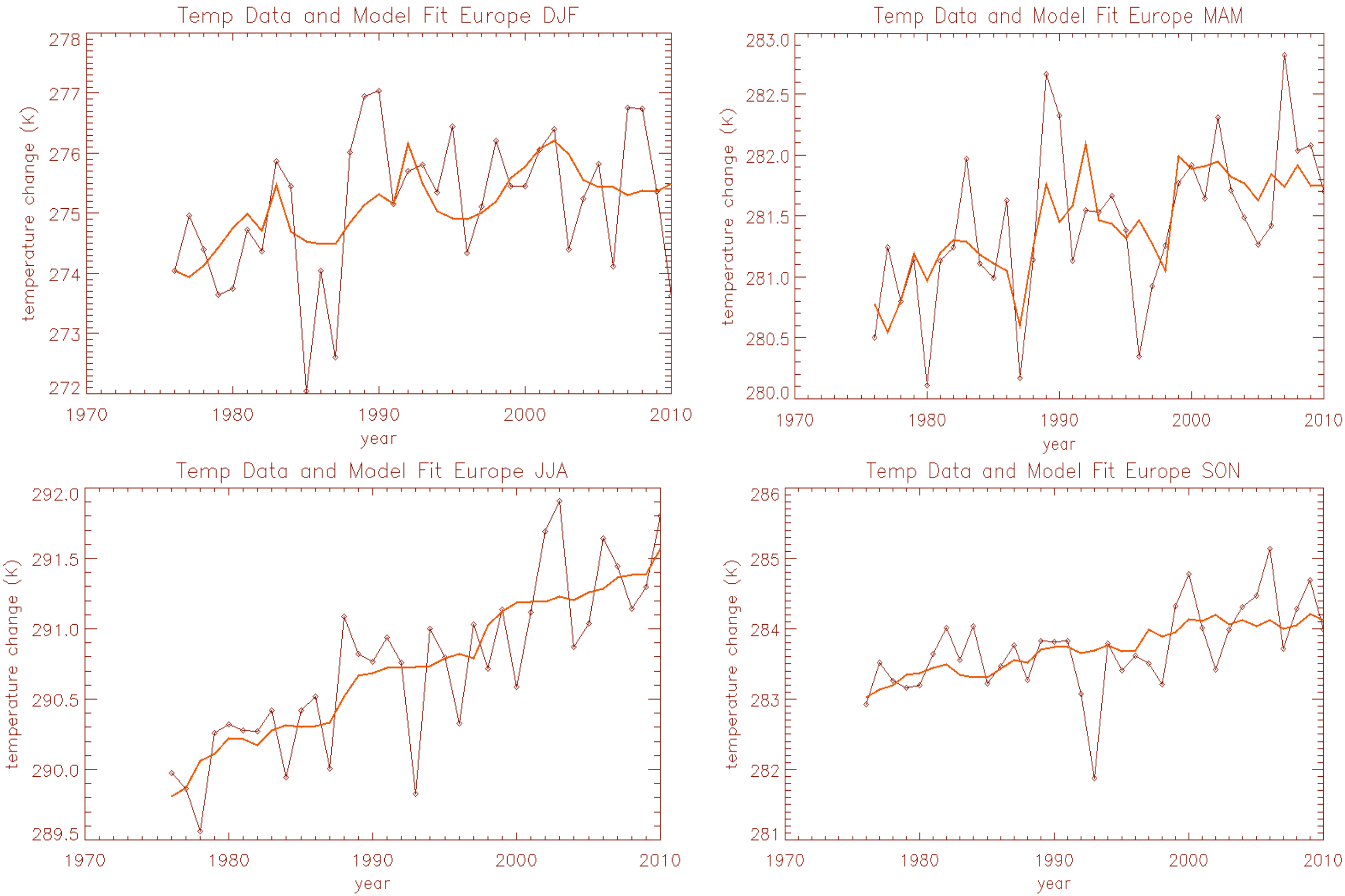


Visual of ENSO

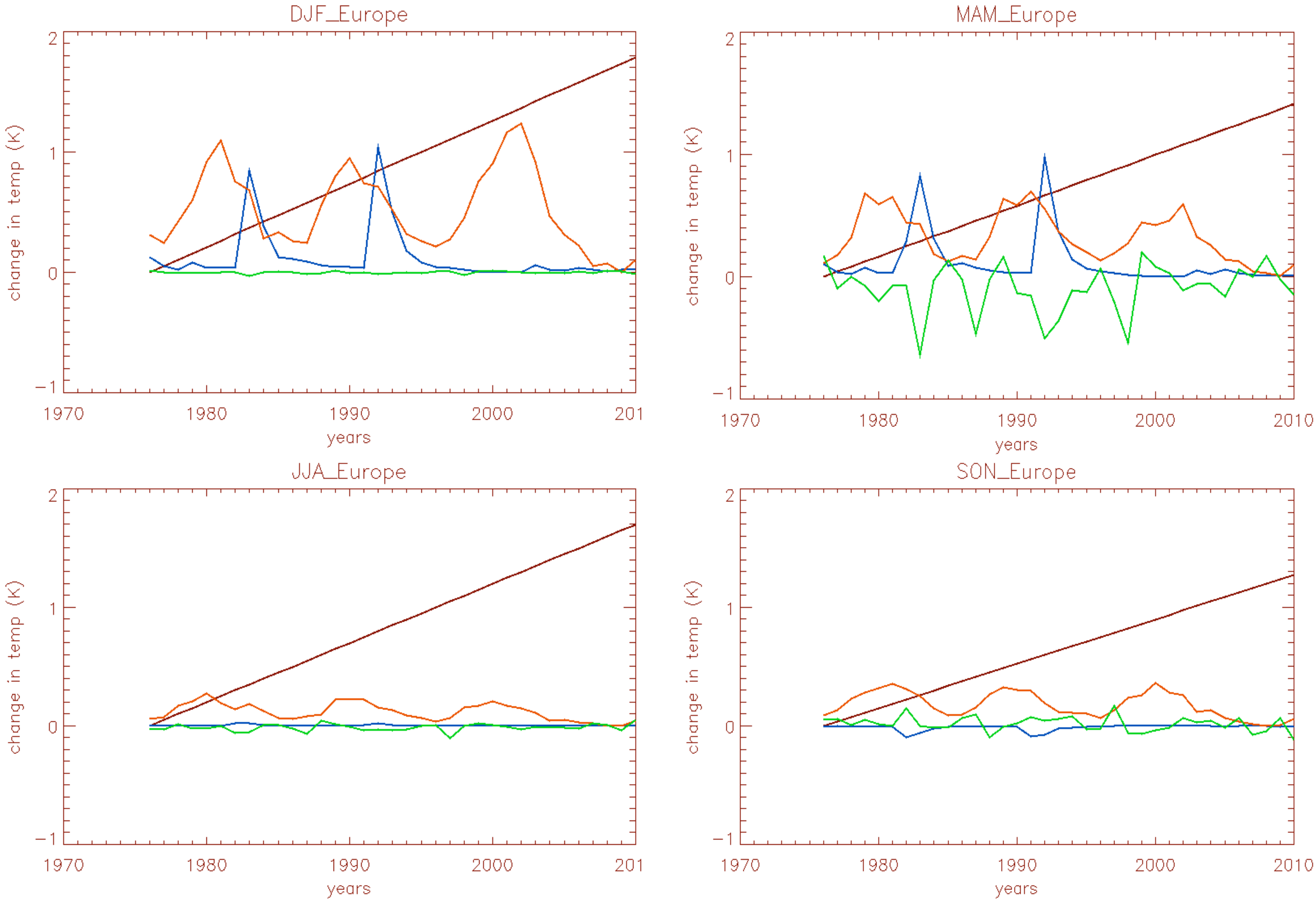


http://rst.gsfc.nasa.gov/Sect14/Sect14_11.html

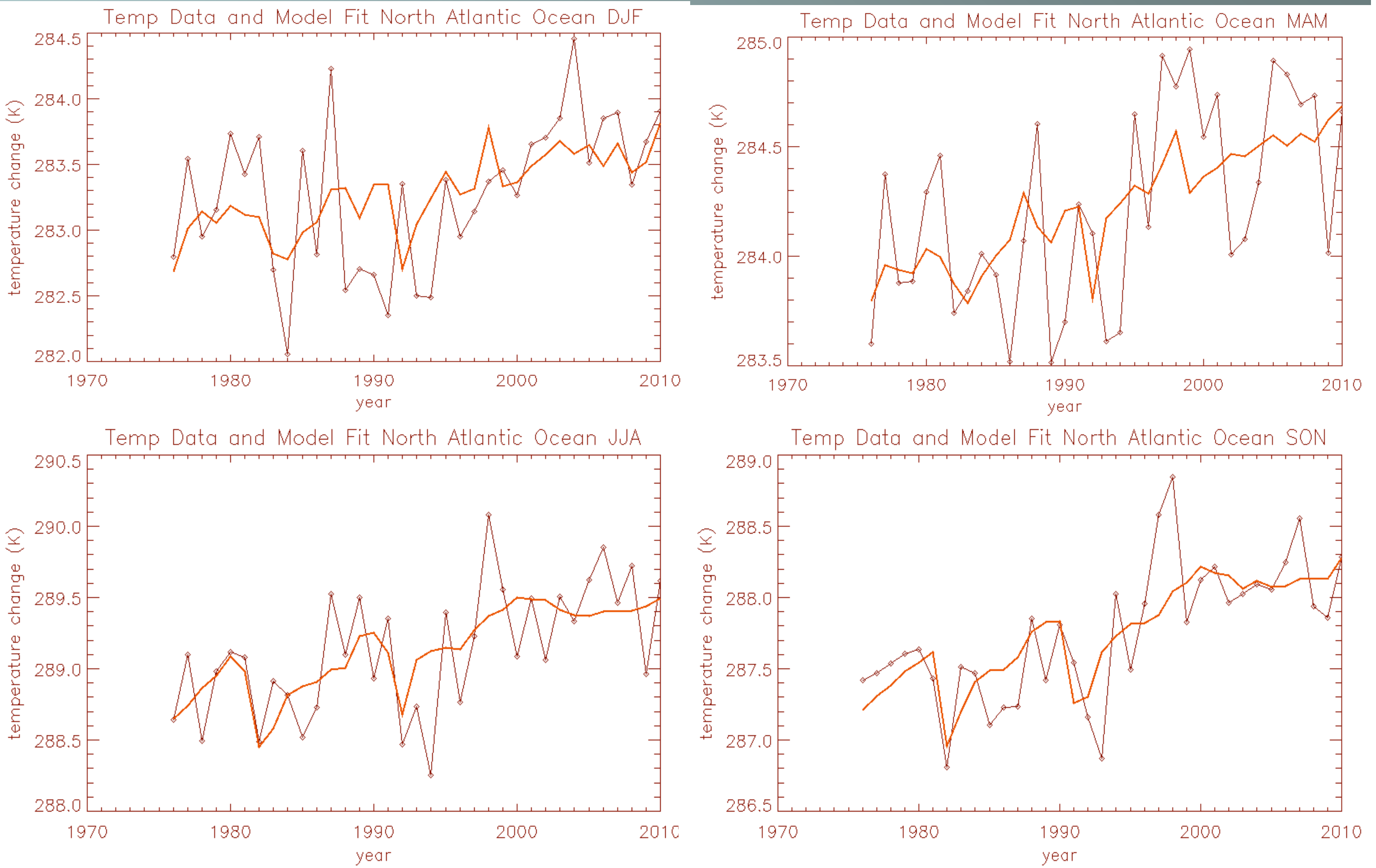
Europe Temp Model fit



Europe Regression



North Atlantic Ocean Temp-Model fit



North Atlantic Ocean Regression