Assignment #10: Multivariate Linear Regression of Global Surface Temperature

Due: Wednesday, 9 November 2016 (at start of class)

Name: ___________________________

140 points total

Late penalty: 20 pts per day

This assignment involves computation of coefficients for multiple linear regression of a global surface temperature anomaly time series versus the predictor variables that represent CO_2 greenhouse forcing, total solar irradiance, volcanic aerosols, and the El Niño Southern Oscillation Index. This exercise is motivated by two papers that appeared in *Geophysical Research Letters* at the time this course was first designed:

Lean and Rind, *GRL*, 2008; Lean and Rind, *GRL*, 2009

File **~rjs/aosc652/week_10/modern_climate_time_series.dat** contains a time series of global surface temperature anomaly (ΔT), total solar irradiance (TSI), El Niño Southern Oscillation Index (ENSO), volcanic aerosol optical depth (Vol_{AER}), and surface radiative forcing due to CO_2 (SRF_{CO2}). This information is on a monthly time grid, starting in 1890.

For ENSO and Vol_{AER}, two time series are given. These two time series are identical until midway through 2015. The time series denoted $ENSO_{FLAT\_AFTER\_PRESENT}$ and $Vol_{AER\_FLAT\_AFTER\_PRESENT}$ represent no change in ENSO or Volcanic forcing after the present time. The series denoted $Vol_{AER\_BIG\_ERUPTION\_2015}$ and $ENSO_{SUPER\_EL\_NIÑO\_2025}$ denote forcings due to a major volcanic eruption and a major El Niño event in years 2015 and 2025, respectively.

The file also contains annual average volume mixing ratio for CO_2. This column of information is given for "completeness" and "traceability". For the exercise, the surface radiative forcing due to CO_2 should be used, rather than the volume mixing ratio of CO_2. The two are related by the expression:

$$\Delta\ SRF_{CO2} = 5.35\ \mathrm{W\ m^{-2}}\ \ln\left(\frac{CO_2\ \ mr\ (t)}{CO_2\ \ mr\_initial}\right)$$

based on a radiative transfer model parameterization described by Myhre *et al.*, *GRL*, 1998.

a) (30 points) Using either FORTRAN, MATLAB, or IDL (or any another computational program you'd like), calculate the regression coefficients between our data (ΔT) and the predictor variables TSI, ENSO, Vol_{AER}, and SRF_{CO2}, as well as the regression constant. Write the results below. Please also give the units of the various coefficients:

Coefficient #1: Constant ____________________

Coefficient #2: SRF_{CO2} ____________________

Coefficient #3: ENSO ____________________

Coefficient #4: Vol_{AER} ____________________

Coefficient #5: TSI ____________________

Since the data (ΔT) are valid only from 1890 to the end of 2012, *either of the ENSO or Vol_{AER} time series may be used to obtain the regression coefficients*.

b) (50 points). Prepare a **ladder plot** comparing the data (time series of ΔT in first column) and the model of this data (*top rung*), which is the sum of the products of the regression coefficients times the predictor variables plus the constant term. For the other rungs of the ladder plot, please show the contributions to ΔT from CO_2 (*second rung*), ENSO (*third rung*), volcanoes (*fourth rung*), and solar irradiance (*fifth rung*).

Does the model capture the essence of the data time series?

What part of this comparison is most favorable?

What part of this comparison is least favorable?

Quantitatively, how much of the variance in ΔT is explained by your multiple linear regression model? Describe how you found this numerical value.

c) (30 points). Now we are going to proceed in a manner similar to Lean and Rind (2009). Assuming the five regression coefficients found in part a) apply to the future, prepare a plot **with two curves showing future temperature**:

- the first should be based on time series for SRF_{CO2}, TSI, $ENSO_{FLAT\_AFTER\_PRESENT}$ and $Vol_{AER\_FLAT\_AFTER\_PRESENT}$ and the regression coefficients found in part a). Please use a **solid line** for this prediction of future ΔT
- the second should be based on time series for SRF_{CO2}, TSI, $ENSO_{SUPER\_EL\_NIÑO\_2025}$ and $Vol_{AER\_BIG\_ERUPTION\_2015}$ and the regression coefficients found in part a). Please use a **dashed line** for this prediction of future ΔT)

For this plot, have the x-axis run from 1980 to 2030, so that your plot will be comparable to **Figure 1** of **Lean and Rind (2009)**.

Based on your figure just completed:

In the next several decades, do we expect warmer conditions than occurred in the past several decades? If so, briefly explain what factor is responsible. If not, please explain why this is the case.

What future event could lead to a short-term (several year), appreciable ***drop*** in globally averaged surface temperature?

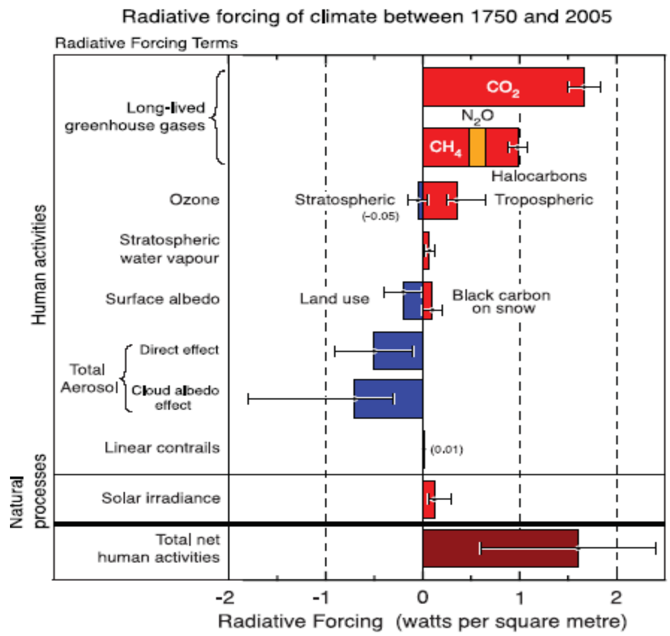
What future event could lead to a short-term (several year), appreciable ***rise*** in globally averaged surface temperature?

d) (30 points). We have used four predictor variables in our description of global average surface temperature: SRF_{CO2}, TSI, ENSO and Vol_{AER}. Our treatment of one of these variables is handled in a notably more simple manner than the treatment used by Lean and Rind.

i) Which variable do we handle in a more simple manner than Lean and Rind?

ii) How does the handling of the forcing due to this variable (i.e., answer to question above) by Lean and Rind differ from our treatment of this forcing?

iii) Based on your answer to the above two questions as well as this iconic figure from IPCC (2007):



FAQ 2.1, Figure 2. *Summary of the principal components of the radiative forcing of climate change. All these*

assess whether the simple model you have constructed might actually provide a reasonable forecast of how global averaged surface temperature will evolve over the next several decades.

> **Note: Am looking for a paragraph that either embraces or rejects this modeling framework, with some justification for this decision.**

Please turn in at least two plots (parts b and c),
written (or typed) answers to the questions,
plus all code (printed using full pathnames) used to complete the assignment.

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