Homework # 4

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ATM S 380
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Problem 1: Using Lorenz's (1996) model to study chaotic behavior.

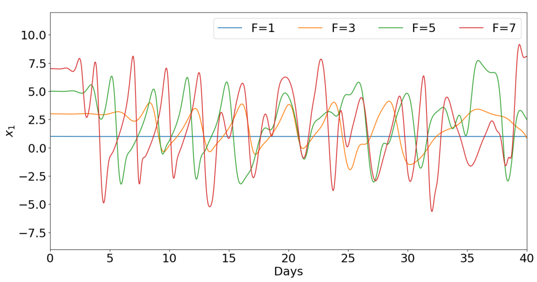
For this problem, we'll be using Lorenz96.ipynb.

(a) Sensitivity to F

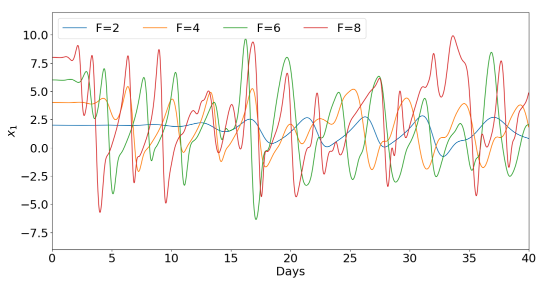
Part a) of the code shows solutions to the Lorenz equations for various small perturbations to the value of of the first longitude variable (x1). As discussed in class, the model shows different behavior for different values of F . Using F = 8 gives chaotic behavior, but here we'll explore other values.

Try a range of F values (F = 1, 2, 3, 4, 5, 6, 7, 8) and solve the equations in part a) of the code for each, plotting the evolution of the first longitude variable (x1) and the relationship between x1 and x2 over time. Describe the behavior of the model under the small perturbation. For what F values does the model damp the perturbation back to the equilibrium state, show somewhat periodic behavior, or show chaotic behavior?

Under this small perturbation, the model begins to have wildly different long-term behavior. When $F = 1$, the behavior is constant, but as we increase F, we see more periodic and chaotic behavior. Specifically, we have somewhat periodic behavior for $F = 2, 3, 4$ and chaos for $F = 5, 6, 7, 8$.

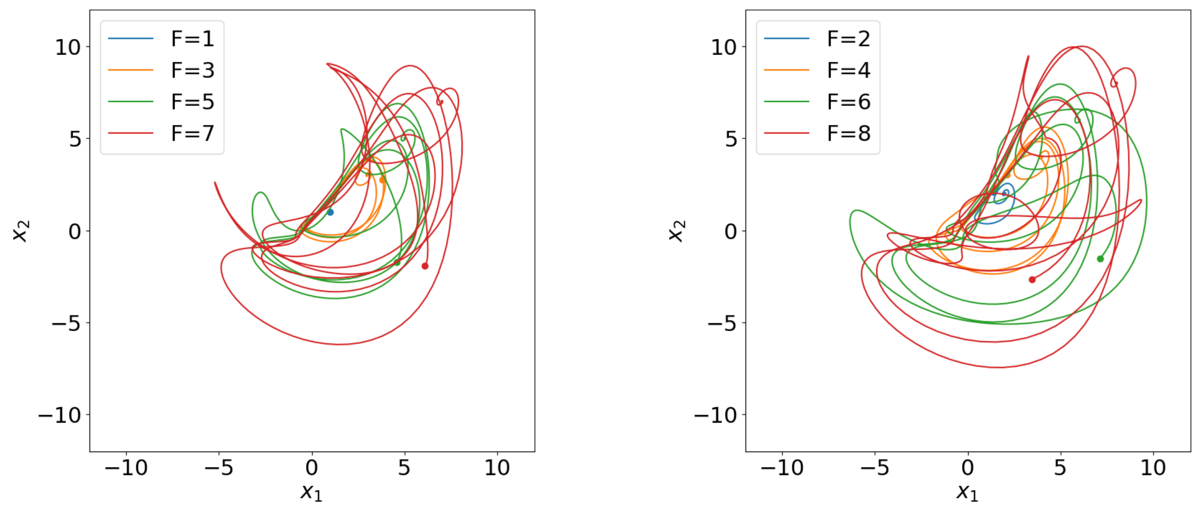


(A) Odd F Values



(B) Even F Values

FIGURE 1. x_1 values over time for various F values



(A) Odd F Values

(B) Even F Values

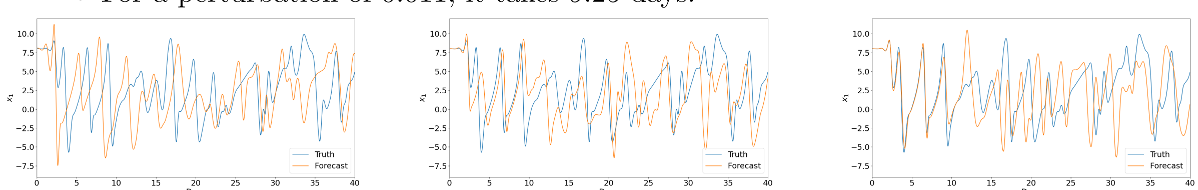
FIGURE 2. x_1 vs x_2 for various F values

(b) Sensitivity to the size of the perturbation

Part b) of the code is currently set up to run the model twice with different size perturbations to the initial state (perturbing x1). The solution with the first perturbation (= 0.01) produces a solution that we'll consider to be the true evolution of the state. The solution with the second perturbation (currently set = 0.1) represents a forecast of the evolution of the state starting from an imperfect initial conditions (think of this as an observation of the first perturbation with some error).

Using the second perturbation = 0.1, about how many days does it take for the forecast of the first longitude variable (x1) to drift away from the truth by at least 2.5? Now modify the second perturbation to be = 0.02 and run the forecast again. About how many days does it take for the forecast of the first longitude variable (x1) to drift away from the truth by at least 2.5? Now modify the second perturbation to be = 0.011 and run the forecast again. About how many days does it take now? For each of these, plot the evolution of the first longitude variable (x1) for both the truth and forecast.

- Using the second perturbation = 0.1, it takes 1.625 days for the forecast of x_1 to drift away from the truth by at least 2.5.
- For a perturbation of 0.02, it takes 2.42 days.
- For a perturbation of 0.011, it takes 9.25 days.



(A) $p = 0.1$

(B) $p = 0.02$

(C) $p = 0.011$

FIGURE 3. x_1 over time for truth and forecast for various perturbations (p)

(c) Error growth

Part c) of the code is set up to generate an ensemble of random initial conditions and plot the error growth (measured by their variance) as a function of time.

Using the code as is, approximately how many days does it take for the average error (variance) to double before saturation occurs? And at what day does saturation occur?

The variance doubles between day 6-13 before saturation, over the course of five days. It takes about 15 days for saturation to occur.

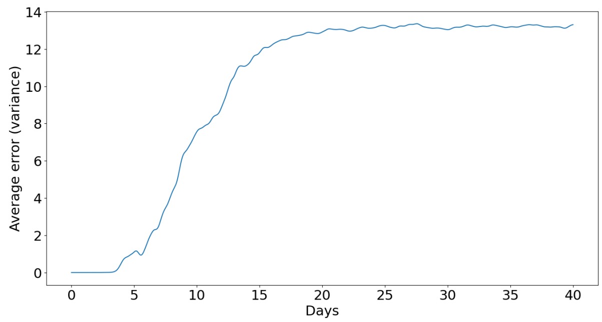


FIGURE 4. Average error over time

Now modify the code to make the size of the initialization uncertainty (the standard deviation, sigma) ten times as large (0.1 instead of 0.01). With this change, describe how the error growth is now different. Did the error change at 1 day, 5 days, and 20 days? Why or why not?

The error growth is a bit different in that the error grows a bit faster during the first two weeks, but then levels out to the same saturation level as previously. The error doesn't change at 1 day, but is a bit higher after 5 days, and by 20 days, has evened out.

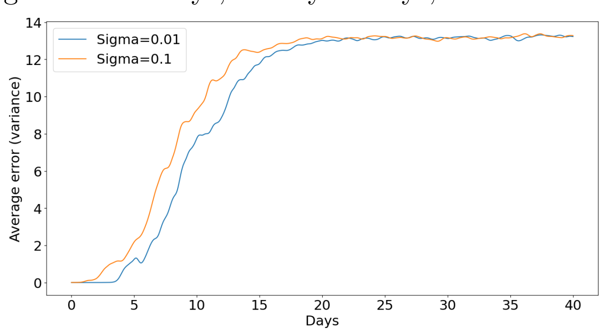


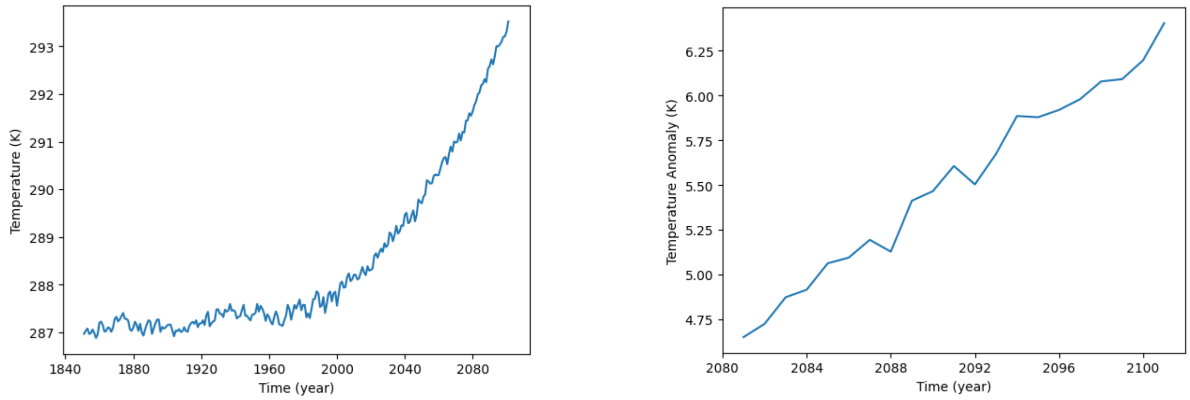
FIGURE 5. Average error over time for various sigma values

Problem 2: Working with GCM output

Find the netcdf (.nc) files containing output from NCAR's Community Earth System Model version 2 (CESM2), which I downloaded from the CMIP6 archive hosted at https://aims2.llnl.gov/search. The files starting with 'tas' have data for monthly-average near-surface air temperatures at each latitude and longitude point for the period 1850-2014 (driven by historical radiative forcing) and for the period 2015-2100 (driven by SSP5-8.5 radiative forcing). The file starting with 'areacella' has data for the area of each atmospheric grid cell, which you'll need to calculate global averages.

(a) Calculate the annual and global mean temperature and plot the timeseries from 1850-2100. What is the global and annual mean temperature anomaly for the period 2080-2100 relative to the period 1850-1900? How does this timeseries compare to what you found in Homework 2?

This temperature timeseries is similar to the one we found in Homework 2 in that there is an increase in temperature, but this timeseries is much more jagged and has several step discontinuities, The anomaly for the period 2080-2100 relative to 1850-1900 is 5.511.



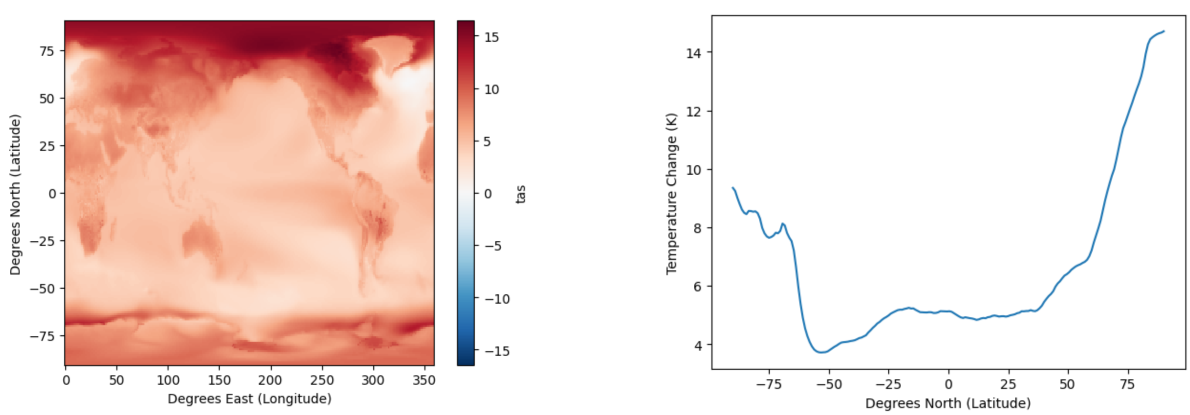
(A) Temperature by Year

(B) Temperature Anomaly

FIGURE 6. Annual and global mean temperature + Anomal from 1850/2080-2100

(b) Plot a map of the annual mean temperature anomaly averaged over the period 2080-2100 relative to the average over 1850-1900. How does this warming pattern compare to what you found in Homework 3?

This warming pattern is very similar to those we found in Homework 3: there is significant temperature change everywhere, but the poles are hit the hardest, especially the north pole (due to polar amplification).



(A) Full Map

(B) Averaged by Longitude

FIGURE 7. Annual mean temp anomaly for 2080-2100 relative to 1850-1900