Some Interesting Results about our Case Study

The baroclinic wave does not grow spontaneously in CAM with the balanced Initial Conditions, even if I run the model for 730 days!
Ensemble Forecasting

Ensemble = A group of complementary parts that contribute to a single effect (from thefreedictionary.com)

Ensemble forecasting = A group of numerical predictions that is used to make a prediction.

Often the ensemble is conducted using slight variations in initial conditions, as in HW3

Although varying parameters (like resolution in HW3, friction coefficient, relative humidity threshold, etc) and parameterization can also produce an ensemble
“Spaghetti plot” shows jet location of individual ensemble members. Where is the jet (and hence storms) forecast most uncertain?

From reading assignment 2, Fig 1.7.2
“Spaghetti plot” shows jet location of individual ensemble members. Where is the jet (and hence storms) forecast most uncertain?
http://mls.jpl.nasa.gov/research/hurricanes.php

Hurricane Rita Track from WRF model
Why ensemble forecast?

Because the average of the ensemble eliminates

1) unwanted error in a weather forecast

2) natural variability in a climate forecast, thus allowing the forced response to be known

To understand from the spread where

1) the probability of the forecast mean and extremes

2) the sensitivity to parameters, parameterizations, resolution, etc
This figure illustrates two types of ensembles: one illustrated by different colors and the other by spread around each curve. Colors = indicate “forcing scenario” or rate of greenhouse gas ramping and spread = the range among models.

Source: IPCC Fourth Assessment Report
Sometimes a single model is run many times and its parameters are varied to create a “perturbed physics” ensemble.

A famous example is …
Experiment Status Summary

Model Years       111,732,437
Active Hosts      52,580

Accomplished with distributed computing, like SETI@home, but SETI has over 3 million hosts
Standard model setup

Perturbed Physics Ensemble

Initial Condition Ensemble

Forcing Ensemble

Overall Grand Ensemble

10000s

10s

10s
This figure shows an ensemble of the first two branches in the previous figure.

All runs have the same “forcing”, which is to double CO2 instantly at year 30.

When equilibrium is reached, the global temperature change $\Delta T$ is the “Climate Sensitivity”. This occurs at year $\sim 60$ or so.
rotate by 90

take $\Delta T$ at end and make histogram

Normalize it so the sum of all bins is 100% and this is a Frequency distribution function

$\Delta T$ or “Climate Sensitivity” (°C)
Frequency Distribution of Global Temperature Change

From Stainforth et al. 2005
Anomaly Correlation =

$$\sum_{i,j} T_{850}'_{\text{truth}}(i,j) T_{850}'_{\text{test}}(i,j)$$

$$/\sqrt{\sum_{i,j} T_{850}'_{\text{truth}}(i,j) T_{850}'_{\text{truth}}(i,j)}$$

$$/\sqrt{\sum_{i,j} T_{850}'_{\text{test}}(i,j) T_{850}'_{\text{test}}(i,j)}$$

i and j are the indices over latitudes and longitudes. This is an example for 850hPa Temperature (T850), where the prime on T850 indicates it is a anomaly, which could mean it has the global mean or zonal mean removed first.

Think of it as a degree of pattern matching 1 = perfect match and 0 is no match whatsoever.
How do you expect the Anomaly Correlation with the average of the ensemble members to compare to the individual ensemble members?

Hence the “test” is the average of the perturbed initial condition ensemble.
The correlation in each line in this figure is computed with the 0.5 deg model as “truth” and the Individual 14 ensemble members. Ensemble mean of the 14 members (average first then correlate). Average of the 14 blue lines (correlate first then average).
Why are there consistent wiggles in the previous set of curves?
If the “truth” is a higher resolution run, as in our case for HW3, the anomaly correlation informs us about the error from inadequacies in the resolution of the ensemble members AND growth of random errors in the initial condition.

What if the “truth” is a run at the same resolution, but with no random error in the initial conditions. Will the Anomaly Correlation be in general higher or lower?
The correlation in each line in this figure is computed with the 2 deg model as “truth” and the individual 14 ensemble members. The ensemble mean of the 14 members (average first then correlate) is also shown. The average of the 14 blue lines (correlate first then average) is compared to the ensemble mean.
Issue 1: large trend, especially in ice volume

6 ensemble members of 20\textsuperscript{th} Century run
Volume Anomaly

6 ensemble members of 20th Century run
Issue 2: Seasonal Cycle in Area Anomaly

6 ensemble members of 20th Century run
Branstator and Teng, 2010, Two types of predictability

1) Growth in spread of green curve indicates range of time initial conditions give useful information.

2) Slope of both distributions from greenhouse warming is another kind of information.
In the case of sea ice, it is declining. Note that different starting points of volume affect the trajectory for at least 2 years. But it is clear the trajectory is going down in the long run.
Part 2: “Perfect Model” Studies with CCSM4

Initialized in year ~2000 of a 20th century run for various start times

Sea Ice Area ($10^6$ km$^2$)

\* = start times

lines = 20th Century runs
Volume Anomaly $10^{12}$ m$^3$
Standard Deviation of Forecast

σ of Volume 10^{12} m^3

Control
Jan 1 Start
Sep 1 Start
Standard Deviation of Forecast

\( \sigma \) of Area \( 10^6 \text{ km}^2 \)

- **Control**
- **Jan 1 Start**
- **Sep 1 Start**
Standard Deviation of Area for Forecast
Normalized by Control

Jan 1 Start
Sep 1 Start
Volume Anomaly $10^{12}$ m$^3$
Predictability and uncertainty recap

The atmosphere is a system with instabilities, and therefore has a finite limit of predictability.

The predictability of weather is about two weeks, though certain conditions can make it longer – like our experiment’s initial conditions.

Even if the model is perfect, the initial conditions have to be known to extreme accuracy (in our case the balanced initial conditions didn’t grow if initial variables were accurate to within double precision, or about 15 decimal places, but did grow when perturbed in the fourth decimal place). Also you saw departures in solutions with minor random number variations.
“Twin experiments” are sometimes used to investigate predictability, where integrations with slightly different initial conditions are compared. One run may be higher resolution and model parameters may be varied.

Used when no observations exists or when we want to evaluate the “potential predictability”

When the model is precisely the same, the experiments are also called “perfect model experiments” because one run is considered “truth”. These experiments do not address model inaccuracies from poor resolution, parameter choices, or wrong physics. They regard the model as “perfect” and loss of predictability is purely due to the instabilities in the system.
Dynamic system with instabilities—two similar initial conditions have trajectories that move apart in time.

A stable system would have converging trajectories after some time.
Lorenz Equations – Lorenz was seeking a set of equations that with instabilities (and non periodic) in 1960, when he succeeded he didn’t know the equations would be sensitive to initial conditions (ICs). He only discovered it by accident. A new field of mathematics was born and our understanding of weather was deepened immeasurably. It pays to explore!
Lorenz Equations – Lorenz was seeking a set of equations that with instabilities (and non periodic)

\[
\begin{align*}
\frac{dx}{dt} &= \sigma(y - x) \\
\frac{dy}{dt} &= x(\rho - z) - y \\
\frac{dz}{dt} &= xy - \beta z
\end{align*}
\]

these equations are nonlinear from xz and xy terms

X = circulation  X>0 clockwise X<0 counter clockwise
Y= temperature difference between ascending and descending plumes of air
Z = departure of vertical temperature gradient from linear
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\(\sigma = \) Prandtl Number, measure of diffusion (or dissipation) by heat conduction versus momentum, when low, heat conduction dominates (e.g. liquid metal), when high momentum wins (e.g. oil)

\(\rho = \) Rayleigh Number, when low, heat transfer is primarily via conduction as compared to convection

Normally \(\sigma=10, \beta=8/3\) and \(\rho\) is varied
Derived for atmospheric convection, though idealized

Fully deterministic – solution always the same for same initial conditions (must perturb ICs to make ensemble)

A minute difference in the initial condition makes the solution eventually very different

This is true for weather too

“Does the flap of a butterfly’s wings in Brazil set off a tornado in Texas?” Edward Lorenz, 1972
Does small error in initial condition change the growth rate and frequency of weather in a prediction?
How do we cope with minute errors in the initial conditions?
Two complete atmosphere models (not adiabatic like ours). One run is perturbed at a single grid point in the 12th decimal place. Here is Sea Level Pressure, 3 days later. The maximum difference is less than 1hPa

http://mustelid.blogspot.com/2005/10/butterflies-notes-for-post.html
14 days later. The maximum difference is about 10hPa (the perturbed grid point was in the Arctic!)
31 days later. The maximum difference is about 25hPa
Things to notice:

The initial differences look convective.

How do you think the growth would differ if the perturbation looked like a storm poised to grow?

If both perturbations are plausible, which is more efficient to create an ensemble of all possible conditions?
Standard deviation of the difference of Sea Level Pressure at each point in the previous maps
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Average of the 14 blue lines (correlate first then average)