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

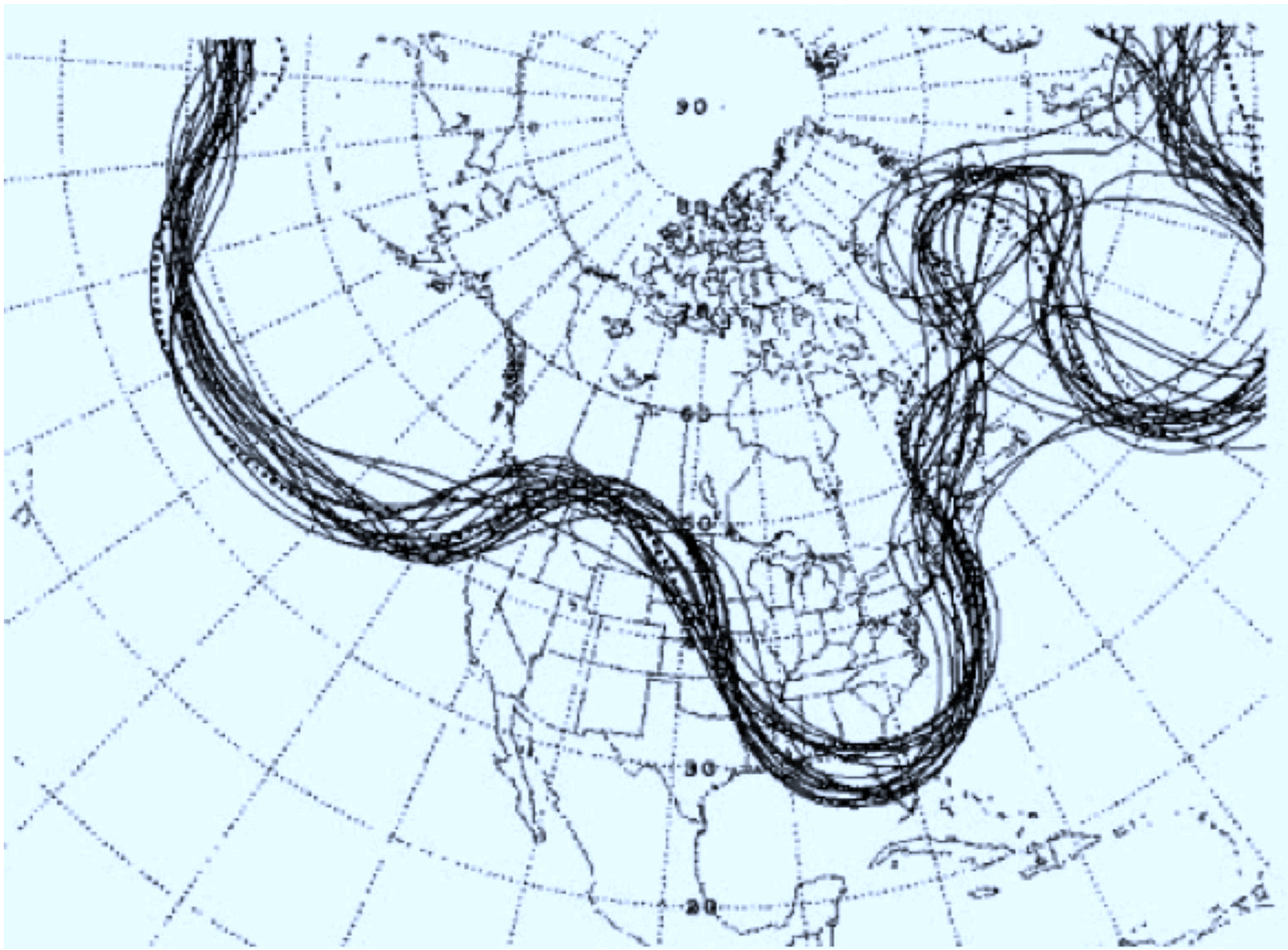
Ensemble = A group of complementary parts that contribute to a single effect (from thefreedictionary.com)

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

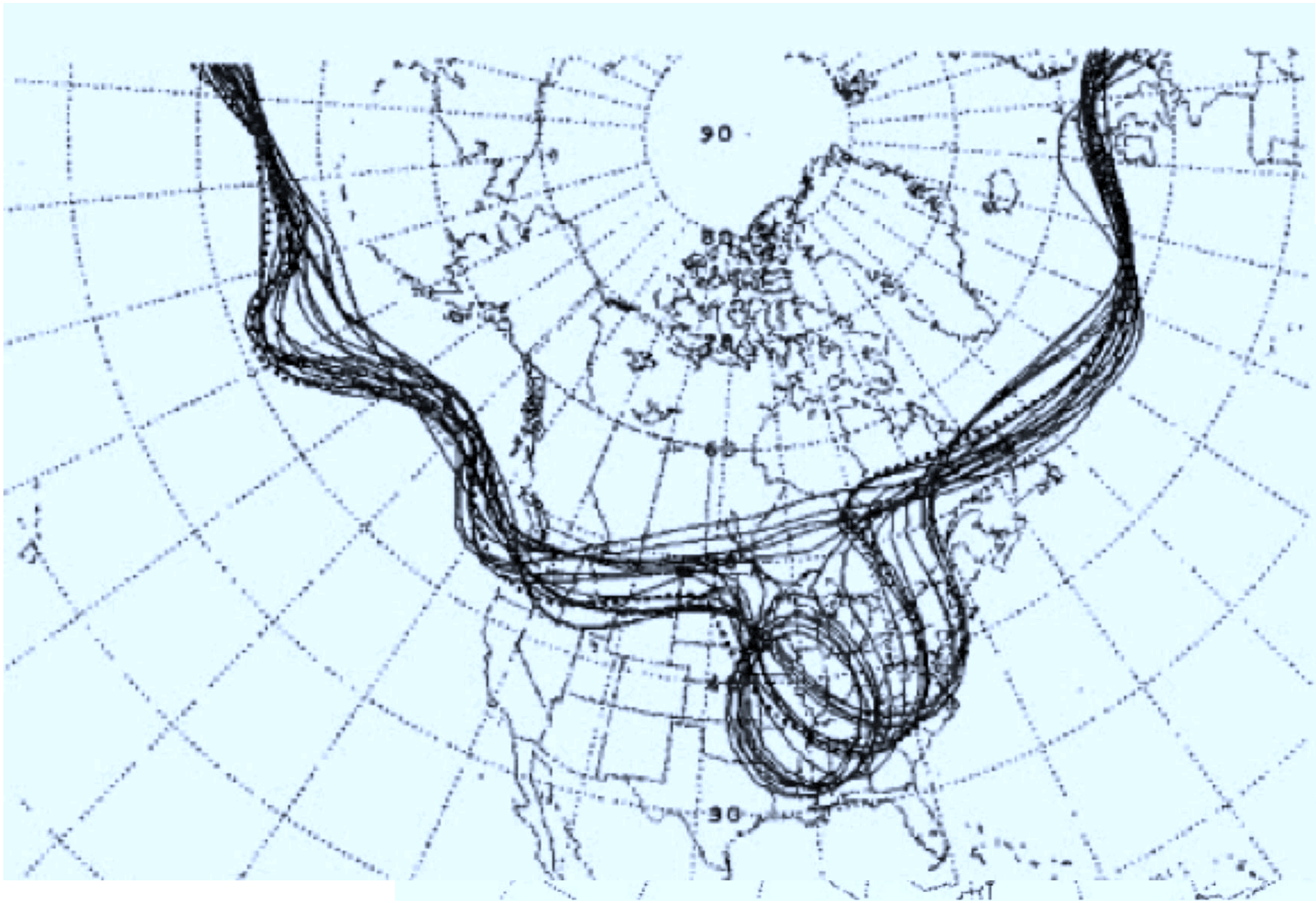
Although varying parameters (like resolution in HW3, friction coefficient, relative humidity threshold, etc) and parameterization can also produce an ensemble

“Spaghetti plot” shows jet location of individual ensemble members. Where is the jet (and hence storms) forecast most uncertain?



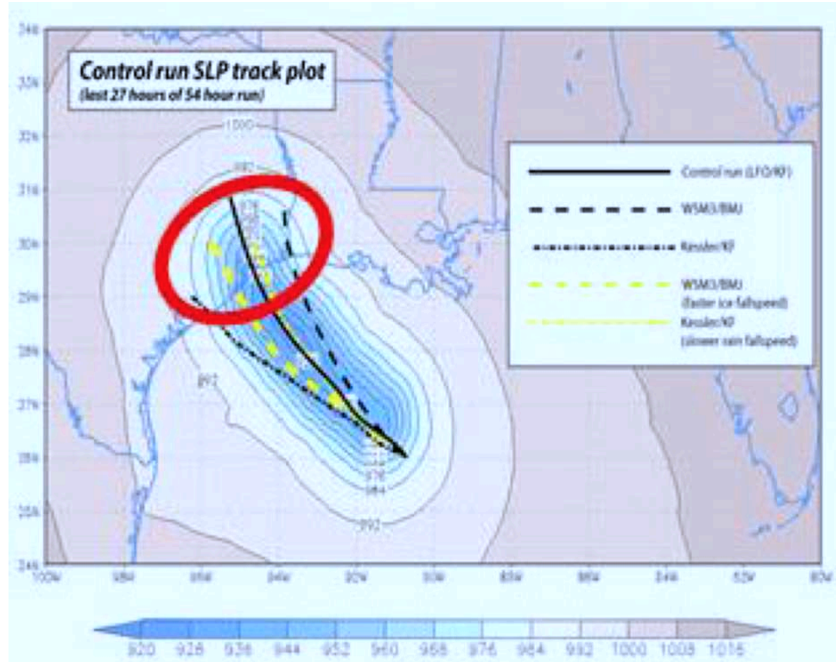
From reading assignment 2, Fig 1.7.2

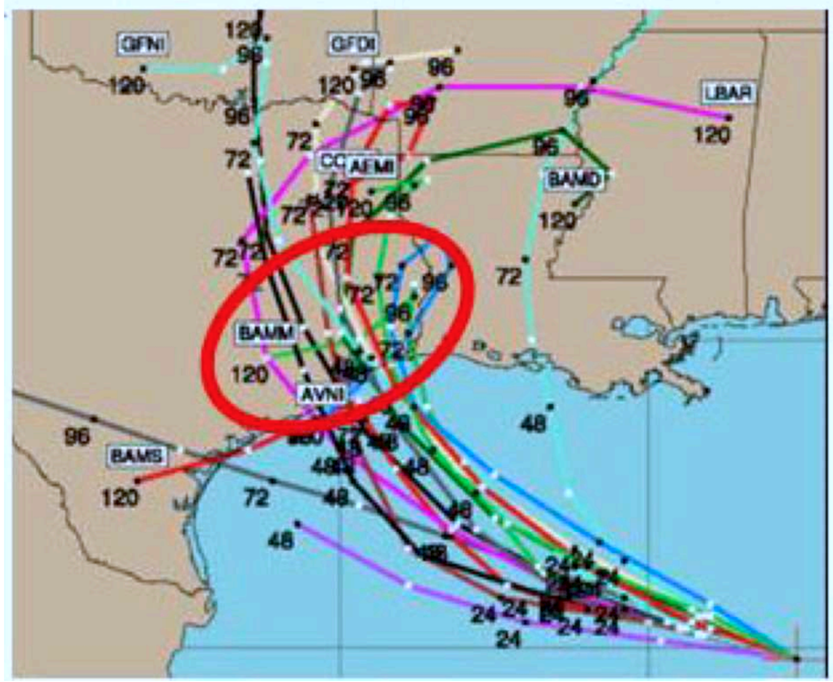
“Spaghetti plot” shows jet location of individual ensemble members. Where is the jet (and hence storms) forecast most uncertain?



http://mls.jpl.nasa.gov/research/hurricanes.php

[Hurrican Rita Track from WRF model](http://mls.jpl.nasa.gov/research/hurricanes.php)





Why ensemble forecast?

Because the average of the ensemble eliminates

1) unwanted error in a weather forecast

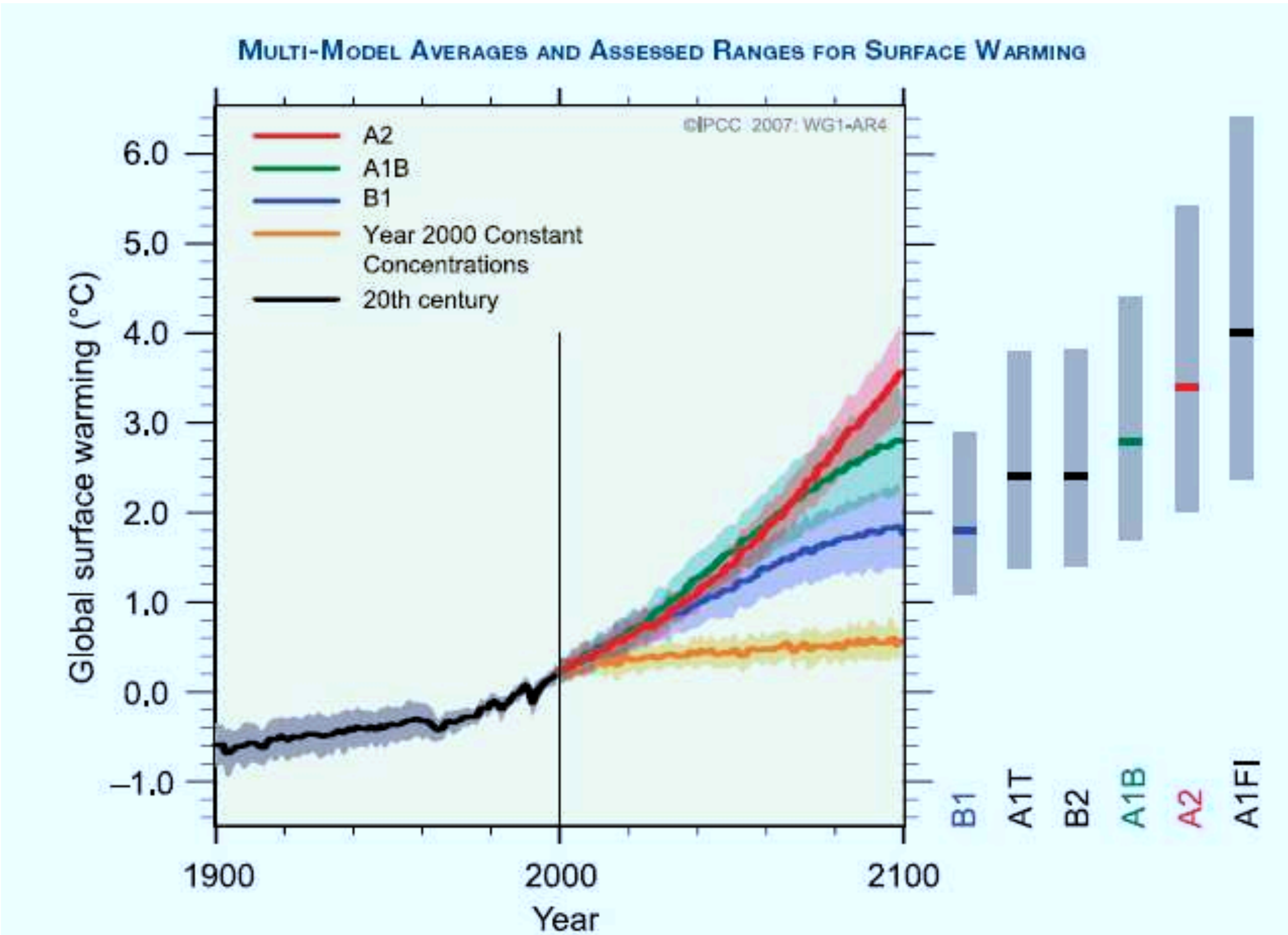
2) natural variability in a climate forecast, thus allowing the forced response to be known

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

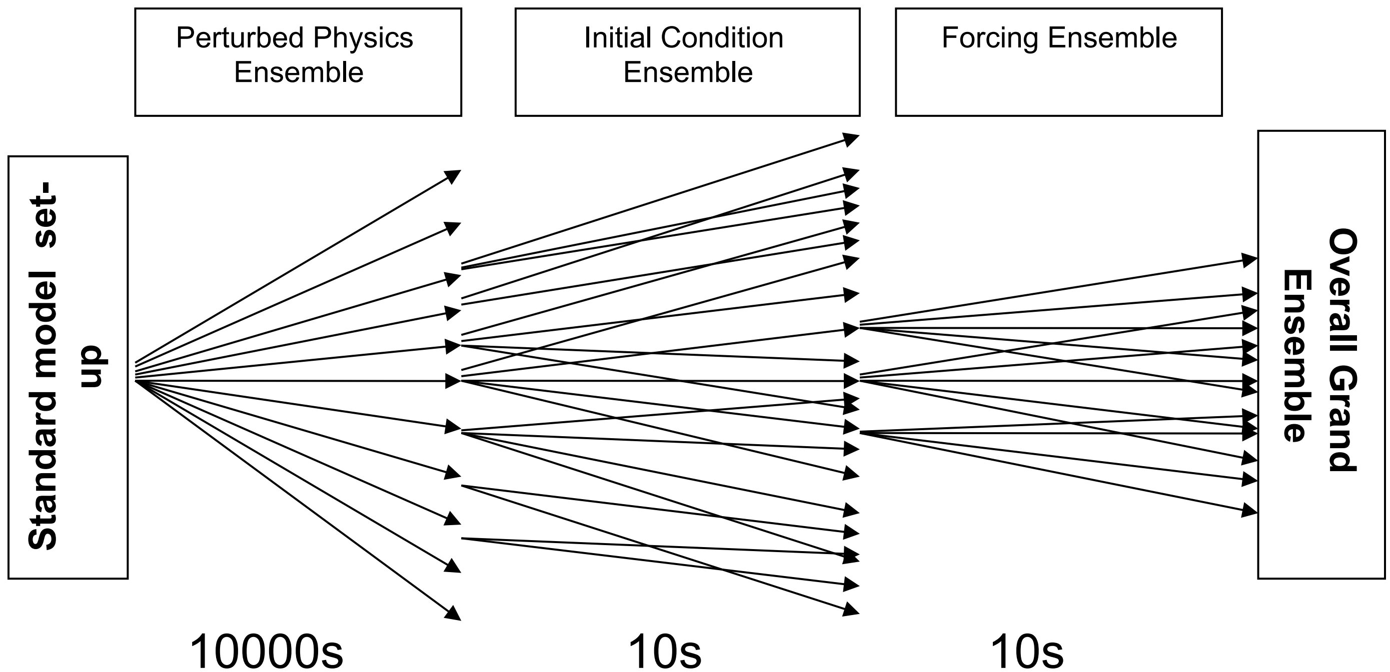
A famous example is …

climateprediction.net

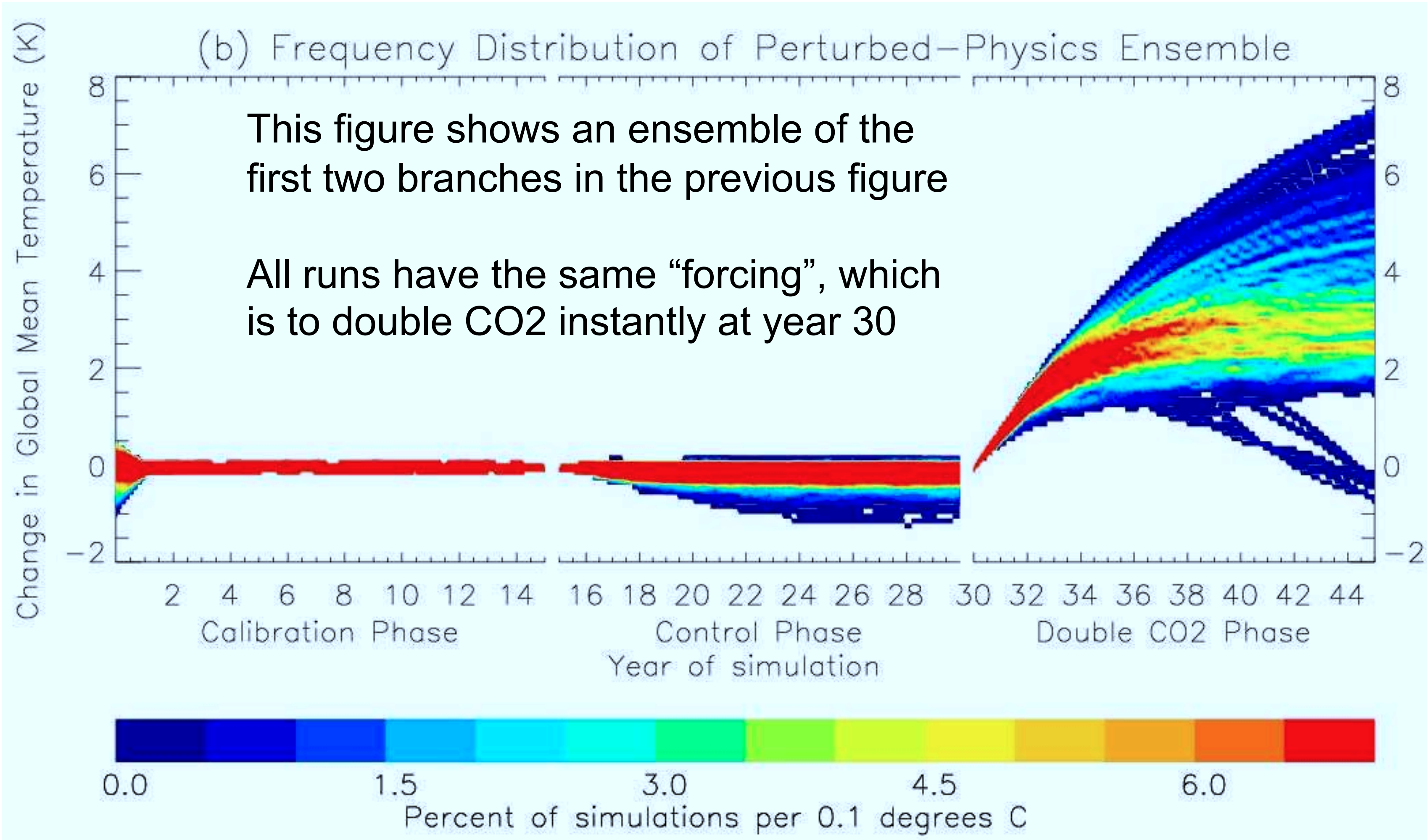
Experiment Status Summary

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

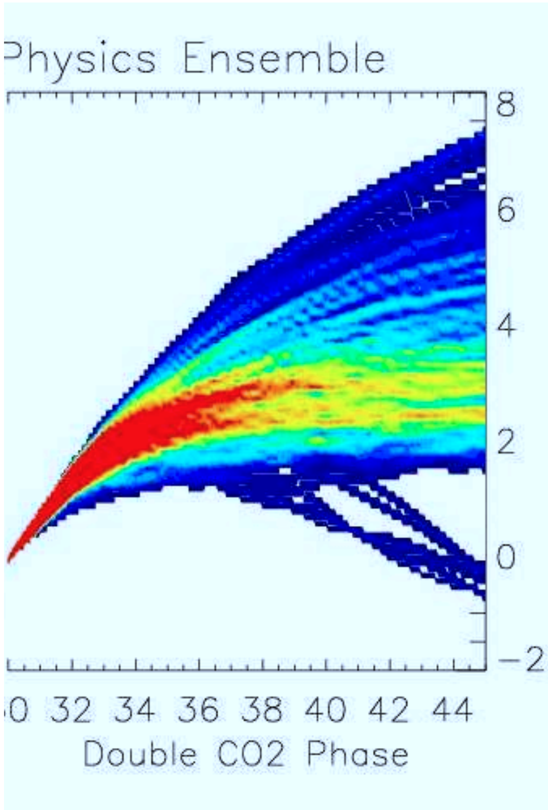
Accomplished with distributed computing, like SETI@home, but SETI has over 3 million hosts



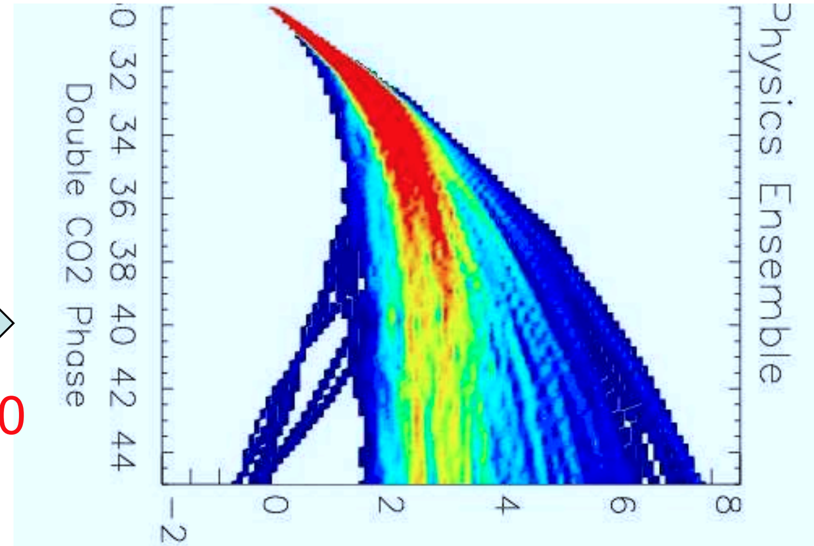
Perturbed Physics Ensemble
Initial Condition Ensemble
Forcing Ensemble
Standard model set-up
Overall Grand Ensemble
10000s
10s
10s



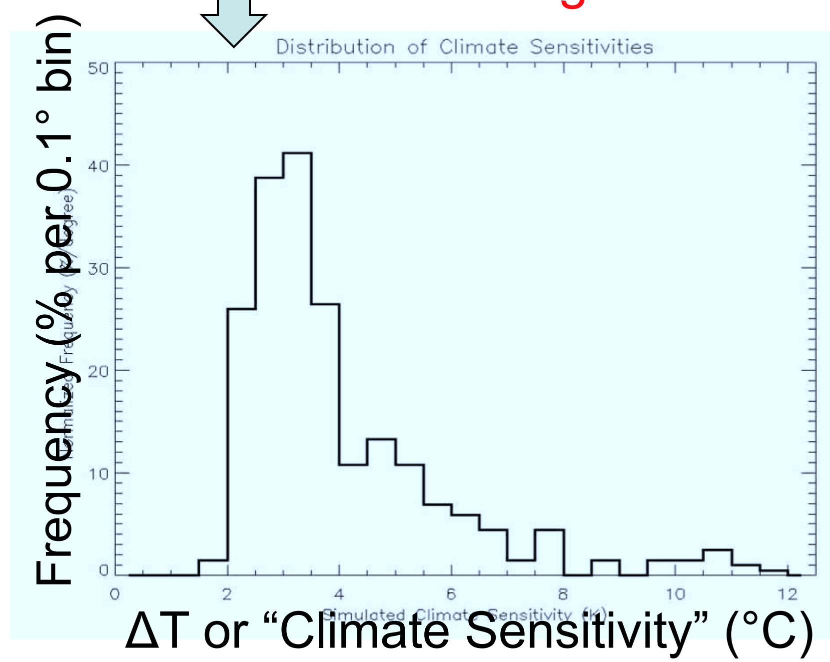
When equilibrium is reached, the global temperature change ΔT is the "Climate Sensitivity". This occurs at year ~60 or so.



rotate by 90

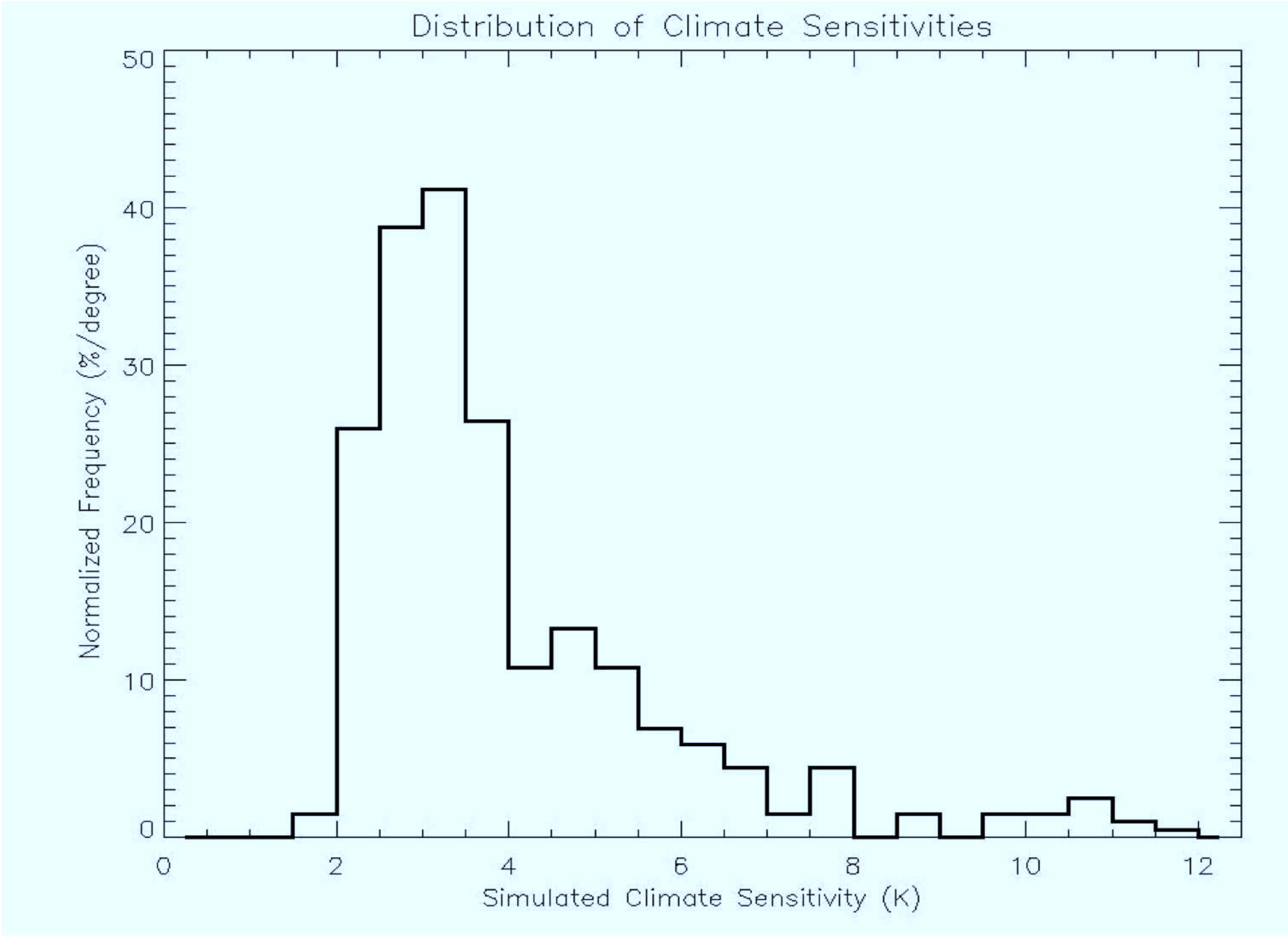


take ΔT at end and make histogram



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

Frequency Distribution of Global Temperature Change



From Stainforth et al. 2005

Anomaly Correlation =

$$\Sigma_{i,j}\, T850'_{truth}(i,j)\; T850'_{test}(i,j)$$

$$/\mathrm{sqrt}(\Sigma_{i,j}\, T850'_{truth}(i,j)\; T850'_{truth}(i,j))$$

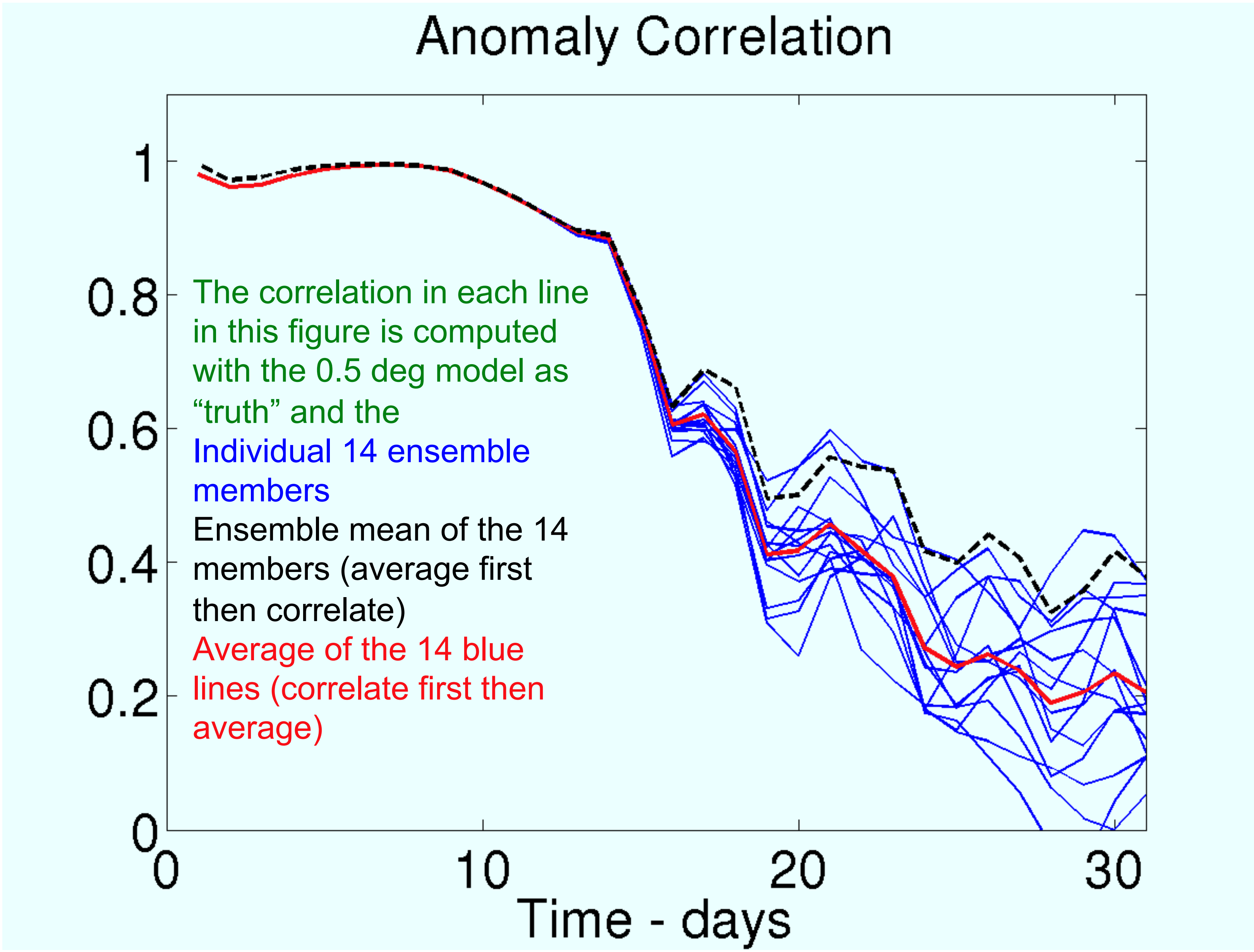
$$/\mathrm{sqrt}(\Sigma_{i,j}\, T850'_{test}(i,j)\; T850'_{test}(i,j))$$

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?

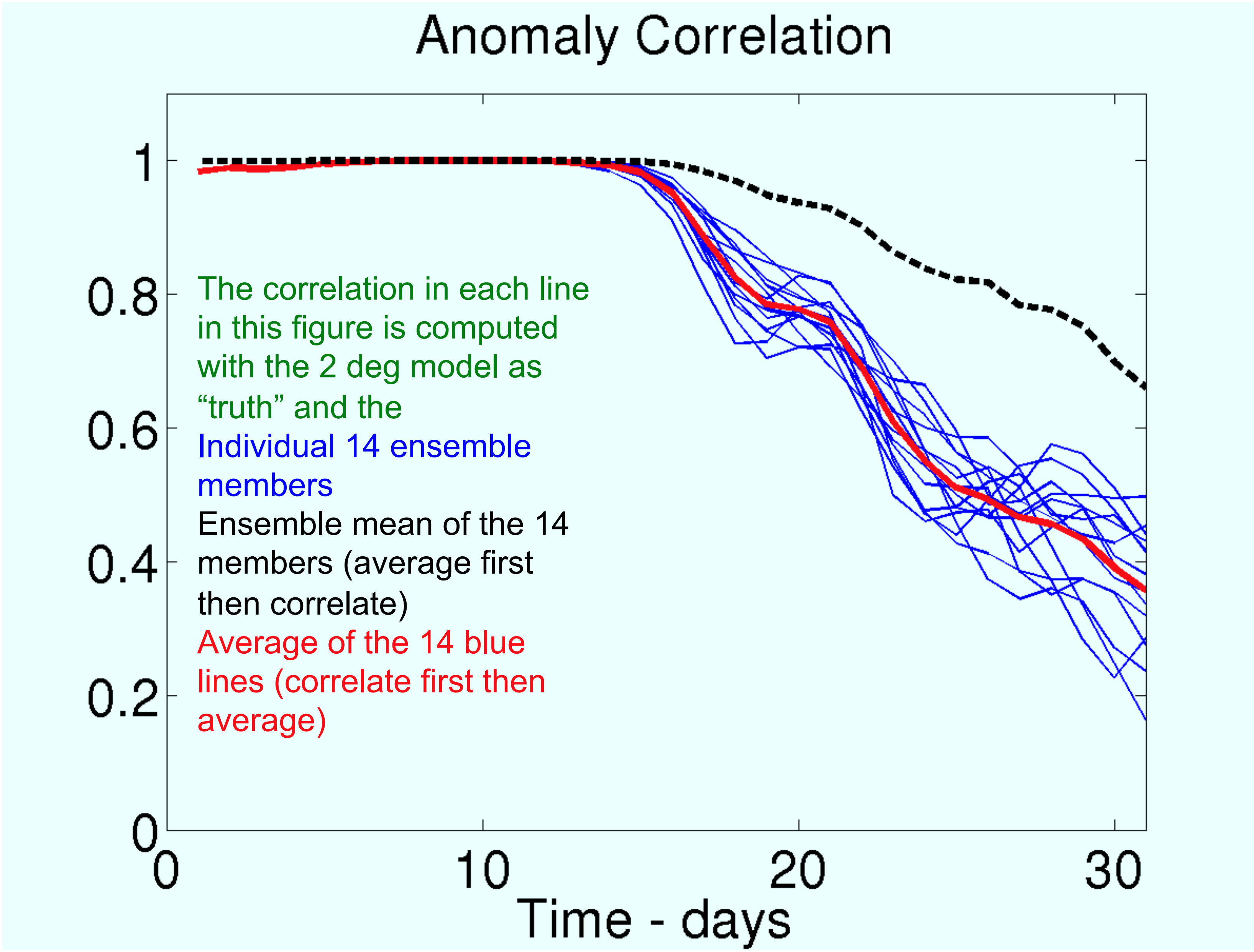
Hence the “test” is the average of the perturbed initial condition ensemble.


Anomaly Correlation
1
0.8
0.6
0.4
0.2
0
0
10
20
30
Time - days
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)

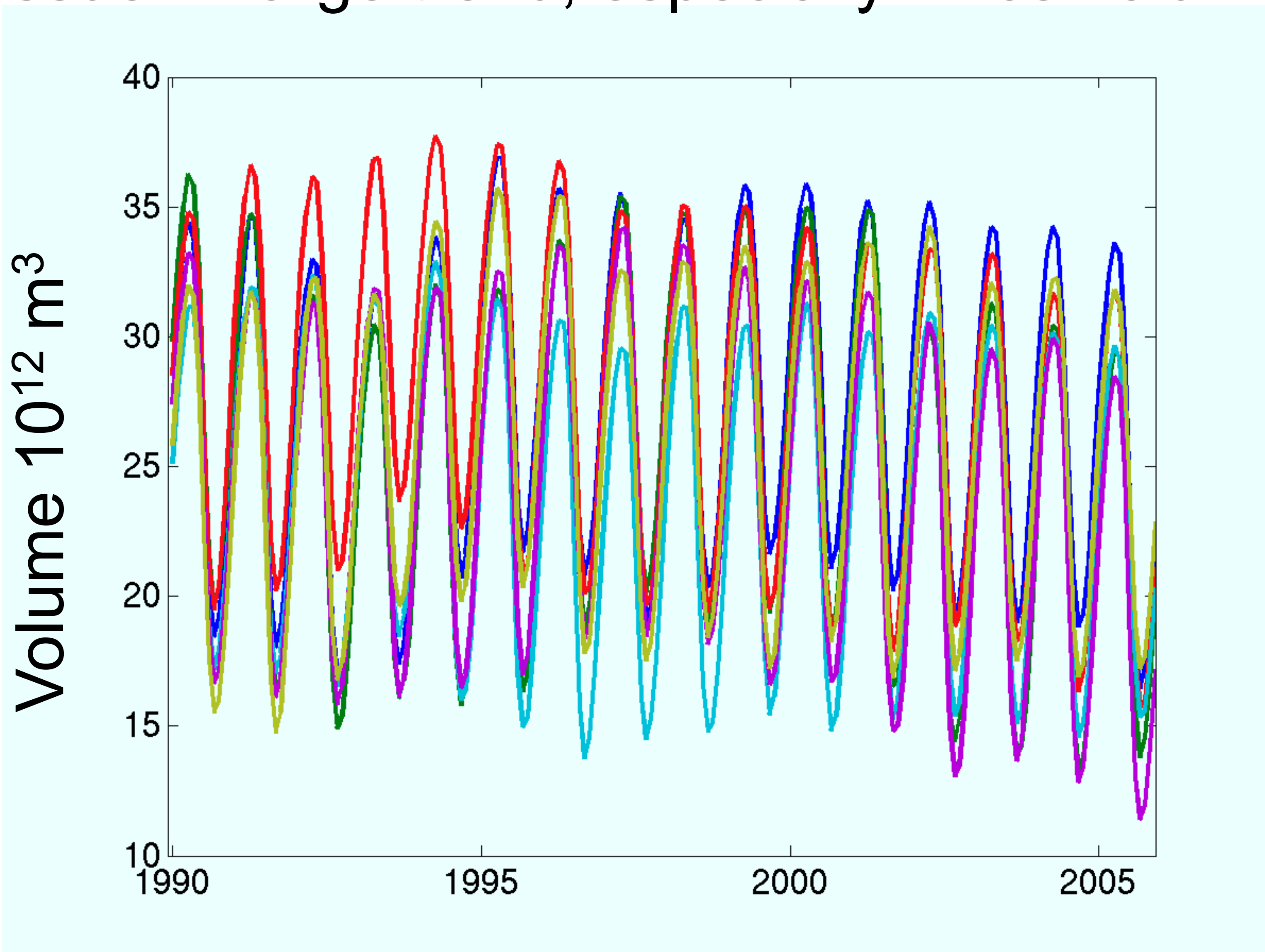
Why are there consistent wiggles in the previous set of curves?

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?

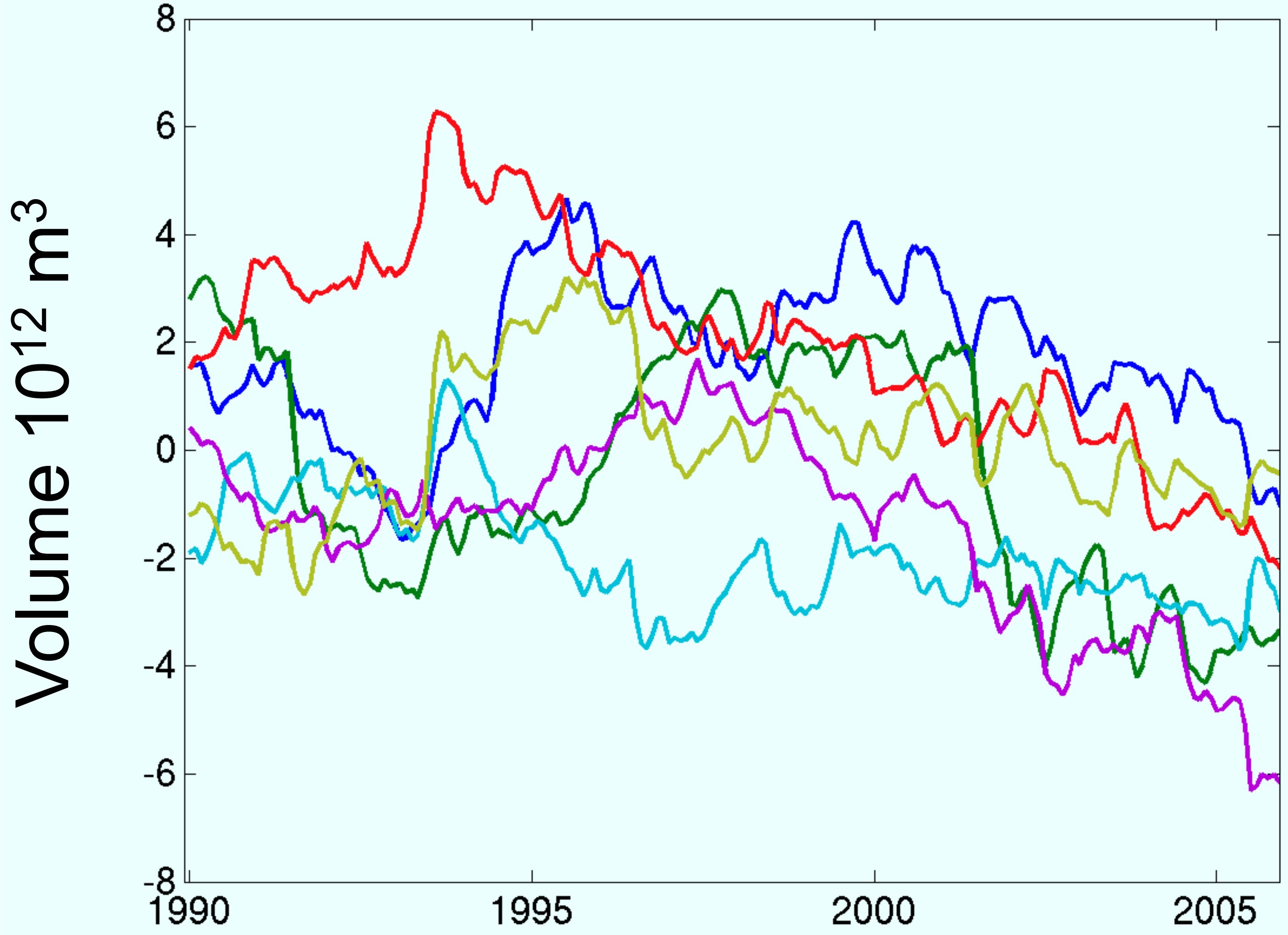

Anomaly Correlation
The correlation in each line
in this figure is computed
with the 2 deg model as
“truth” and the
Individual 14 ensemble
members
Ensemble mean of the 14
members (average first
then correlate)
Average of the 14 blue
lines (correlate first then
average)
0
0.2
0.4
0.6
0.8
1
0
10
20
30
Time - days

Issue 1: large trend, especially in ice volume



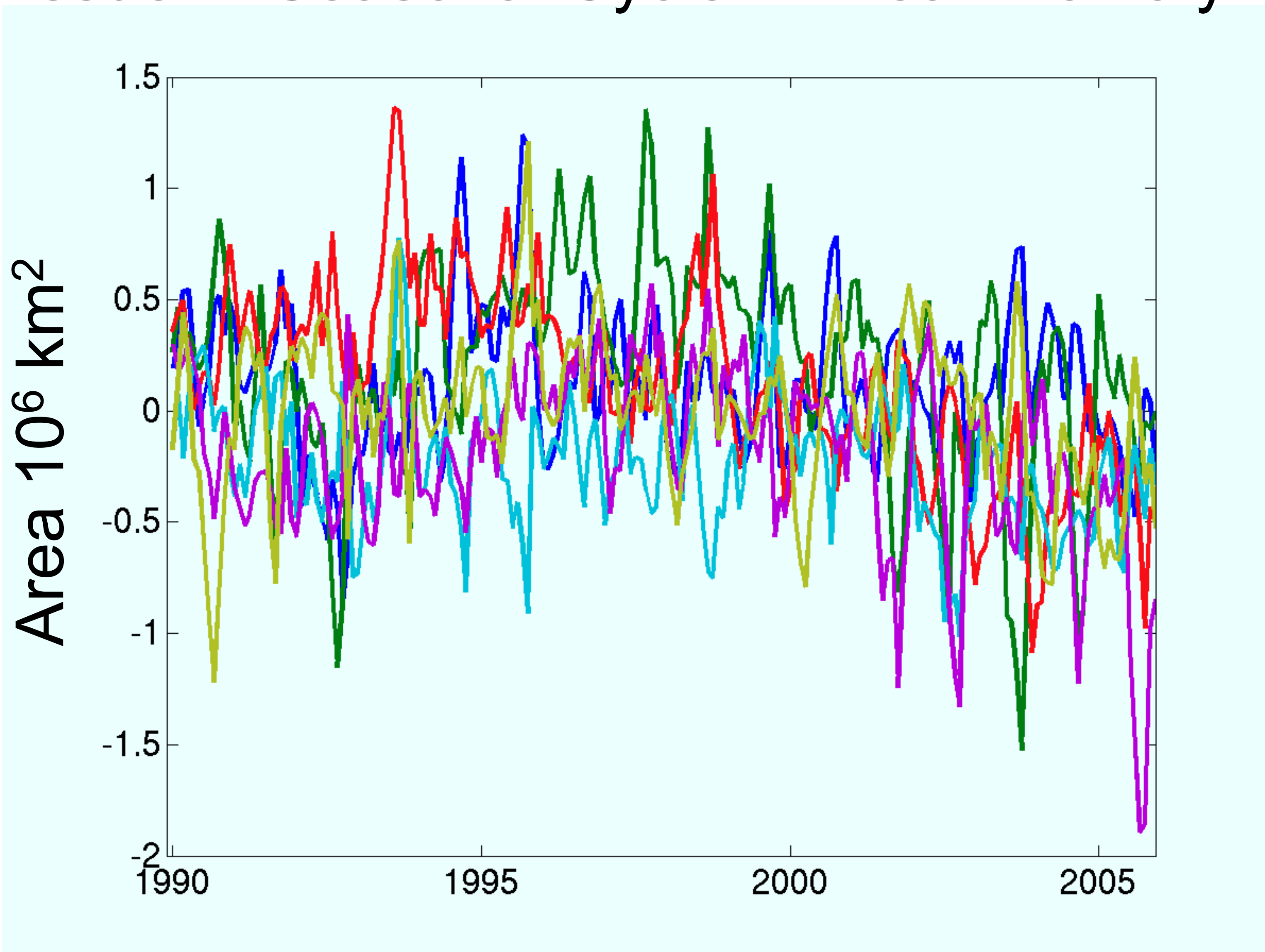
6 ensemble members of 20th Century run

Volume Anomaly



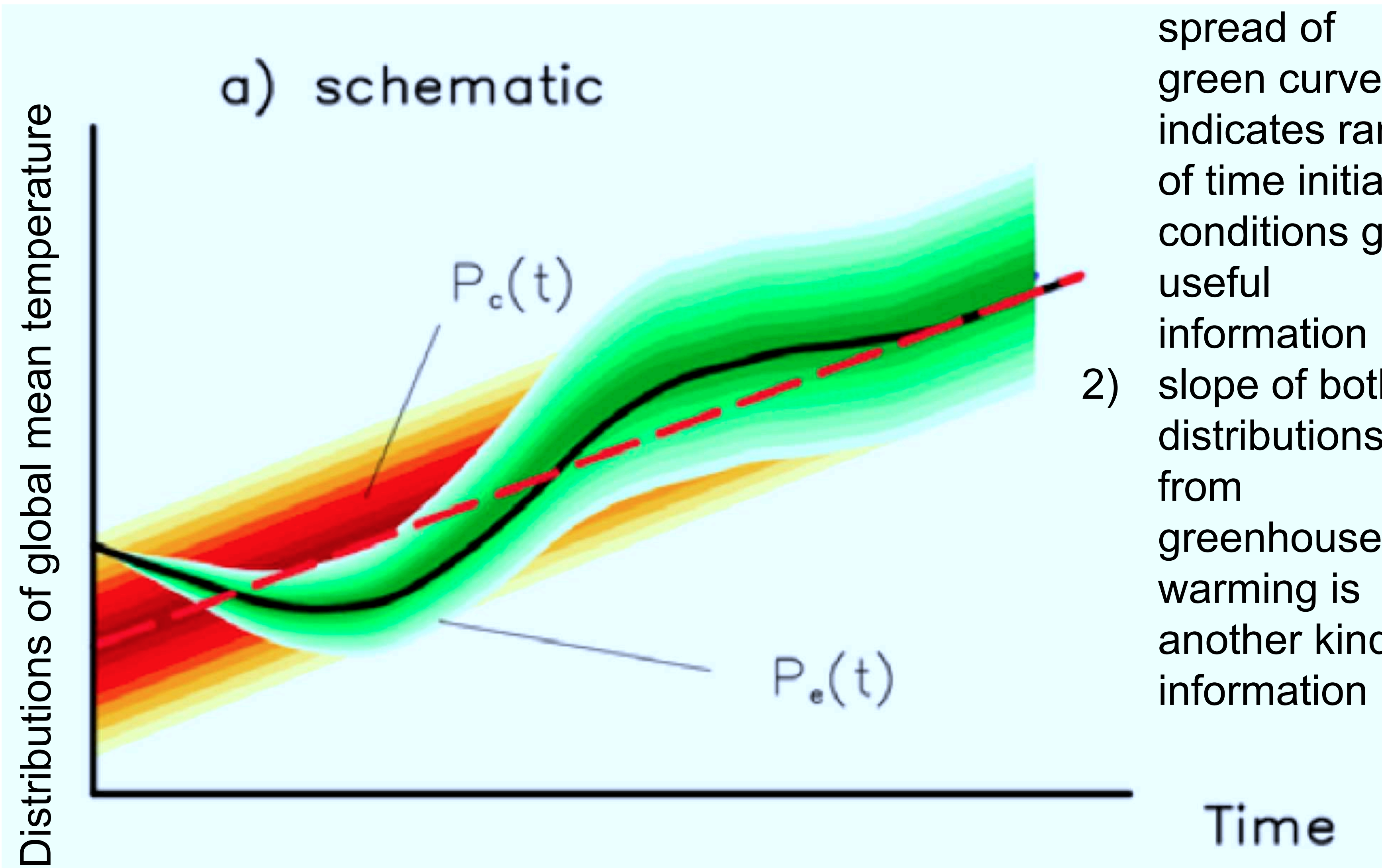
6 ensemble members of 20th Century run

Issue 2: Seasonal Cycle in Area Anomaly



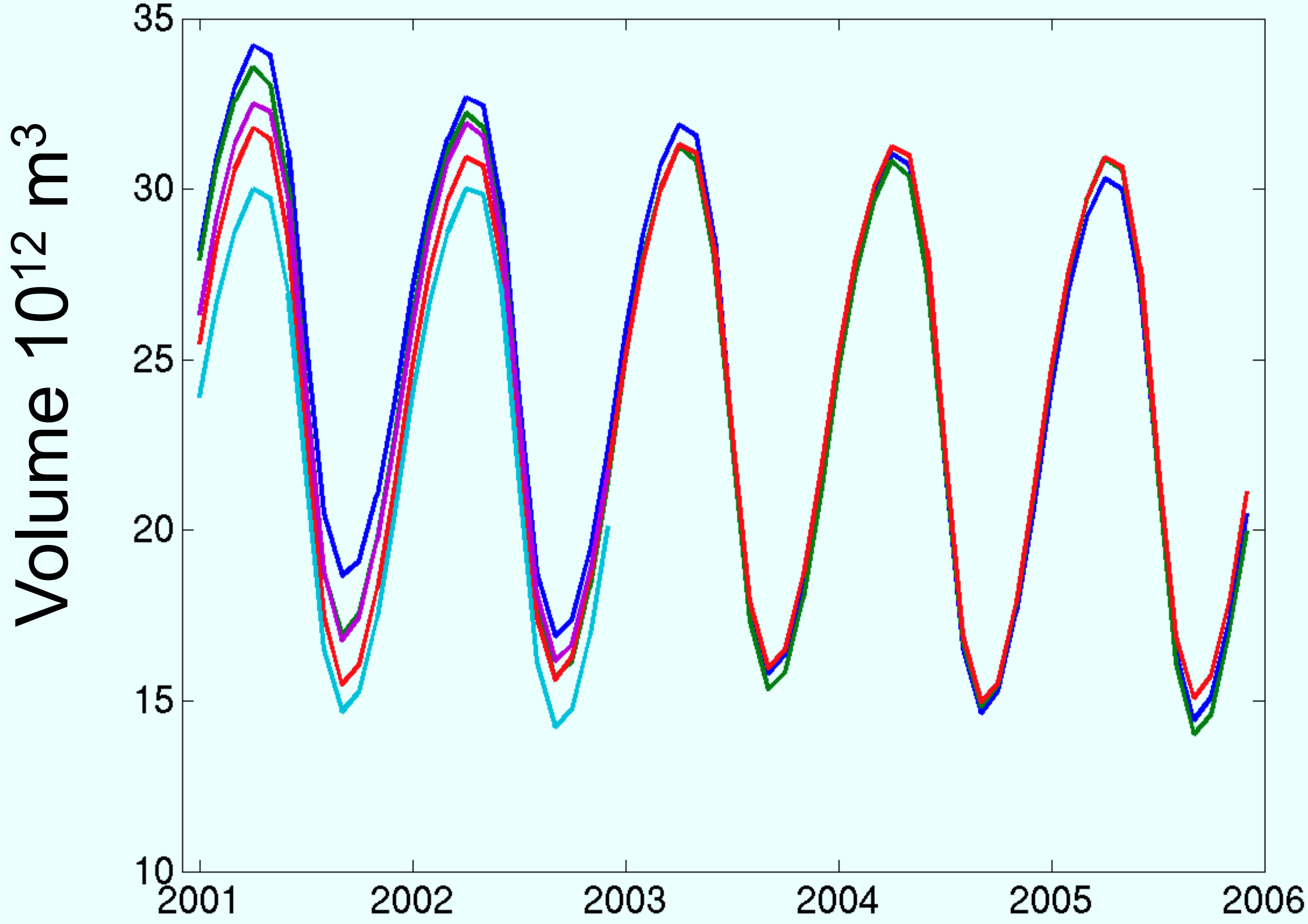
6 ensemble members of 20th Century run

Branstator and Teng, 2010, Two types of predictability



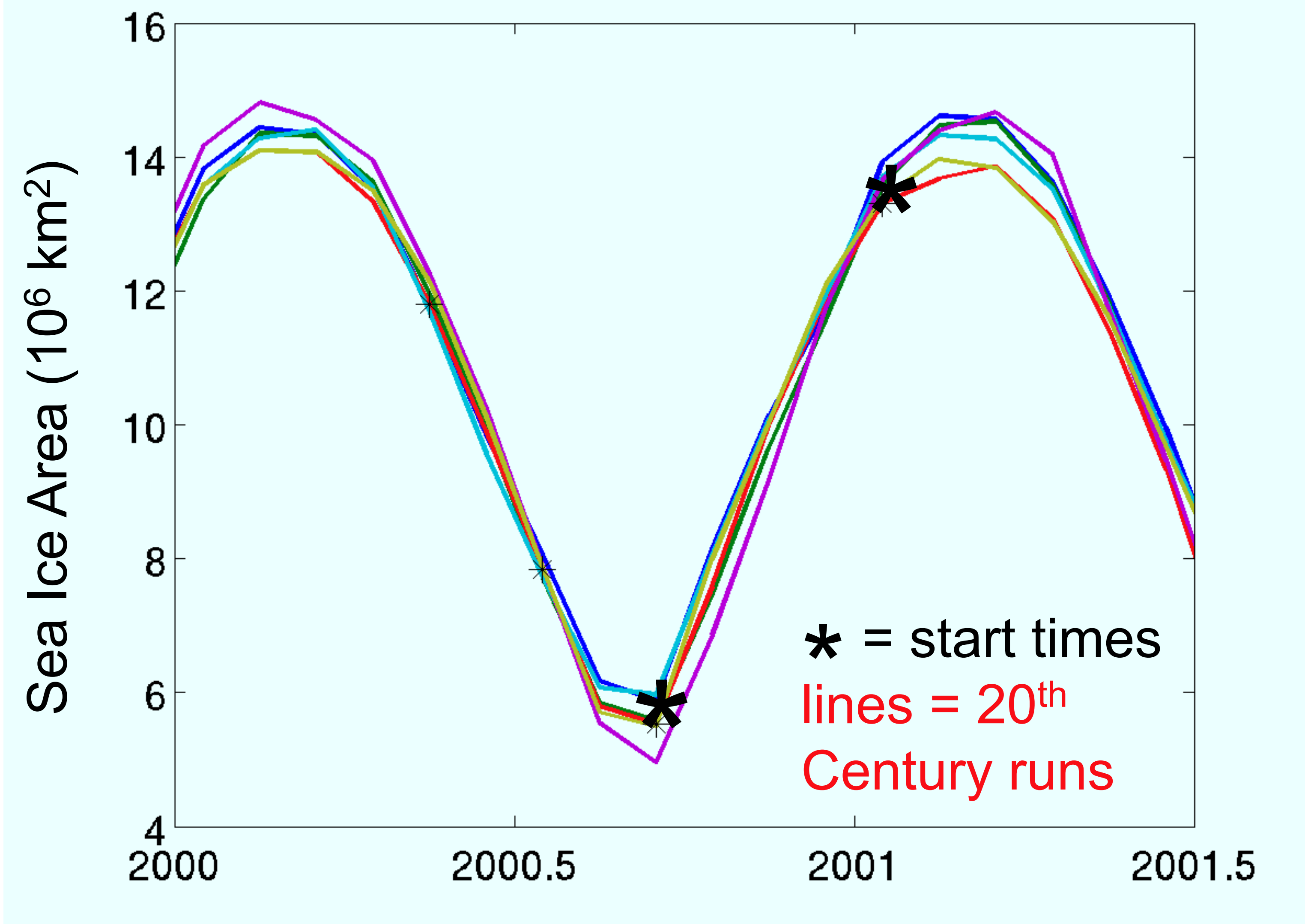
1) growth in spread of green curve indicates range of time initial conditions give useful information
2) slope of both distributions from greenhouse warming is another kind of information

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.

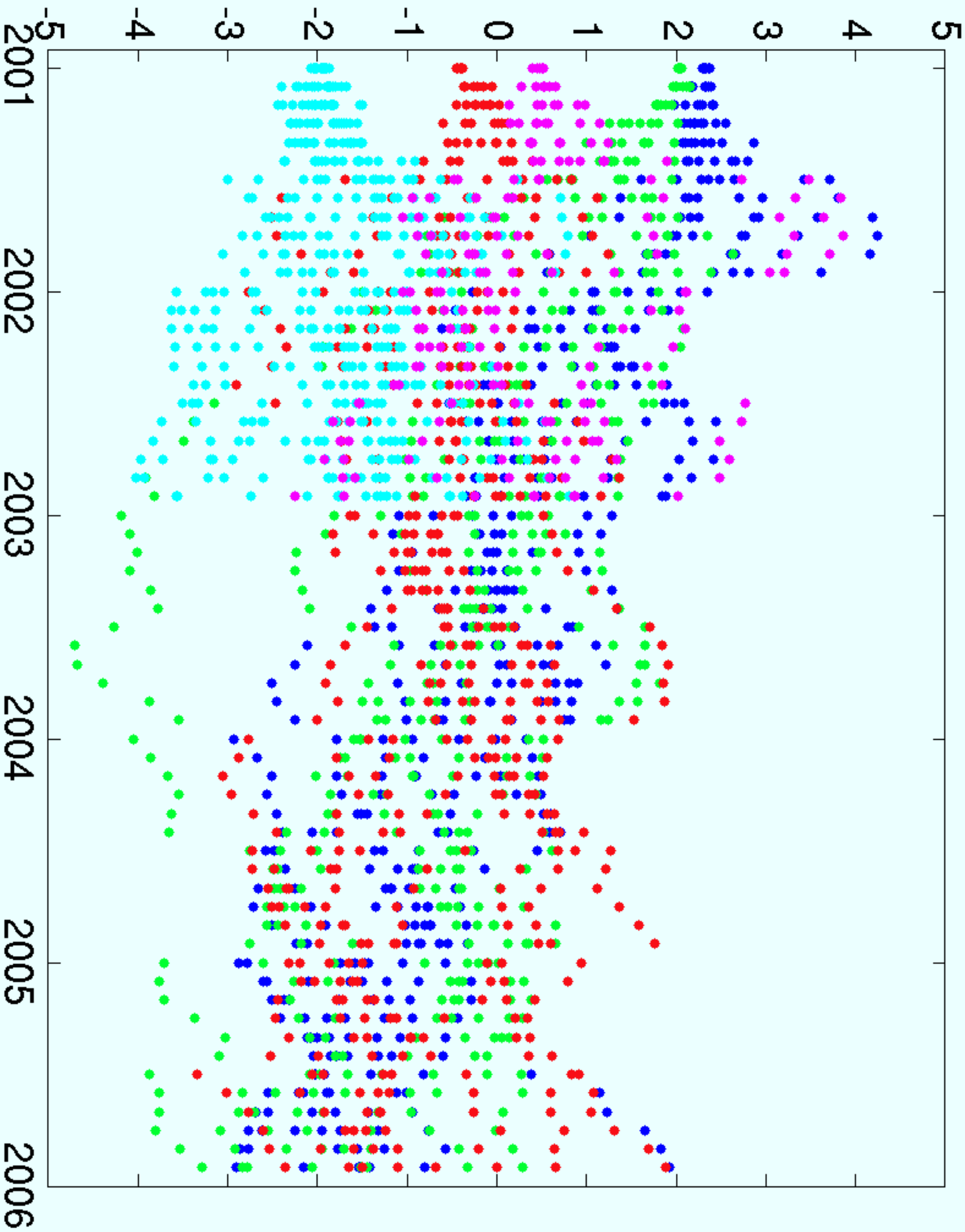


Part 2: “Perfect Model” Studies with CCSM4

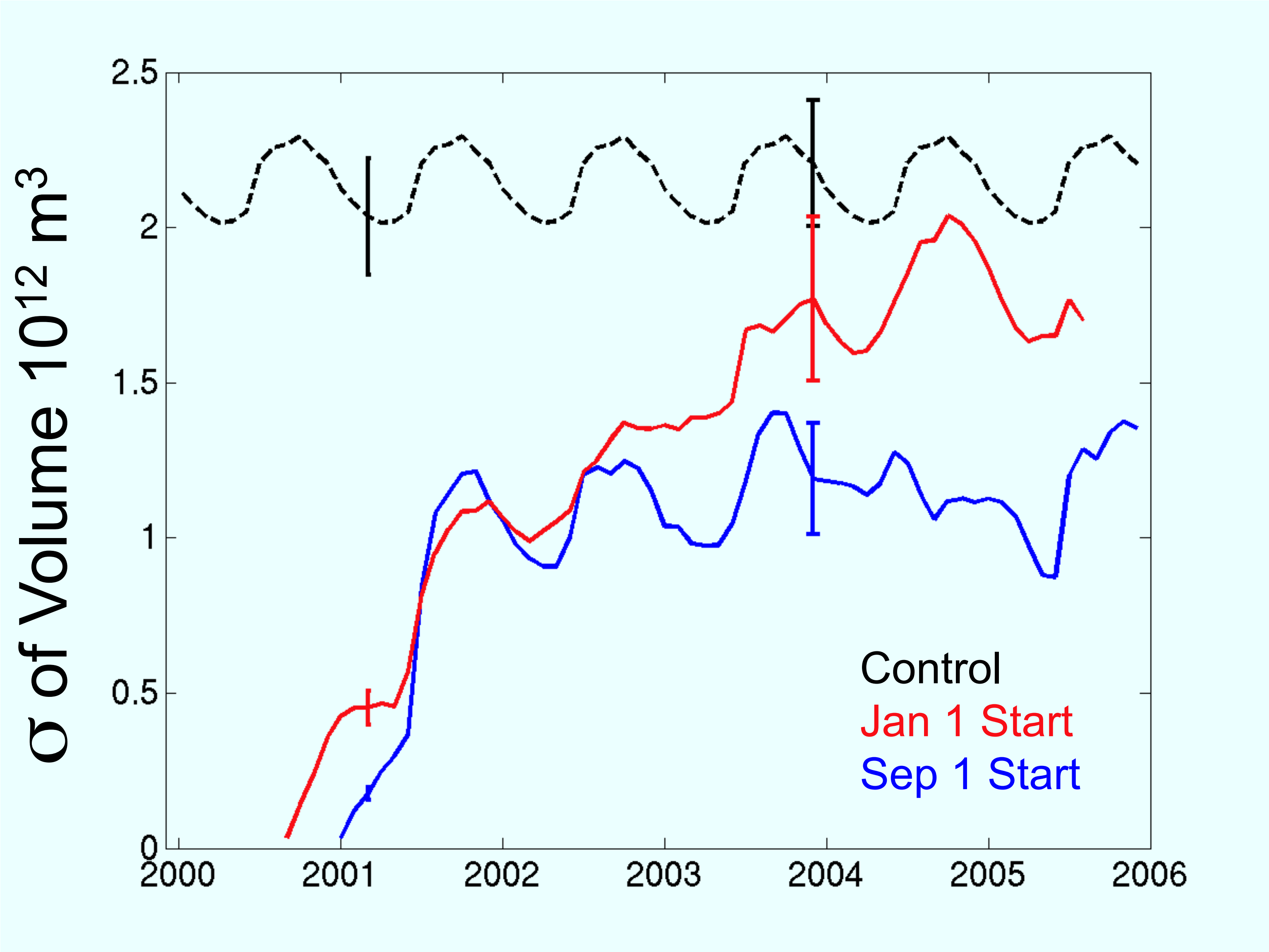
Initialized in year ~2000 of a 20th century run
for various start times



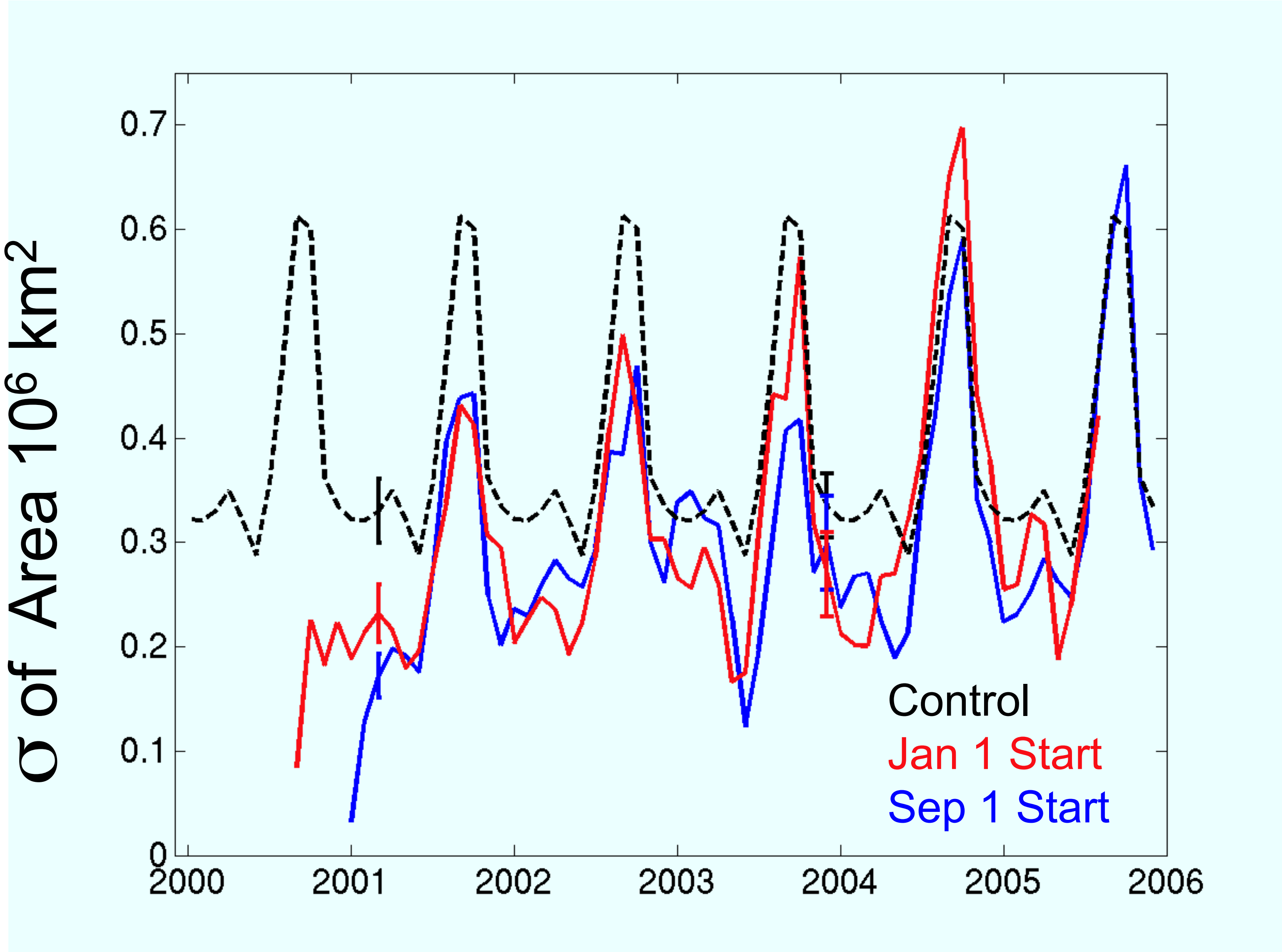
Volume Anomaly 10^{12} m^3

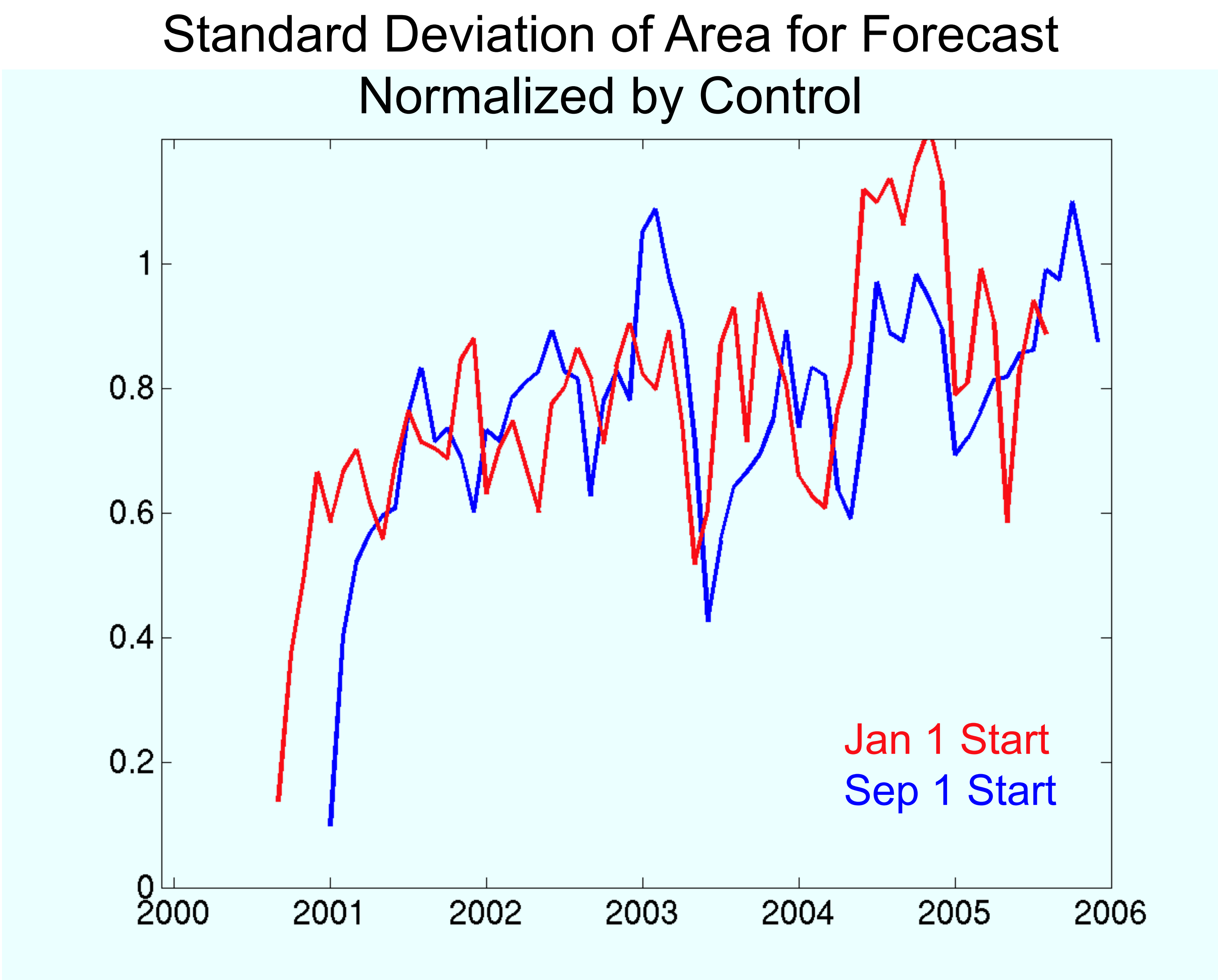


Standard Deviation of Forecast

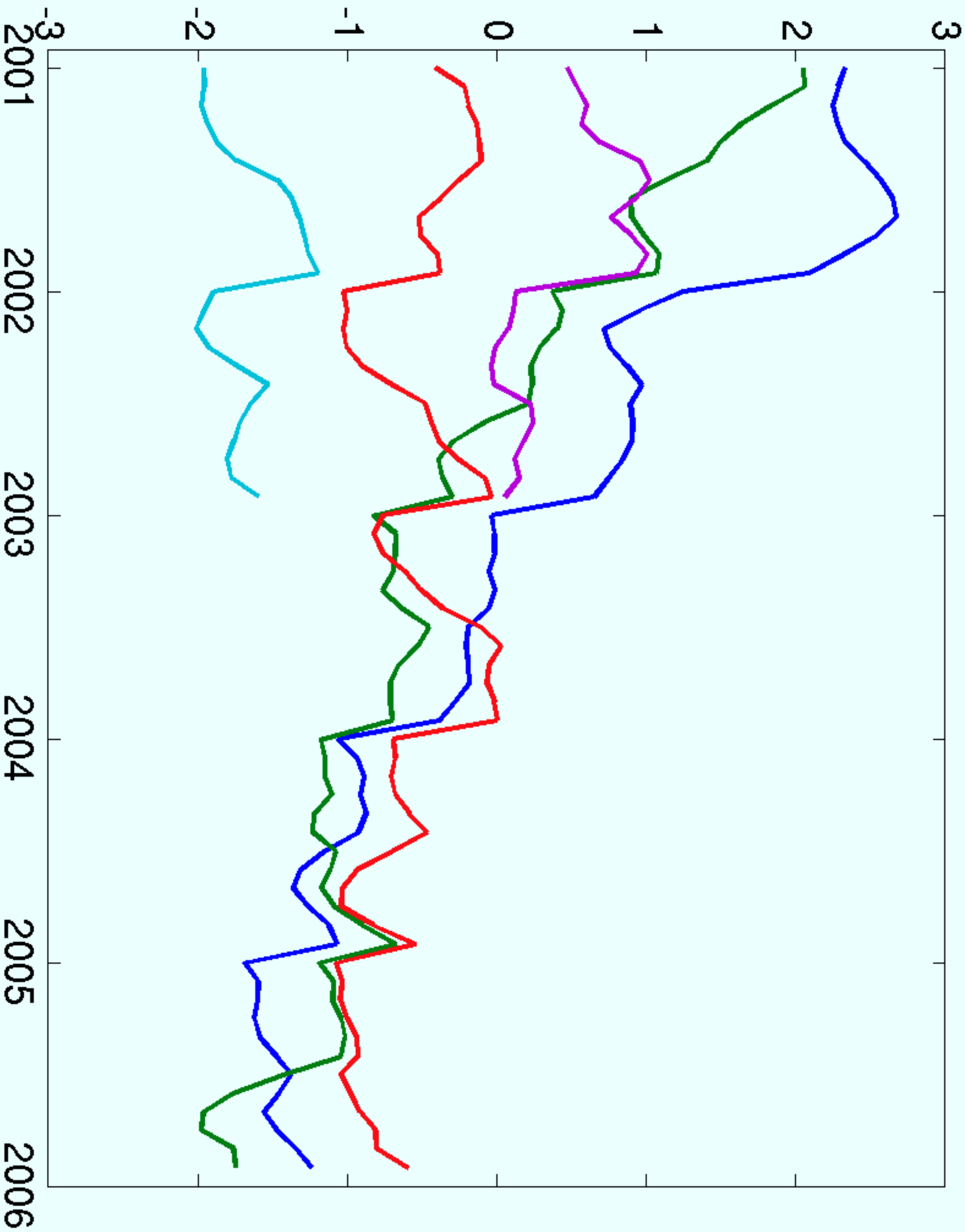


Standard Deviation of Forecast




Standard Deviation of Area for Forecast
Normalized by Control
1
0.8
0.6
0.4
0.2
0
2000
2001
2002
2003
2004
2005
2006
Jan 1 Start
Sep 1 Start

Volume Anomaly 10^{12} m^3



Wednesday Jan 26, 2011

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

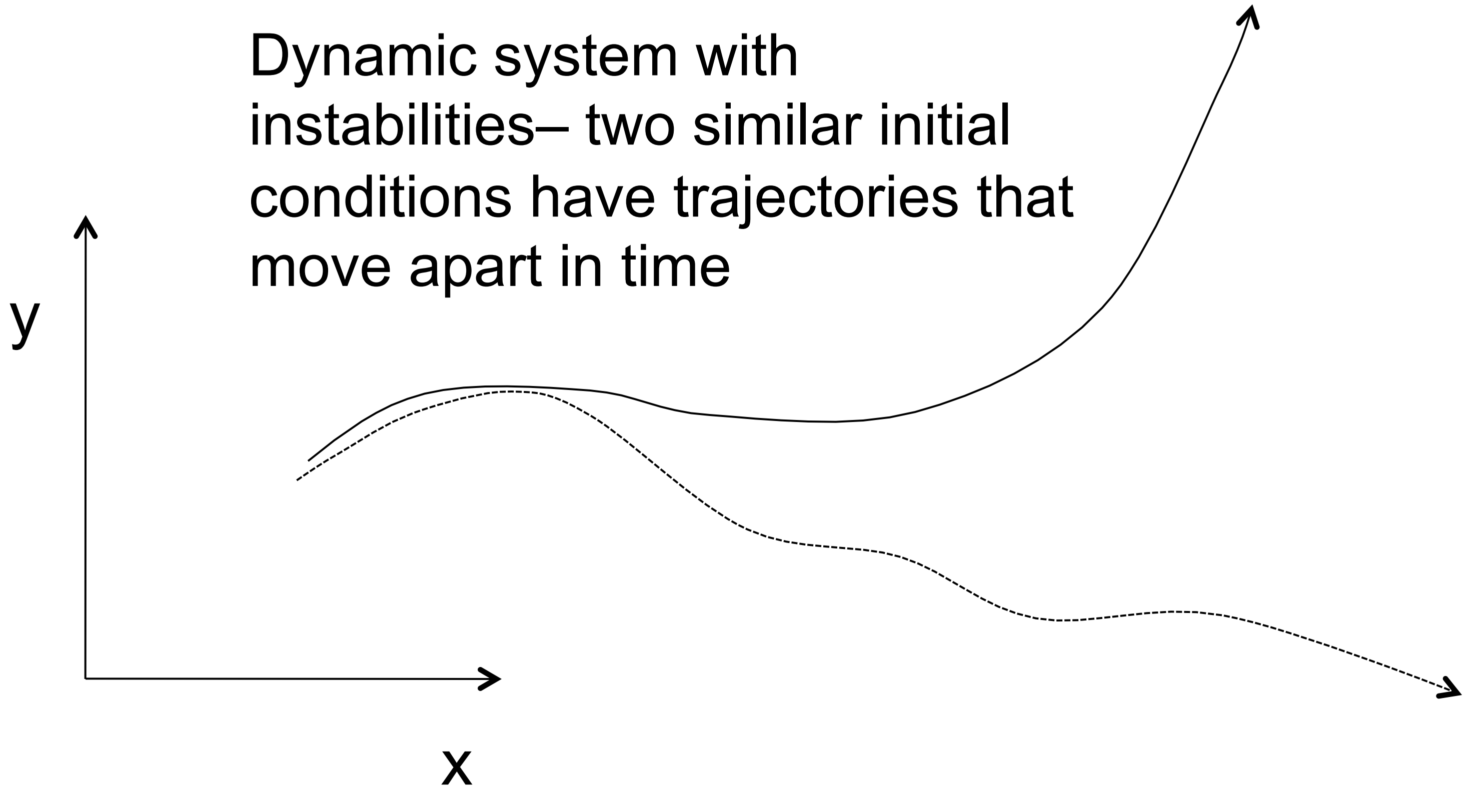
Even if the model is perfect, the initial conditions have to be known to extreme accuracy (in our case the balanced initial conditions didn't grow if initial variables were accurate to within double precision, or about 15 decimal places, but did grow when perturbed in the fourth decimal place). Also 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)

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = x(\rho - z) - y$$

$$\frac{dz}{dt} = xy - \beta z$$

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

Lorenz Equations – Lorenz was seeking a set of equations that with instabilities (and non periodic)

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = x(\rho - z) - y$$

$$\frac{dz}{dt} = xy - \beta z$$

σ = 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)

ρ= Rayleigh Number, when low, heat transfer is primarily via conduction as compared to convection

Normally σ=10, β=8/3 and ρ is varied

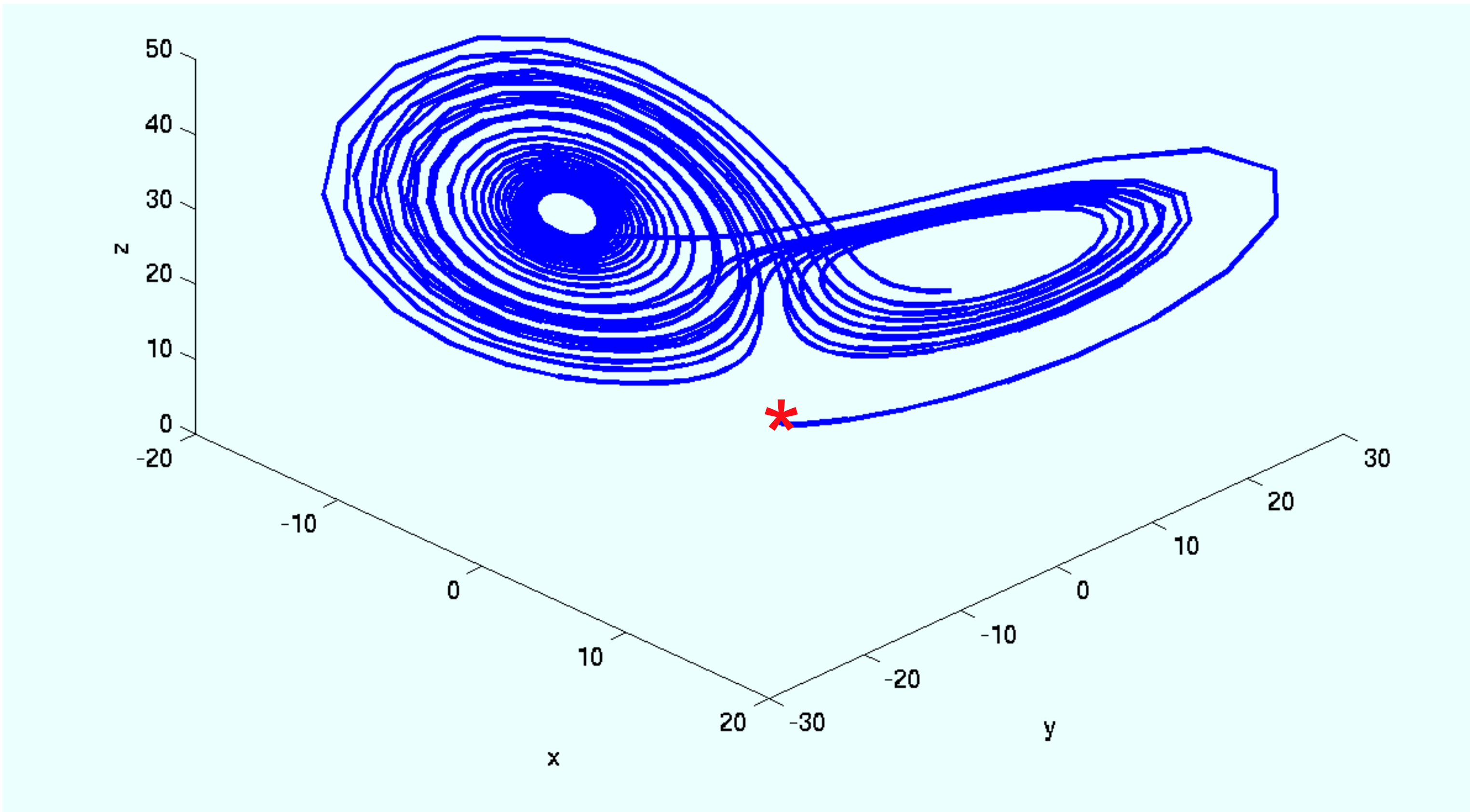
Derived for atmospheric convection, though idealized

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

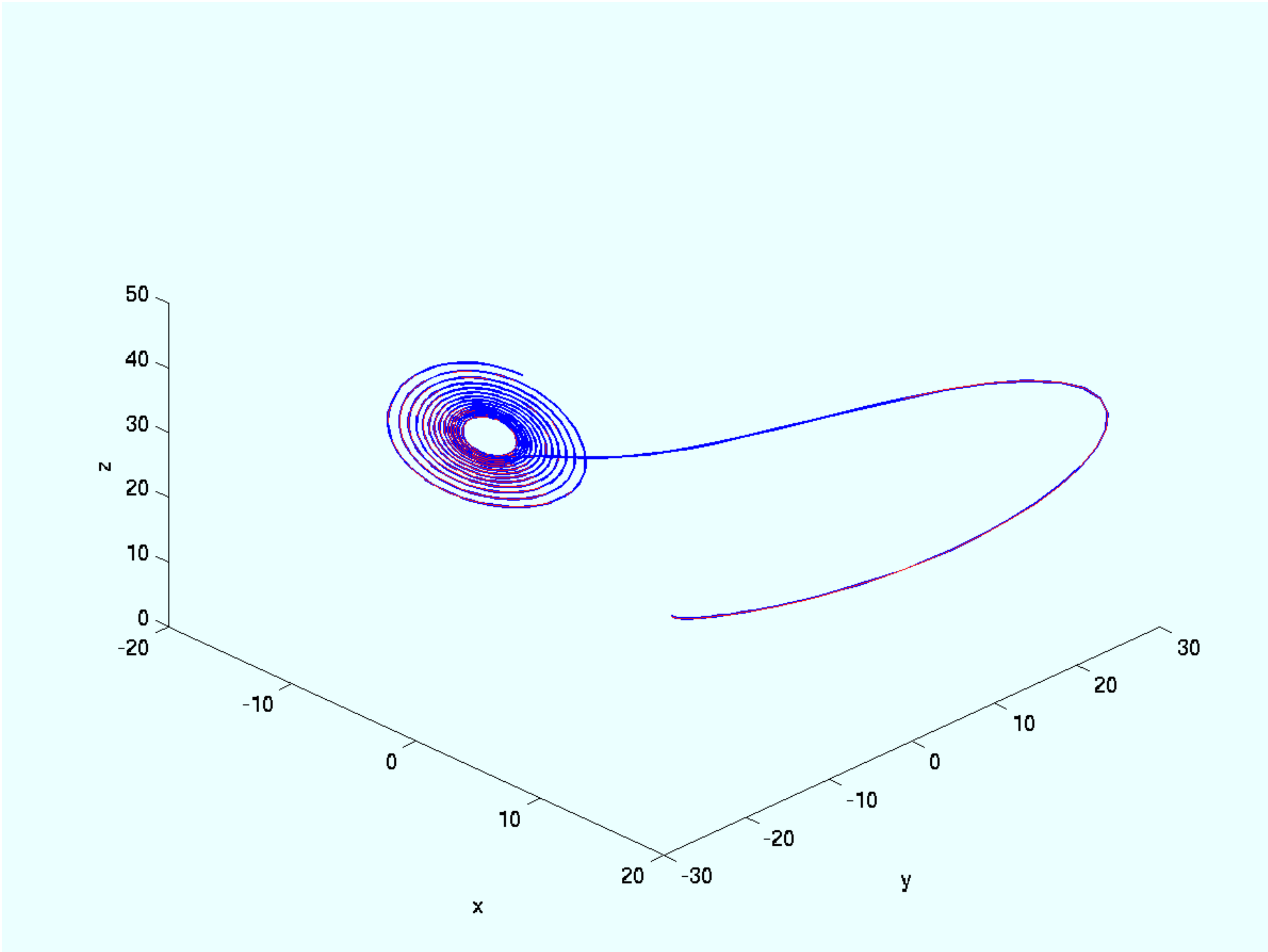
A minute difference in the initial condition makes the solution eventually very different

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



z
50
40
30
20
10
0
-20
-10
0
10
20
x
-30
-20
-10
0
10
20
30
y



50
40
30
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z
-20
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x
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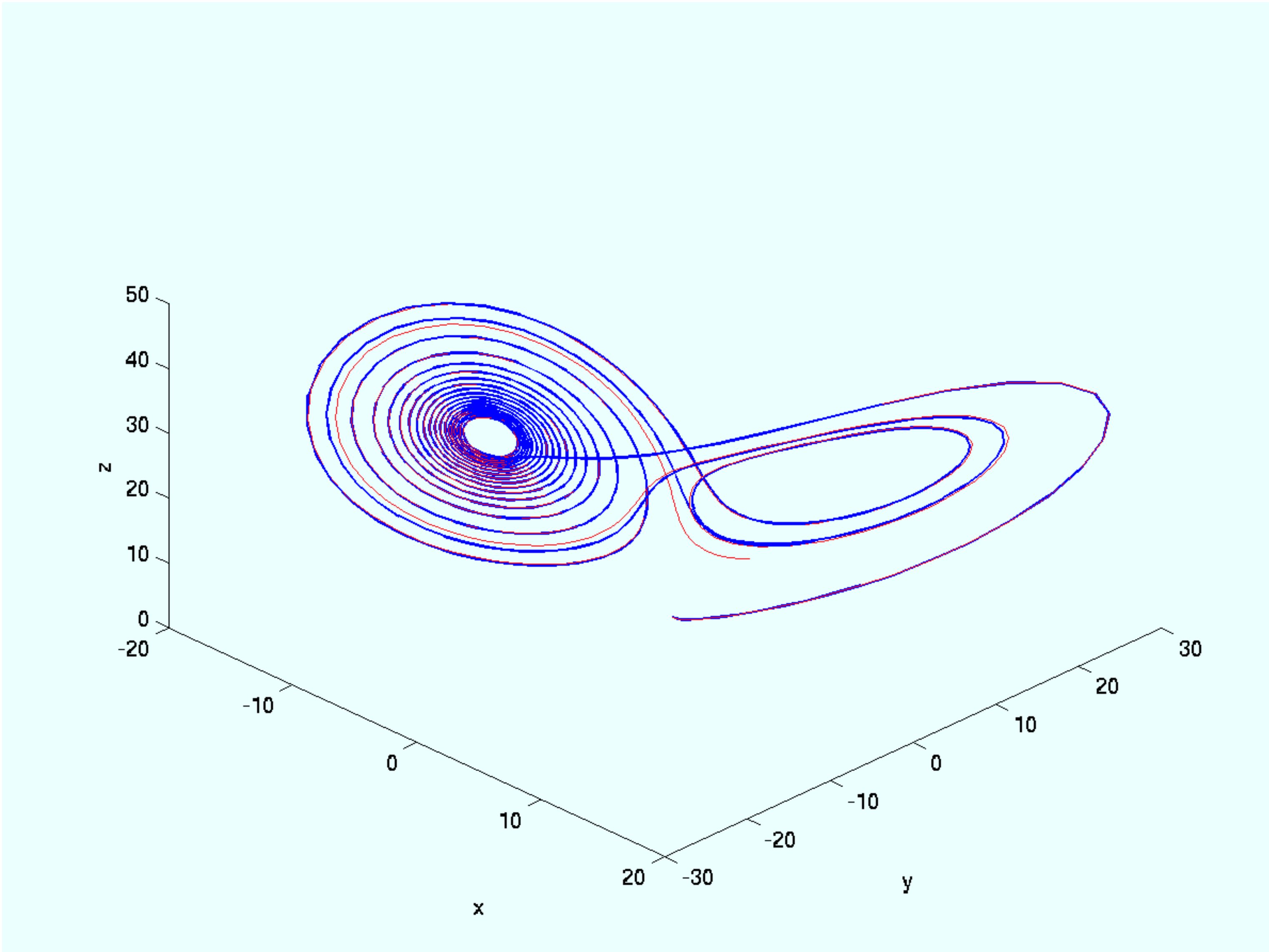
-20
-10
0
10
20
30
y



50
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z
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-10
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20
x
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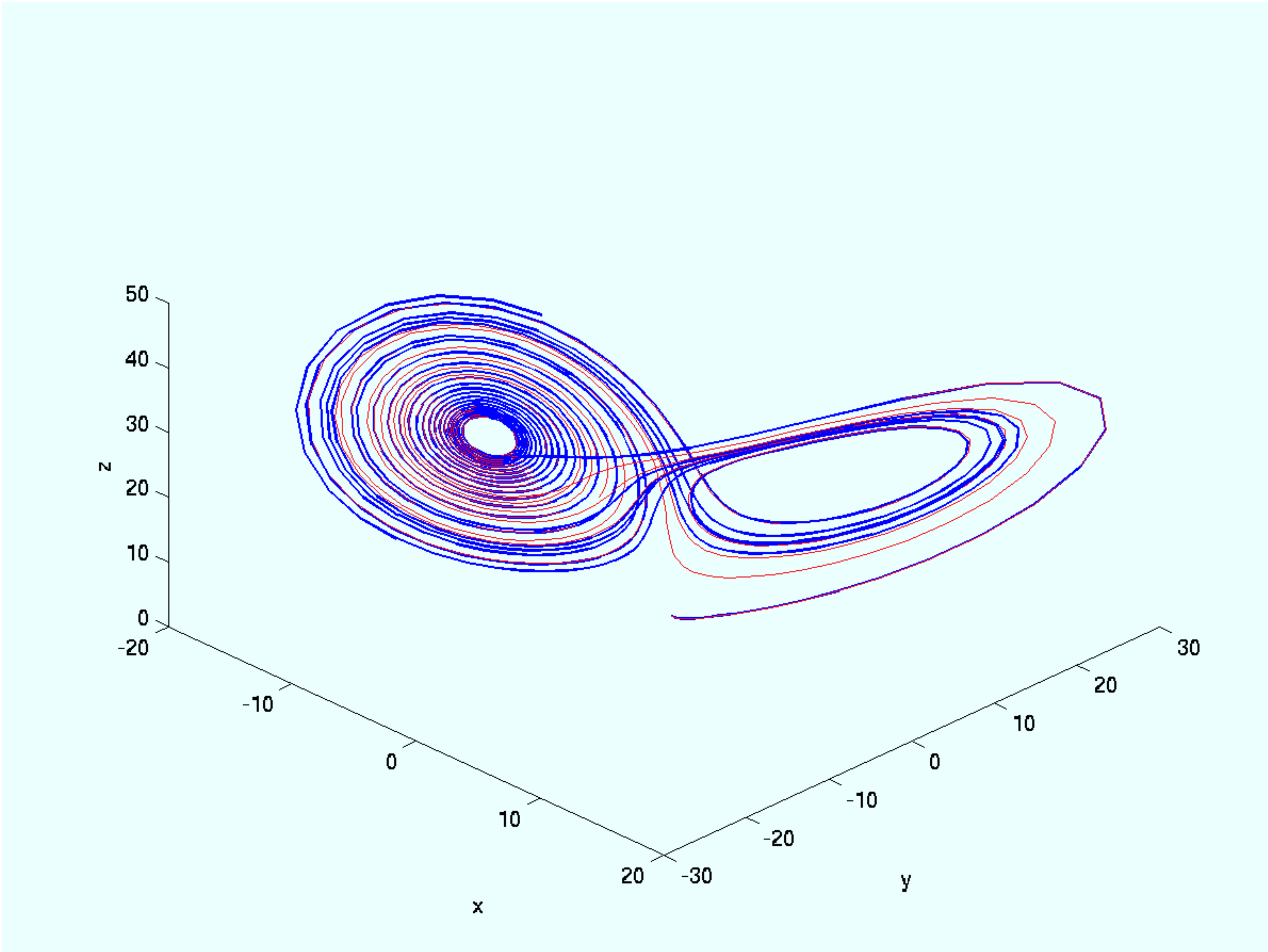
-20
-10
0
10
20
30
y



z
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40
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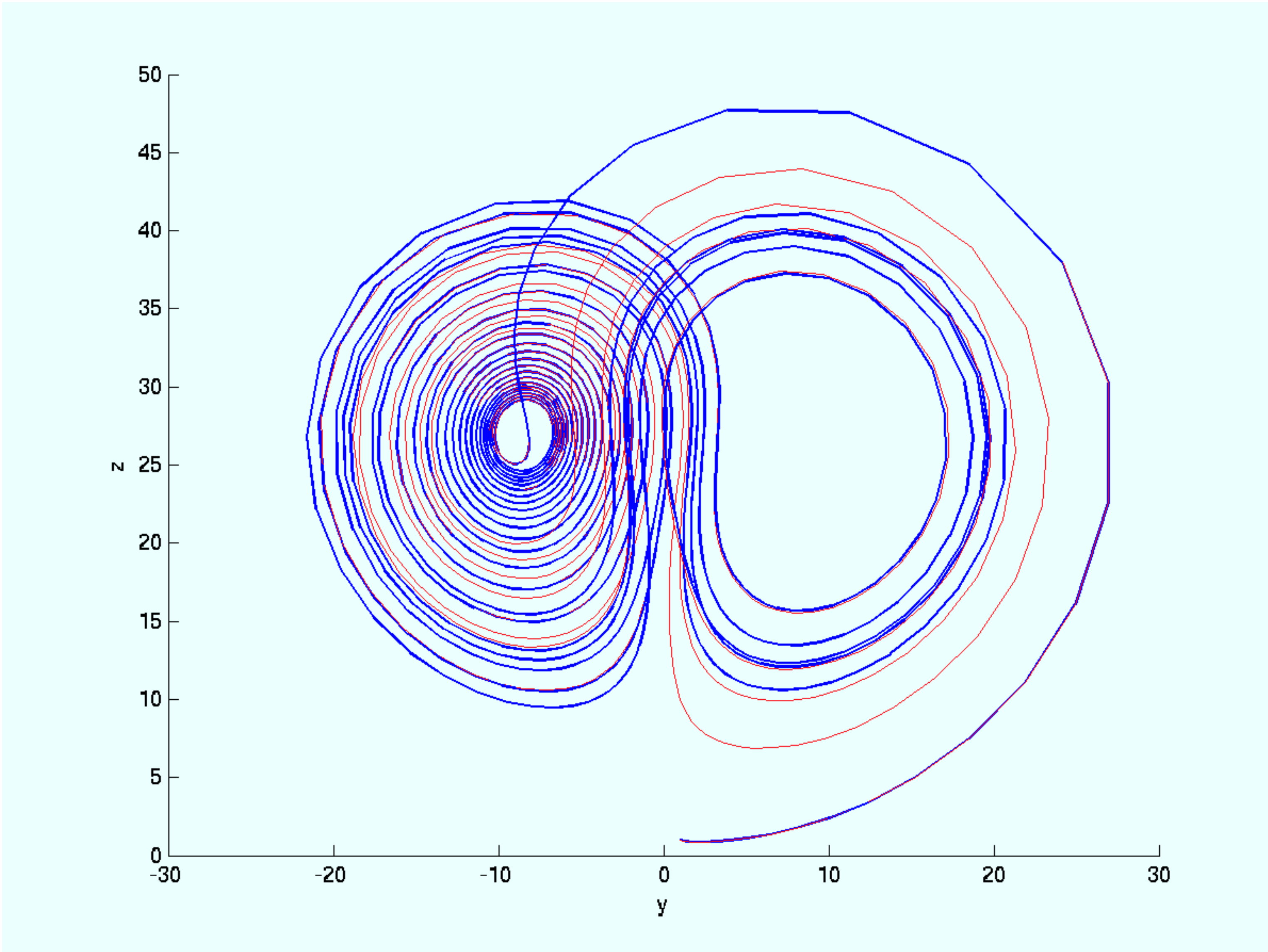
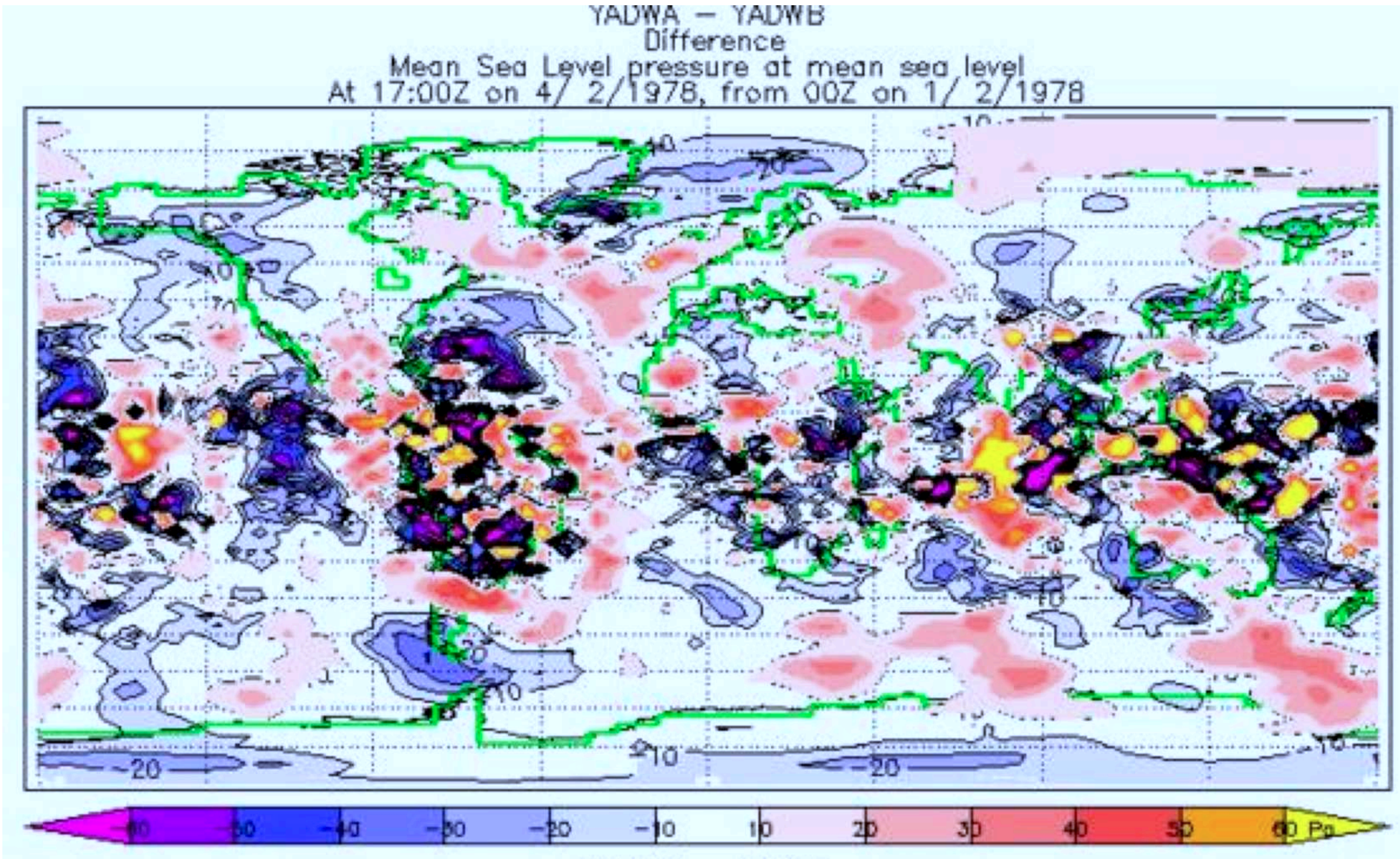
20
10
0
-20
-10
0
10
20
x
-30
-20
-10
0
10
20
30
y


50
45
40
35
30
25
20
15
10
5
0
z
-30
-20
-10
0
10
20
30
y

Does small error in initial condition change the growth rate and frequency of weather in a prediction?

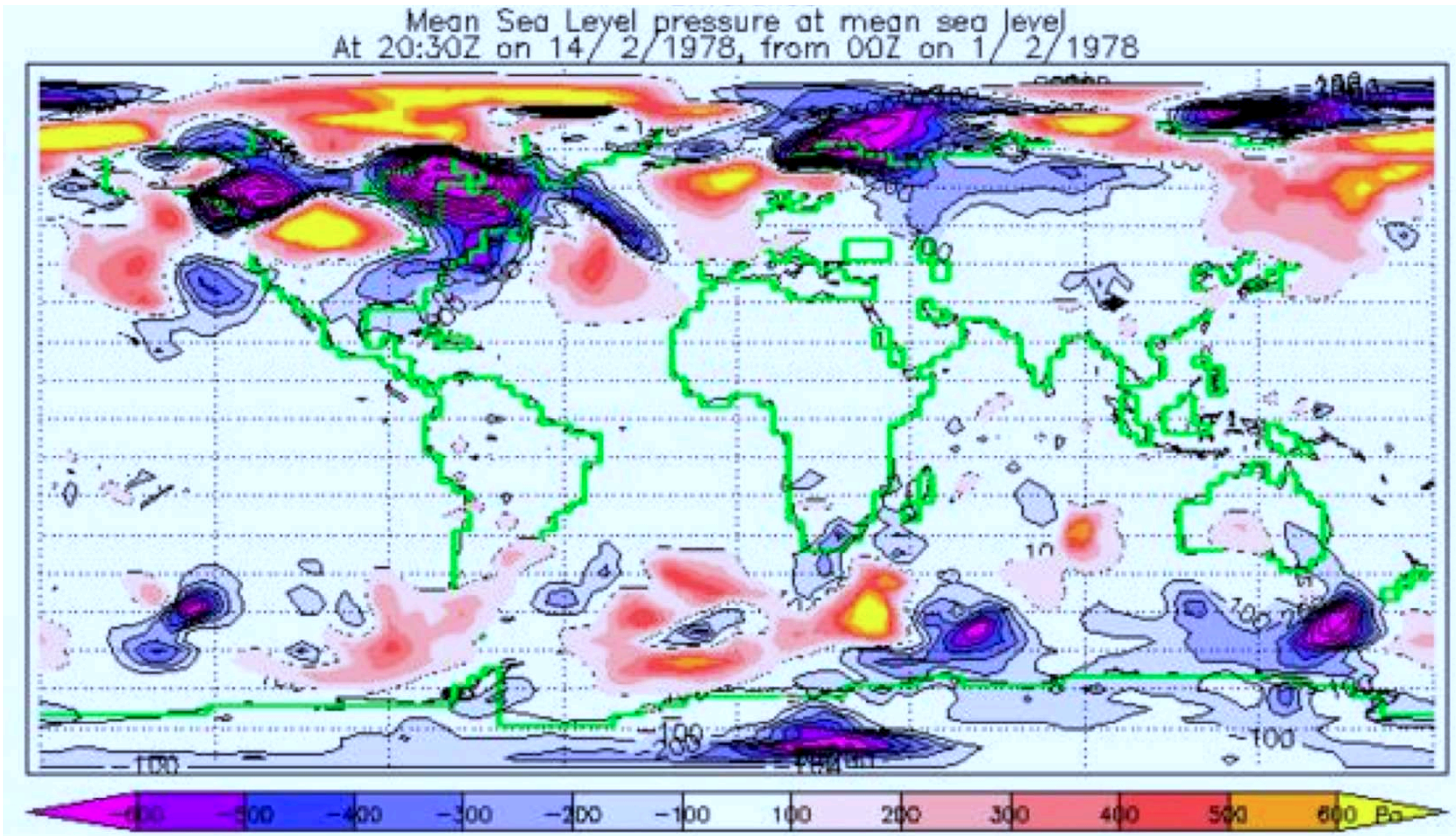
How do we cope with minute errors in the initial conditions?

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

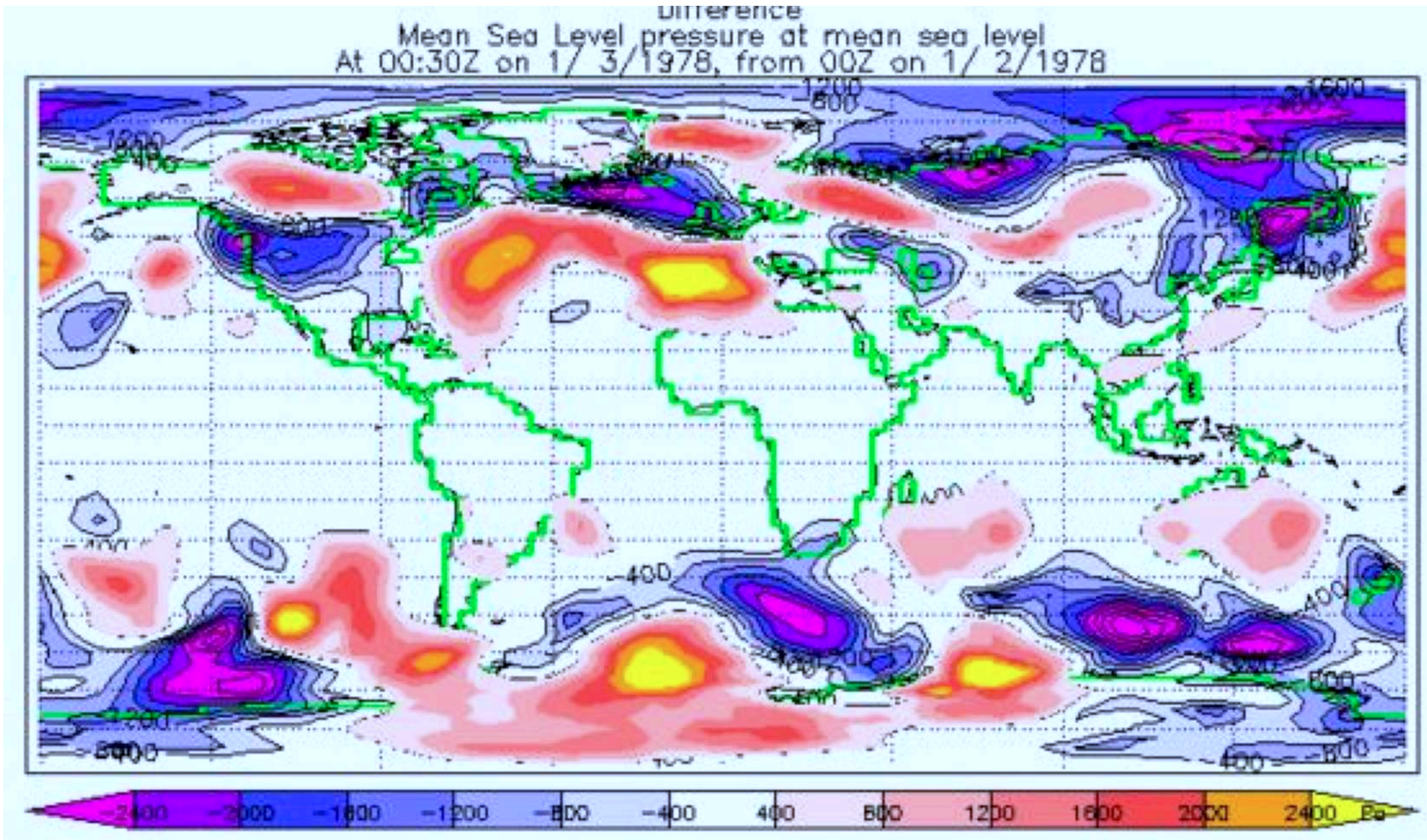


http://mustelid.blogspot.com/2005/10/butterflies-notes-for-post.html

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



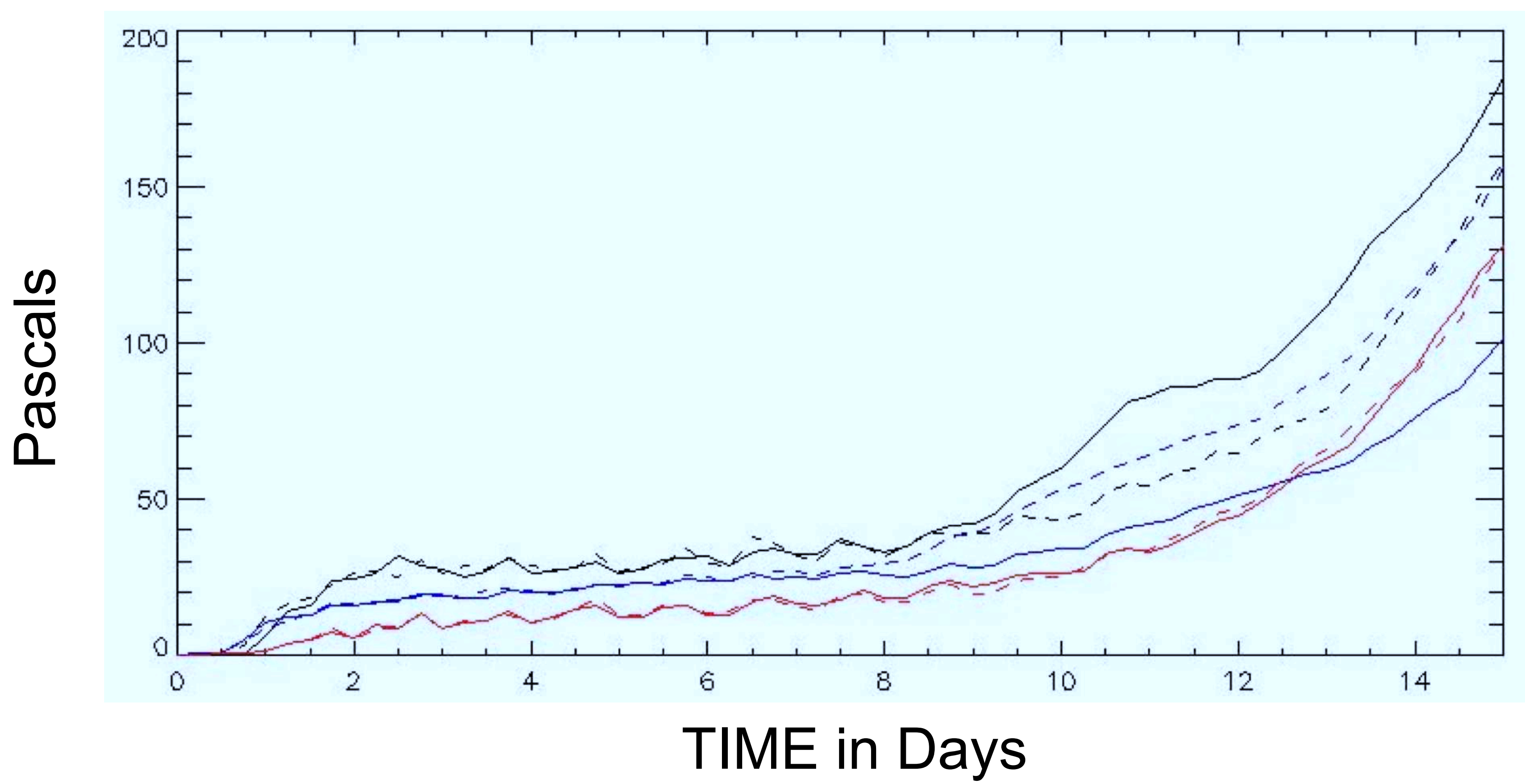
Things to notice:

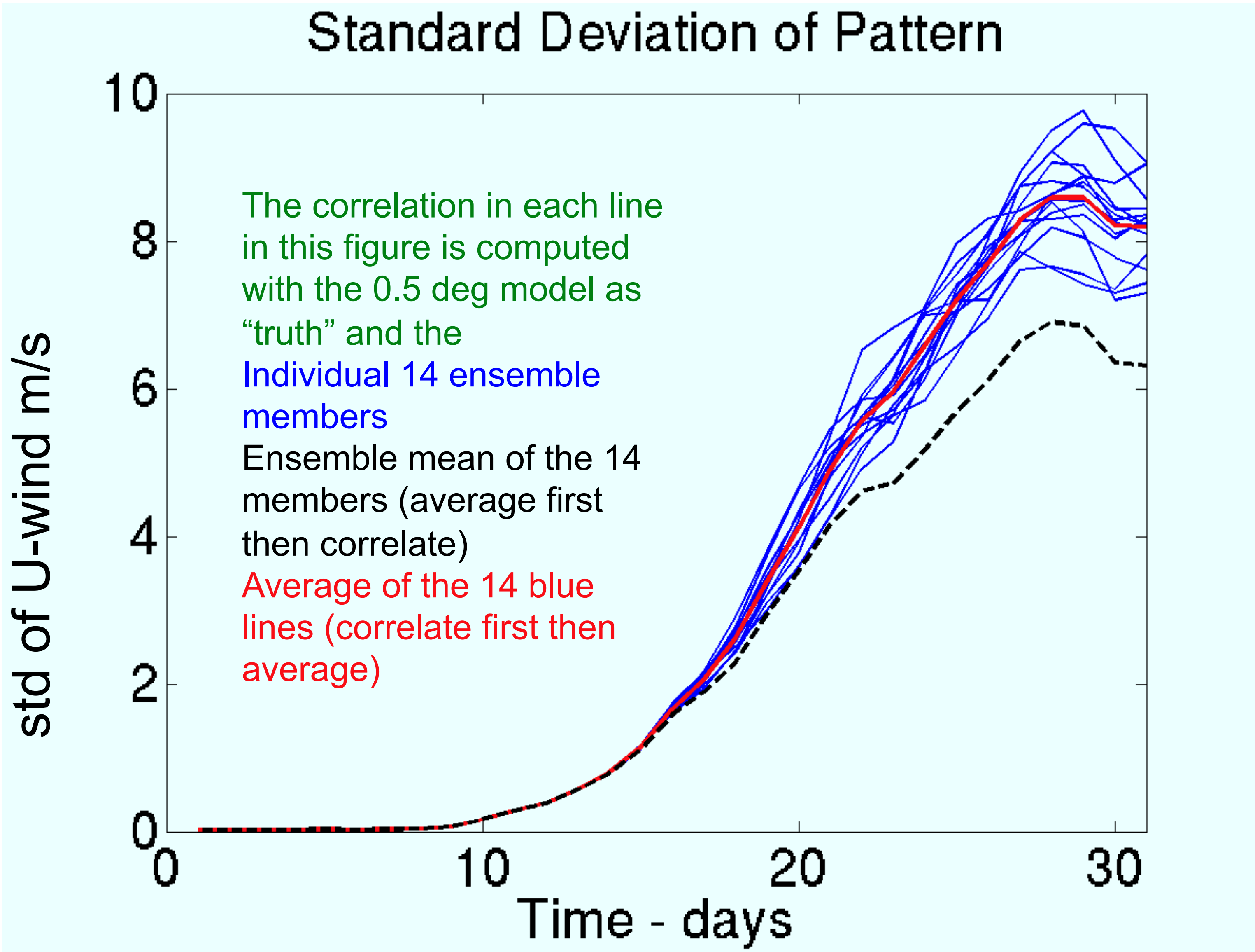
The initial differences look convective.

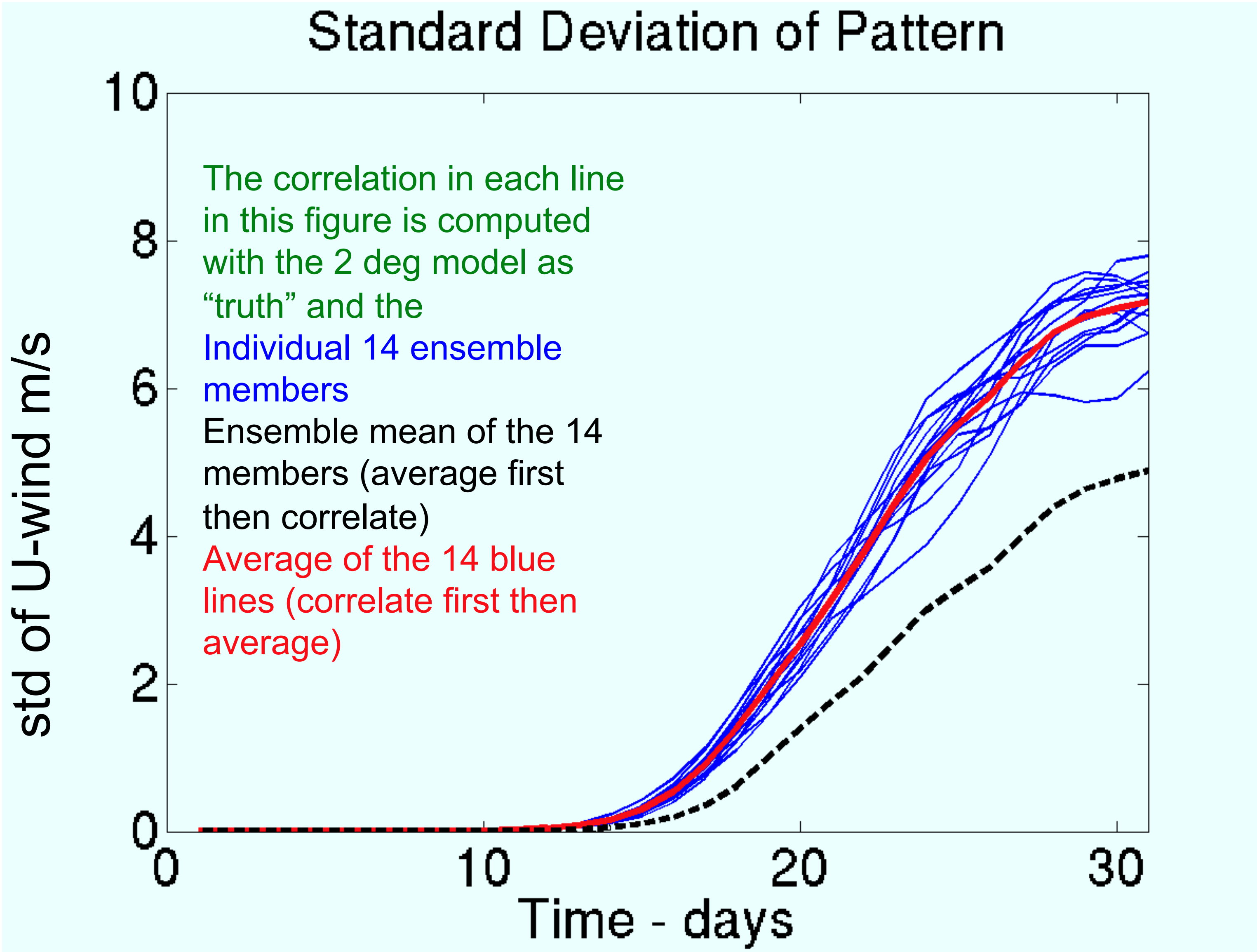
How do you think the growth would differ if the perturbation looked like a storm poised to grow?

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




Standard Deviation of Pattern
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)
std of U-wind m/s
Time - days
0
2
4
6
8
10
0
10
20
30



Standard Deviation of Pattern
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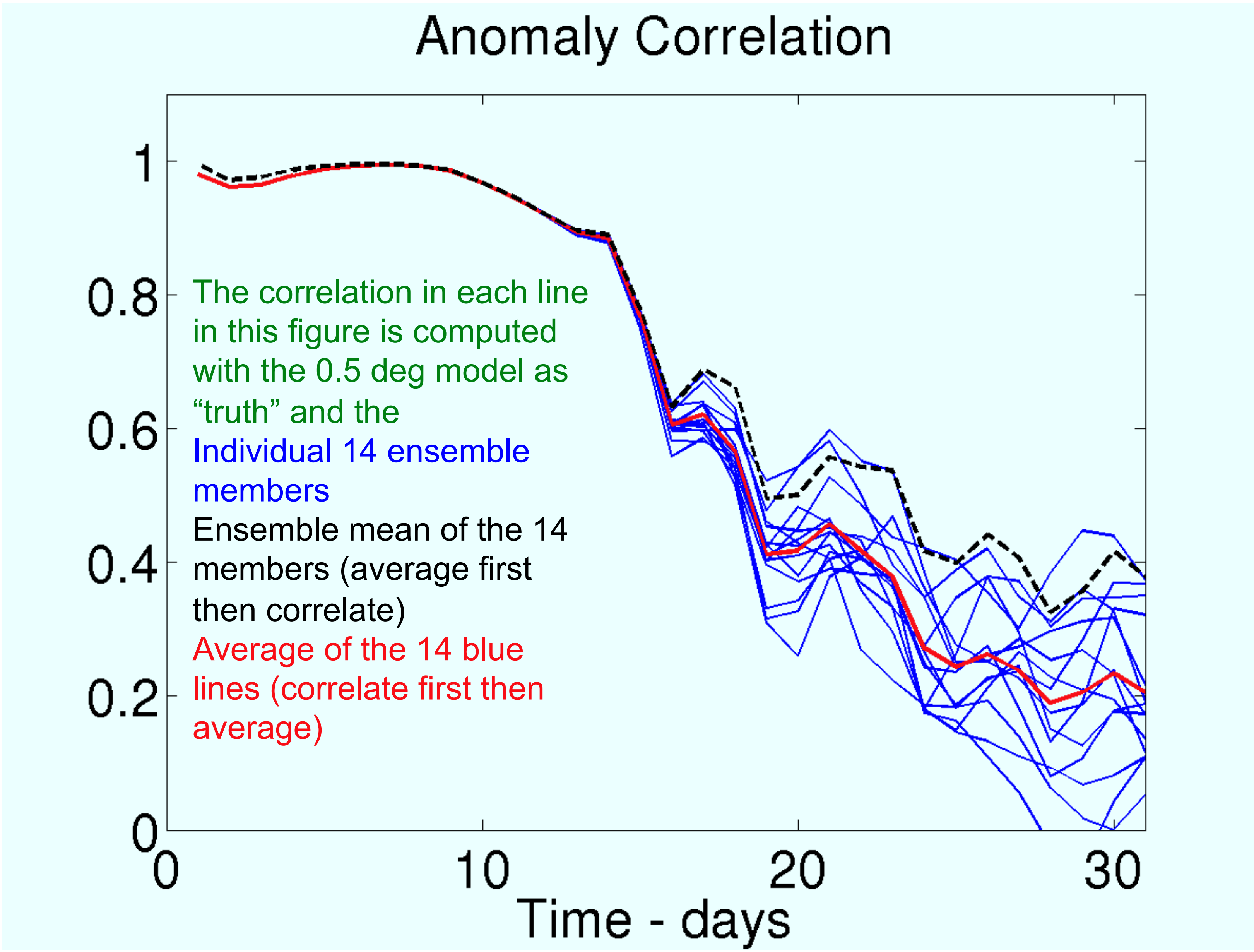
10
0
10
20
30


Anomaly Correlation
1
0.8
0.6
0.4
0.2
0
0
10
20
30
Time - days
The correlation in each line in this figure is computed with the 0.5 deg model as “truth” and the
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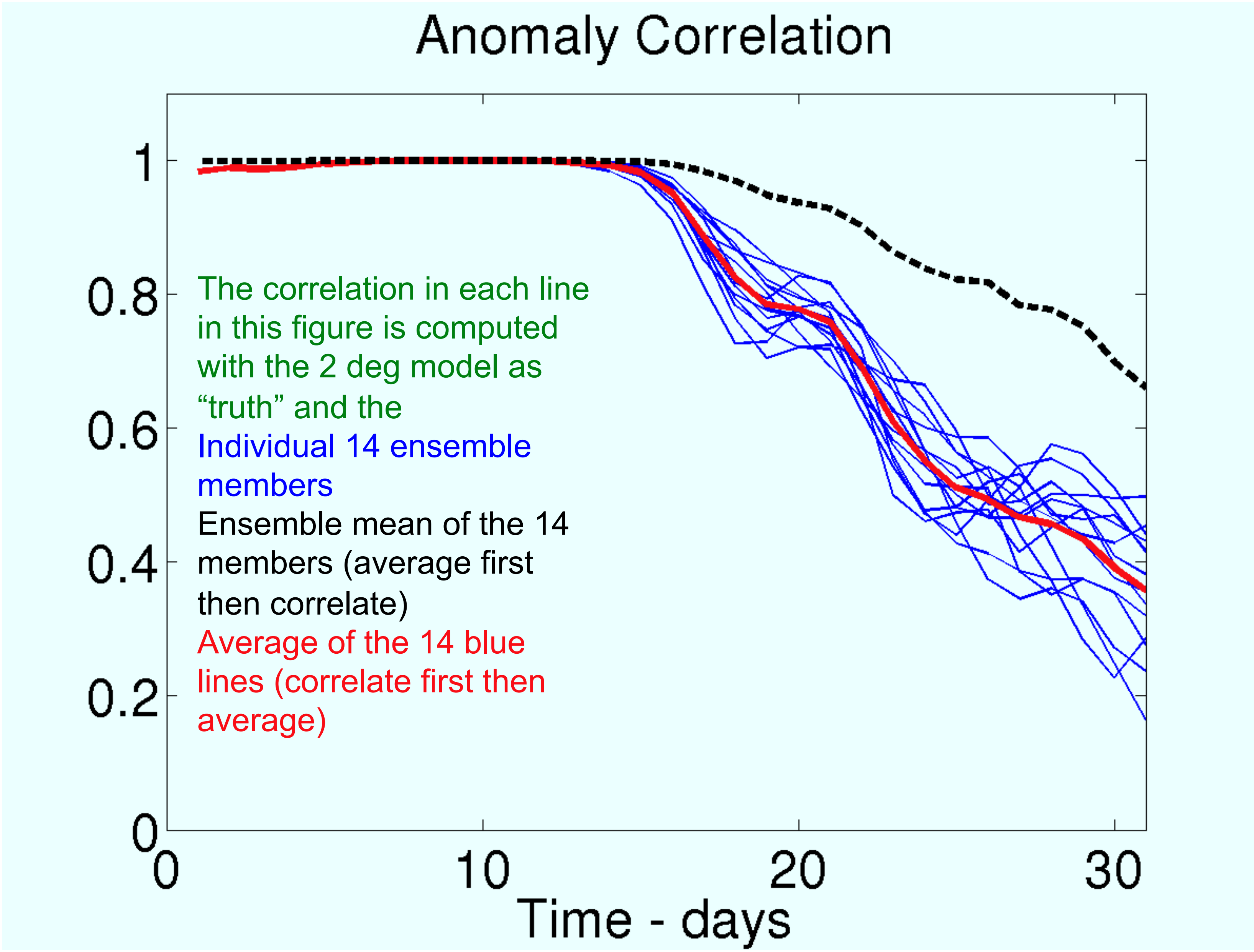
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