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# *Climate Modeling*

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*Mathematics and Computer Science  
Division*

*Argonne Open House, August 29th, 2009*

## *An old saying....*

*“Climate is what you expect, weather is what you get”*

- Climate is the *average* of weather.
- The (predicted) high temperature today, August 29th, is 65F
- The average high temperature is 79F. This is calculated by taking the average of several (usually 30) August 29th highs.

$$\frac{(T \text{ on Aug } 29^{\text{th}}, 1979) + (T \text{ on Aug } 29^{\text{th}}, 1980) + \dots + (T \text{ on Aug } 29^{\text{th}}, 2008))}{30}$$

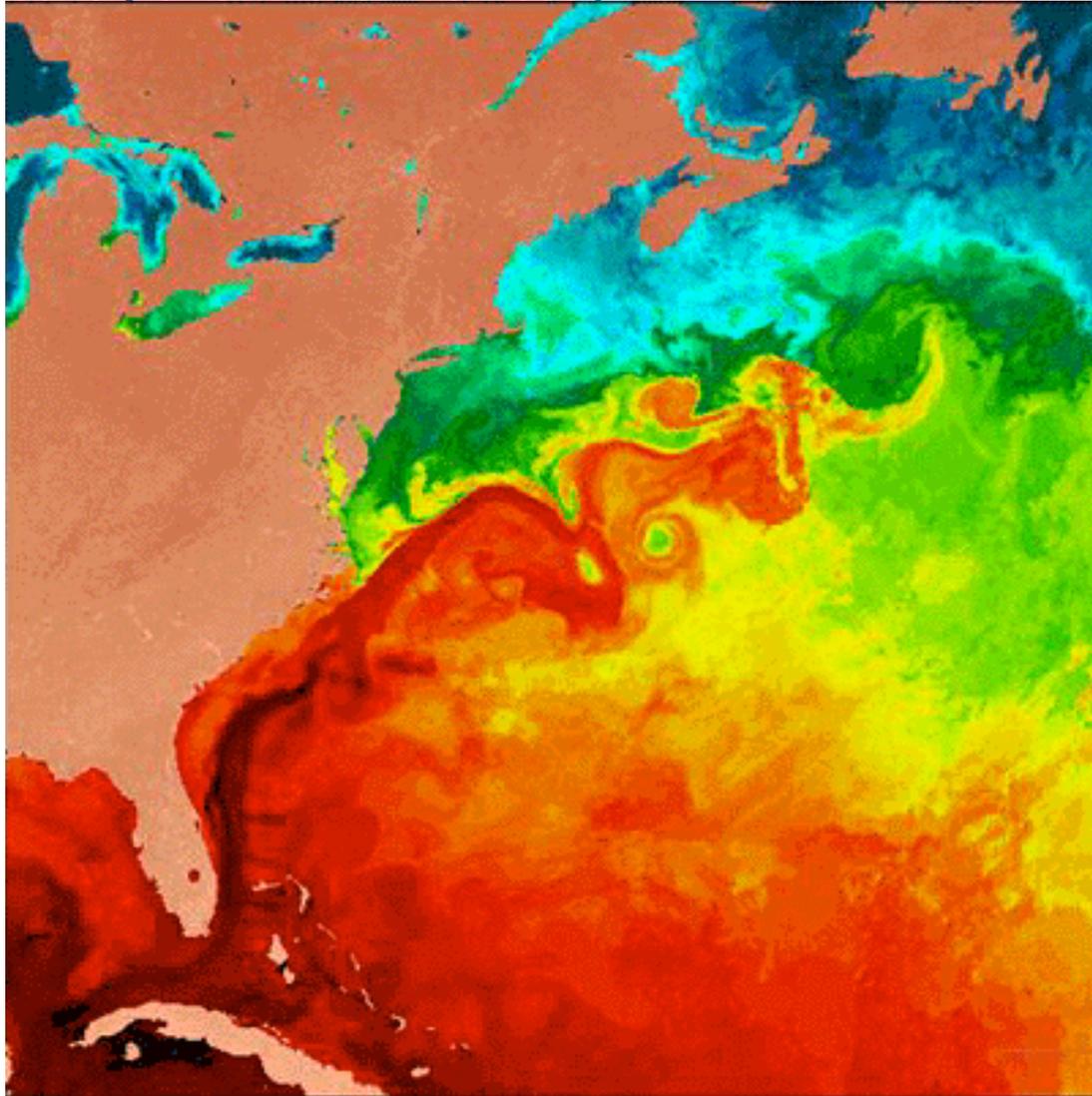
30

Similar calculation for **average** rainfall, wind, humidity, etc.

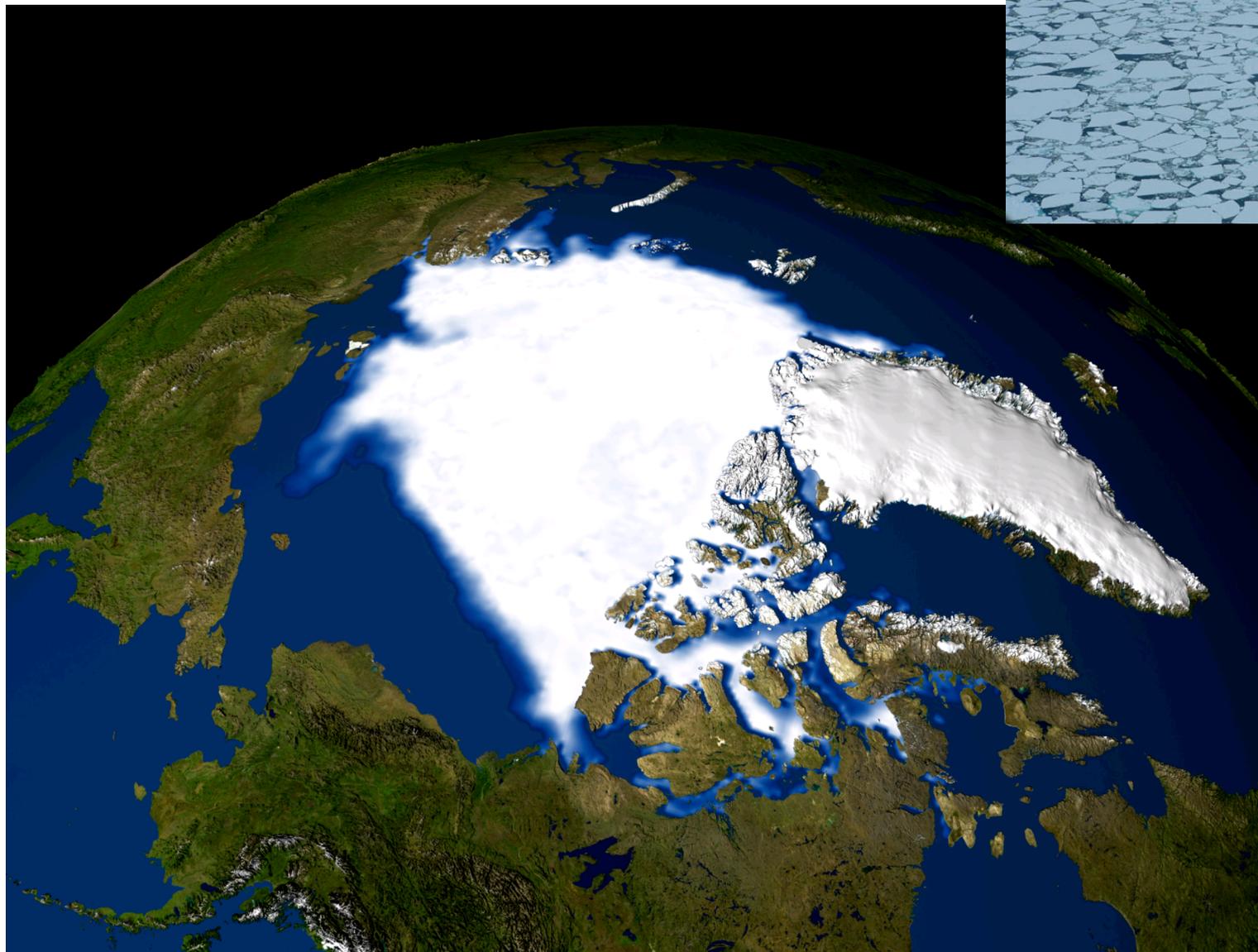
*Our weather is constantly changing. Its part of a large continuous motion called the “General Circulation”.*



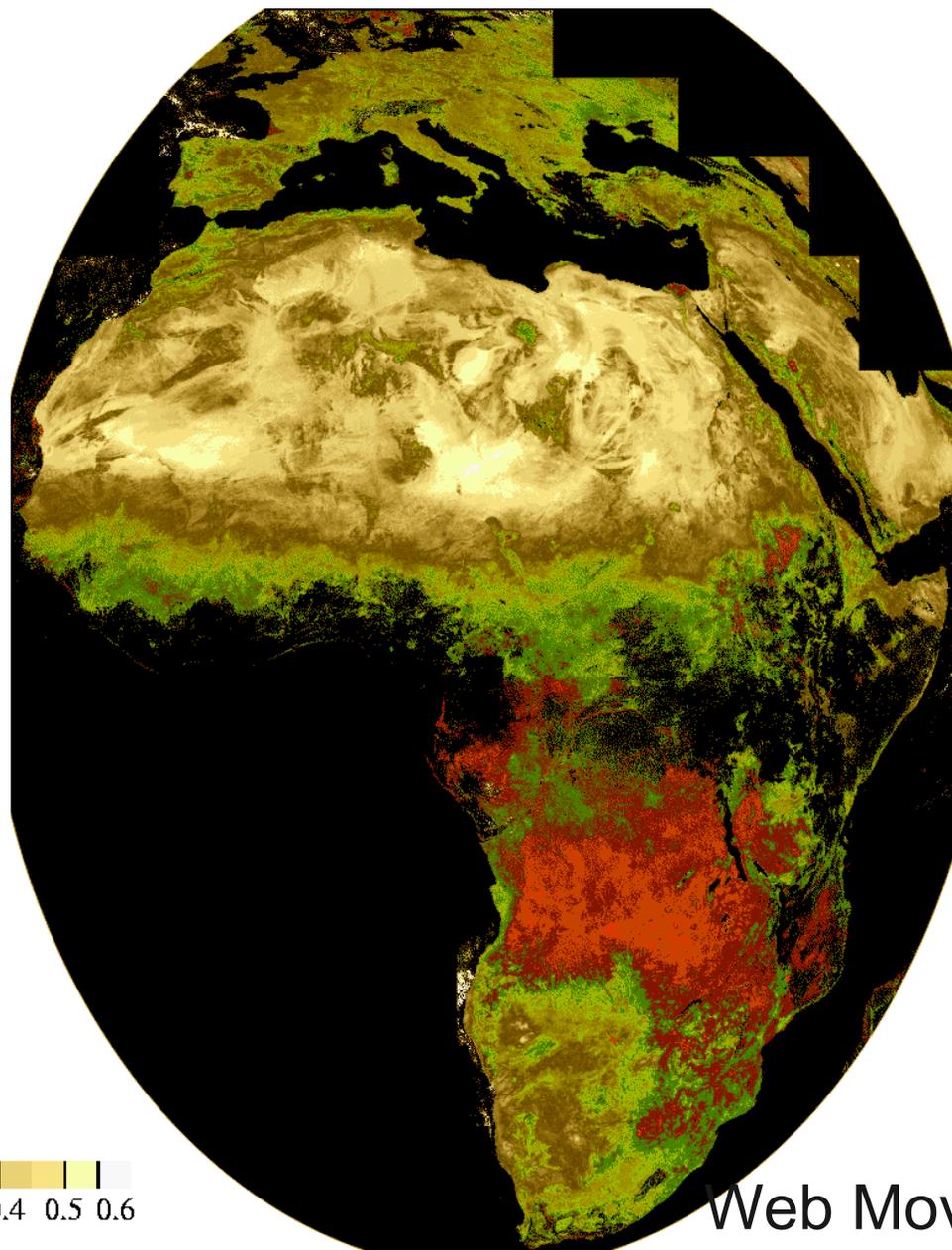
*The ocean also plays a role in determining the global climate.  
(and can effect regions in the Midwest!)*



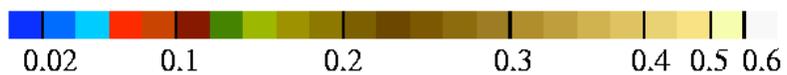
*As does Sea Ice....*



## *And the land surface*



Amount of sunlight reflected



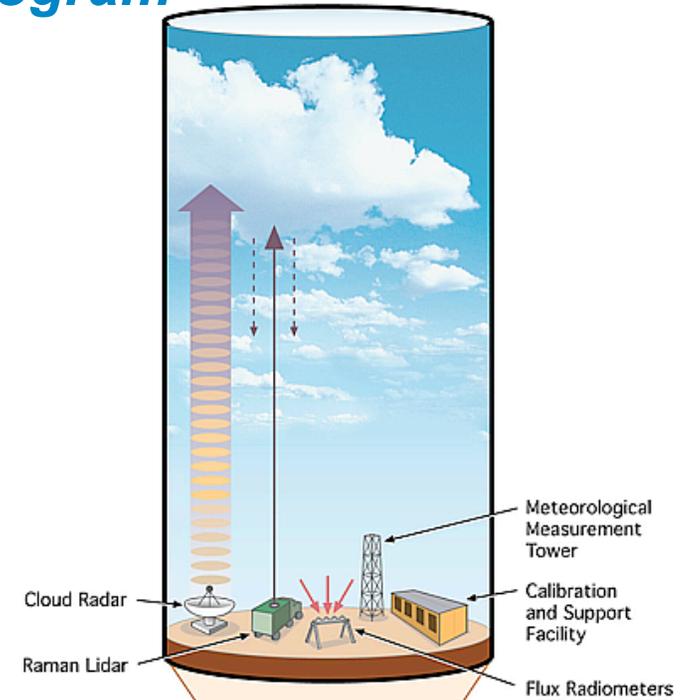
Web Movie

## *Measuring the climate is not easy!*

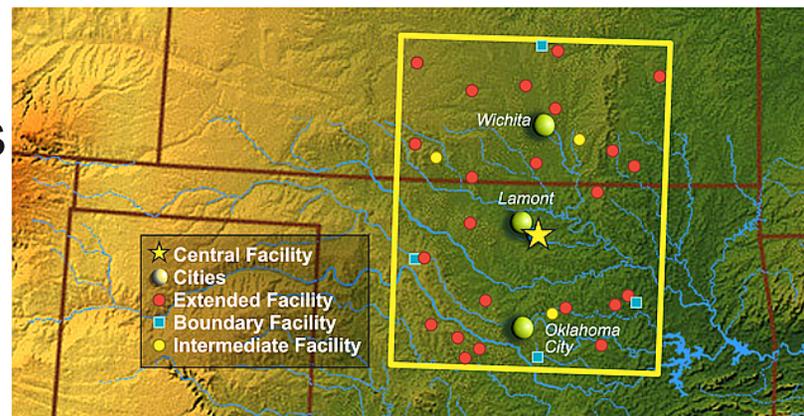
- Should cover the whole planet from the bottom of the ocean to the top of the atmosphere
- Need to measure many variables
- Must take measurements for decades.

We do not come close to meeting all these goals!

# Atmospheric Radiation Measurement Program

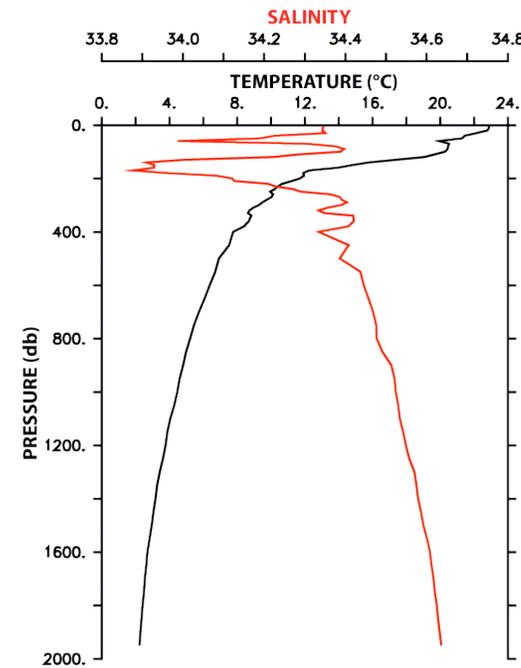
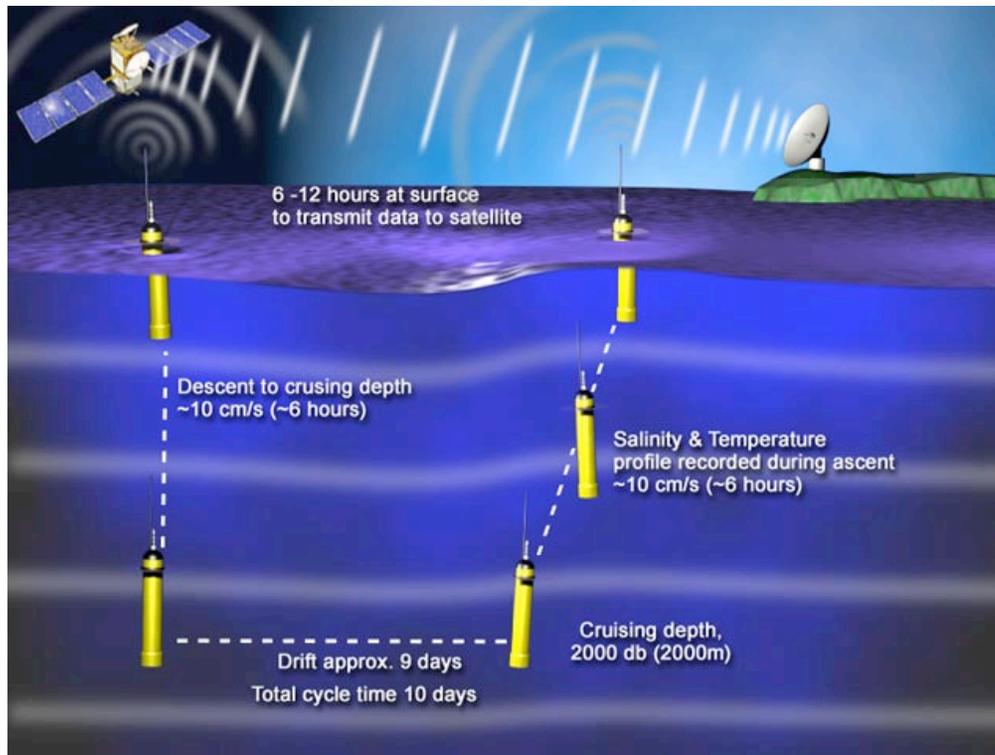
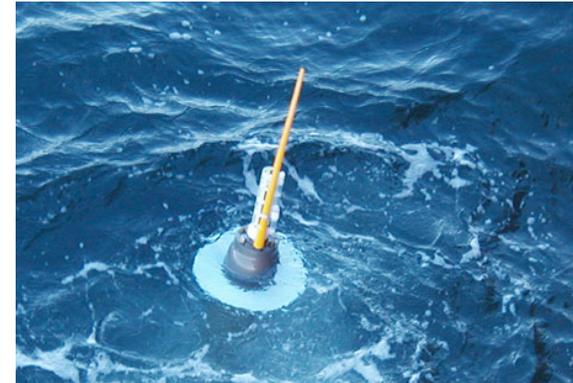
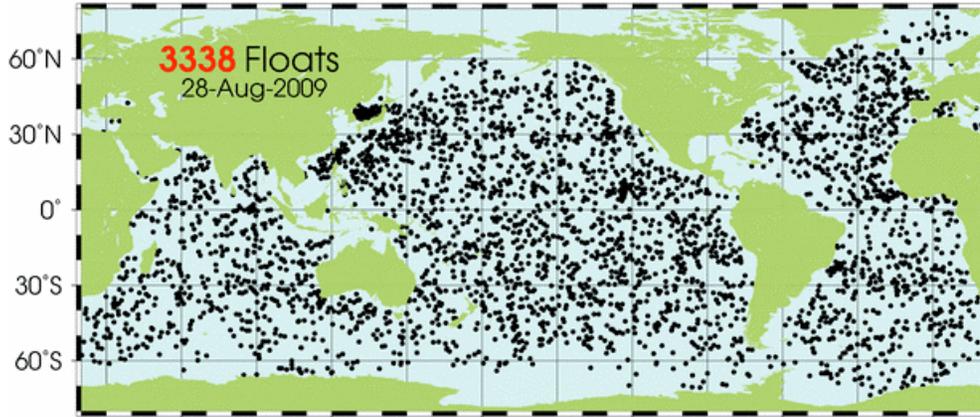


See instruments  
in tent outside  
building 203!

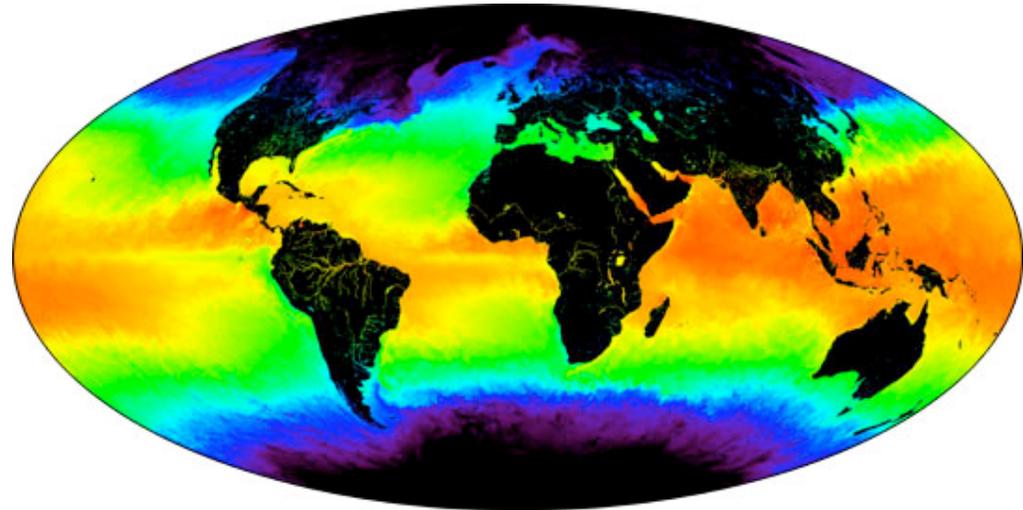
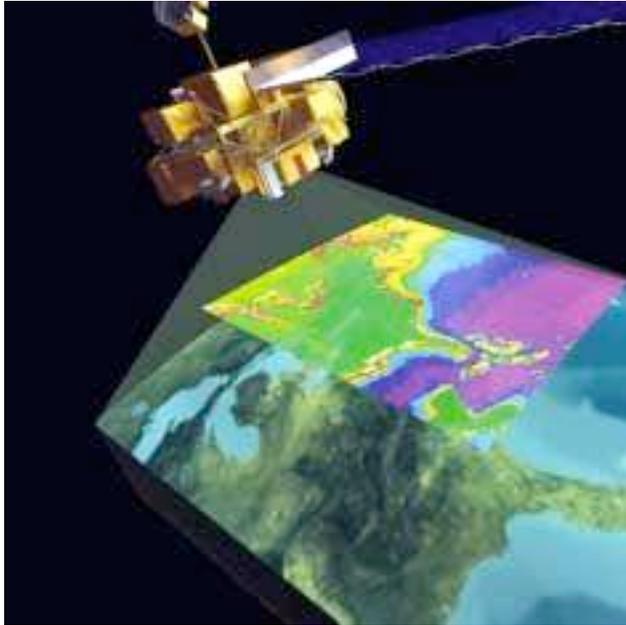


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# The Argo Project: Measuring the global ocean



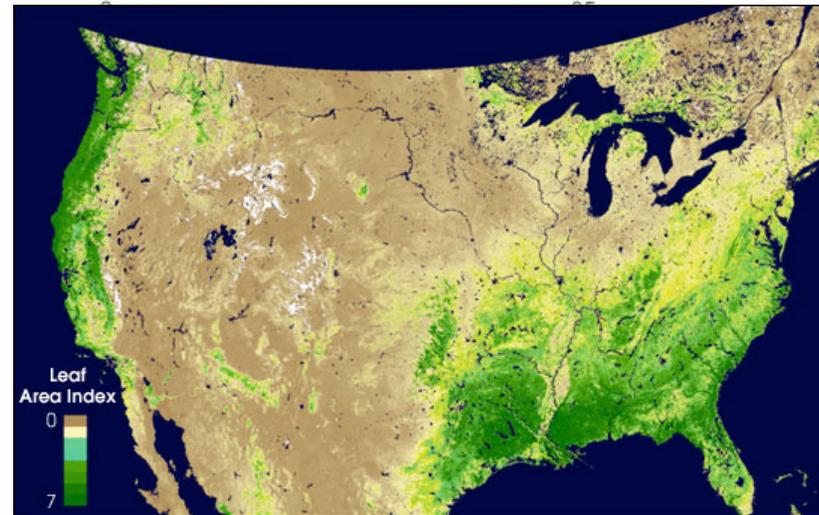
# Satellites



Sea Surface Temperature (°C)

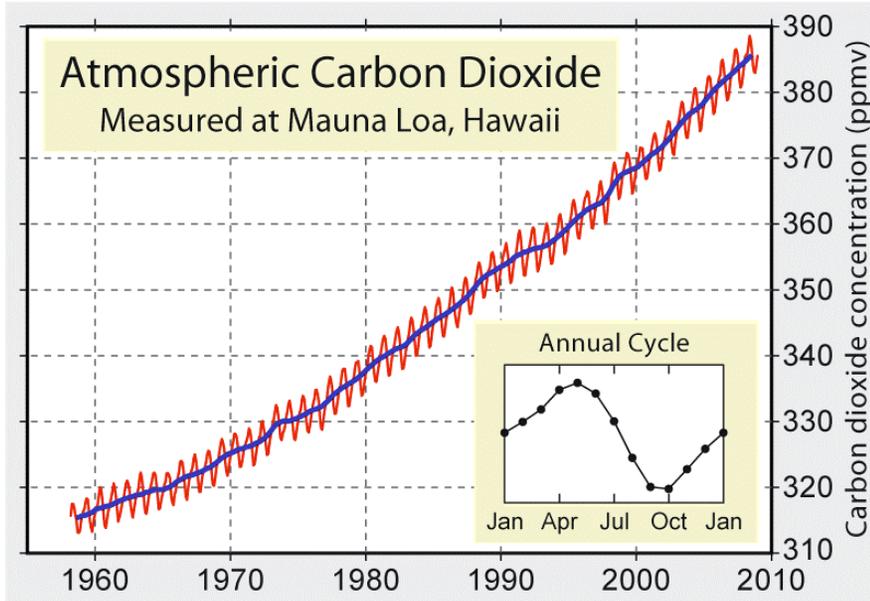


Shortcomings:  
-Only a few years  
-2D pictures

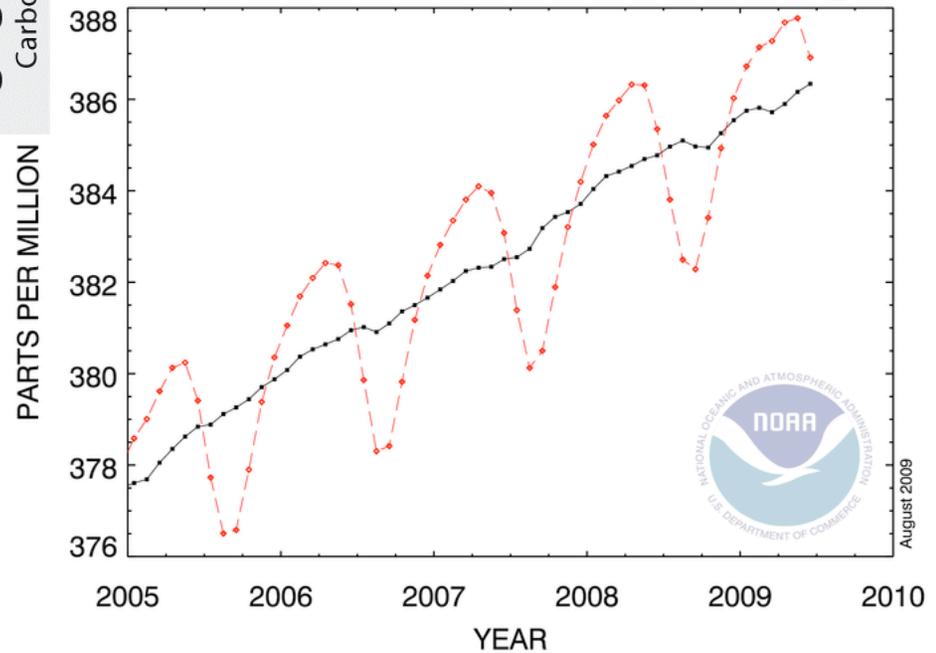


Leaf Area Index  
0  
7

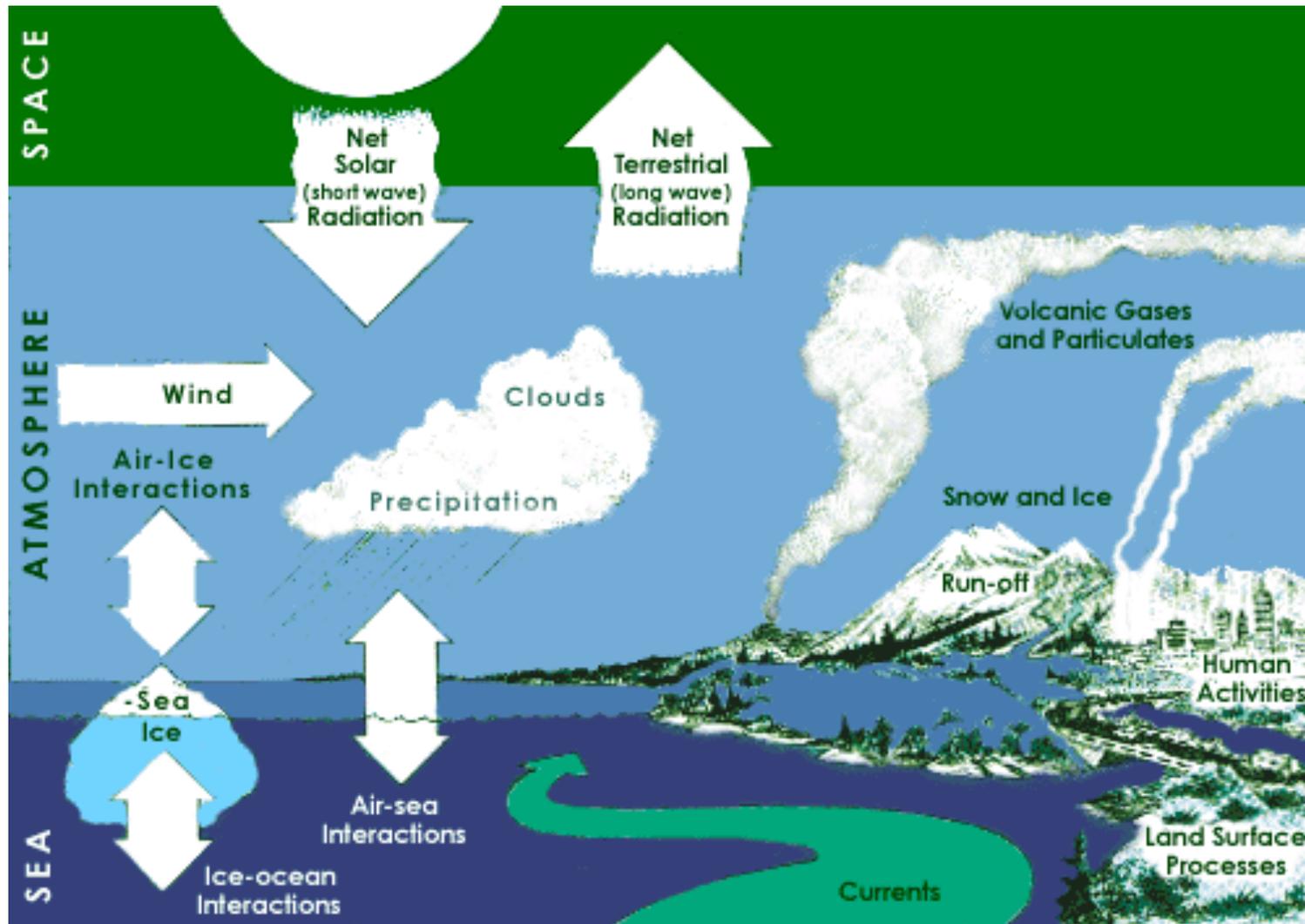
# Long records of climate come from a few individual instruments.



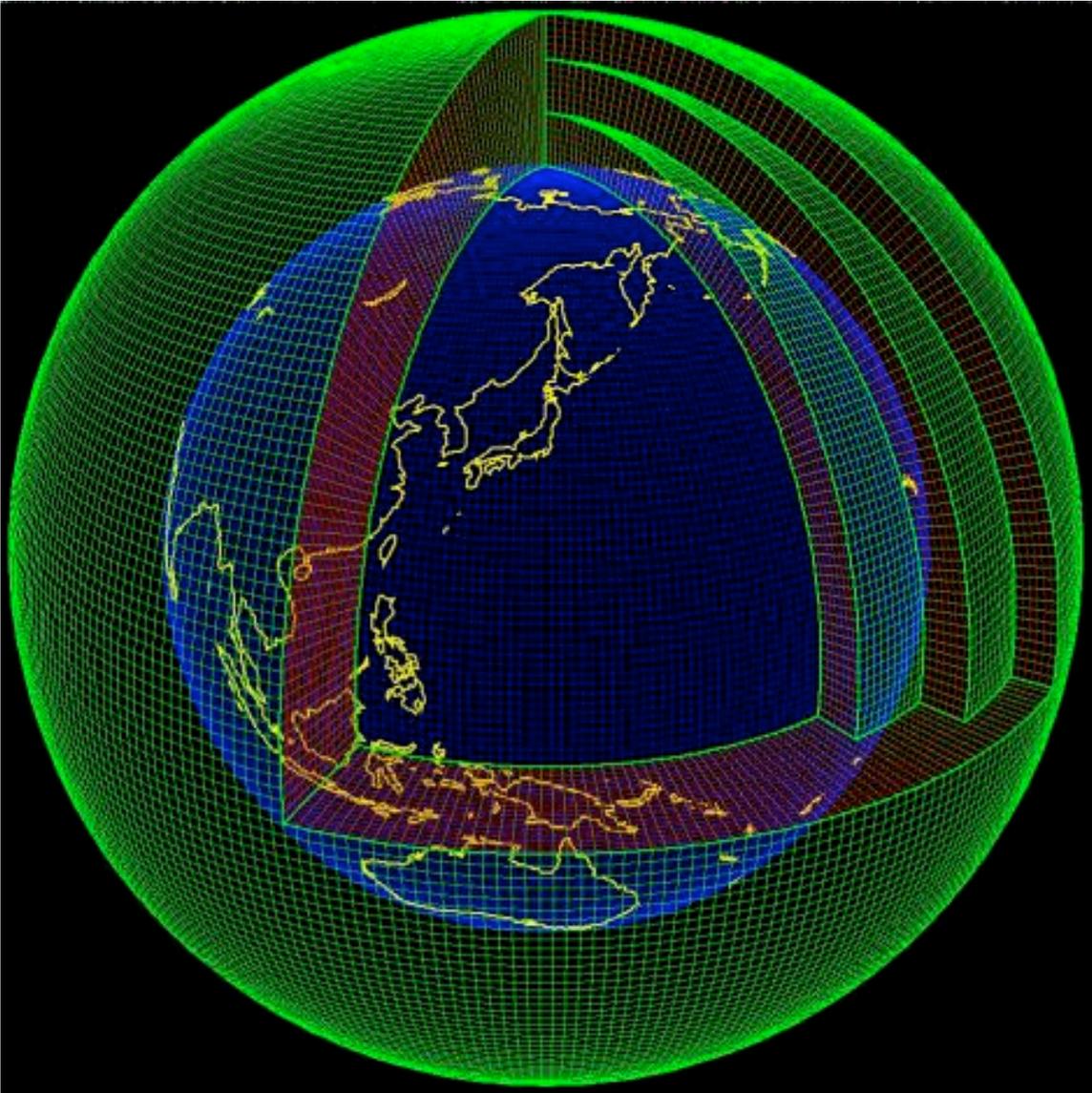
### RECENT GLOBAL MONTHLY MEAN CO<sub>2</sub>



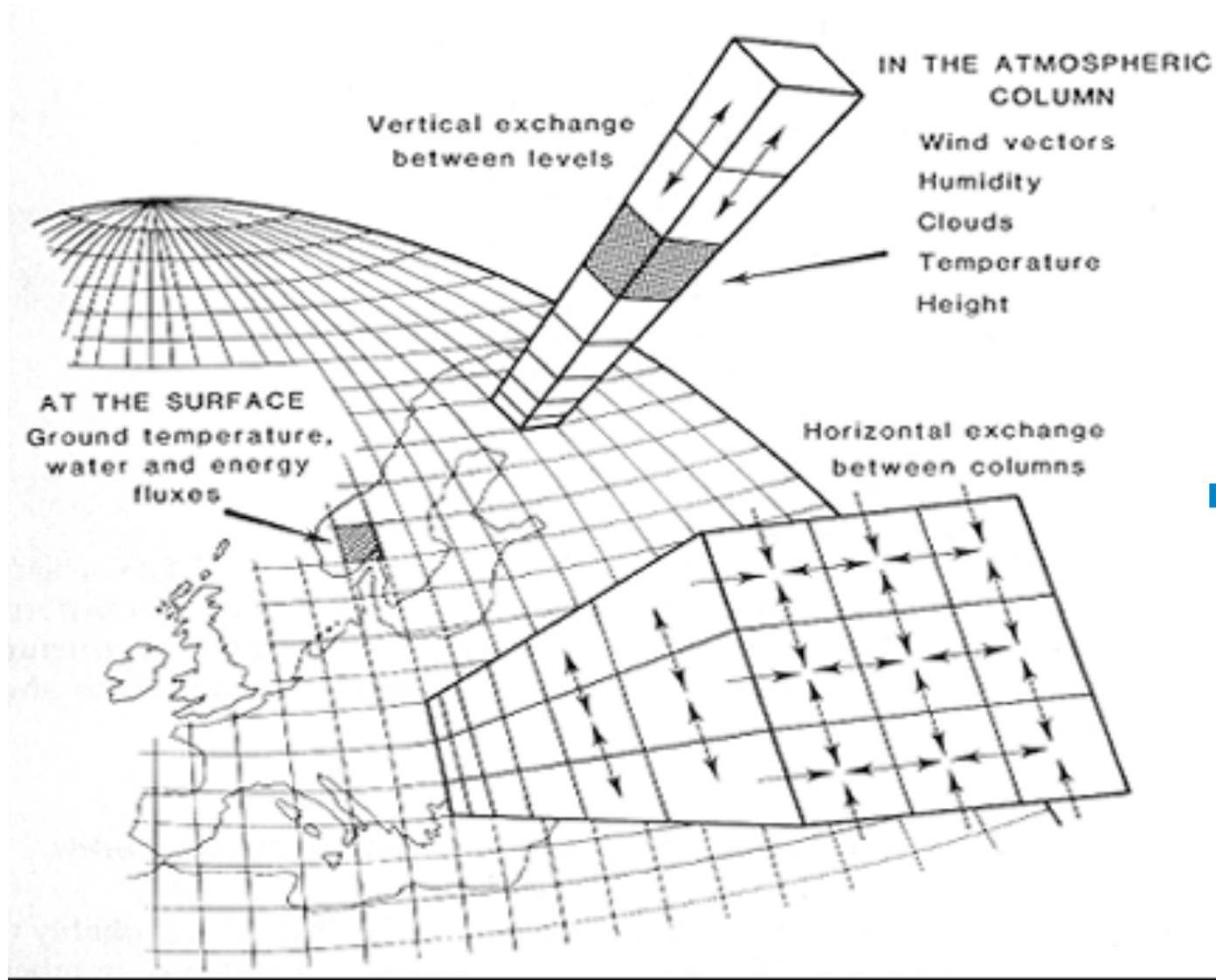
*To simulate the local climate.....must simulate the whole climate system! Over the entire earth!*



*Cover the Earth with a grid on boxes.  
Each box has center point.*



## Calculate properties of atmosphere in each grid box

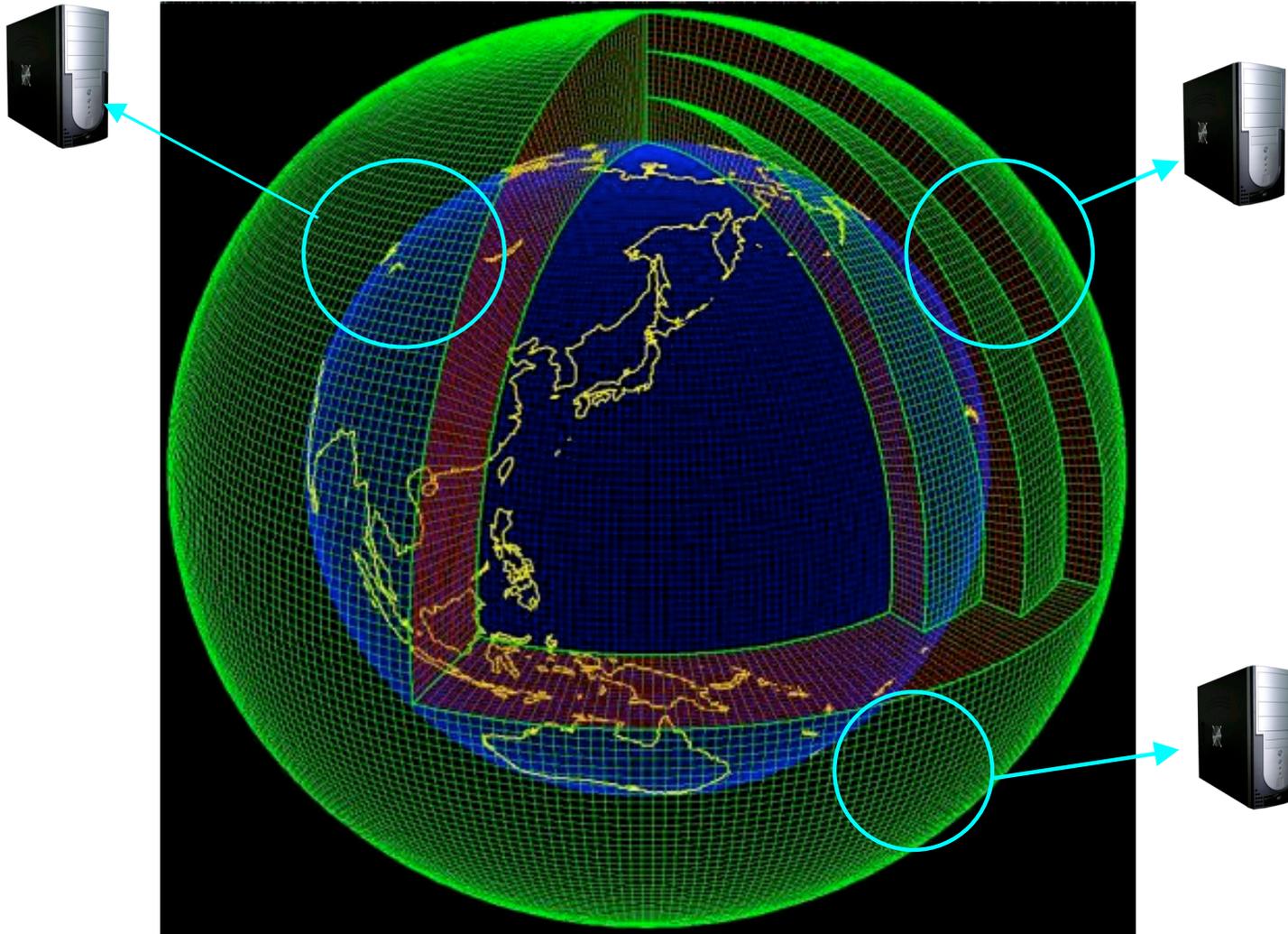


- Similarly for ice, ocean and land

## How many calculations?

- **Millions** of points!
  - 1000's of calculations **at each point**
  - Calculations based on equations describing air motion, solar radiation, clouds, heat transfer.
- Do all of the above over a **million times** to simulate a 100 years of climate!
  - Start with temperatures, winds, etc. taken from observations.
  - Calculate all the changes that will occur over a single *time step*, typically **20 minutes**
  - Apply the changes to the initial values.
  - Repeat!
- 1,000,000,000,000,000 calculations to simulate a year of climate!

*Parallel computing.  
give pieces of the grid to many computers*

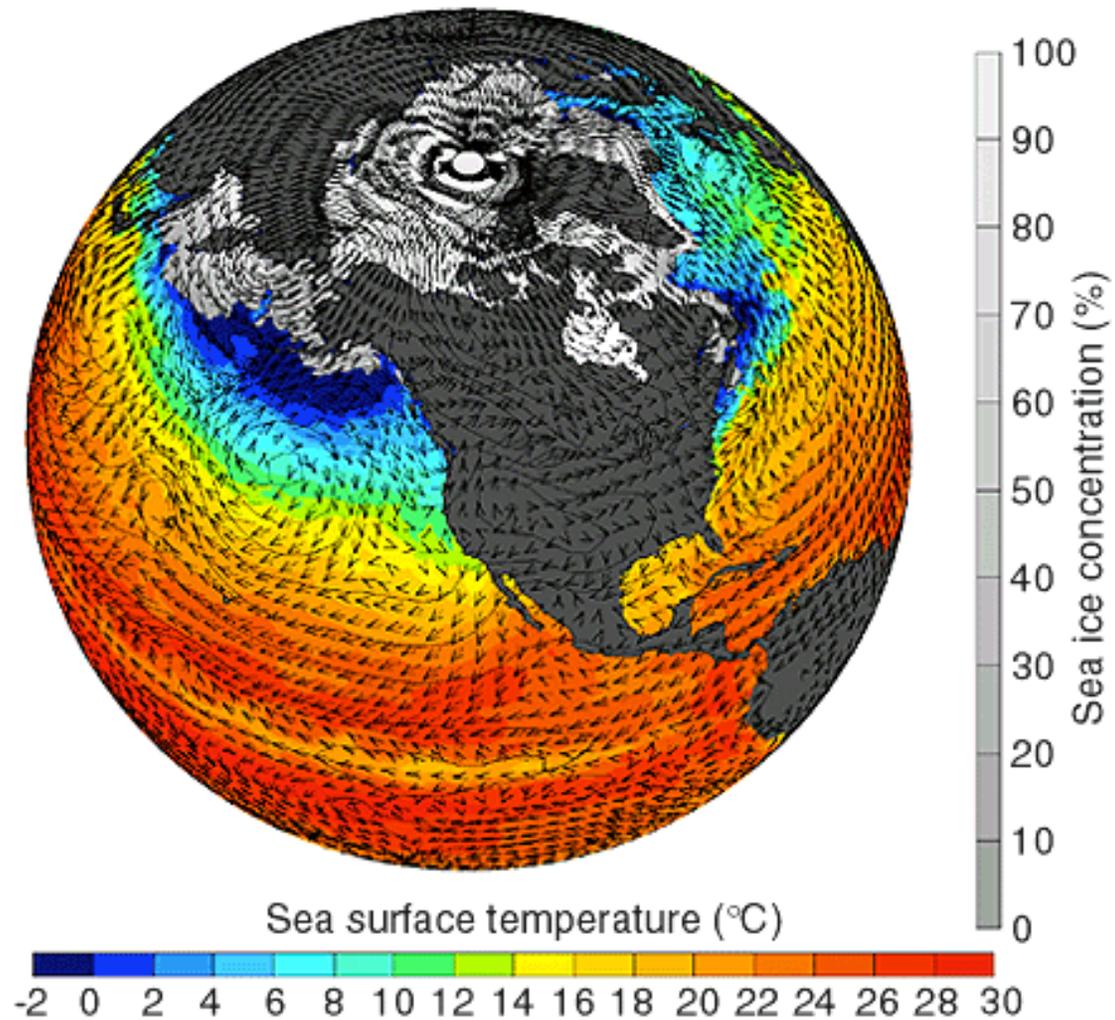


## Output from models.....lots of numbers!

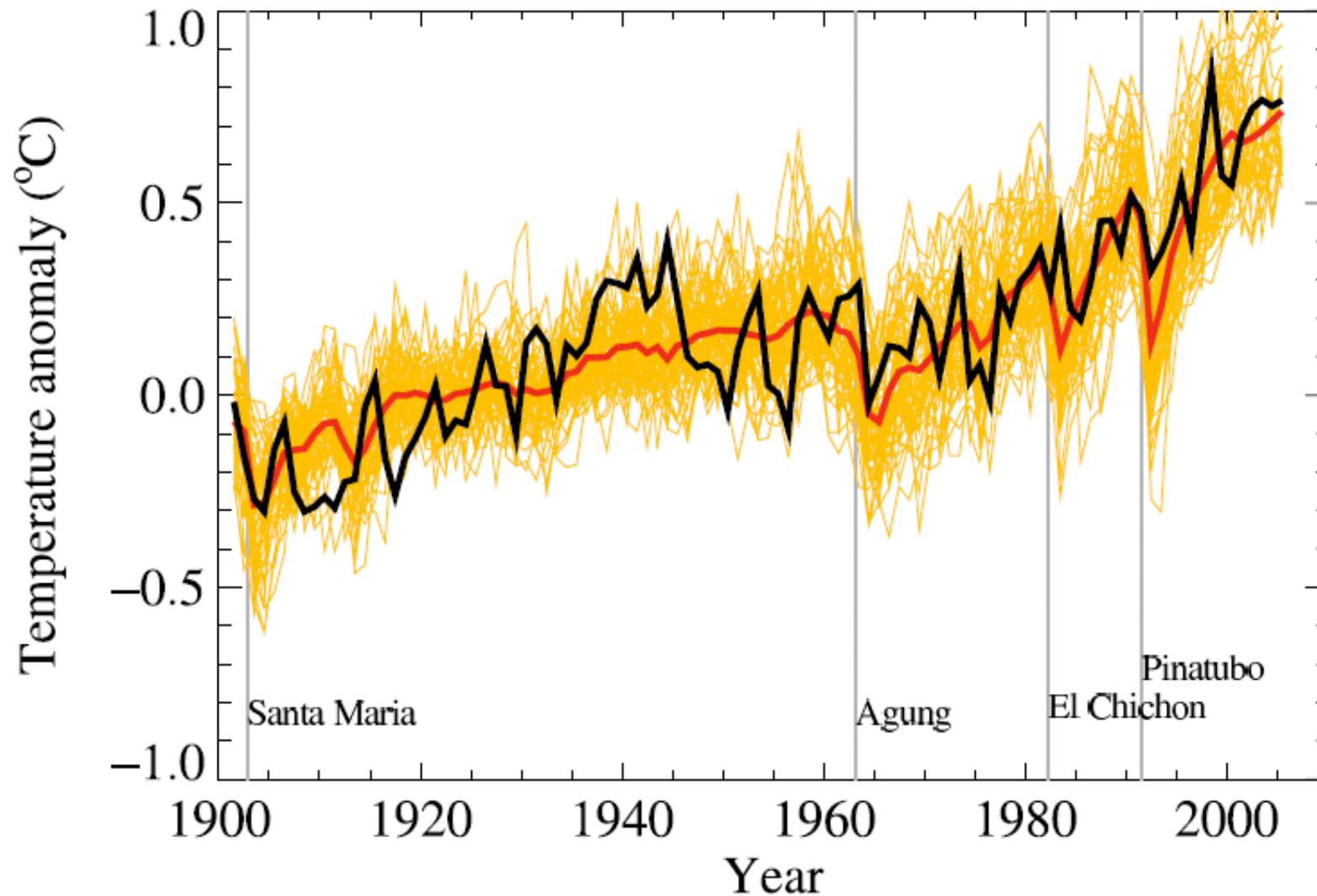
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223.6427, 223.7941, 223.4224, 223.054, 223.095, 223.156, 223.023,  
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Typically instruct the model to write out the average values of **100 variables** at **each point** every simulated month

## *Understand output through visualization*



*Test climate models with 20th century simulation.*



## *A simple experiment*

100 year simulation:  $\text{CO}_2 = \text{constant}$



100 year simulation:  $\text{CO}_2$  increases



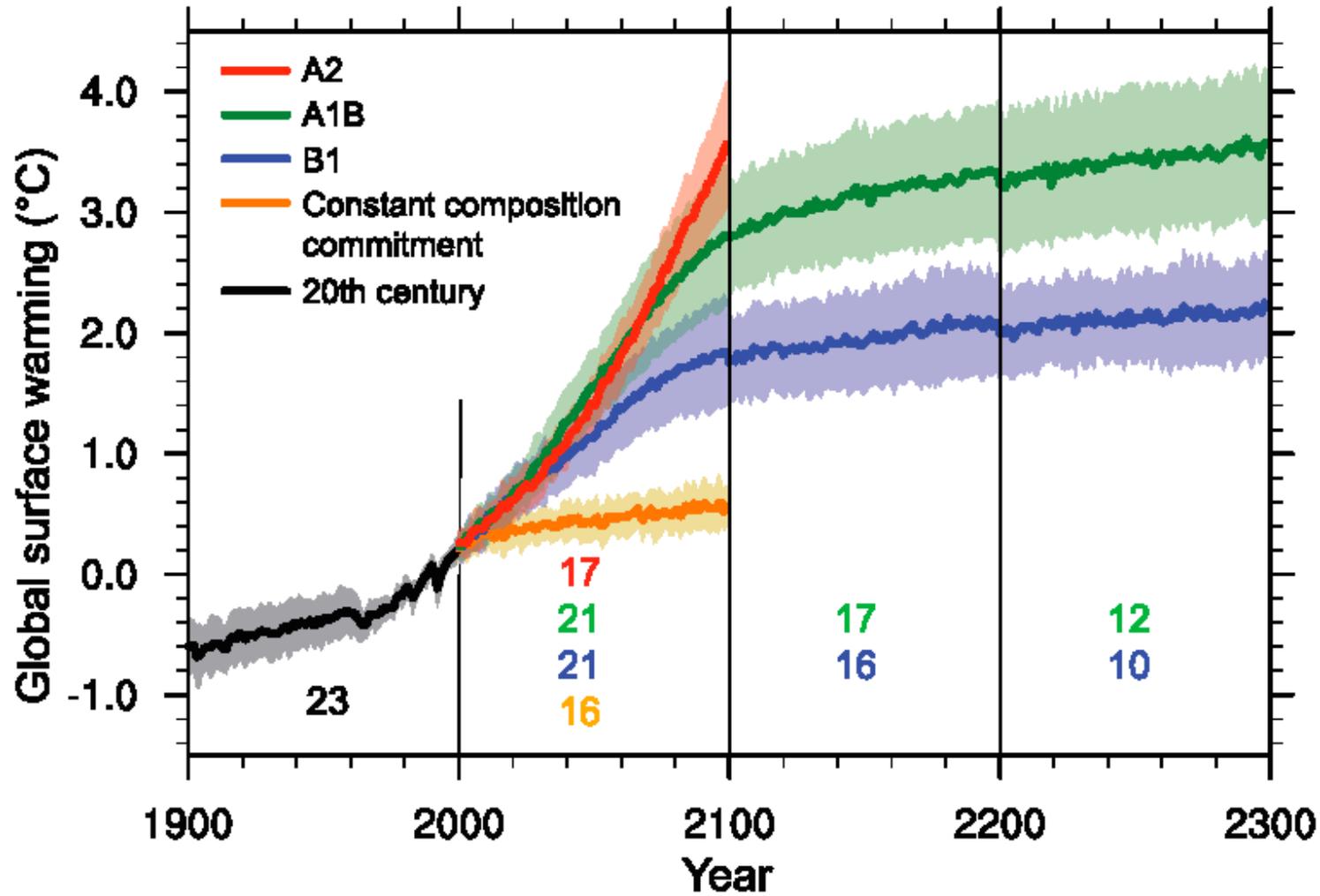
Output at each year.

Subtract output from the “increase” simulation from the output at the same time from the “constant” simulation

Vis5d

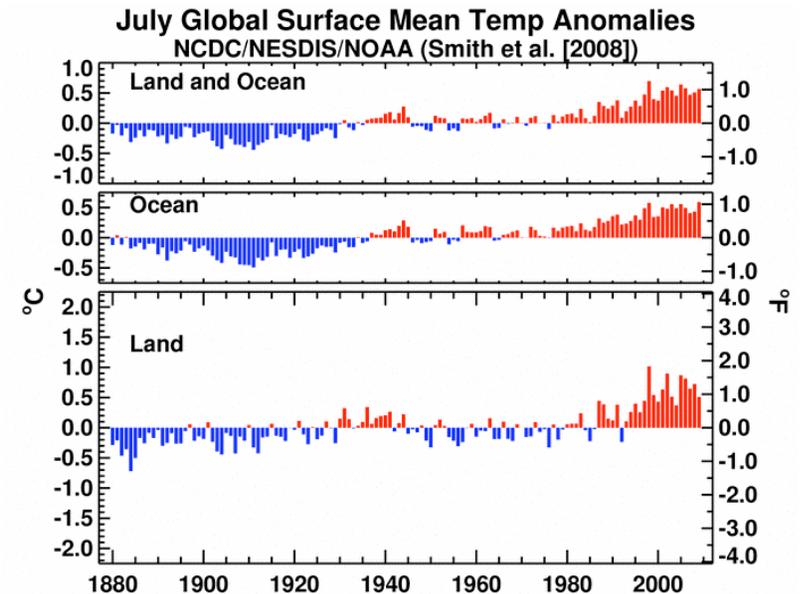


*Test our knowledge by applying different models to the same problem*



## Challenge: Resolving regional climate changes

- The Central U.S. (Ohio, Illinois, Indiana, West Virginia) experienced their coolest July ever in 115 years of records. Wisconsin and Michigan had second coolest.
  - Arizona had 3rd warmest, New Mexico and Washington had 9th warmest
  - Southern Texas has had extreme or exceptional drought for weeks.
- Globally, July 2009 was the 5th warmest on record.
  - Global surface ocean temperatures were warmest on record. Broke record set in 1998.
  - Land temperatures were 9th warmest.



## *Regional climate needs more points!*

- Requires more computer power (See BlueGene/P)
- Outputs more data (Petabytes). A huge visualization challenge!
- Early attempts are promising.

