Climate change, does it add up?

Chris Budd

CliMathNet

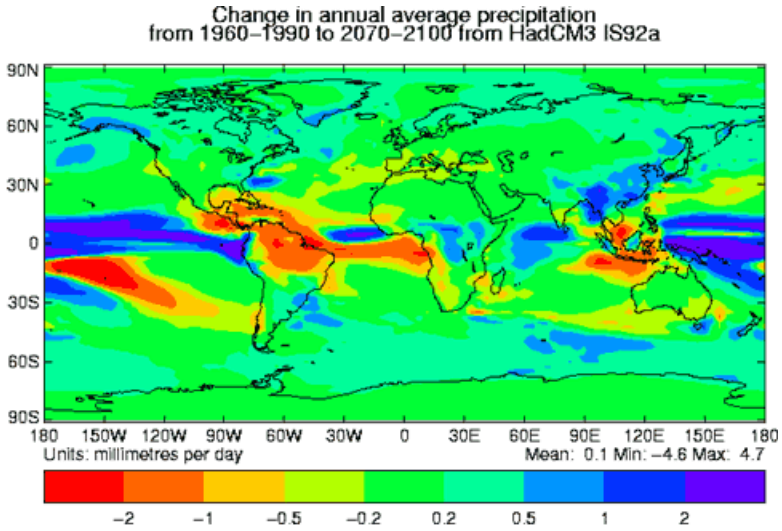
Met Office

UNIVERSITY OF BATH

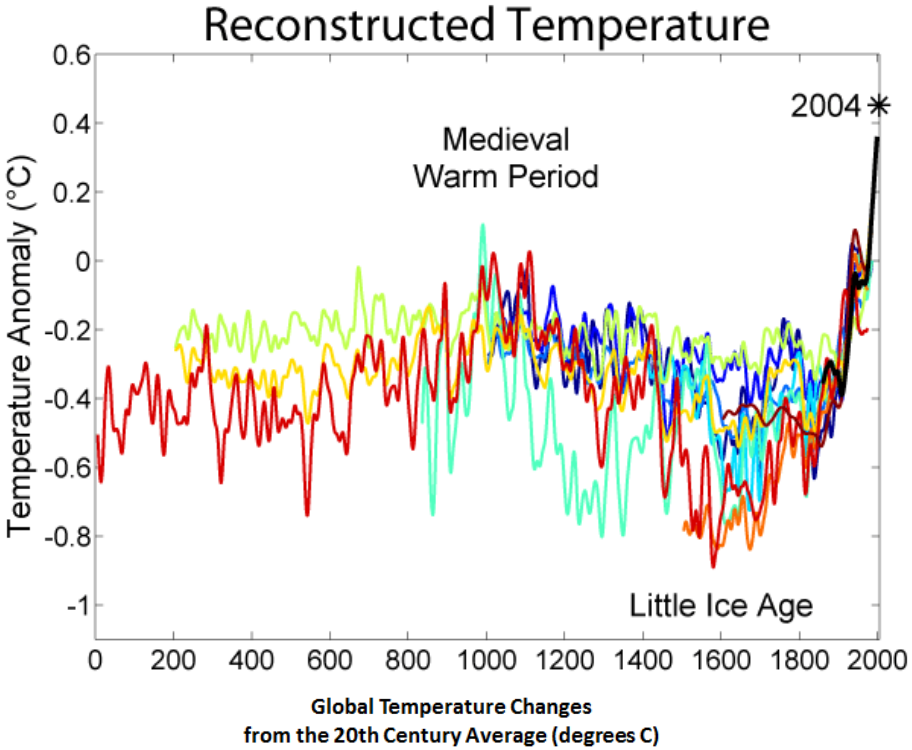
Human made climate change is:

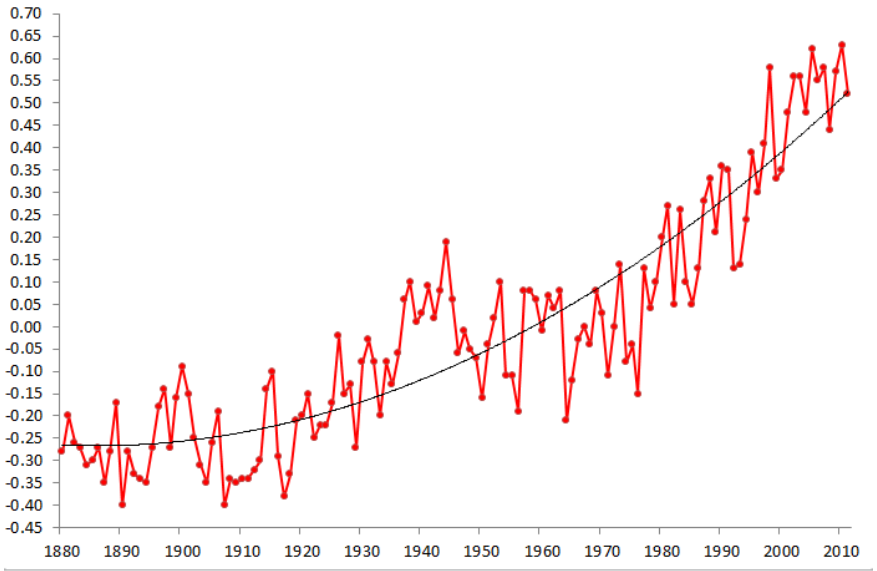
- Controversial
- Important
- A meeting place of scientists, mathematicians and policy makers

Five ‘official’ indicators of climate change IPCC



1. Increasing temperatures

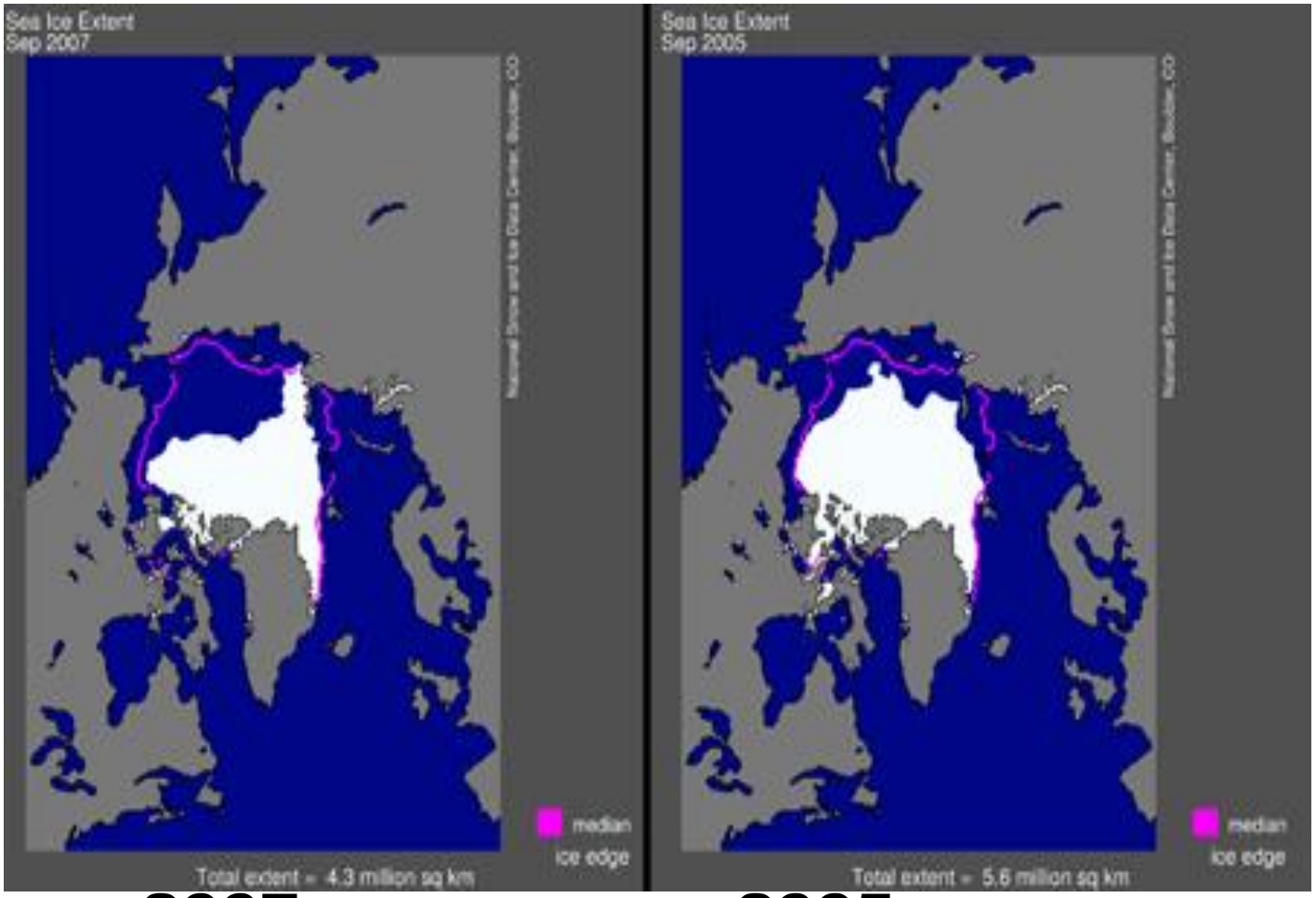




2005 was the hottest year ever recorded!

But note the last ten years

2. The Melting Arctic



2007 **2005**

Every year we lose Arctic ice the size of Scotland!

Nasa's conclusion

Arctic sea ice has become thinner by around 43% over the last 25 years

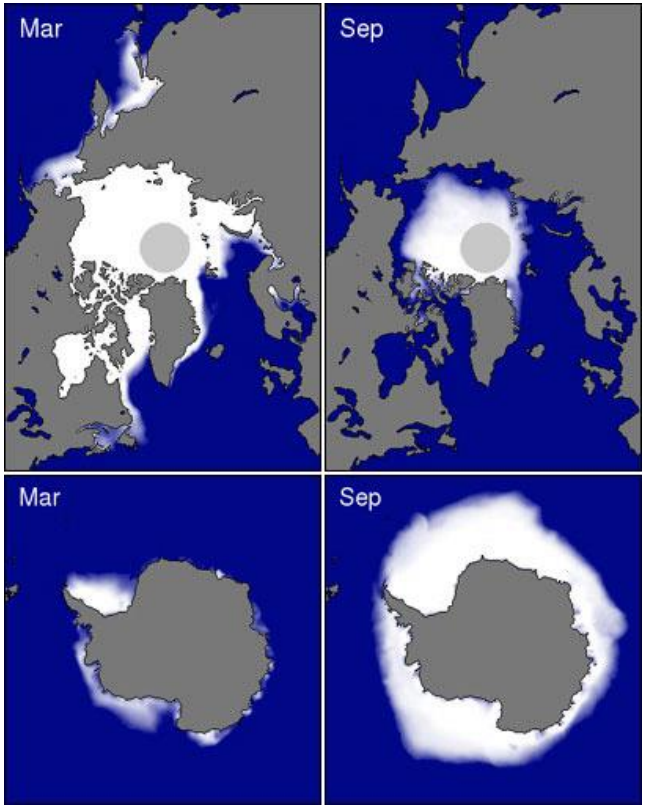
Also Greenland land ice is melting fast

... and this trend is continuing

But … from a New Zealand perspective

Antarctic sea ice is actually increasing!

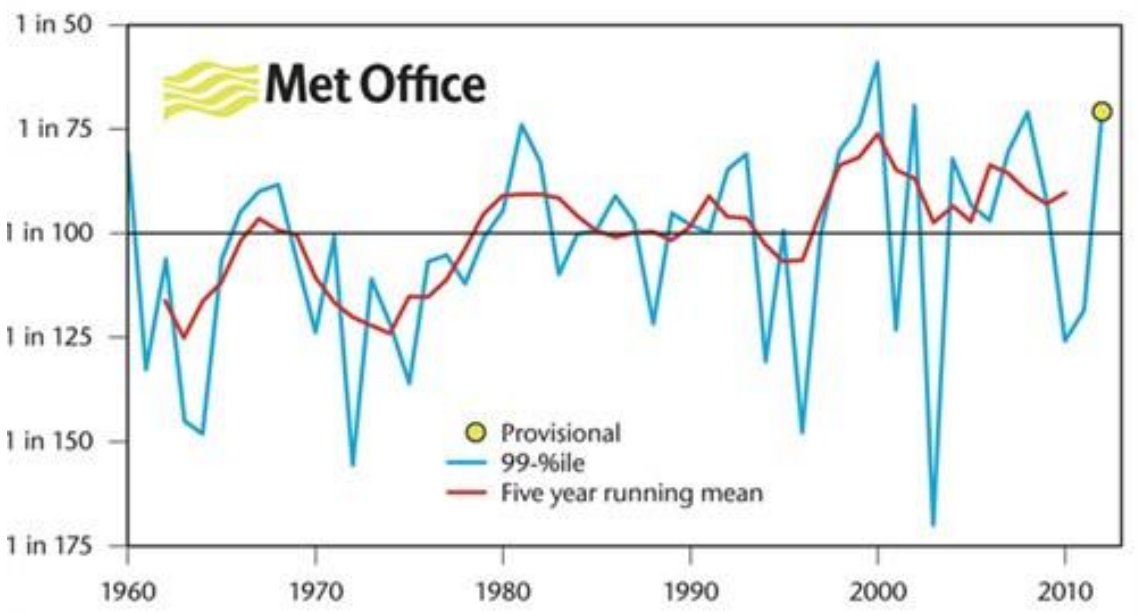
Although land ice is decreasing



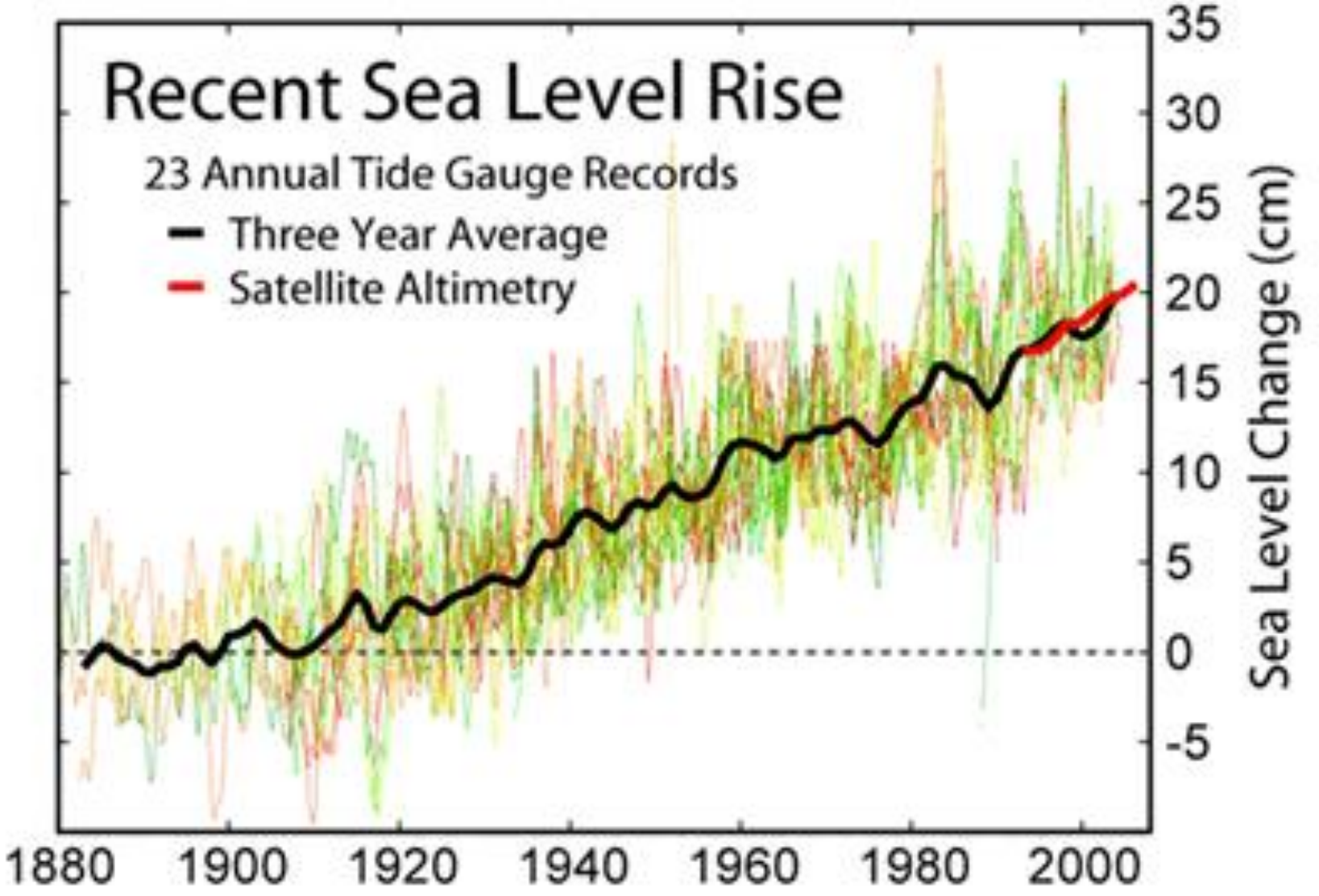
3. Changes in rainfall patterns (UK)

2000: Wettest year ever, 2012 second wettest

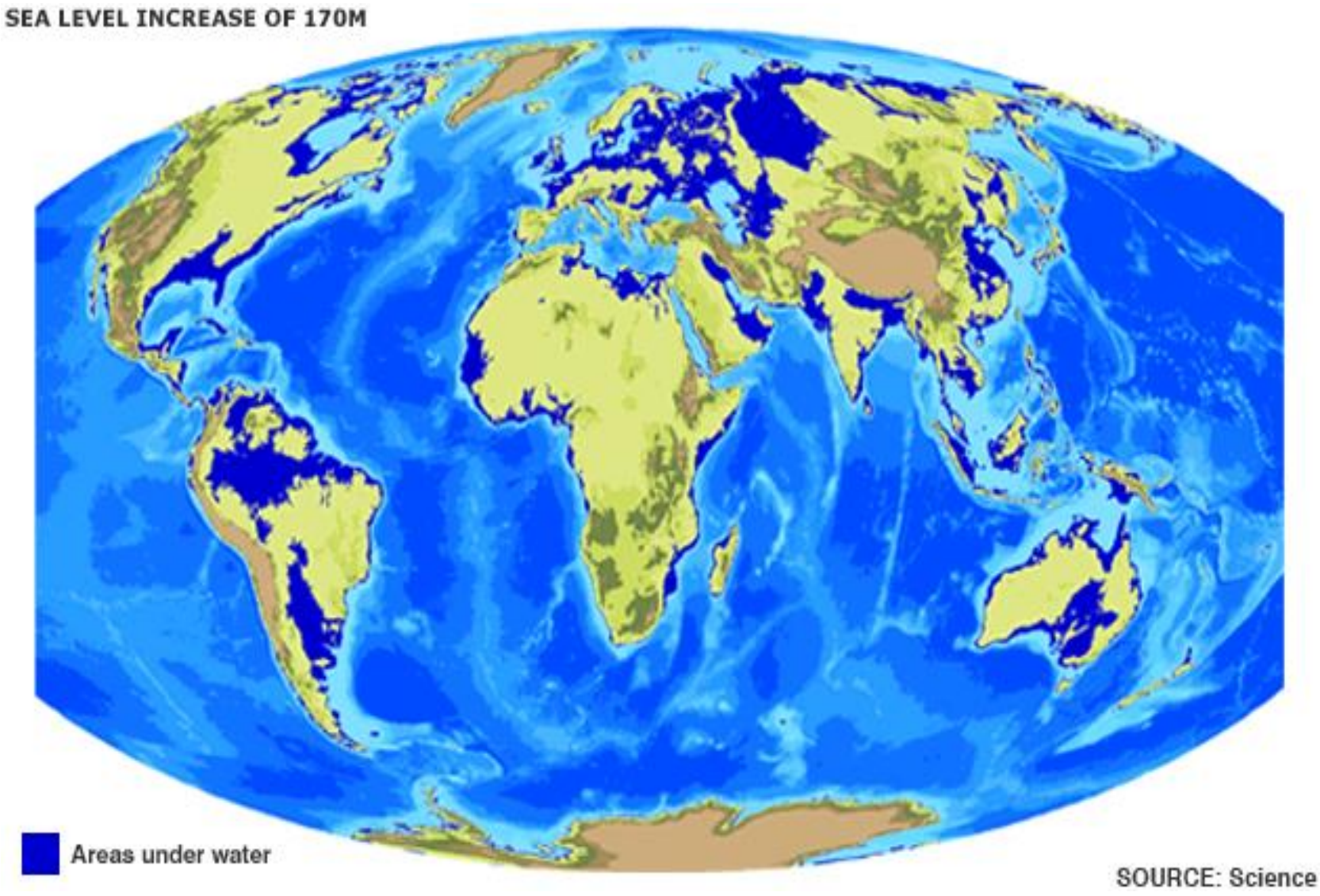
Top five wettest years in the UK		
1	2000	1337.3 mm
2	2012	1330.7 mm
3	1954	1309.1 mm
4	2008	1295.0 mm
5	2002	1283.7 mm



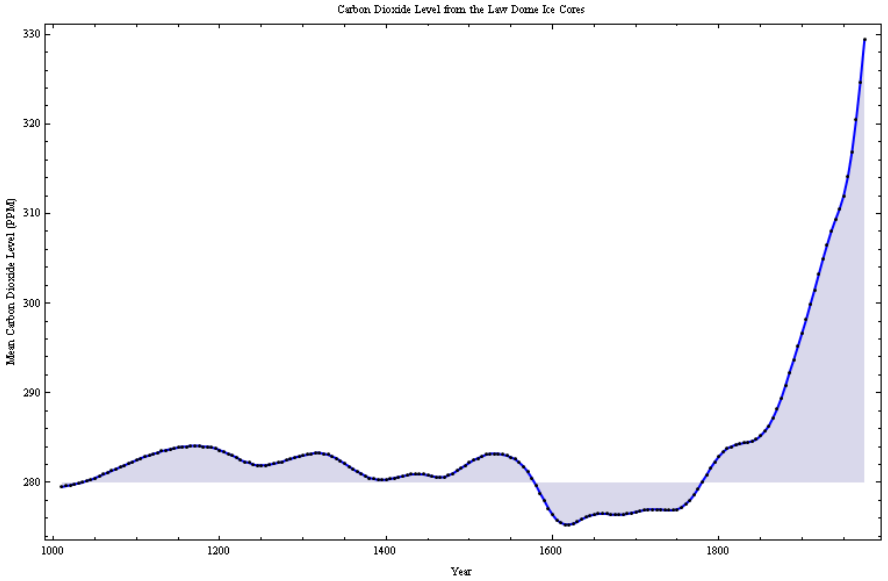
4. Sea Level Rise

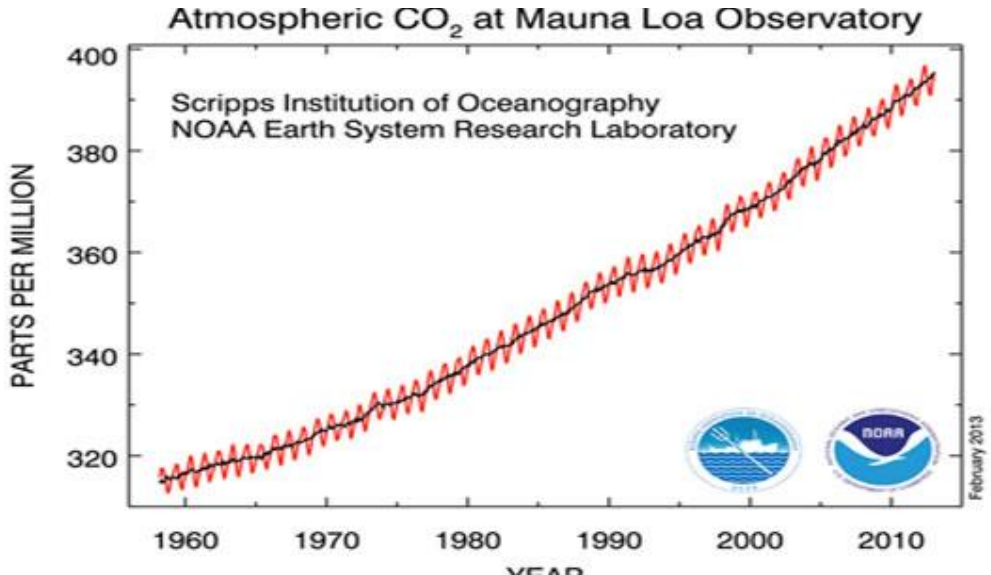


Huge political consequences!

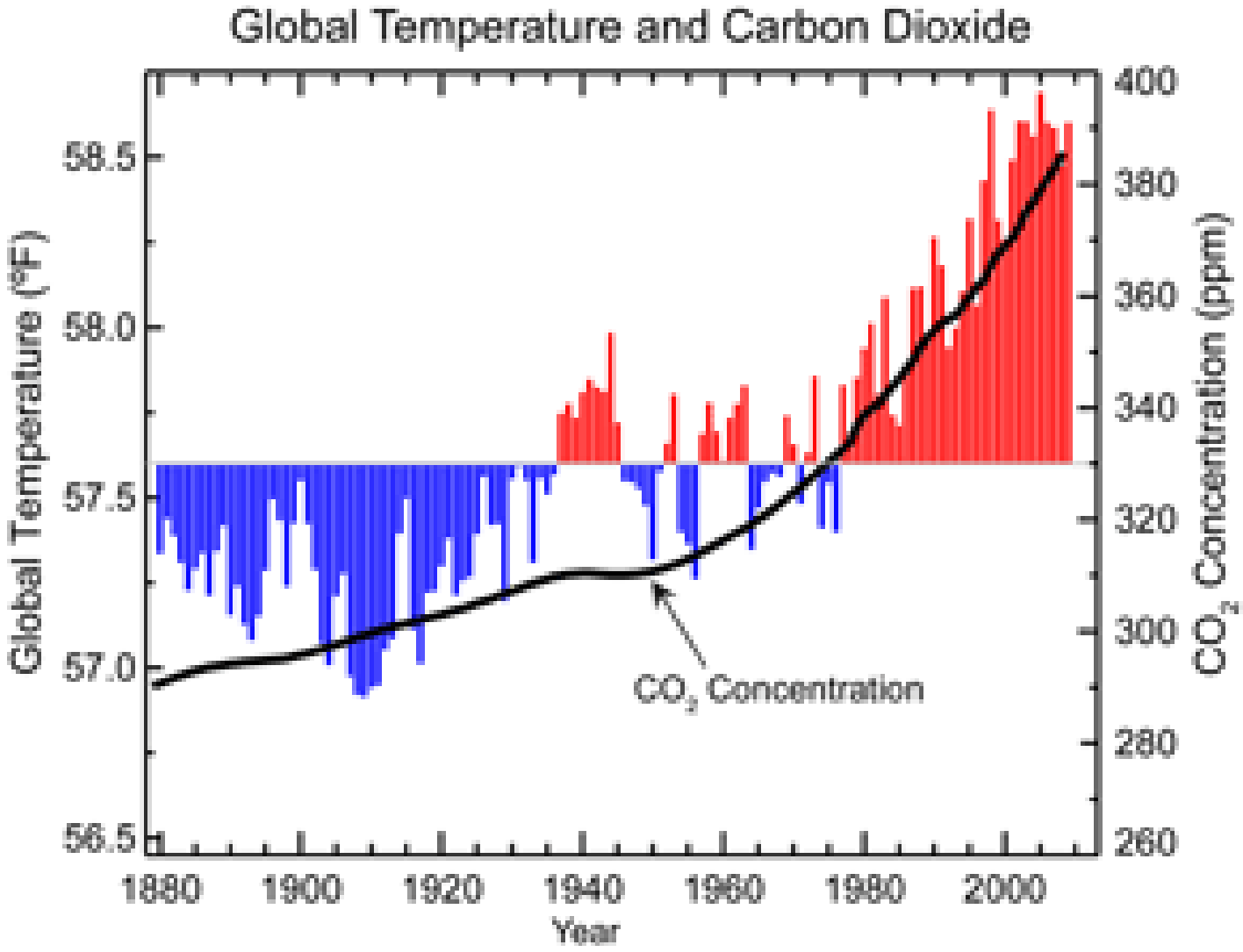


5. Increase in Atmospheric Carbon Dioxide



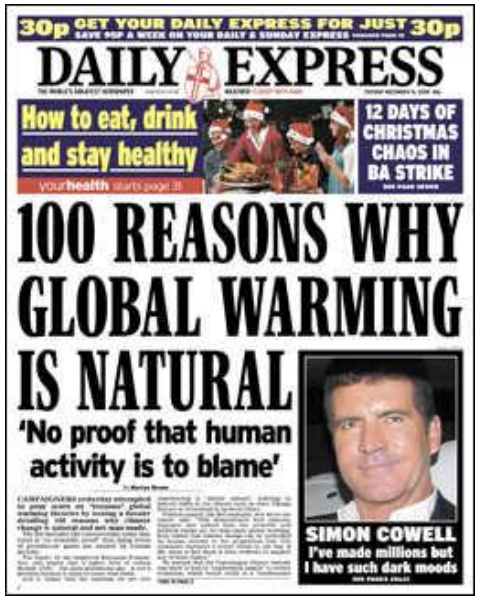


There is a connection with rising temperatures



Not everyone agrees!

"This is nonsense….there has been no statistically significant global warming for at least a decade”.”



Watts up with that

And maybe it's all a big conspiracy!

ClimateGate

Why is climate science so hard?

It is difficult to predict anything, especially about the future! *Niels Bohr*

Some reasons for the uncertainty

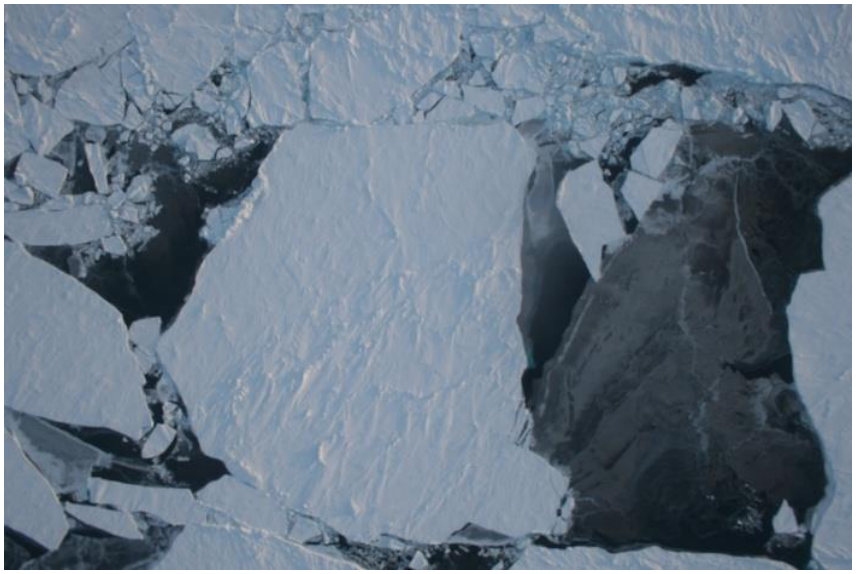
Statistical variation in dodgy data

Chaos

Complexity of the system

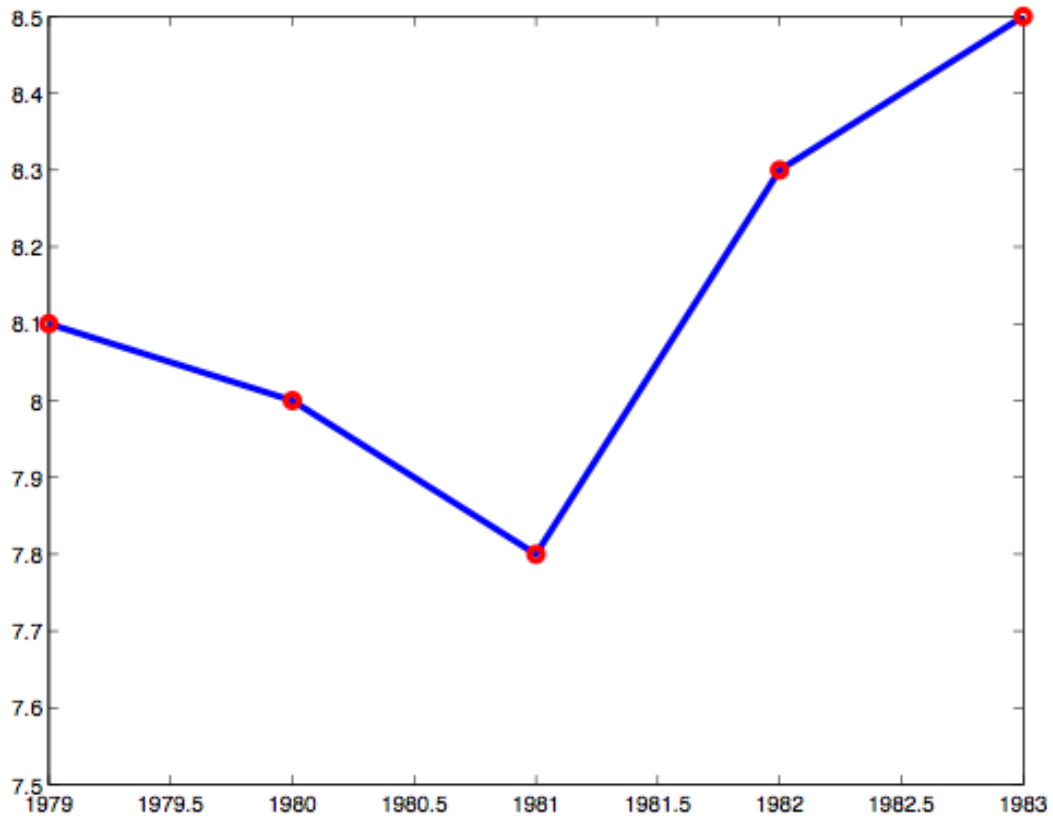
Distinguishing between natural and human made variation

Example: How much Arctic Sea Ice Is There?



NASA: National Snow and Ice Data Center NSIDC

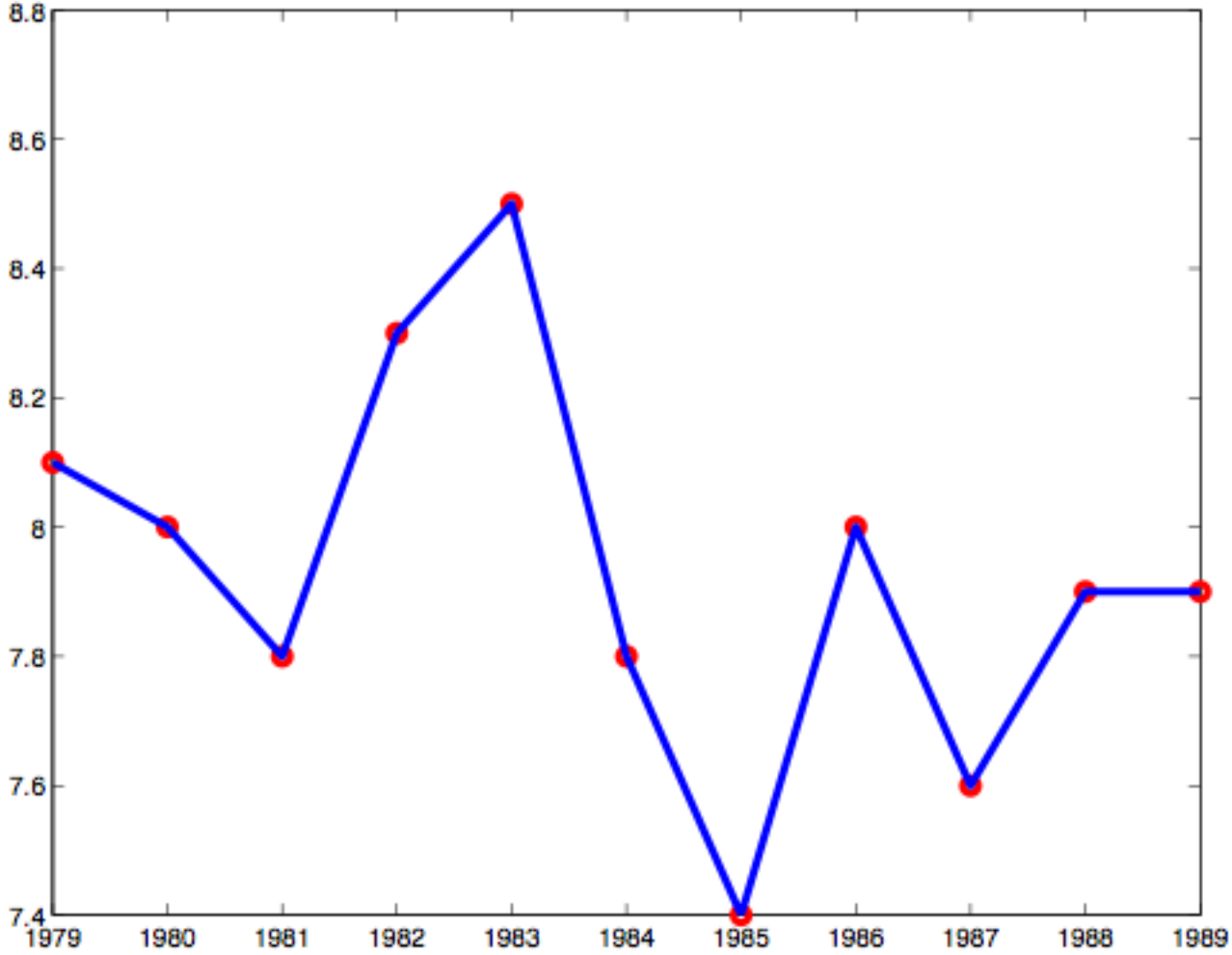
How much Ice is there in millions of square km?



Year

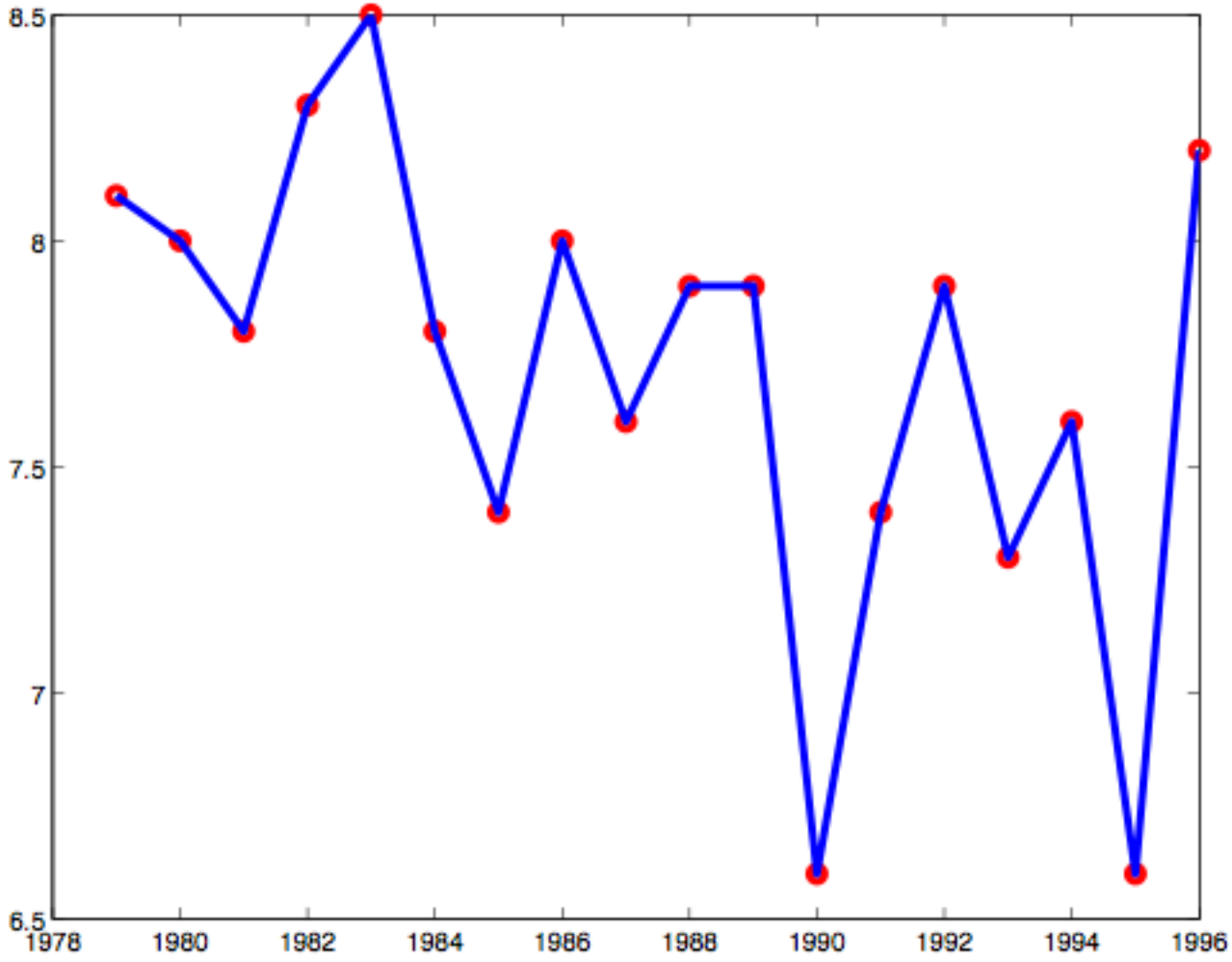
What happens next?

How much Ice is there in millions of square km?



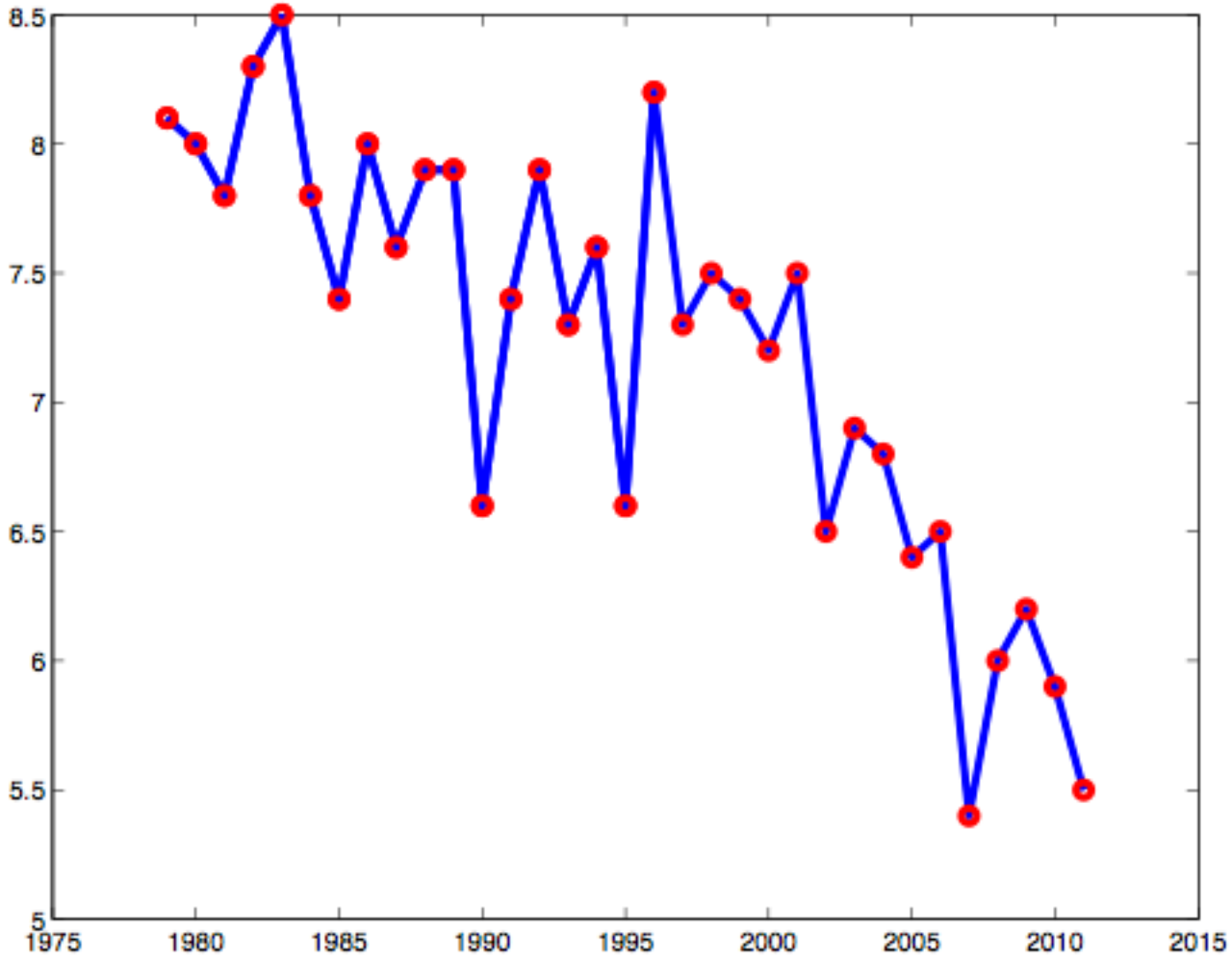
Year

How much Ice is there in millions of square km?



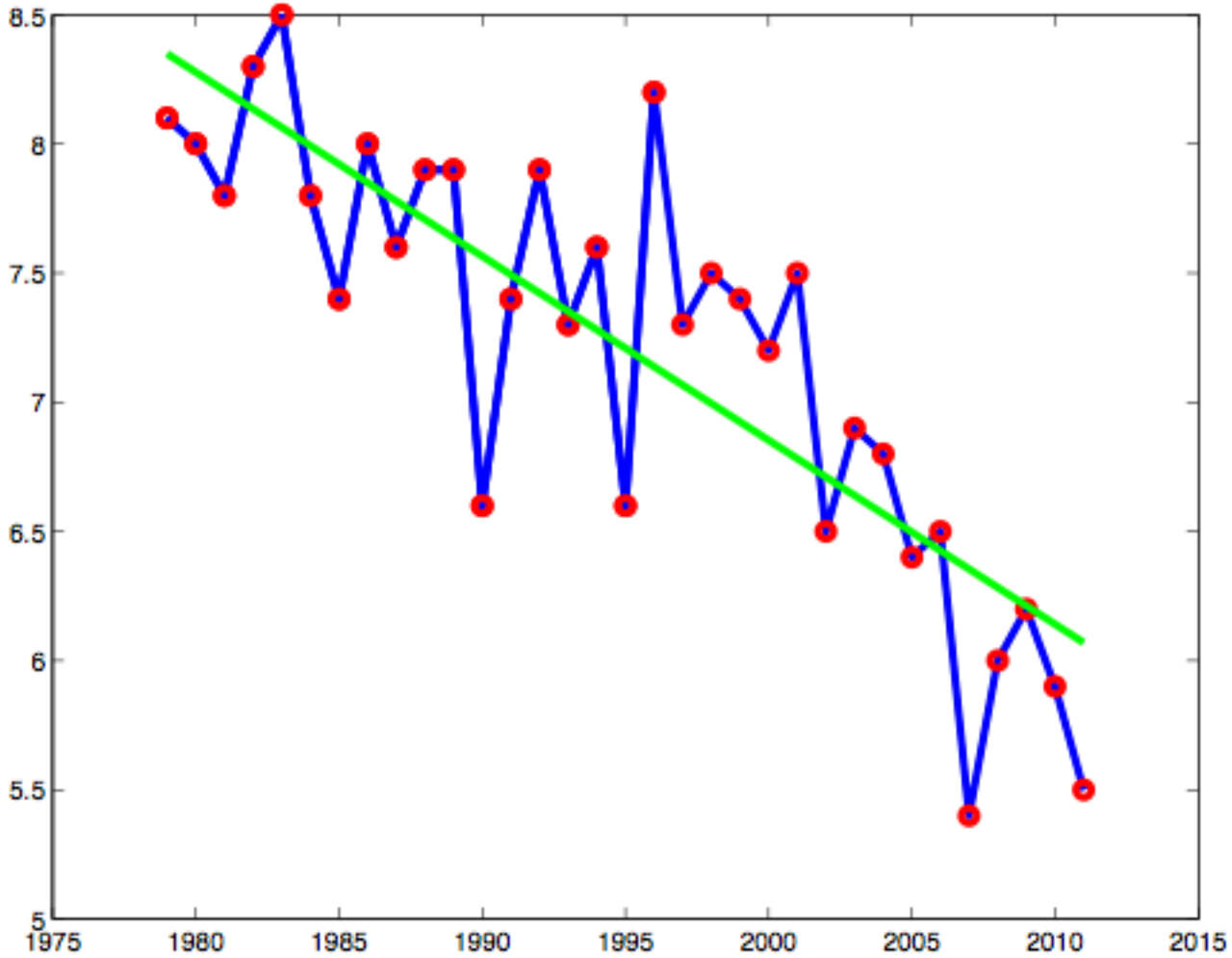
Year

How much Ice is there in millions of square km?



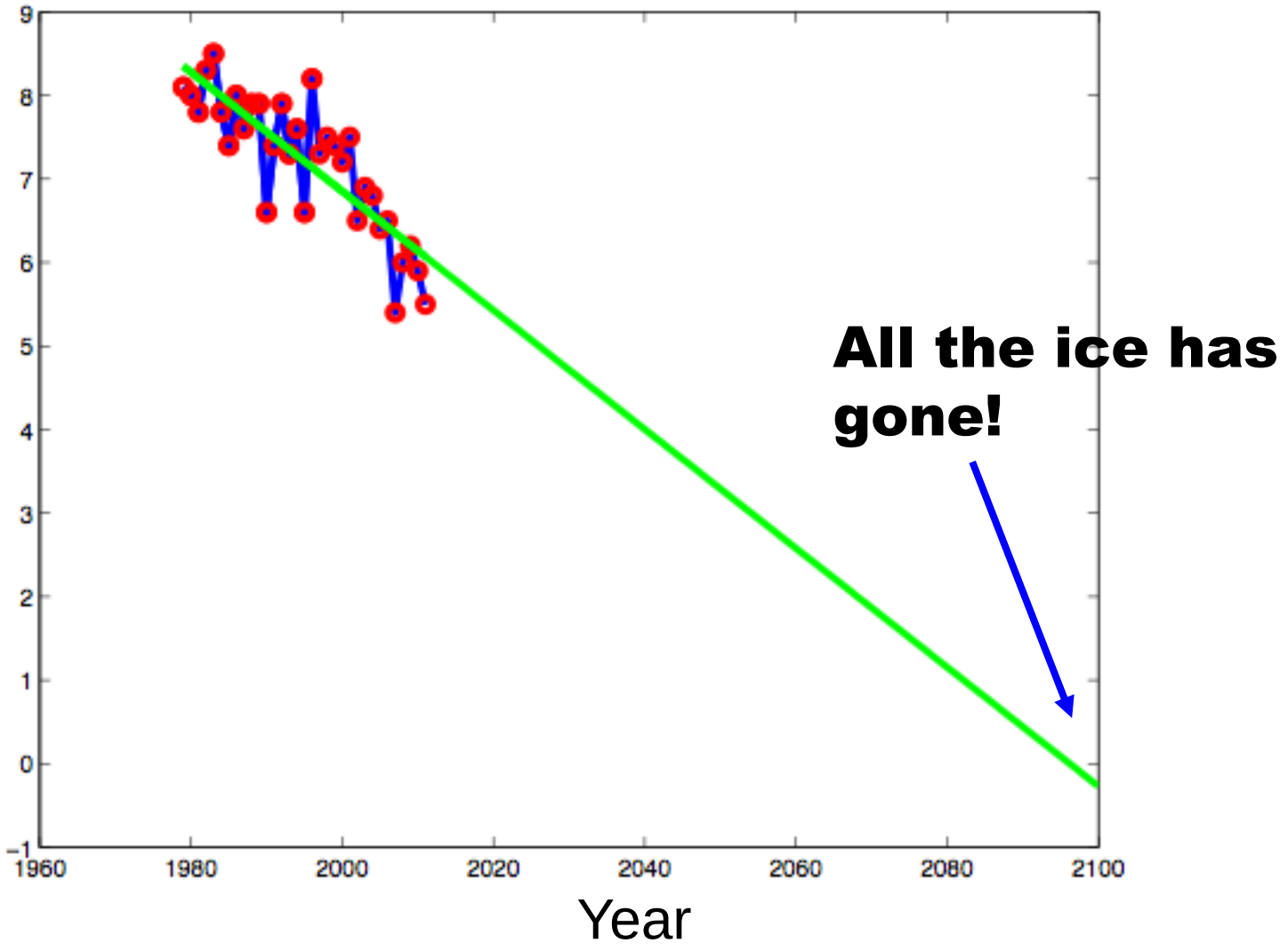
Best fit straight line (statistics)

How much Ice is there in millions of square km?



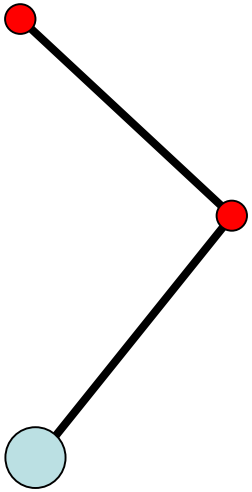
Future prediction???

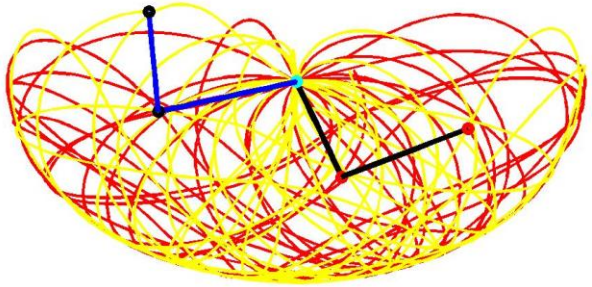
How much Ice is there in millions of square km



Chaos theory tells us that there is …

A limit to our scientific understanding of the future





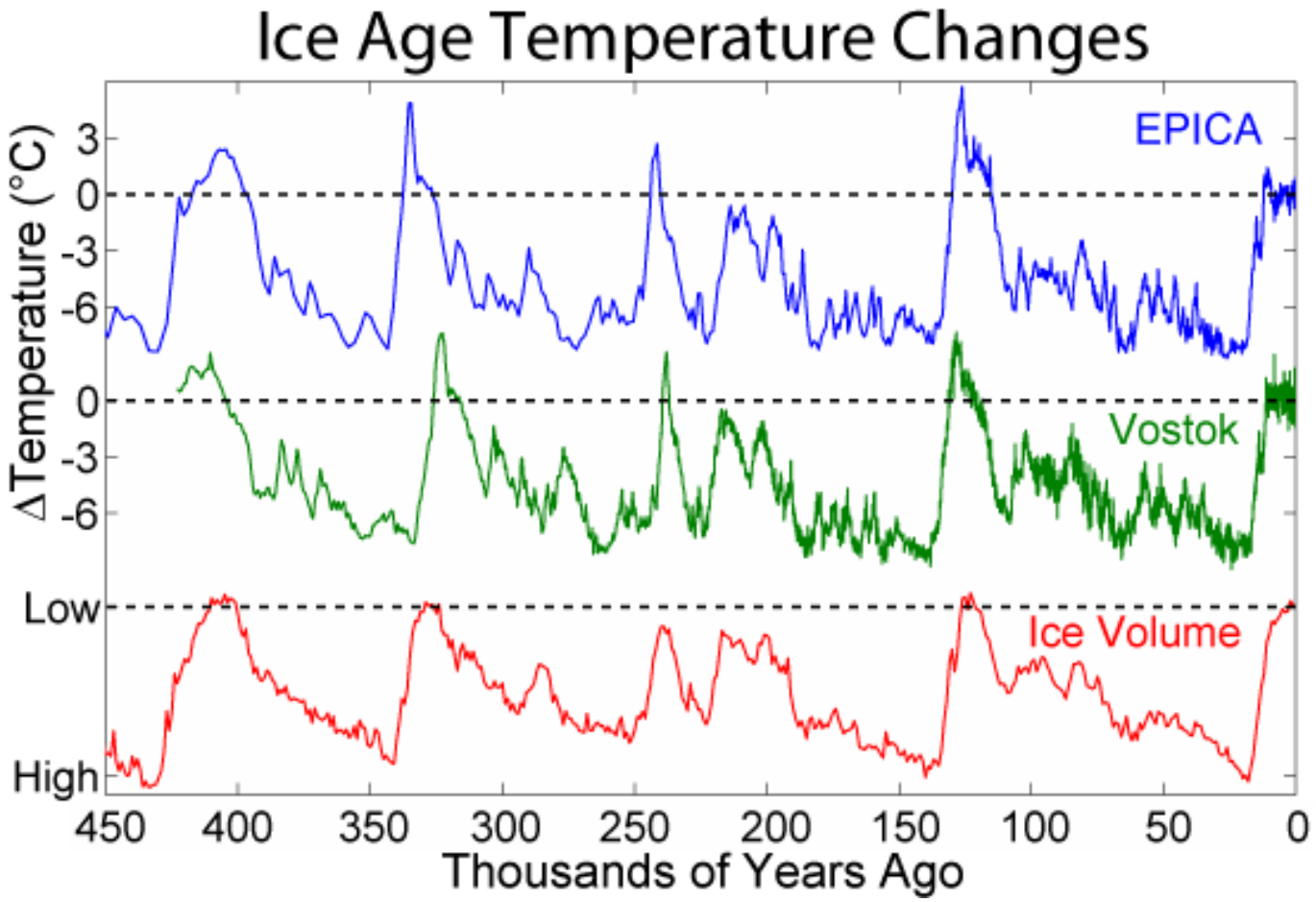
Motion can be Chaotic and unpredictable

Even if we understand something we can't always predict it with certainty!!!!!!

3. But can we really tell the future from the past?

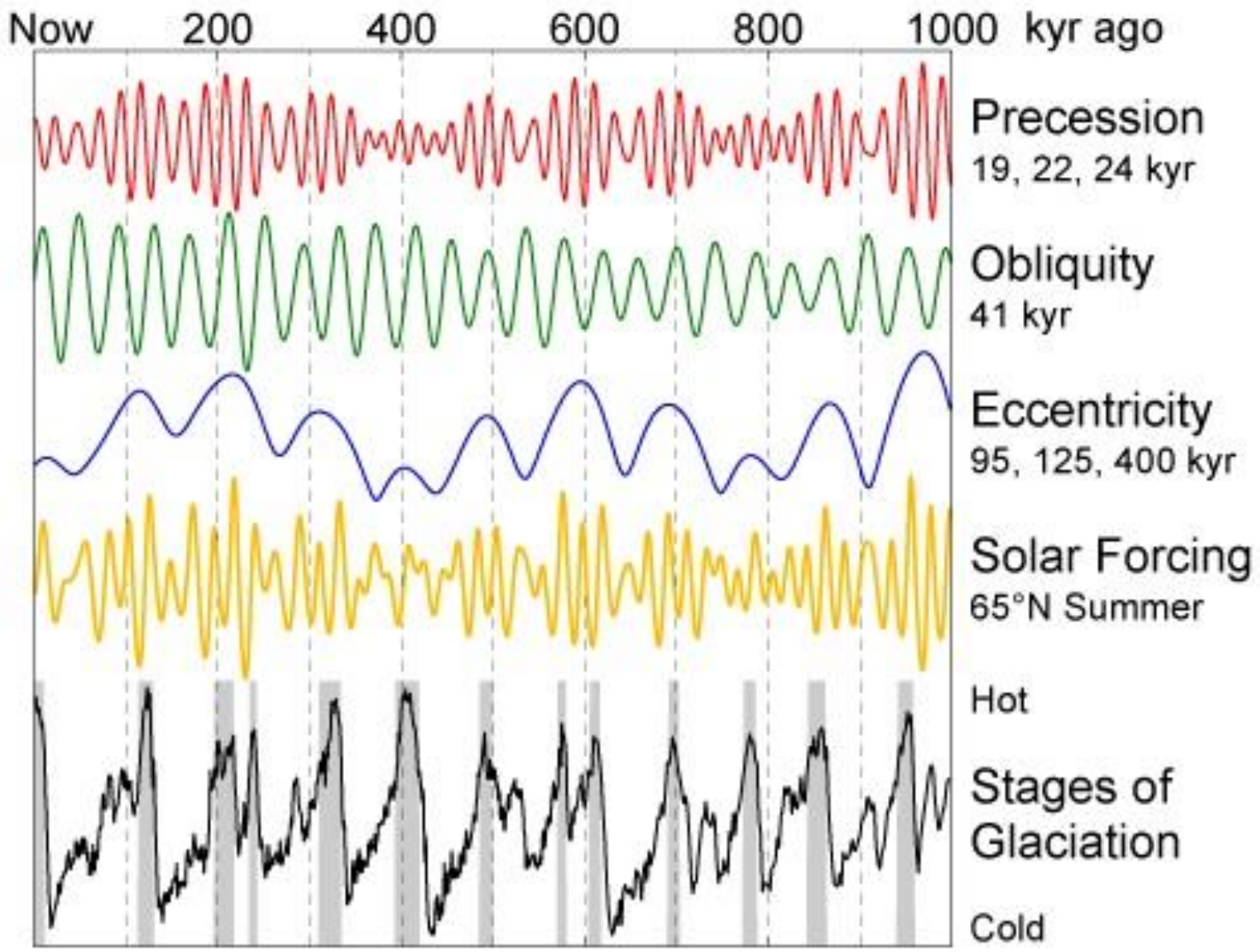
Surely climate has been changing a lot over the past
Isn't what we see now just part of that natural change?

What happened in the last half a million years?



Appearance of large temperature increases in a short time intervals, gradual cooling over 100kyr, with smaller oscillations in the cooler phases.

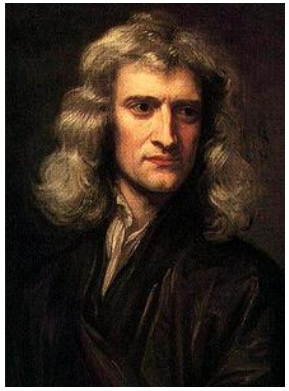
External Solar Input S(t) seems to be partly responsible:
Milankovitch cycles: What happens next?



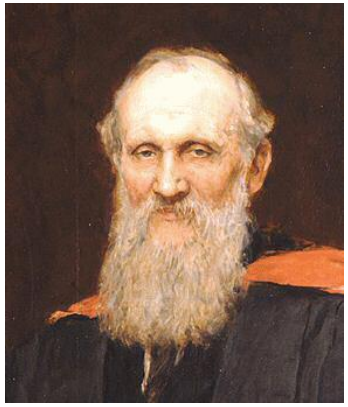
Climate Centres try to work this out

Met Office Hadley Centre

Take laws of physics



Motion



Heat

Turn them into (partial differential) equations

Solve these on a supercomputer to try to predict the climate

What makes up the climate?

Air Pressure p

Air Velocity u

Air/Ocean Temperature T

Air density *r*

Moisture q

Same for the oceans + ice + salt

All affected by:

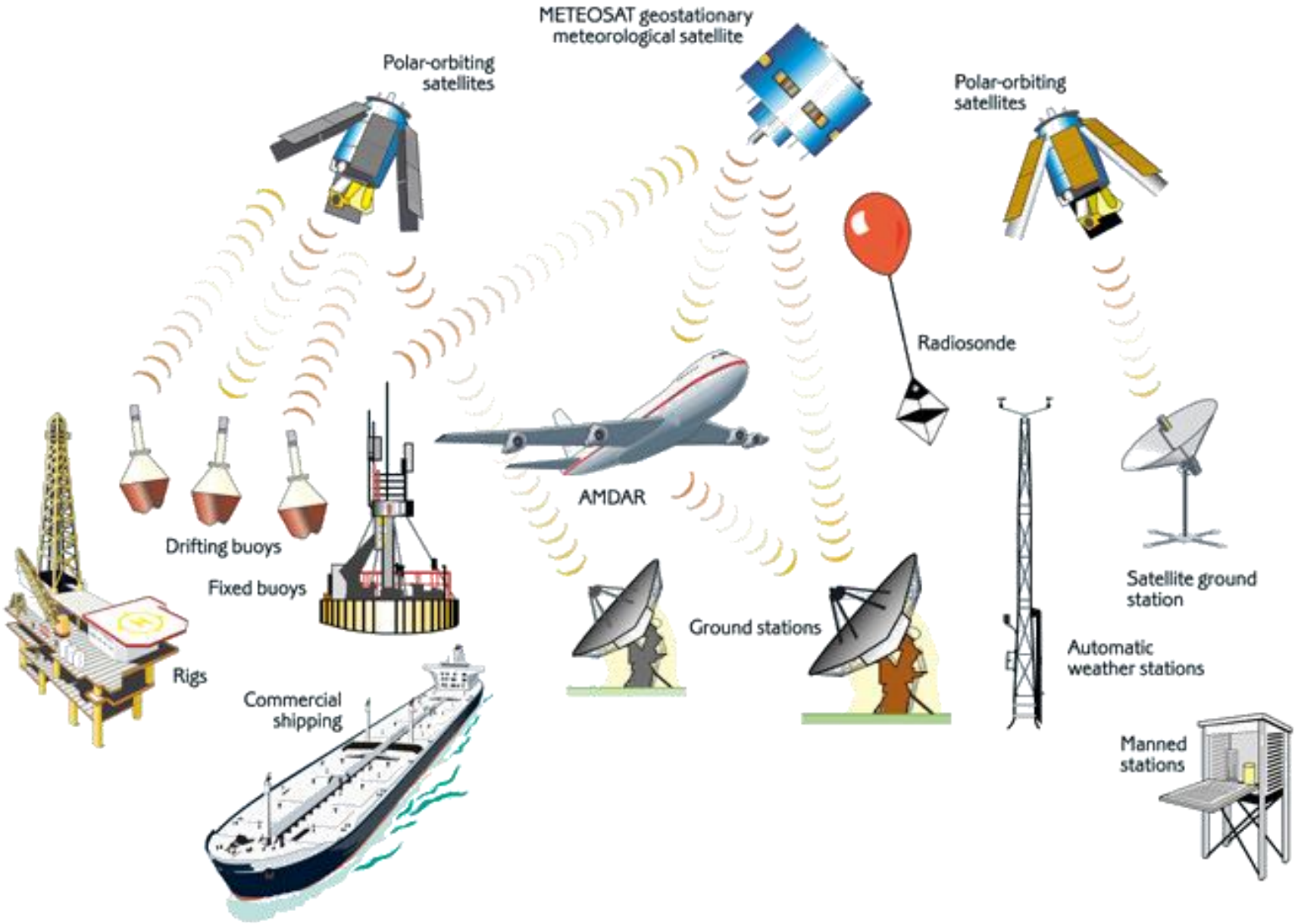
Solar radiation S

Earth's rotation f

Gravity g

Mountains, vegetation, ice, CO2, …

Data: Sources of observation



Basic equations were derived by Euler and describe the weather

$$\frac{Du}{Dt} + 2f \times u + \frac{1}{\rho}\nabla p + g = \nu\nabla^2 u,$$

$$\frac{\partial \rho}{\partial t} + \nabla .(\rho u) = 0,$$

$$C\frac{DT}{Dt} - \frac{RT}{\rho}\frac{D\rho}{Dt} = \kappa_h \nabla^2 T + S_h + LP,$$

$$\frac{Dq}{Dt} = \kappa_q \nabla^2 q + S_q - P,$$

$$p = \rho RT.$$

Motion

Density

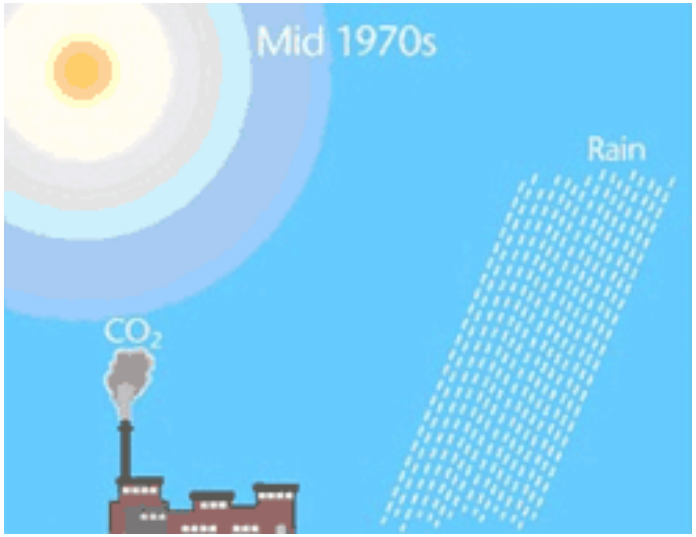
Temperature

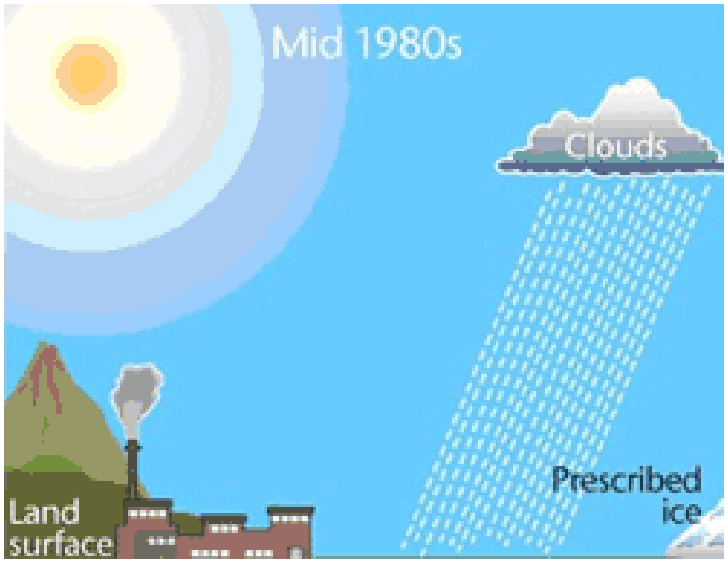
Moisture

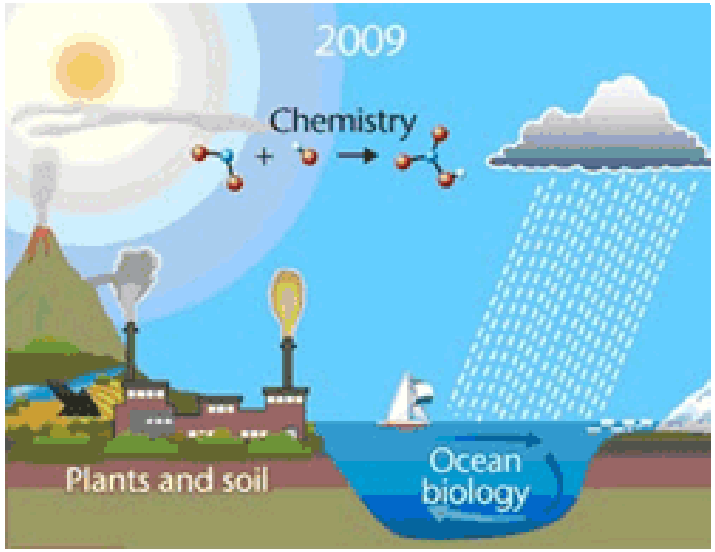
Pressure

For climate add in ice, CO2, ocean currents, …

Climate models are constantly improving to cope with complexity







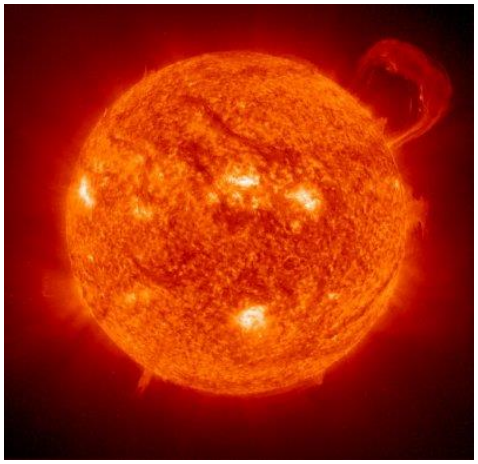
Met Office Hadley Centre

Tested by comparing with the past data

But .. Only one data set!!

Whole range of models from simple to complex

Let's see if we can forecast an aspect of the climate with a simple climate model using energy balance

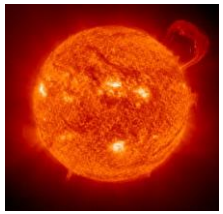


Heat into space

Heat from Sun: S

Earth's mean temperature: T

Heat absorbed $\longrightarrow (1-a)S$



a Albedo: How well the earth reflects the Sun's rays

Heat radiated away $\longrightarrow e\sigma T^4$

e emissivity: How much energy is radiated into space

Balance these to give a steady state

$$e\sigma T^4 = (1-a)S$$

If we know e, σ, a, S we can work out T !!!!

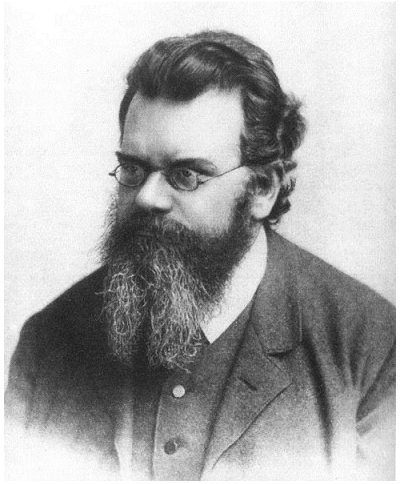
Currently

Emissivity e = 0.605,

Boltzmann $\sigma = 5.67 \times 10^{-8}$

Albedo a = 0.31,

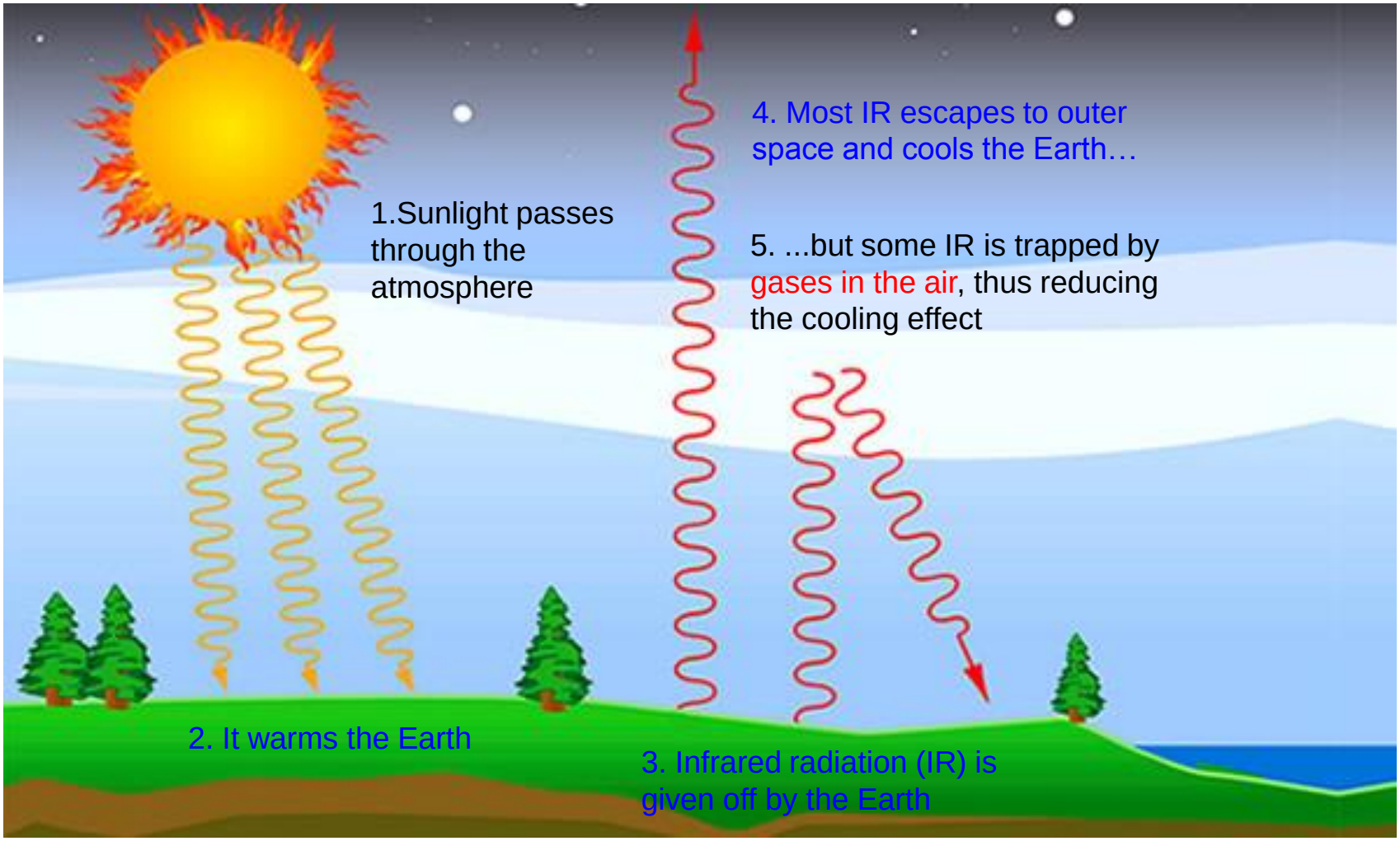
Solar heating S = 342 W/metre^2



Work out T from the heat balance equation

$$e\sigma T^4 = (1 - a)S \rightarrow T = \sqrt{\sqrt{(1 - a)S / e\sigma}}$$

The greenhouse effect



The greenhouse effect

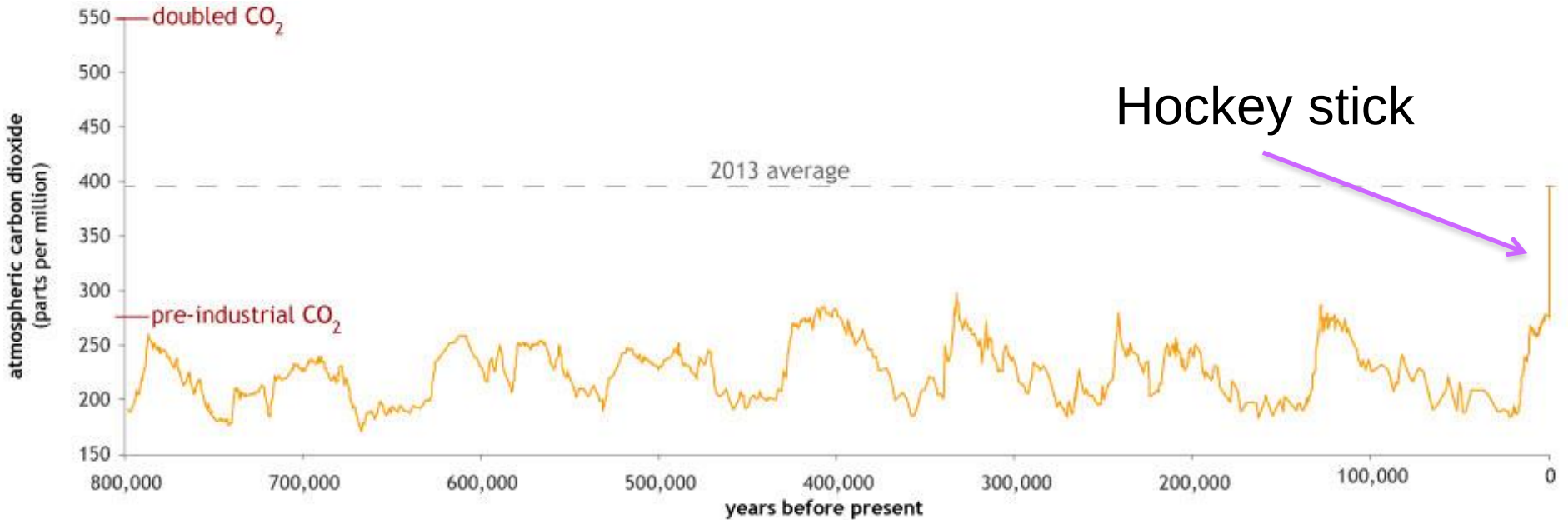
If CO2 increases

Then e decreases

$$T = \sqrt{\sqrt{(1- a)S / e\sigma}}$$

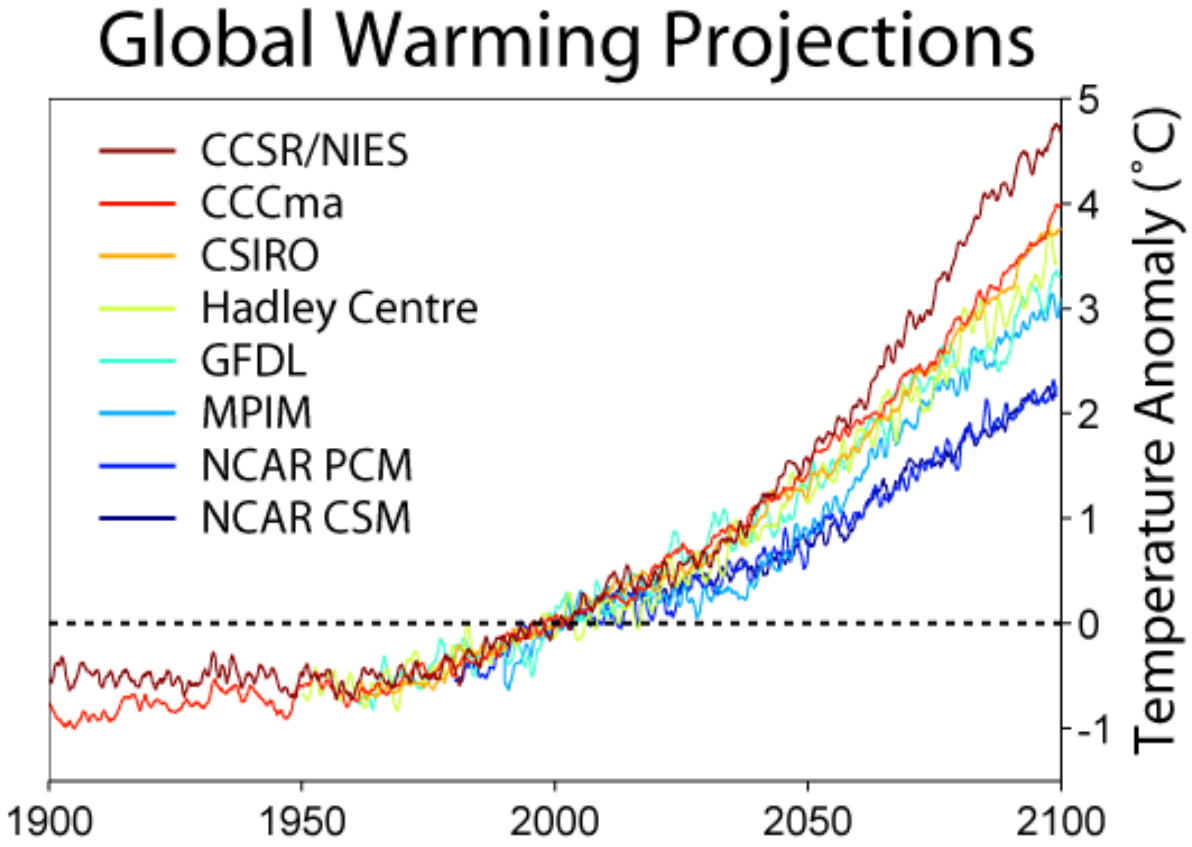
Formula tells us that T increases!!

Level of Carbon Dioxide (ppm)	Emissivity e_{CO2}
200	0.194
400	0.14
600	0.108
800	0.085



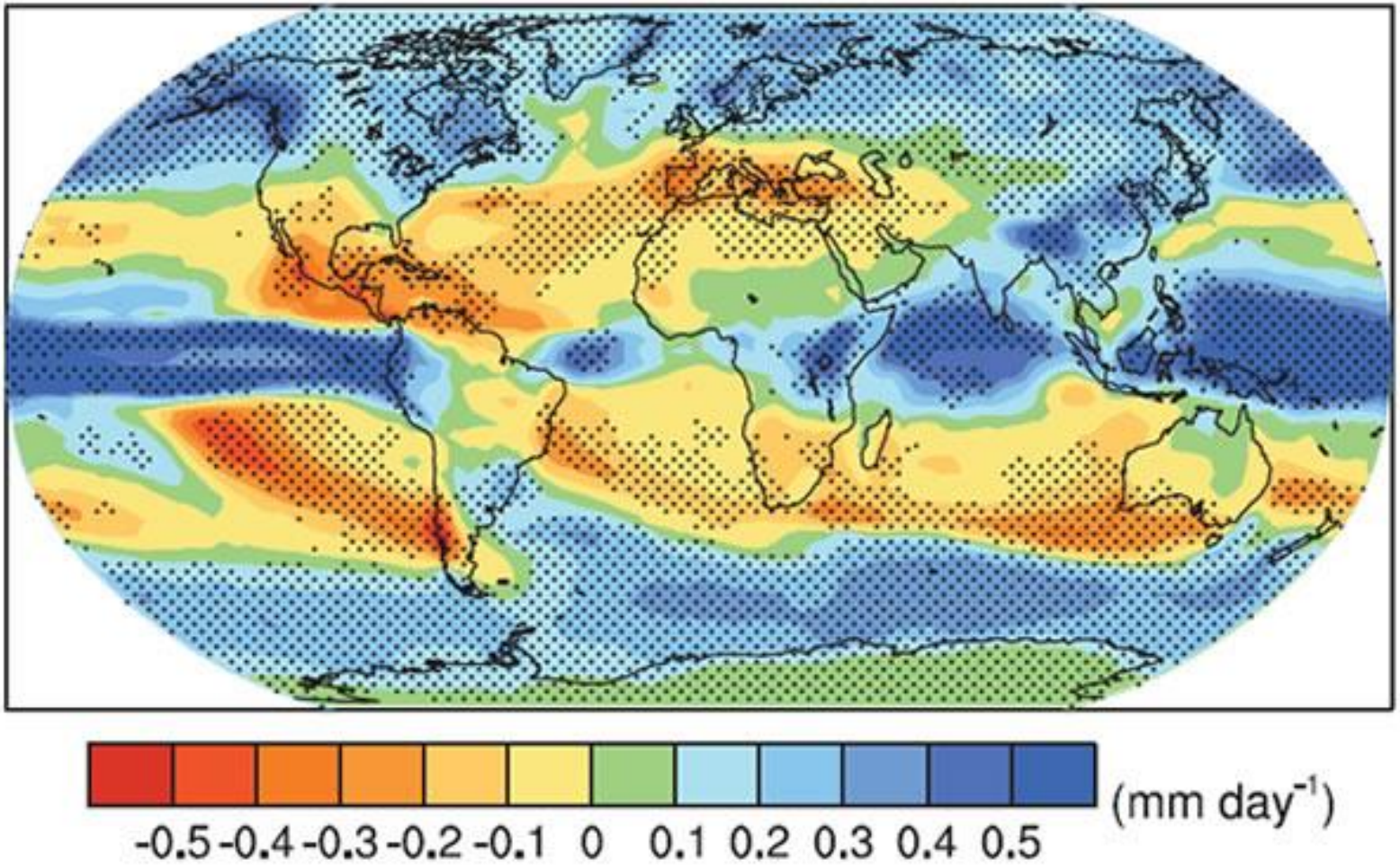
Now used to predict the future:

gradual rise in temperature



Between a 2 and 5 degree increase by 2100

North-South Differences in rainfall predictions



But .. Things could change more rapidly

As T increases the darkness d deceases

Leads to a feedback loop

Sea ice melts

Planet gets darker

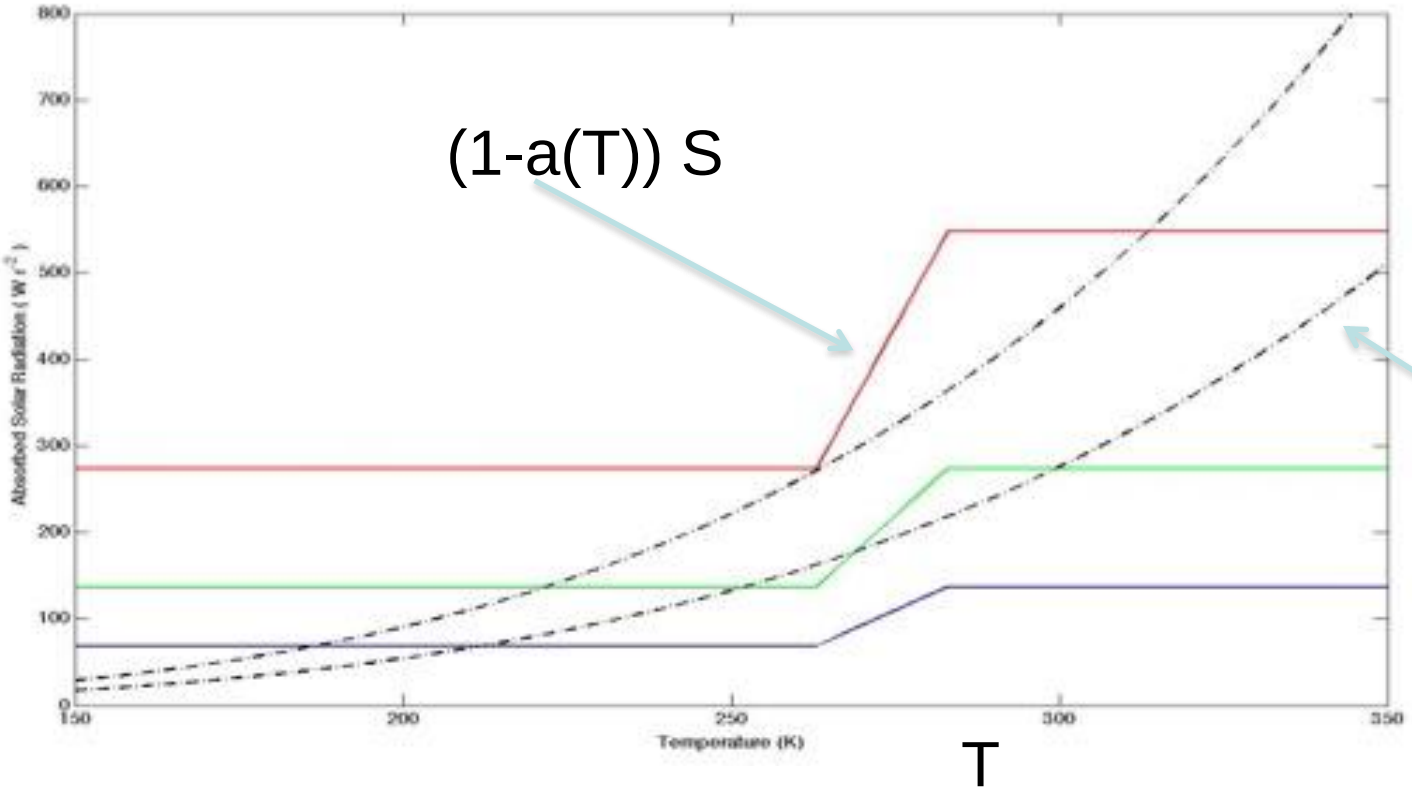
Temperature rises

This means that future temperatures may be even higher!

TIPPING POINT??

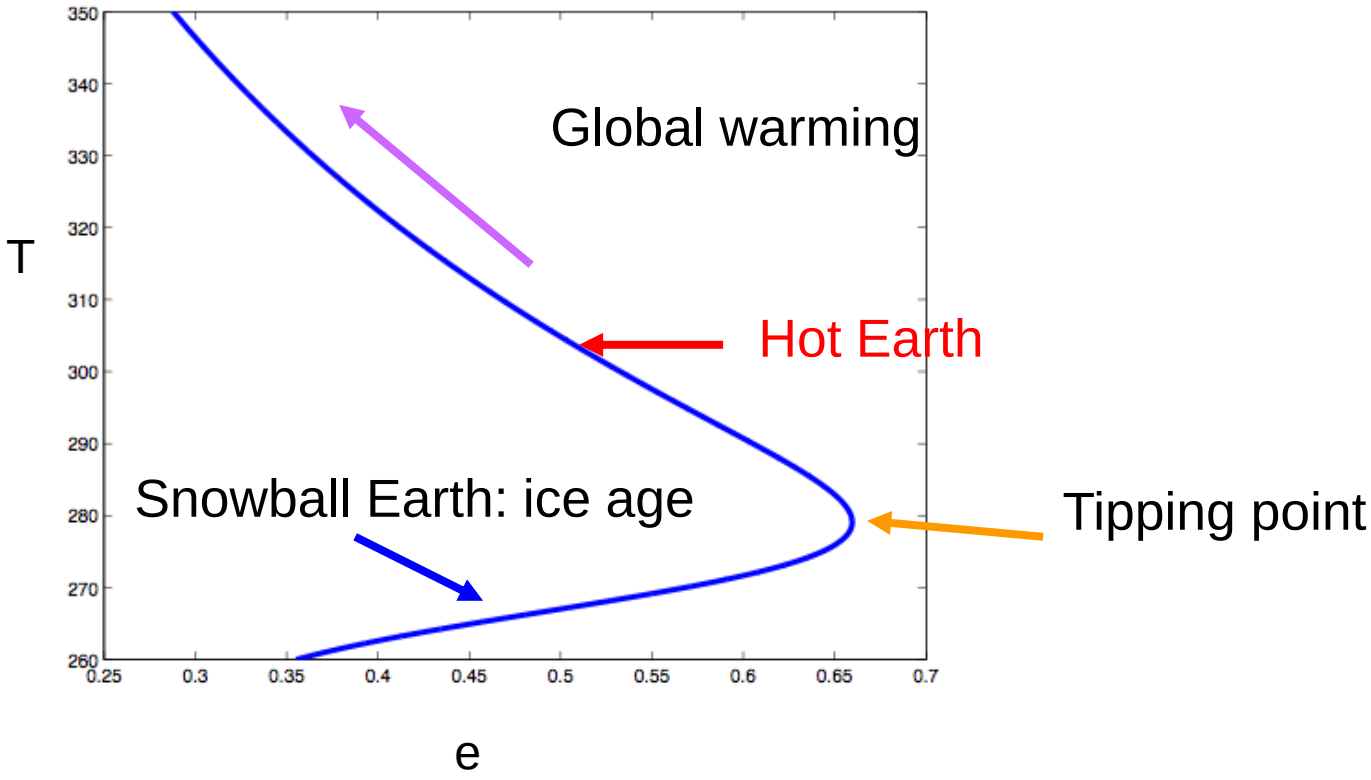
Improve the model by linking darkness to temperature

Simplest model for (1-a)(T) is a rapidly varying piecewise continuous or discontinuous model.



Eg. http://climatephys.org/2012/06/03/ice-albedo/

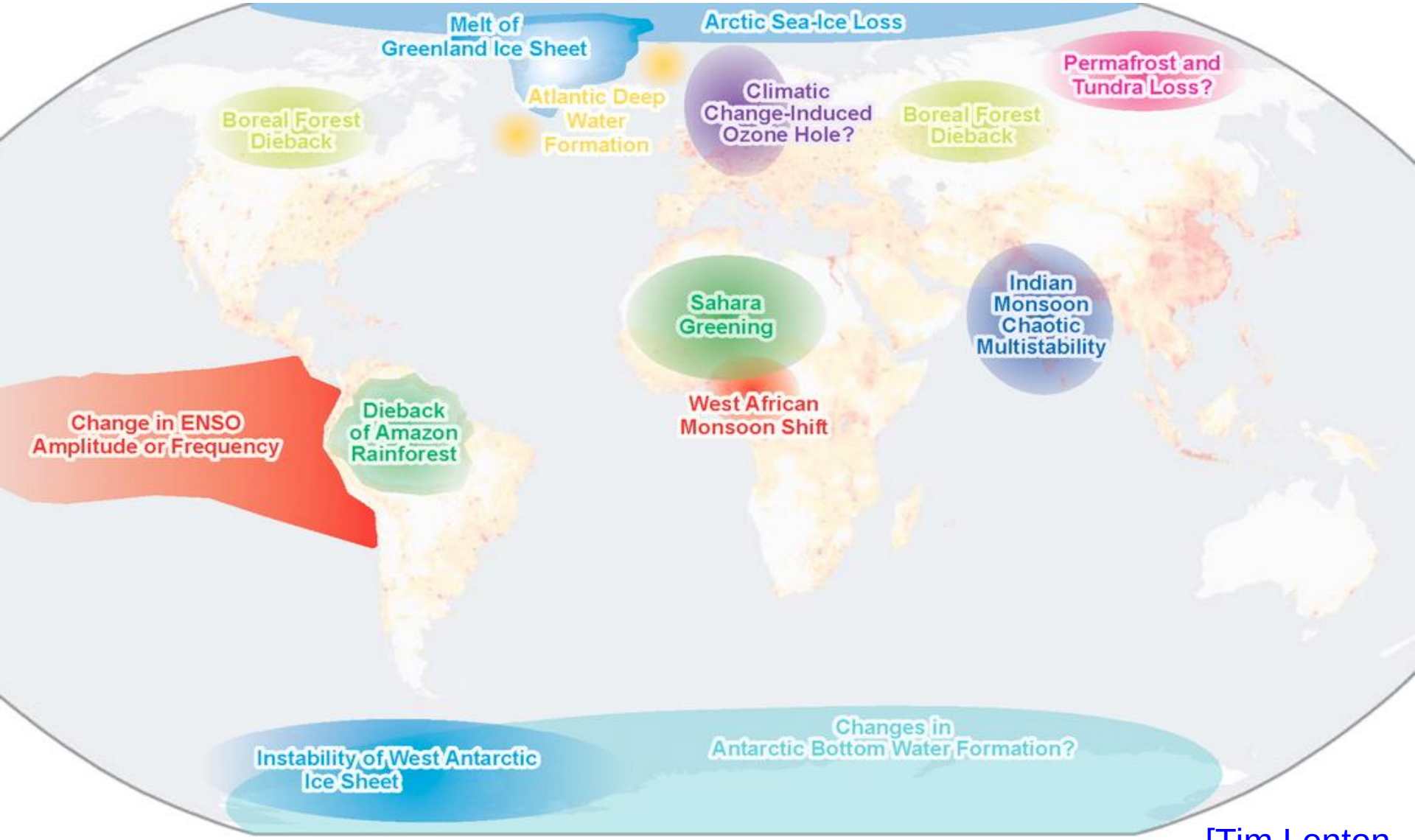
Multiple states observed, consistent with the observed past climates


T
e
350
340
330
320
310
300
290
280
270
260
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
Global warming
Hot Earth
Snowball Earth: ice age
Tipping point

Small changes lead to large effects

Potential Tipping Points In The Climate:

What many people are worried about!



[Tim Lenton

So .. Are we all doomed?

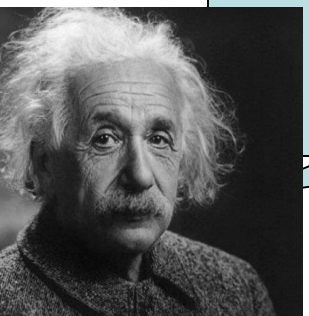
Not necessarily!!

Practical ways to save the planet

Most of the energy we generate we simply throw away!

Can we use some of this instead?

and run the world from a cup of coffee



Halve the number of power stations

Stirling Engine

Conclusion

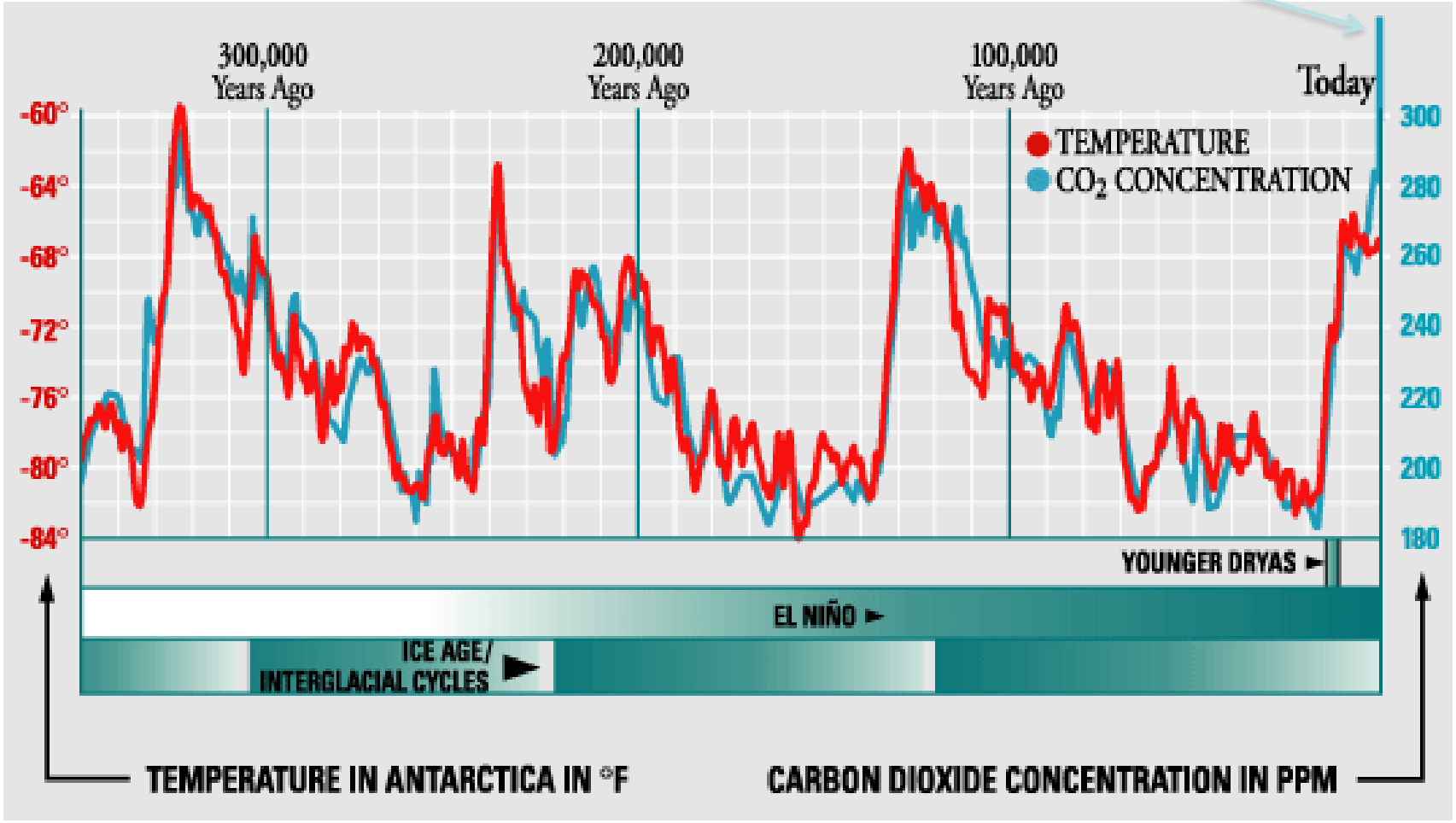
$$T = \sqrt{\sqrt{(1 - a)S / e\sigma}}$$

What should a mathematician do about climate change?

- Think of ways to use less energy
- Think of better ways to produce energy
- Be aware of what is happening to our planet
- Always use your mathematical judgment when listening to what the papers say!

CliMathNet

Hockey stick!



Temperature and CO2 and Ice volume in synchronisation!

Some different views

90% of scientists agree: the earth is warming and man made CO2 is responsible.

vs

Jan 27th 2012

16 Scientists in the Wall St. Journal say

'No need to panic about global warning'