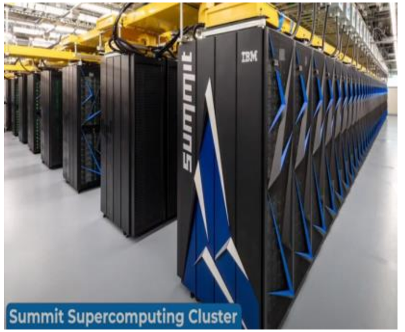
CLIMATE MODELLING

Ian Hawker



Climate models are used to predict long term changes to the Earth's climate

They are mathematical representations of the climate system

They use a variety of data inputs, temperature, precipitation & wind patterns to simulate the changing climate

Climate & weather predictions are becoming more accurate as computers get faster
Climate change prediction models are more complex than weather forecasting models

How will the climate change if we continue emitting green house gases at the current rate?

What will be the impact of reducing green house gas emissions?

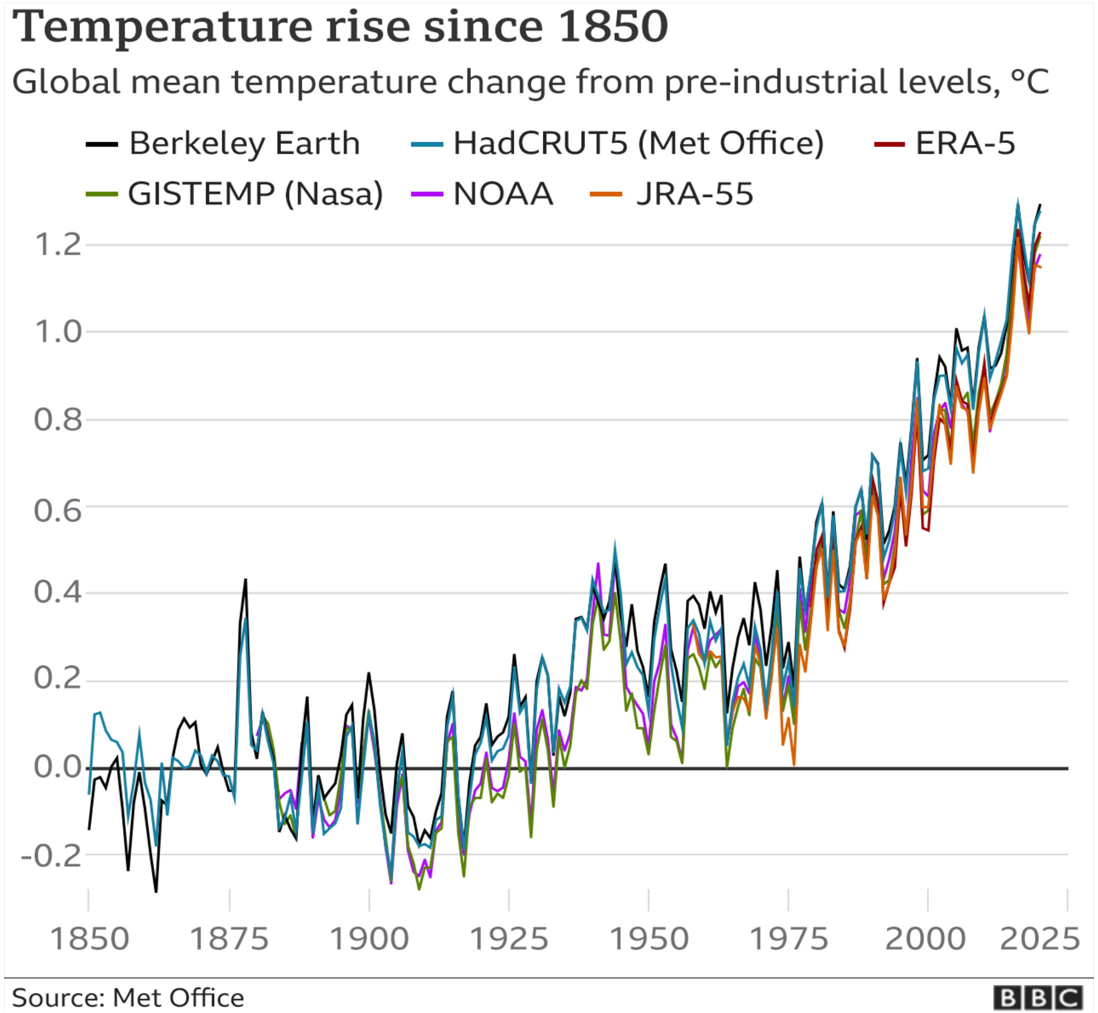
Will we reach tipping points & trigger accelerated temperature change?

What is the effectiveness of geoengineering methods to 'fix the planet'?

More broadly how is climate change related to societal change & ecosystem response?

How will climate change effect mass migration from equatorial regions?

AVERAGE GLOBAL TEMPERATURE RISE



Temperatures predicted to rise by 2.5 – 2.9C by 2100

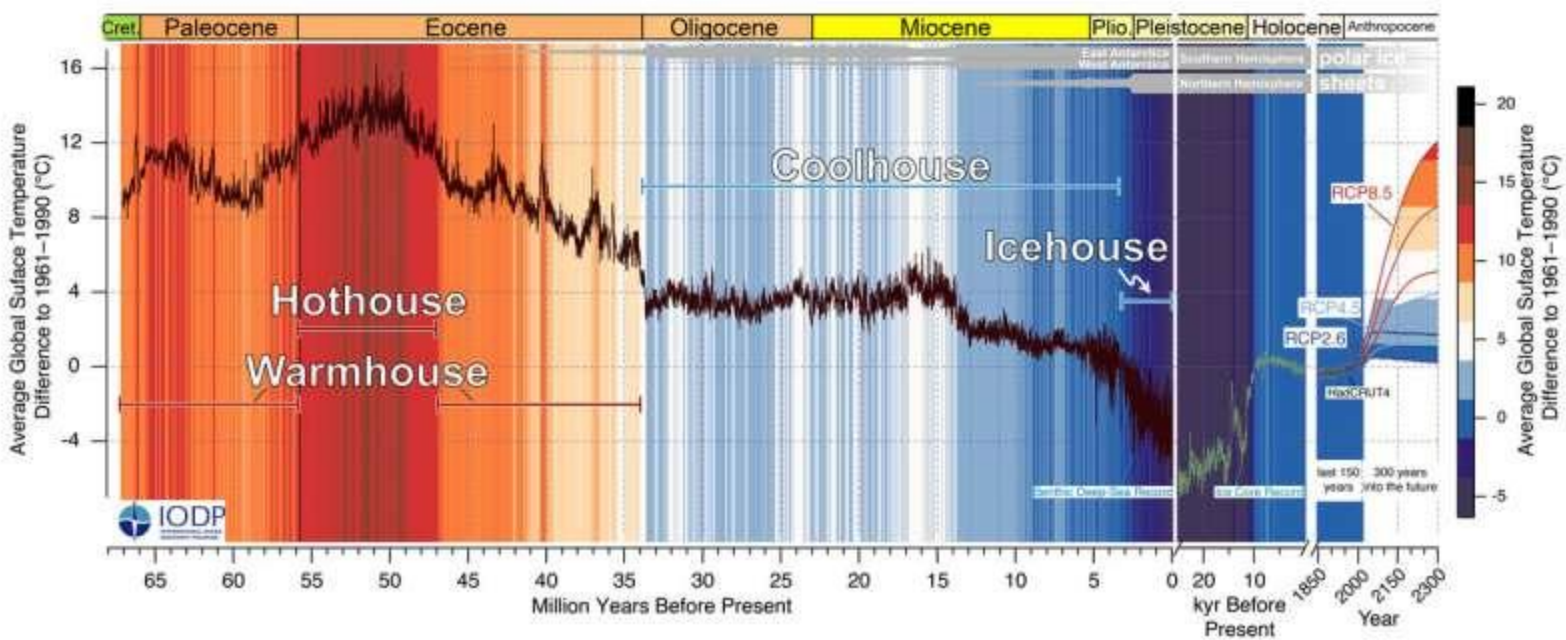
Climate Action Tracker

CLIMATE HISTORY

The world was a lot hotter in the past when CO_2 levels were higher

It gradually cooled as CO_2 was absorbed into rocks over millions of years

<u>Today</u> carbon dioxide levels are rising at a higher rate than anytime in last 75 million years



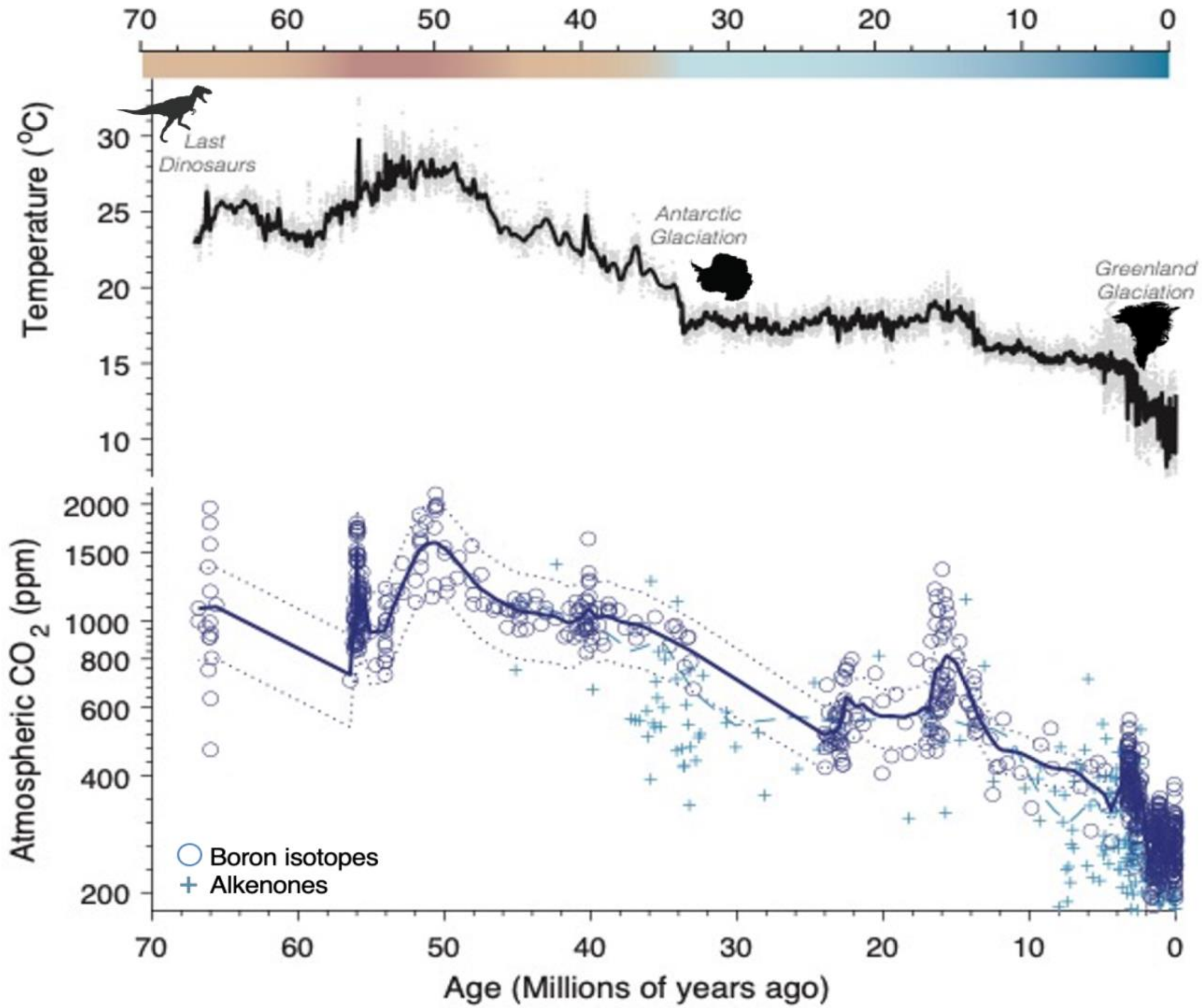
What happens next?

Predicted temperature rise 2.6 - 2.9C by 2100

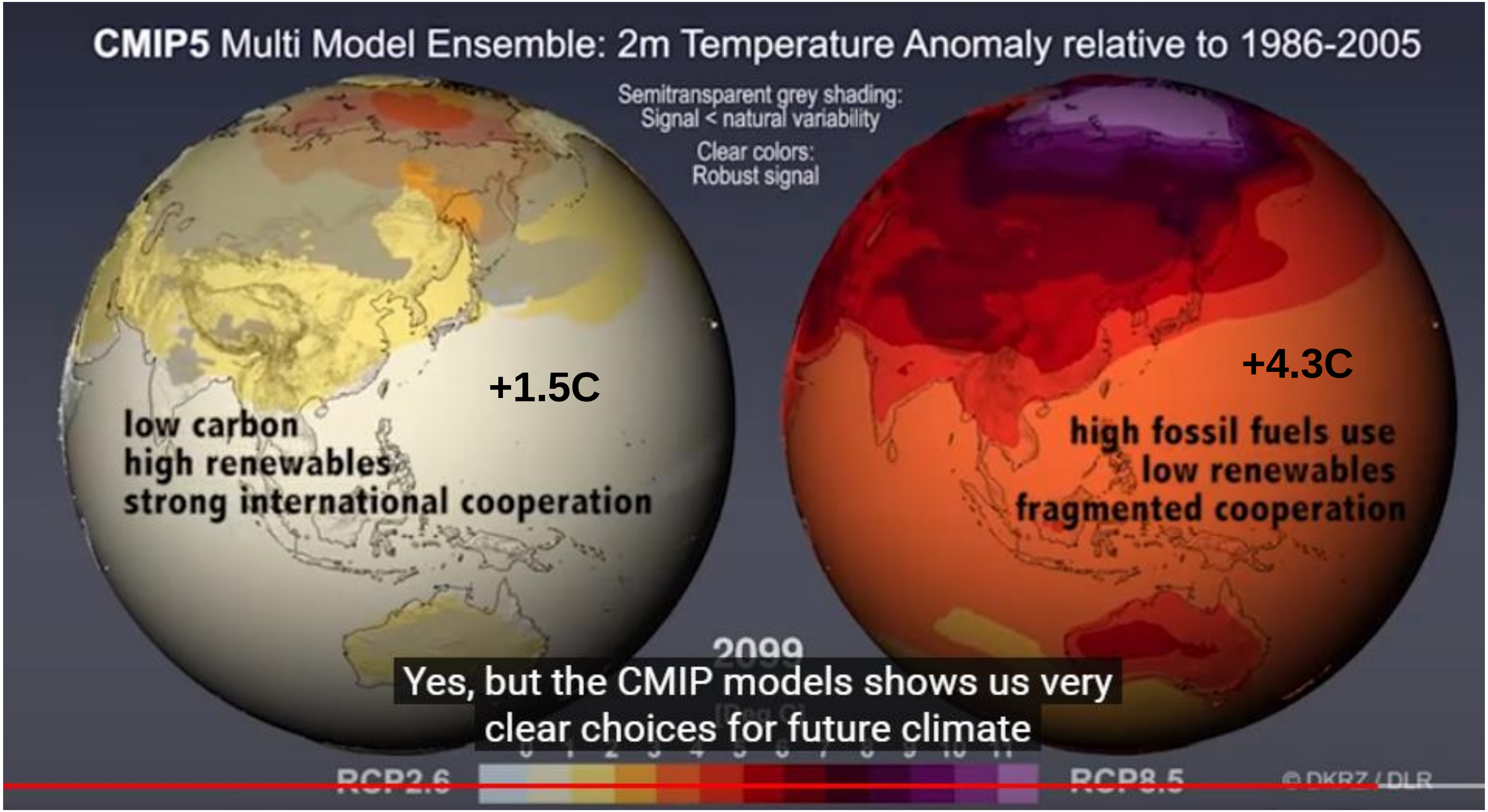
Longer term temperature rise >3C

INCREASED CO2 LEVELS MAKE THE WORLD HOTTER

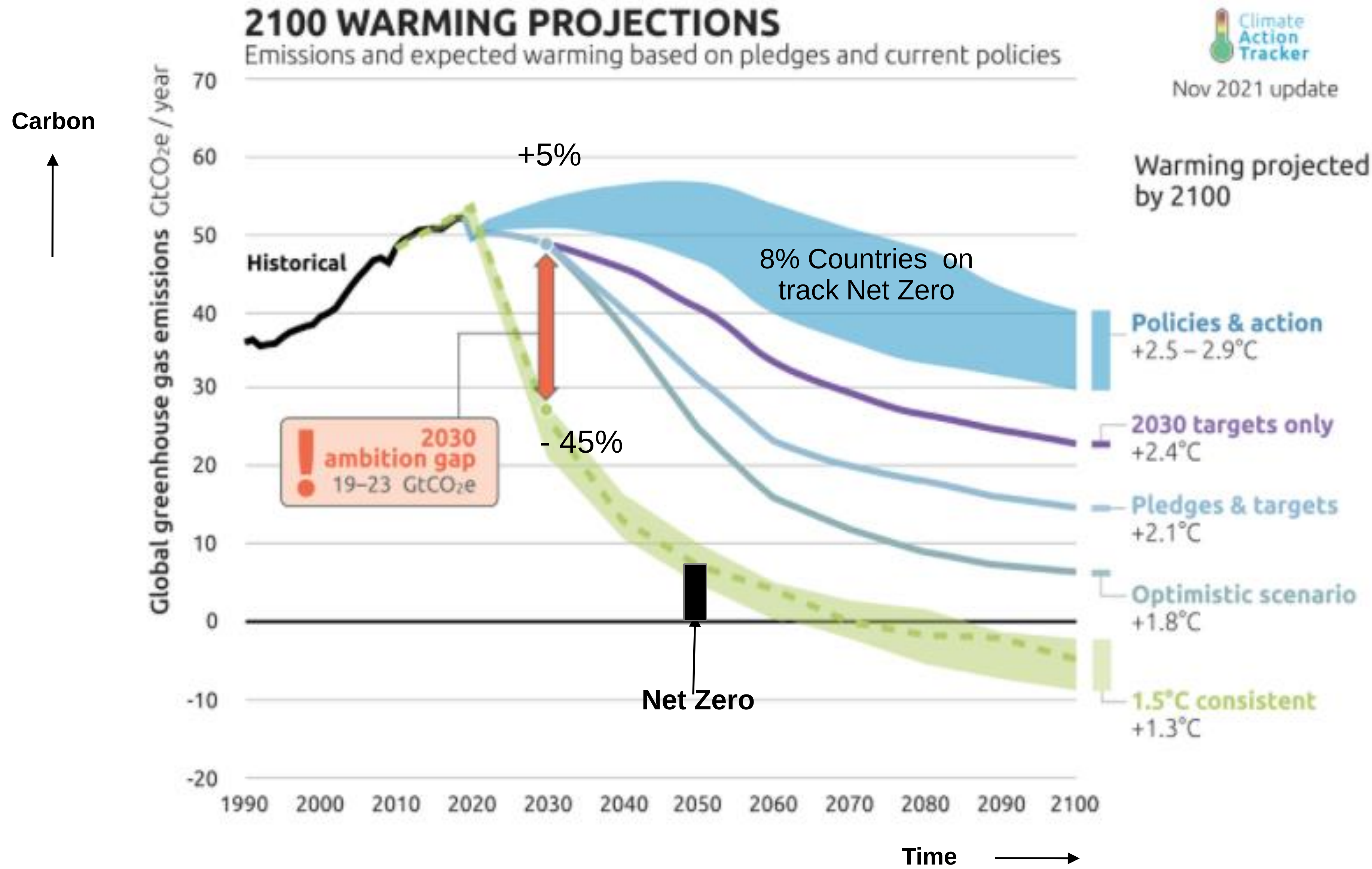
Temperature rise & CO2 emissions are highly correlated



COMPUTER MODEL TEMPERATURE RISE PREDICTIONS 2100



The choice is ours



2100 WARMING PROJECTIONS
Emissions and expected warming based on pledges and current policies
Climate Action Tracker
Nov 2021 update
Carbon
Global greenhouse gas emissions GtCO2e / year
70
60
50
40
30
20
10
0
-10
-20
Historical
+5%
8% Countries on track Net Zero
2030 ambition gap
19–23 GtCO2e
- 45%
Net Zero
Warming projected by 2100
Policies & action
+2.5 – 2.9°C
2030 targets only
+2.4°C
Pledges & targets
+2.1°C
Optimistic scenario
+1.8°C
1.5°C consistent
+1.3°C
1990
2000
2010
2020
2030
2040
2050
2060
2070
2080
2090
2100
Time

NET ZERO RATING BY COUNTRY

All countries need to strengthen their emission targets to reach Net Zero emissions by 2050

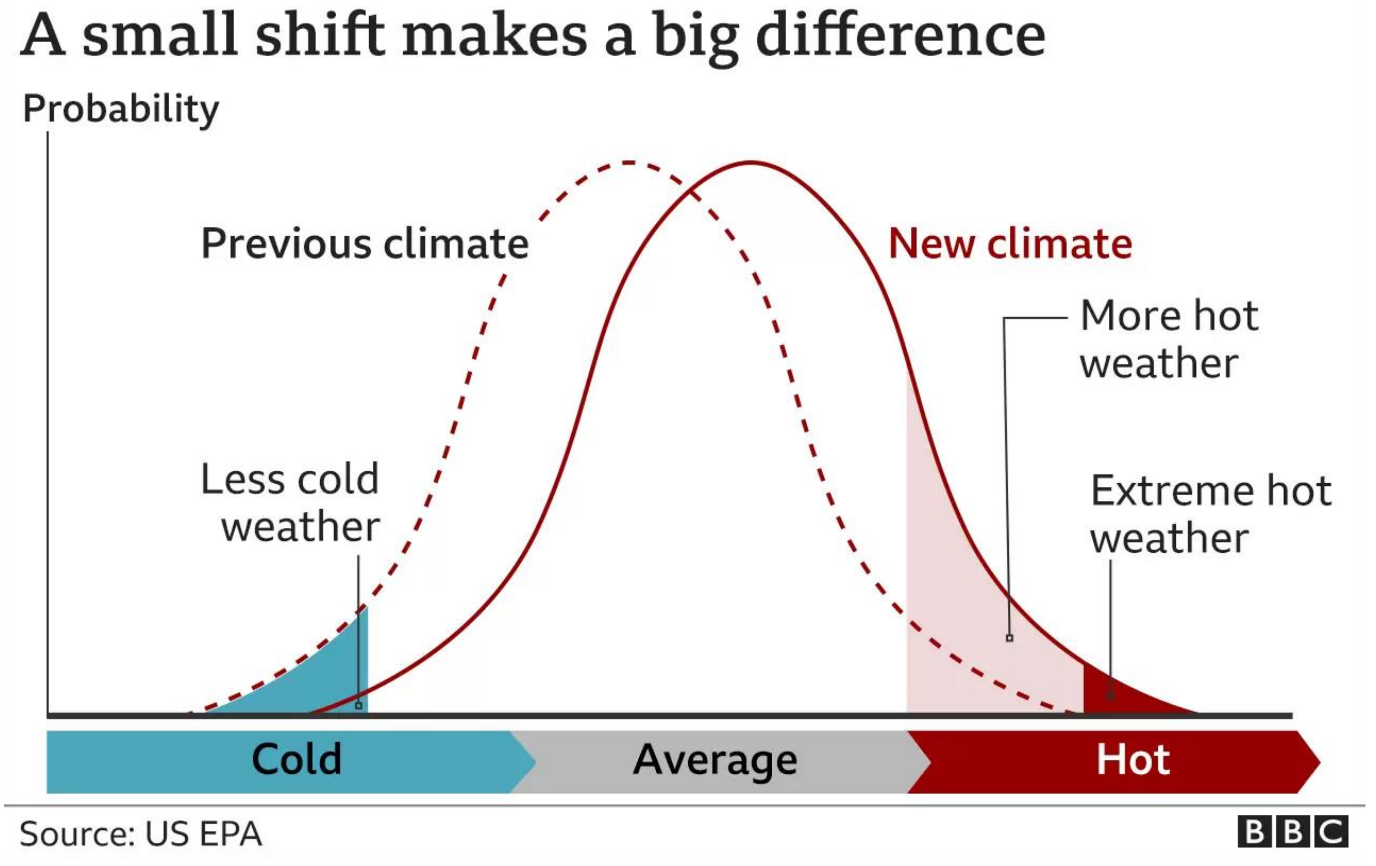
CRITICALLY INSUFFICIENT	HIGHLY INSUFFICIENT	INSUFFICIENT	ALMOST SUFFICIENT	1.5°C PARIS AGREEMENT COMPATIBLE
IRAN (ISLAMIC REPUBLIC OF)	ARGENTINA	AUSTRALIA	BHUTAN	
MEXICO	CANADA	BRAZIL	COSTA RICA	
RUSSIAN FEDERATION	CHINA	CHILE	ETHIOPIA	
SINGAPORE	EGYPT	COLOMBIA	KENYA	
THAILAND	INDIA	EU	MOROCCO	
TÜRKIYE	INDONESIA	GERMANY	NEPAL	
VIET NAM	NEW ZEALAND	JAPAN	NIGERIA	
	SAUDI ARABIA	KAZAKHSTAN	NORWAY	
	SOUTH KOREA	PERU	THE GAMBIA	
		PHILIPPINES	UNITED KINGDOM	
		SOUTH AFRICA		
		SWITZERLAND		
		UAE		
		USA		

Climate Action Tracker

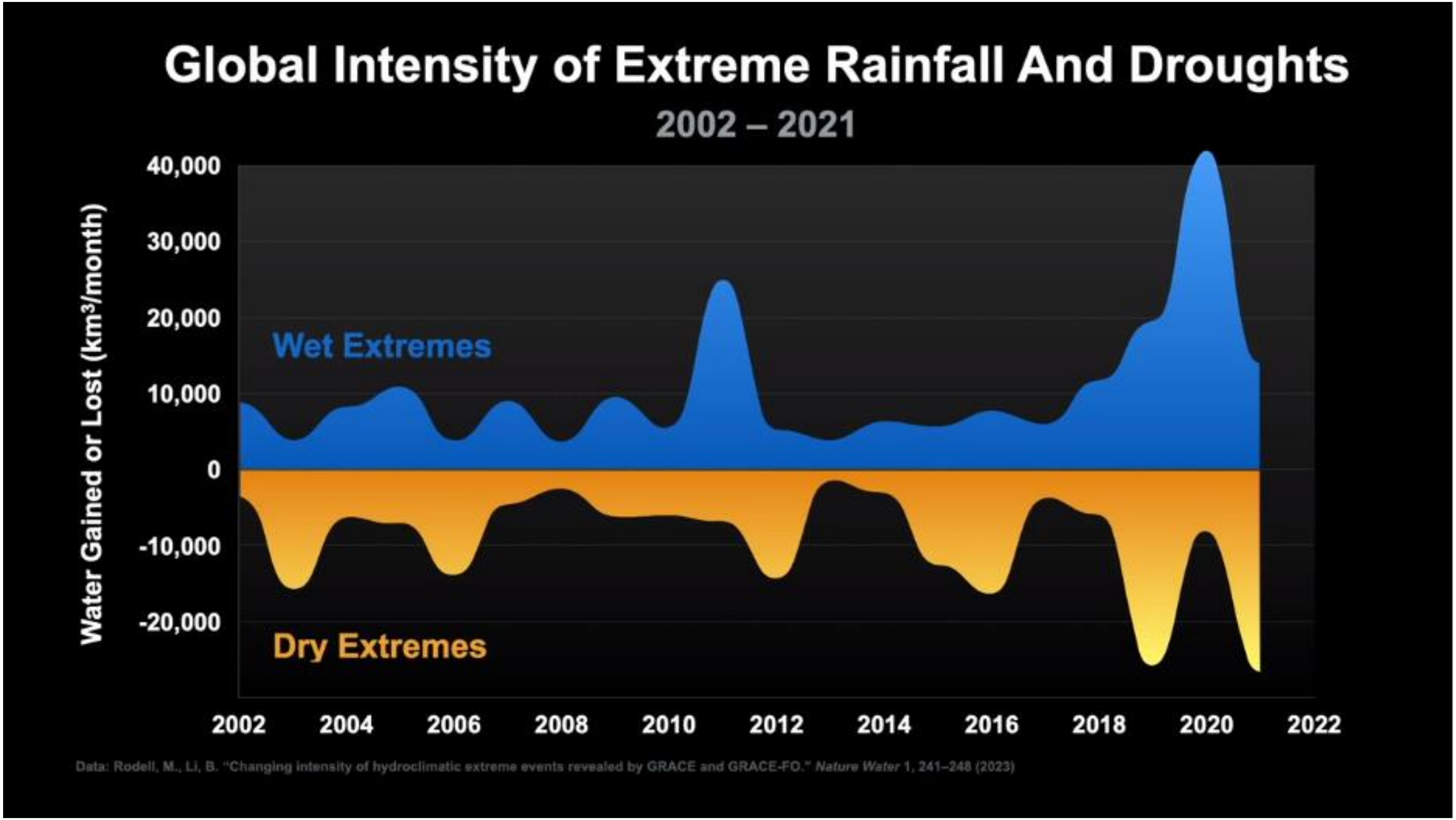
EXTREME WEATHER FREQUENCY

Daily temperature distribution across the world shifting to warmer levels

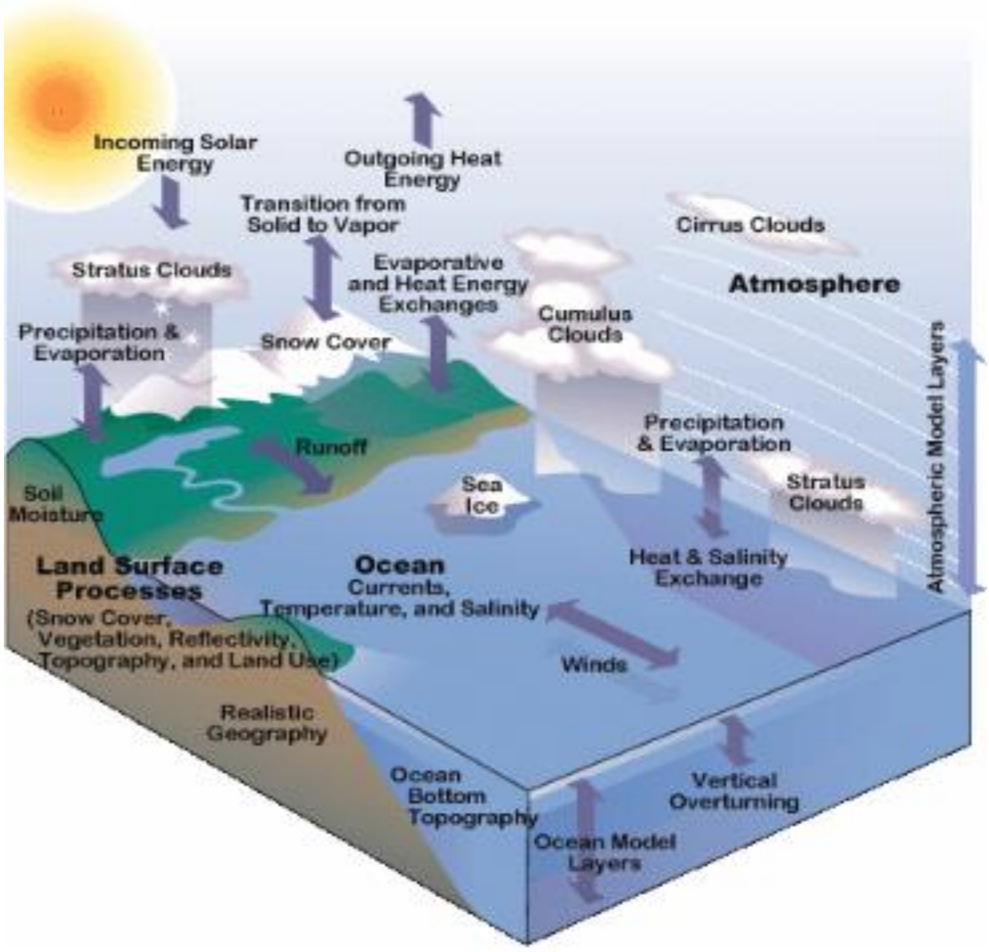
Periods of extreme temperatures much more likely (x10)



EXTREME RAINFALL & DROUGHTS



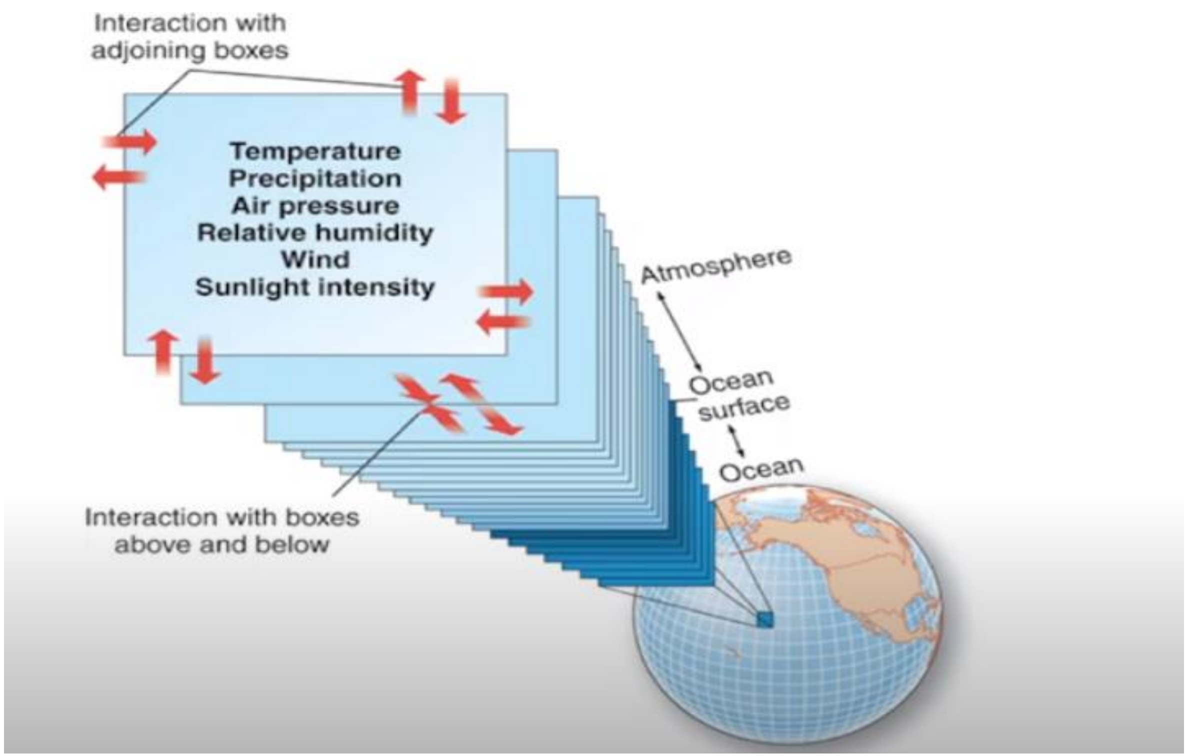
CLIMATE MODELLING IS COMPLEX



Solve mathematical equations to characterize how energy and matter interact in different parts of the ocean, atmosphere & land

GLOBAL CLIMATE MODELS

Divide the planet into grid boxes extended vertically & horizontally



Compute the parameters for each location then move to the next time increment

Verify the model against historical climate data (isotope mix, ice cores...)

Make climate change predictions into the future

CLIMATE MODELLING

Numerical solution of complex equations on super computers

Basic Equations

Conservation of momentum:

$$\frac{\partial \vec{V}}{\partial t} = -(\vec{V} \bullet \nabla)\vec{V} - \frac{1}{\rho}\nabla p - \vec{g} - 2\vec{\Omega} \times \vec{V} + \nabla \bullet (k_m \nabla \vec{V}) - \vec{F}_d$$

Conservation of energy:

$$\rho c_v \frac{\partial T}{\partial t} = -\rho c_p (\vec{V} \bullet \nabla) T - \nabla \bullet \vec{R} + \nabla \bullet (k_T \nabla T) + C + S$$

Conservation of mass:

$$\frac{\partial \rho}{\partial t} = -(\vec{V} \bullet \nabla)\rho - \rho(\nabla \bullet \vec{V})$$

Conservation of H_2O (vapor, liquid, solid):

$$\frac{\partial q}{\partial t} = -(\vec{V} \bullet \nabla) q + \nabla \bullet (k_q \nabla q) + S_q + E$$

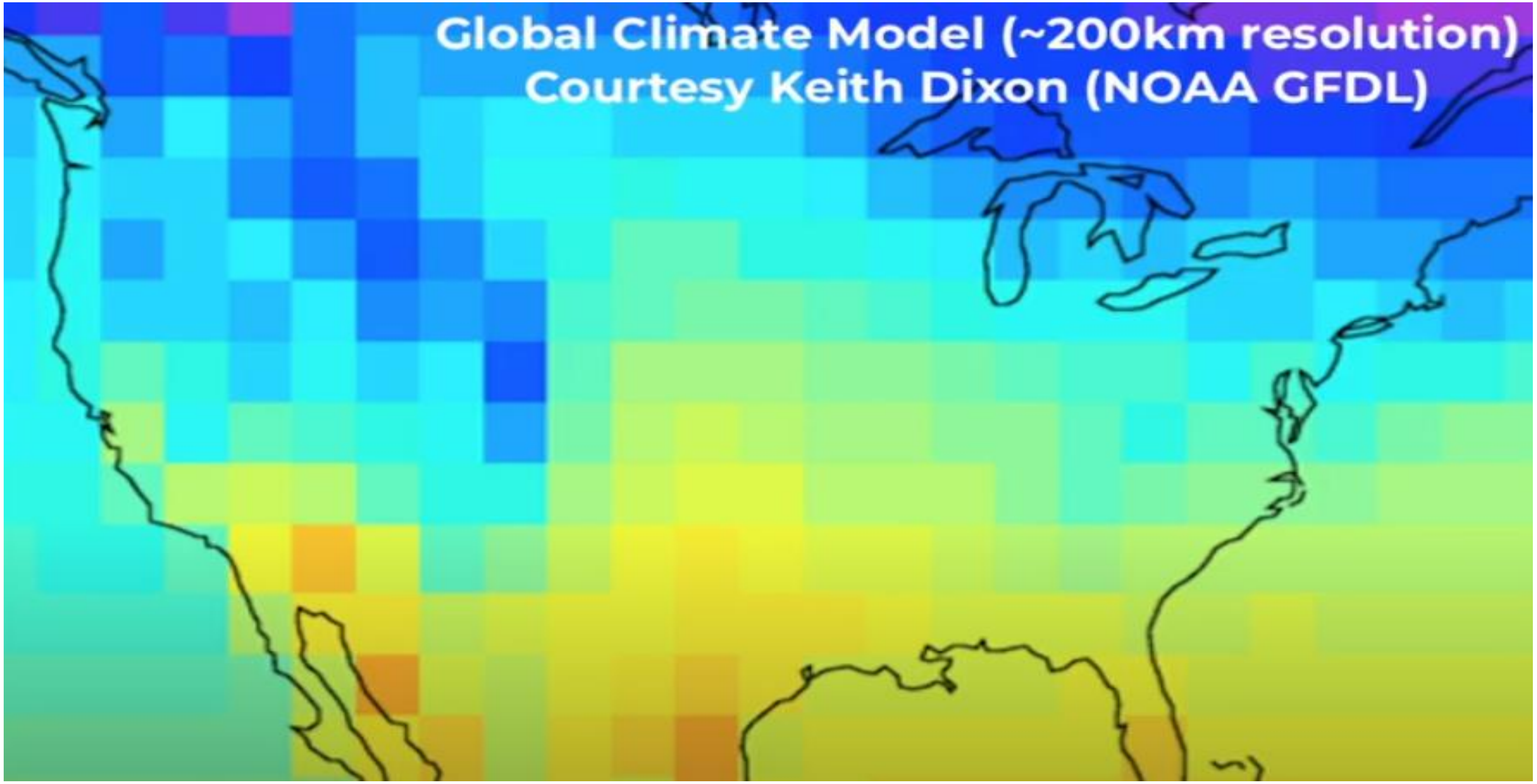
Equation of state:

$$p = \rho R_d T$$

V = velocity
T = temperature
p = pressure
ρ = density
q = specific humidity
g = gravity
Ω = rotation of earth
F_d = drag force of earth
R = radiation vector
C = conductive heating
c_p = heat capacity, const. p
E = evaporation
S = latent heating
S_q = phase-change source
k = diffusion coefficients
R_d = dry air gas constant

GLOBAL CLIMATE MODELS

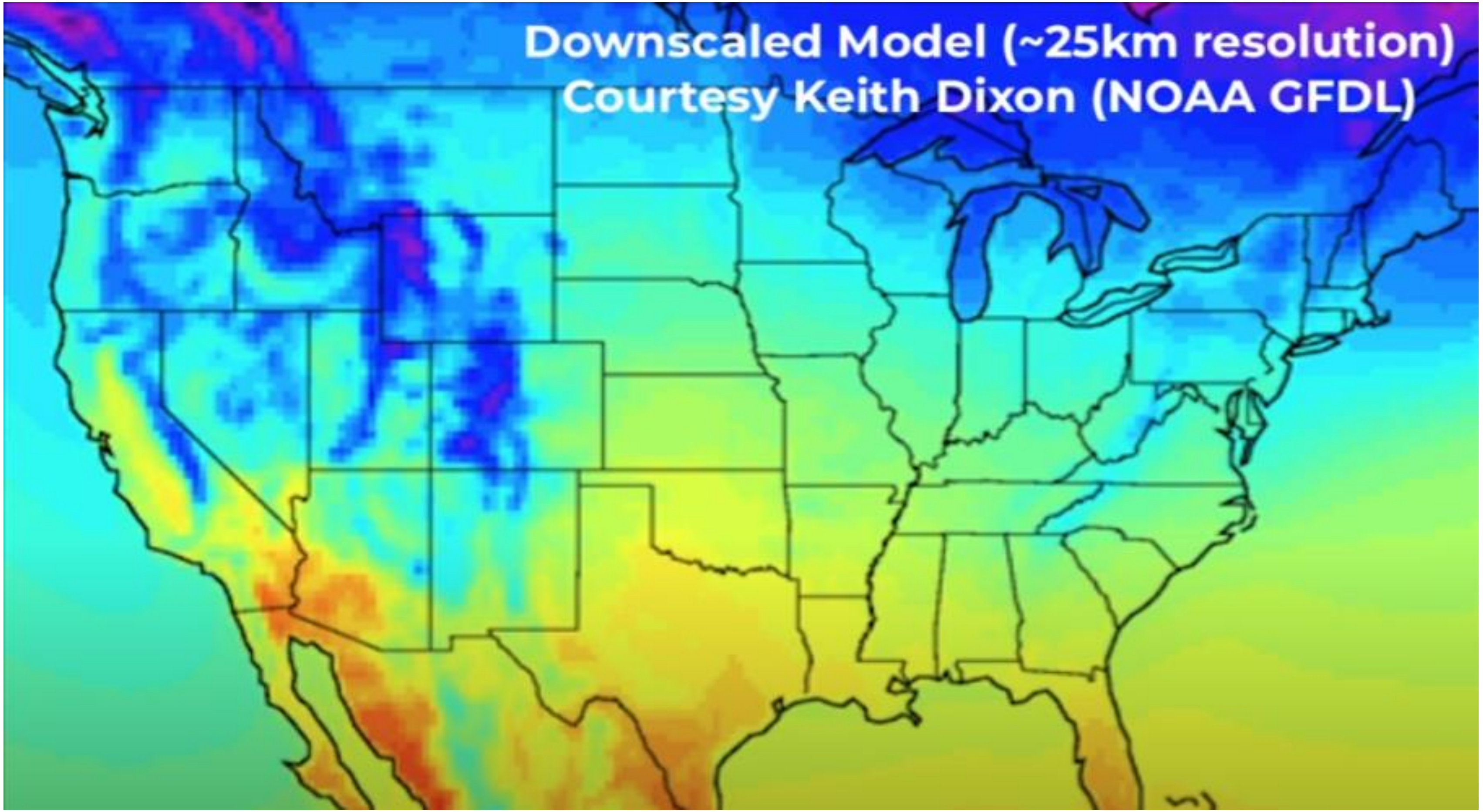
Global climate models began 1970s course 200km x 200km cell size



Greater computing power required!

CLIMATE MODELLING TODAY

Downscaling to a 25km grid gives much higher resolution



Can be applied down to a town or city geography

MULTIPLE GLOBAL CLIMATE MODELS

Climate modelling institutions across the world have created dozens of models

They all use the same physics

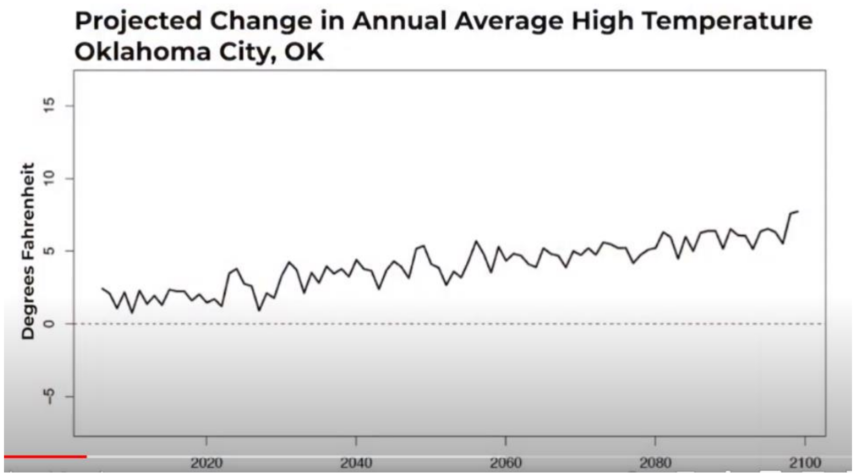
Co-ordination of modelling efforts is ongoing under project CMIP

Modeling Center (or Group)	Institute ID	Model Name
Commonwealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia	CSIRO-BOM	ACCESS1.0 ACCESS1.3
Beijing Climate Center, China Meteorological Administration	BCC	BCC-CSM1.1 BCC-CSM1.1(m)
Instituto Nacional de Pesquisas Espaciais (National Institute for Space Research)	INPE	BESM OA 2.3*
College of Global Change and Earth System Science, Beijing Normal University	GCESS	BNU-ESM
Canadian Centre for Climate Modelling and Analysis	CCCMA	CanESM2 CanCM4 CanAM4
University of Miami - RSMAS	RSMAS	CCSM4(RSMAS)*
National Center for Atmospheric Research	NCAR	CCSM4
		CESM1(BGC) CESM1(CAM5)

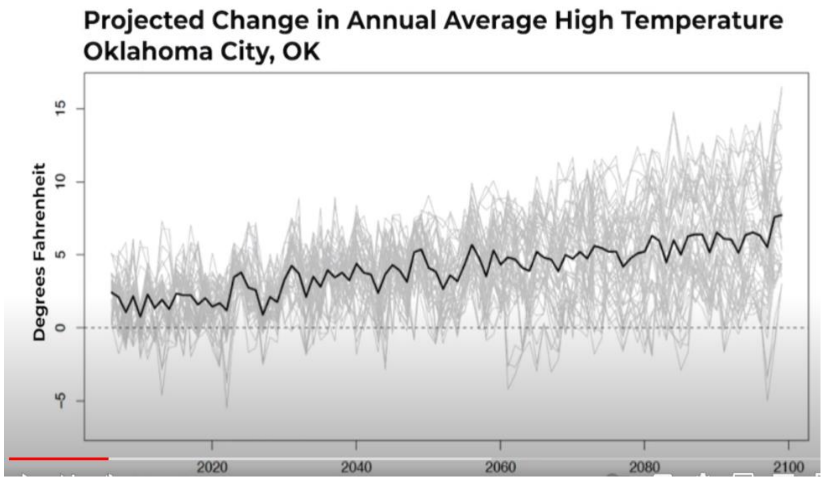
CMIP – Coupled Model Inter-comparison Project

OKLAHOMA CITY CLIMATE PROJECTIONS

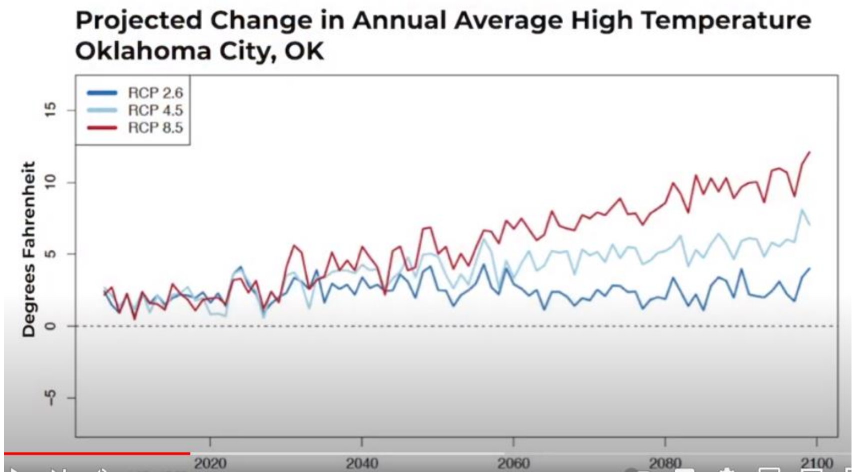
1. A single projection



2. Multiple projection scenarios



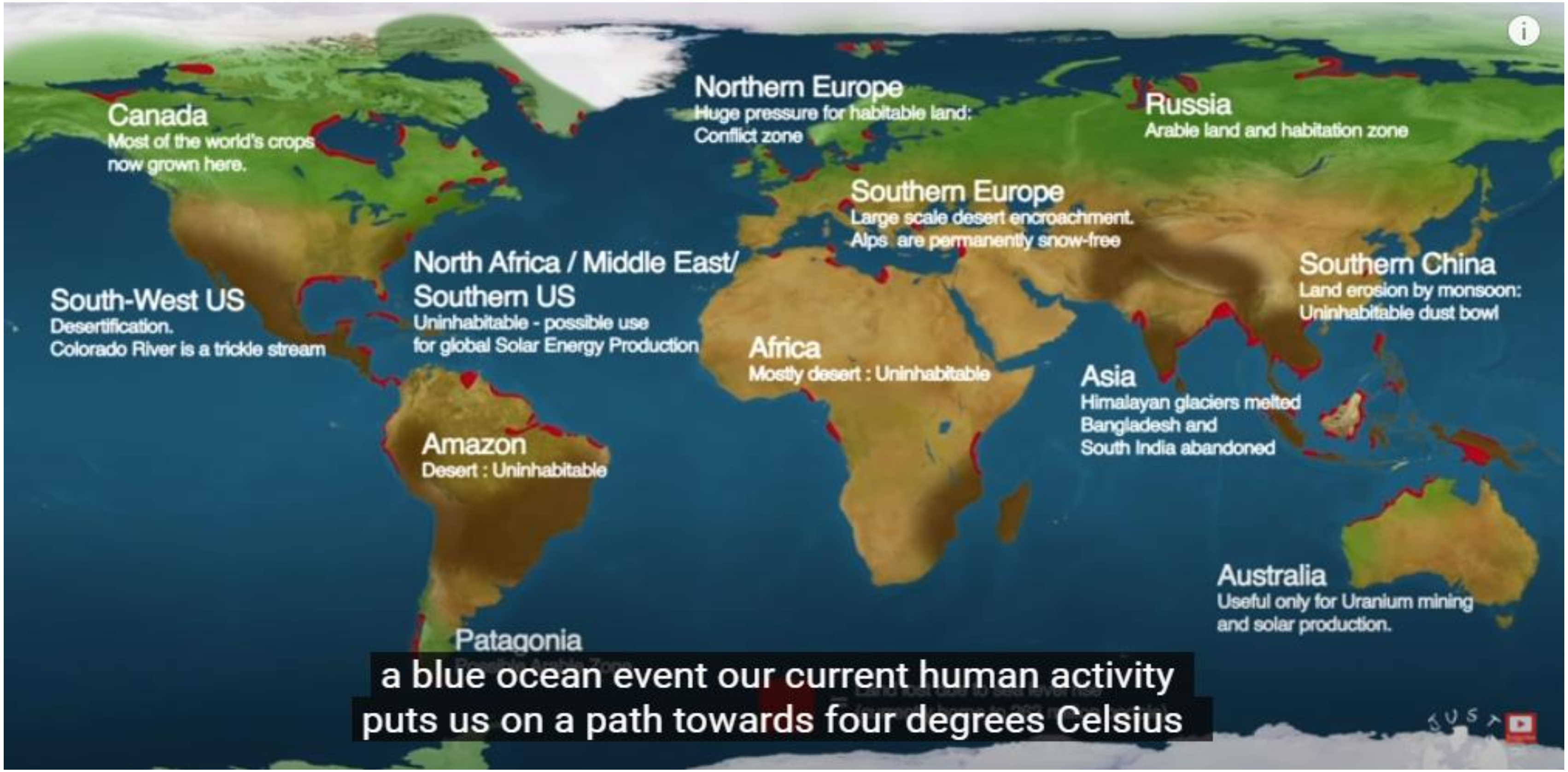
3. Best & worst cases
RCP 2.6 Strong use of renewable energy
RCP 8.5 High emissions



RCP = Representative Concentration Pathway

GLOBAL CLIMATE MODEL PREDICTION 2100

Predicted global average temperature rise 2.6C – 2.9C

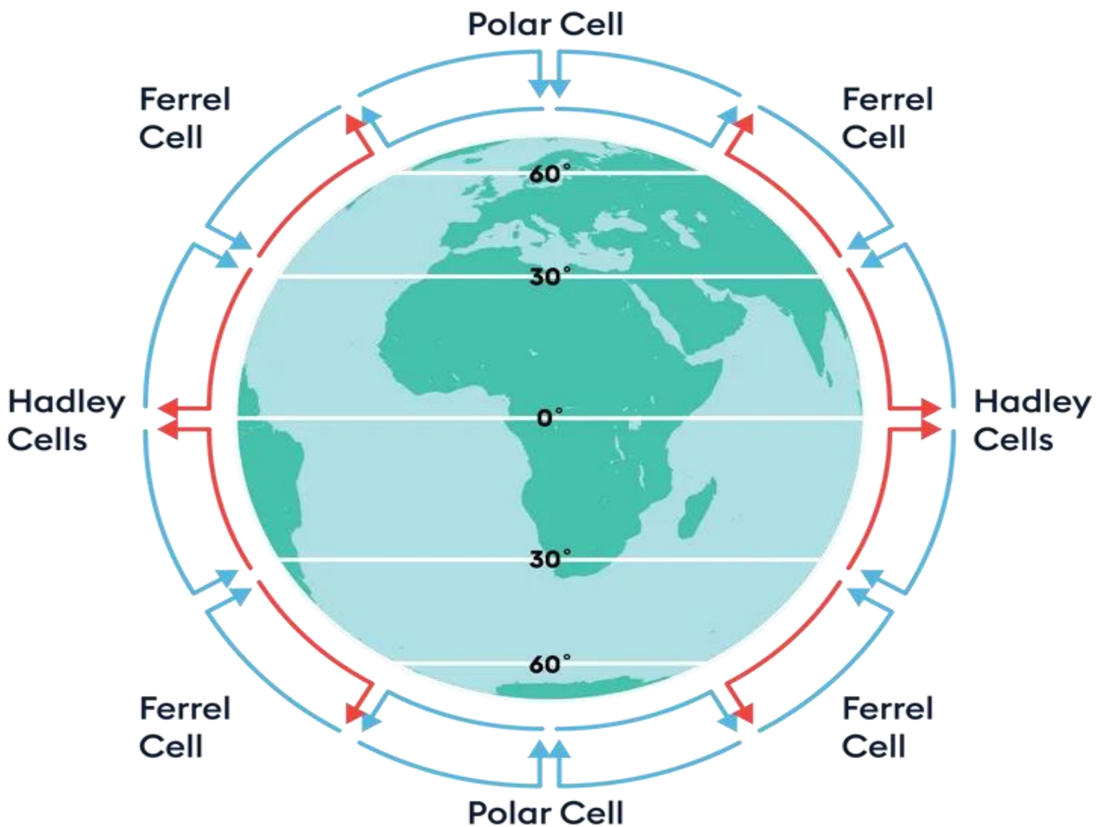


Increased desertification | Water Supply | Food Production | Mass migration

Extreme weather | Coastal Flooding | Coastal cities move inland

HADLEY CELLS

Hadley Cells are low-latitude circulations where air rising at the equator sinks at about 30° latitude

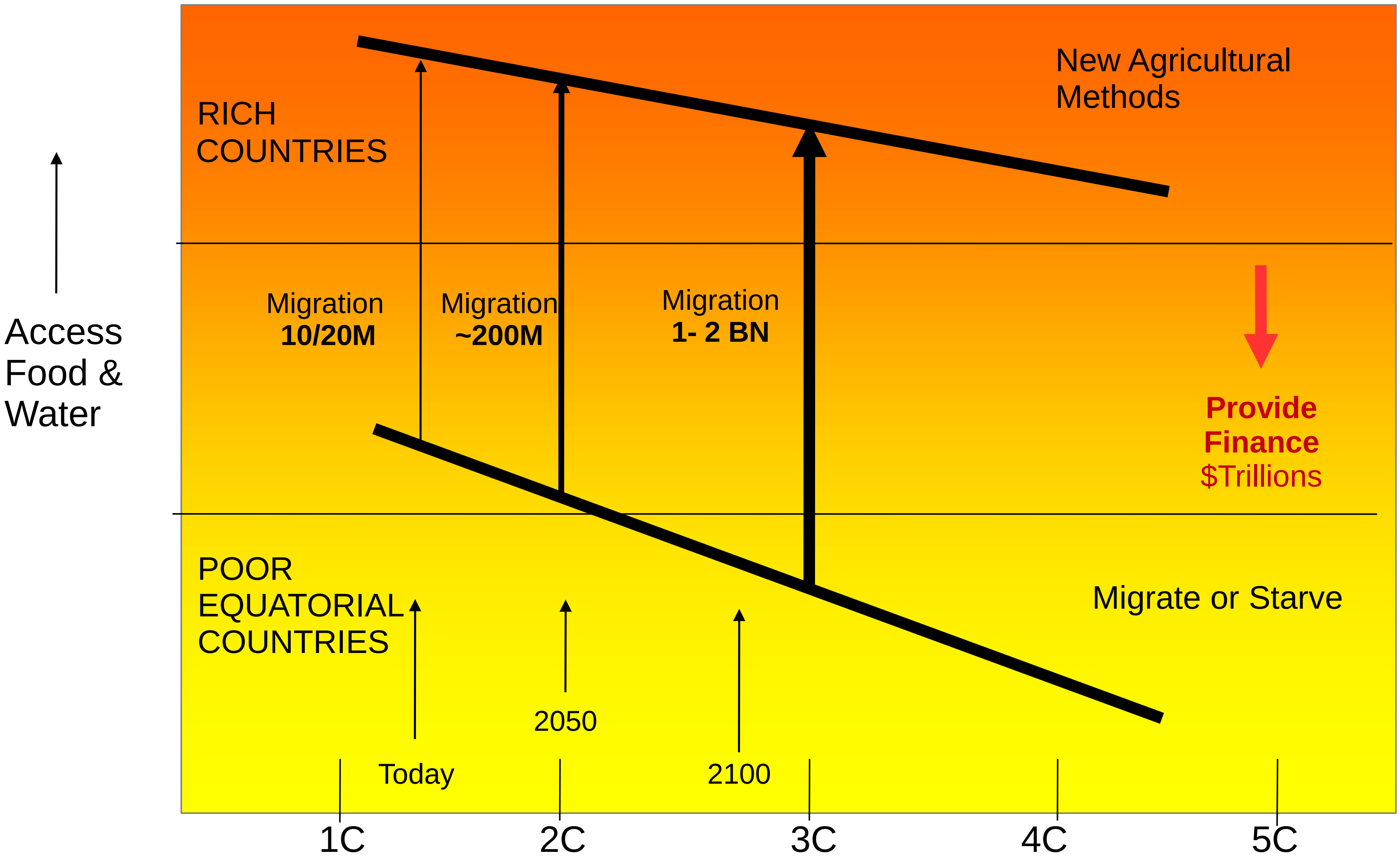


Hadley cell expands as global temperatures rise due to greater energy in the atmosphere

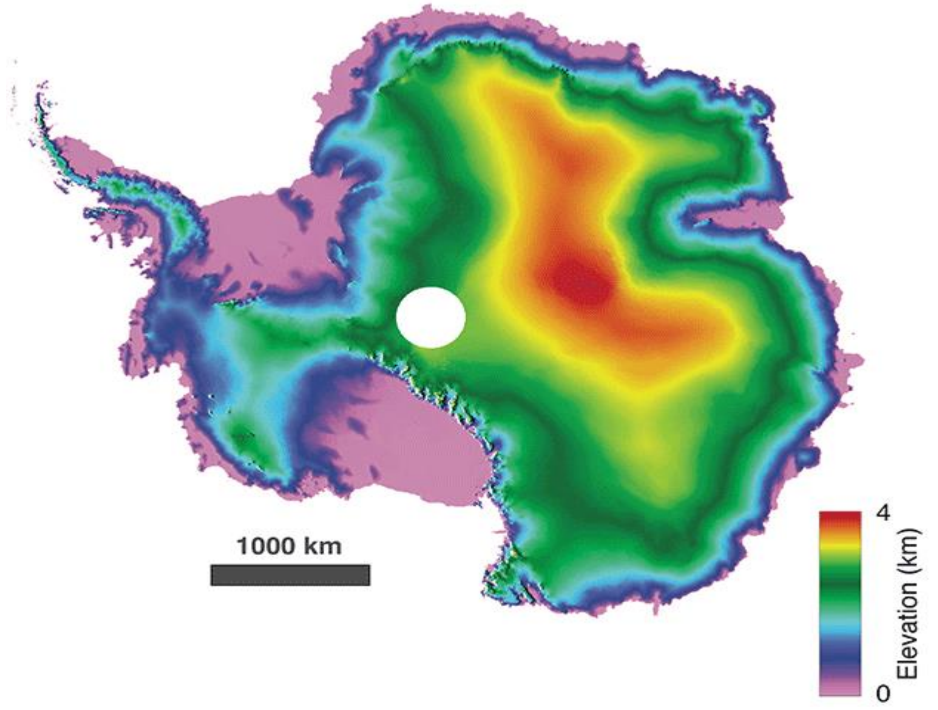
The Sahara moves north into Europe & south into S Africa

MASS MIGRATION FROM EQUATORIAL COUNTRIES

International Environmental Partnership (IEP)



SEA LEVEL RISE



2100
0.3 – 2.0 metres sea level rise
Displaces 150-200M people

Future
Greenland Ice Sheet Melted + Western Antarctic = 13 Metre Rise
Displaces 2 billion people

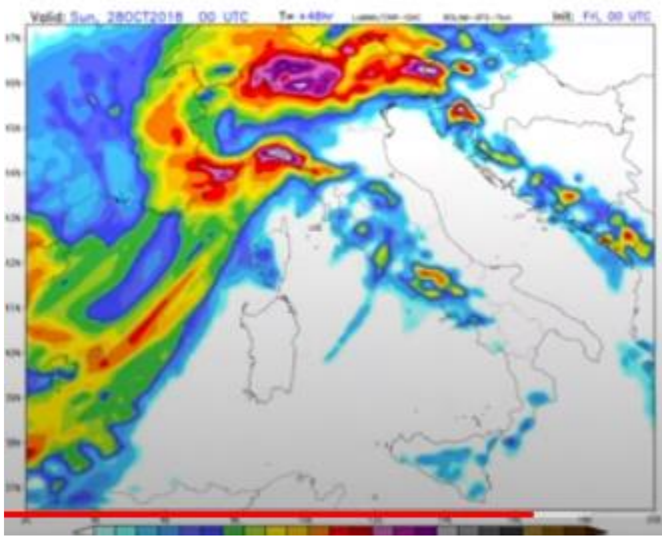
Future
Eastern Antarctic Ice Sheet Melted = 70-80 Metre Rise
Displaces 4 billion people

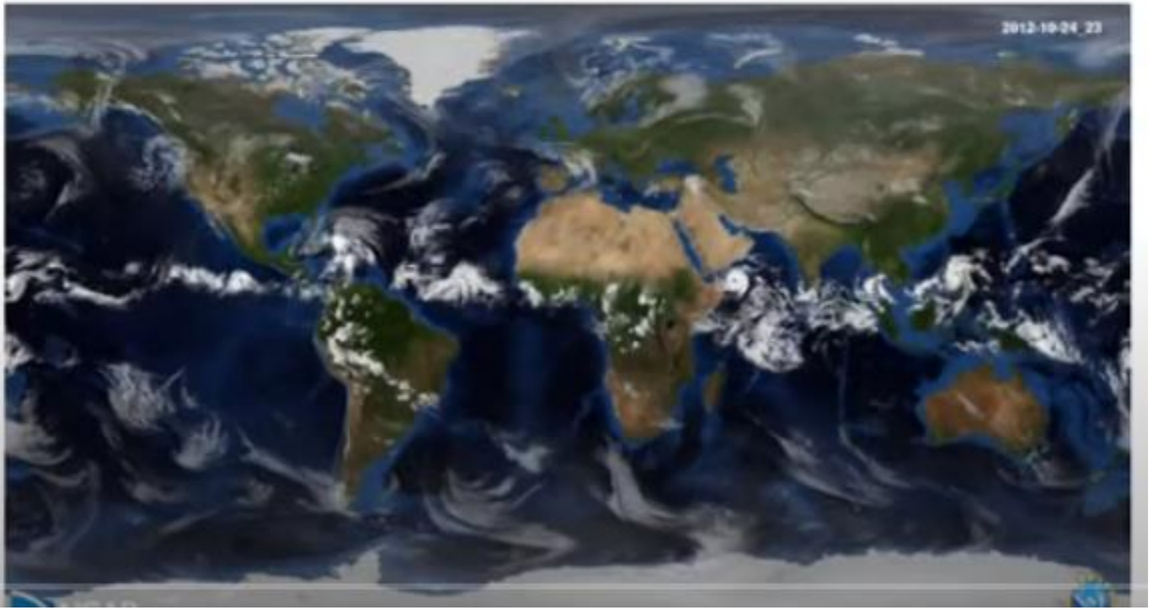
EXTREME EVENT MODELLING

Worst impacts of climate change arise from extreme events (hurricanes, typhoons...)

How likely are these extreme events going forward?

How will their intensity change into the future?





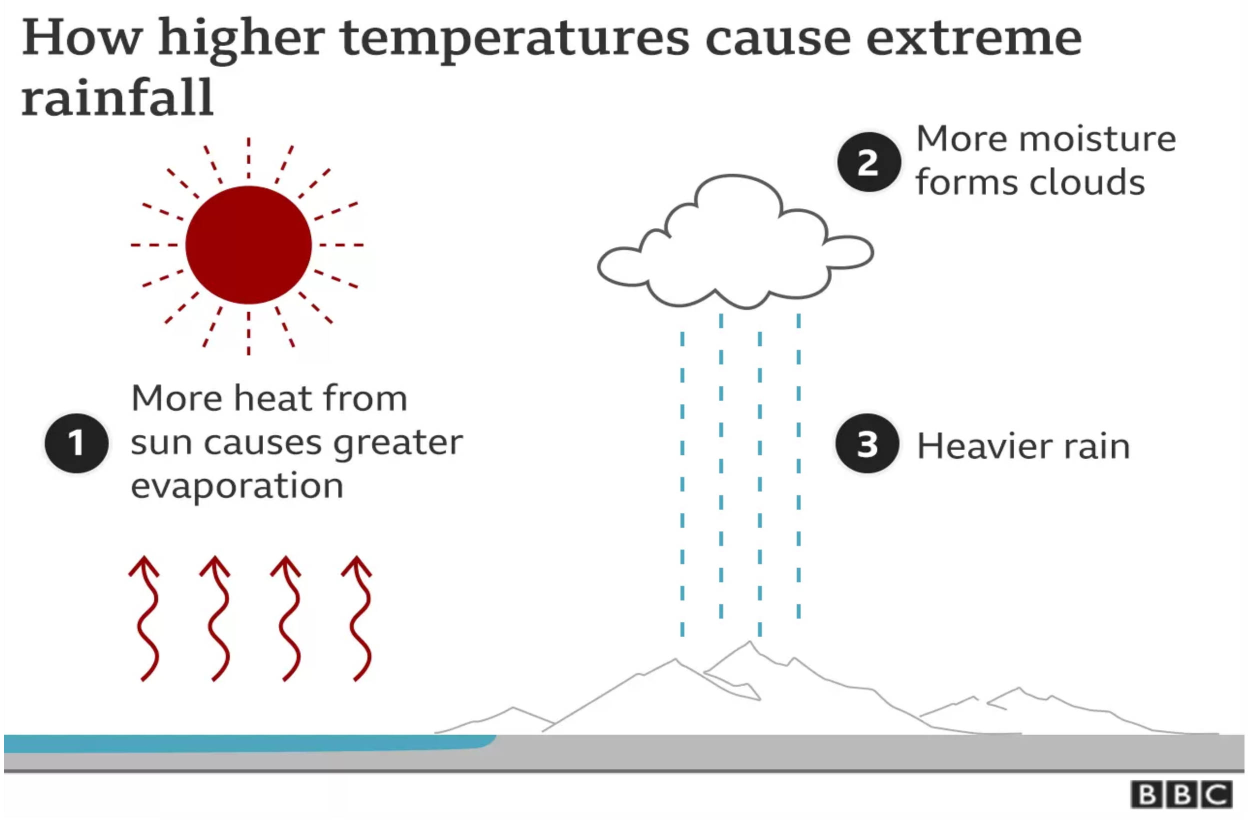
This type of climate modelling requires very high resolution & massive computing power

Provides a broad picture of how the climate will change

EXTREME RAINFALL

The warmer it becomes, the more moisture the atmosphere can hold.

This results in heavier rainfall in a shorter space of time and over a smaller area.



In 2022, Pakistan experienced its wettest July and August on record, triggering devastating floods affecting more than 33 million people

HOLISTIC CLIMATE MODELLING

Modelling systems which incorporate natural & human systems

Explore interactions between climate change, societal change & ecosystem response

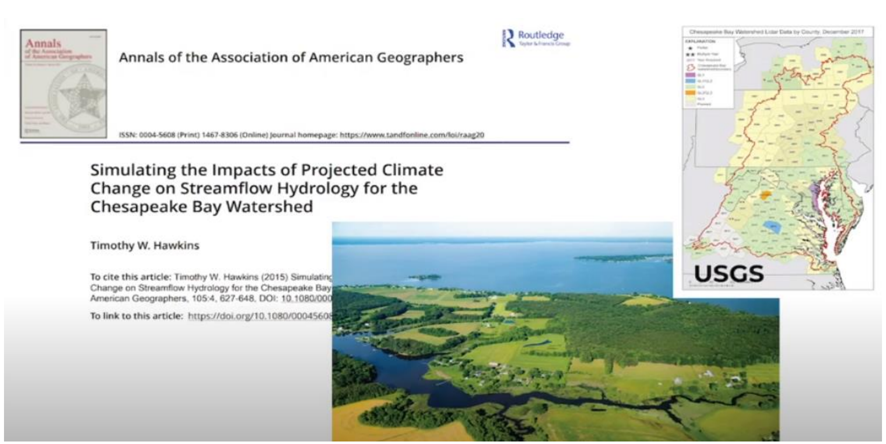
How will Climate Change Mitigation affect the environment?

Impact of Climate Adaptation Scenarios on agriculture, water supply?

Impact on use of natural resources?

CLIMATE MODELLING APPLICATIONS

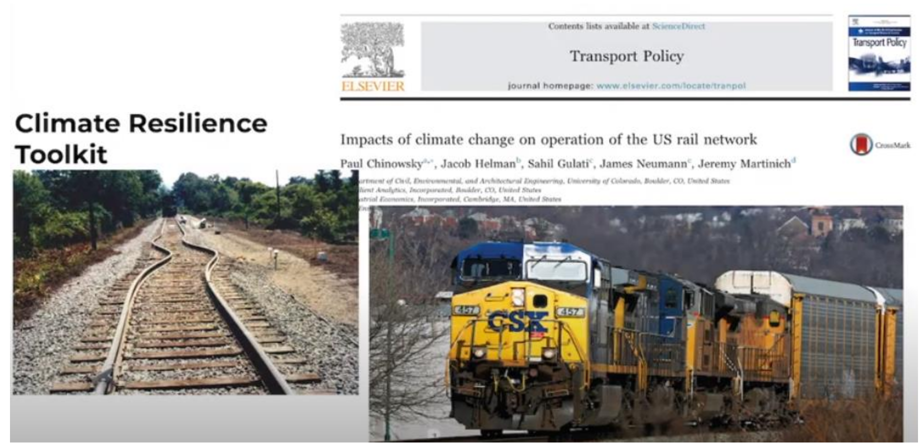
Impact On Water Supply



Impact On Agriculture

Impact On Environment

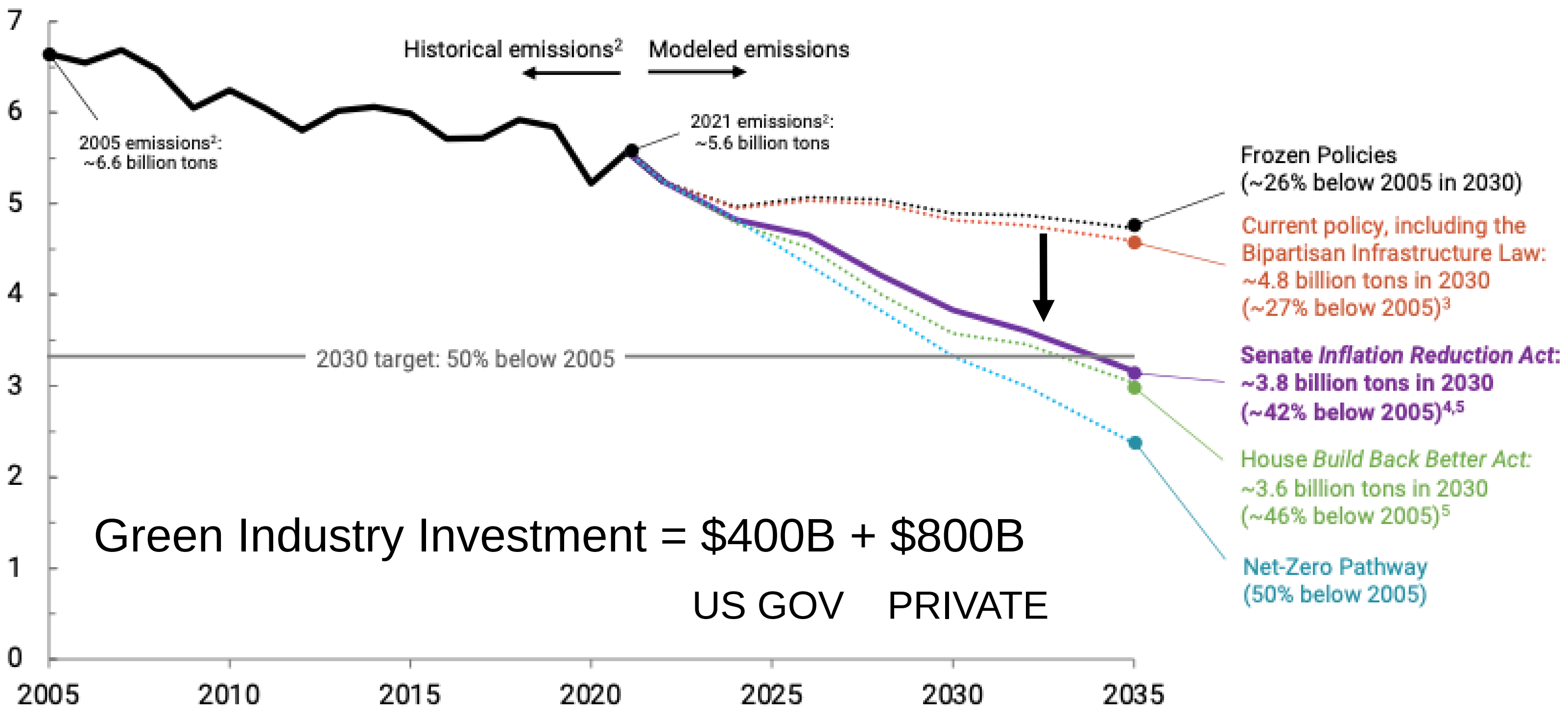
Impact On Infrastructure



THE COST OF CLIMATE CHANGE MITIGATION?

US Inflation Reduction Act

Green Industry Investment for Net Zero



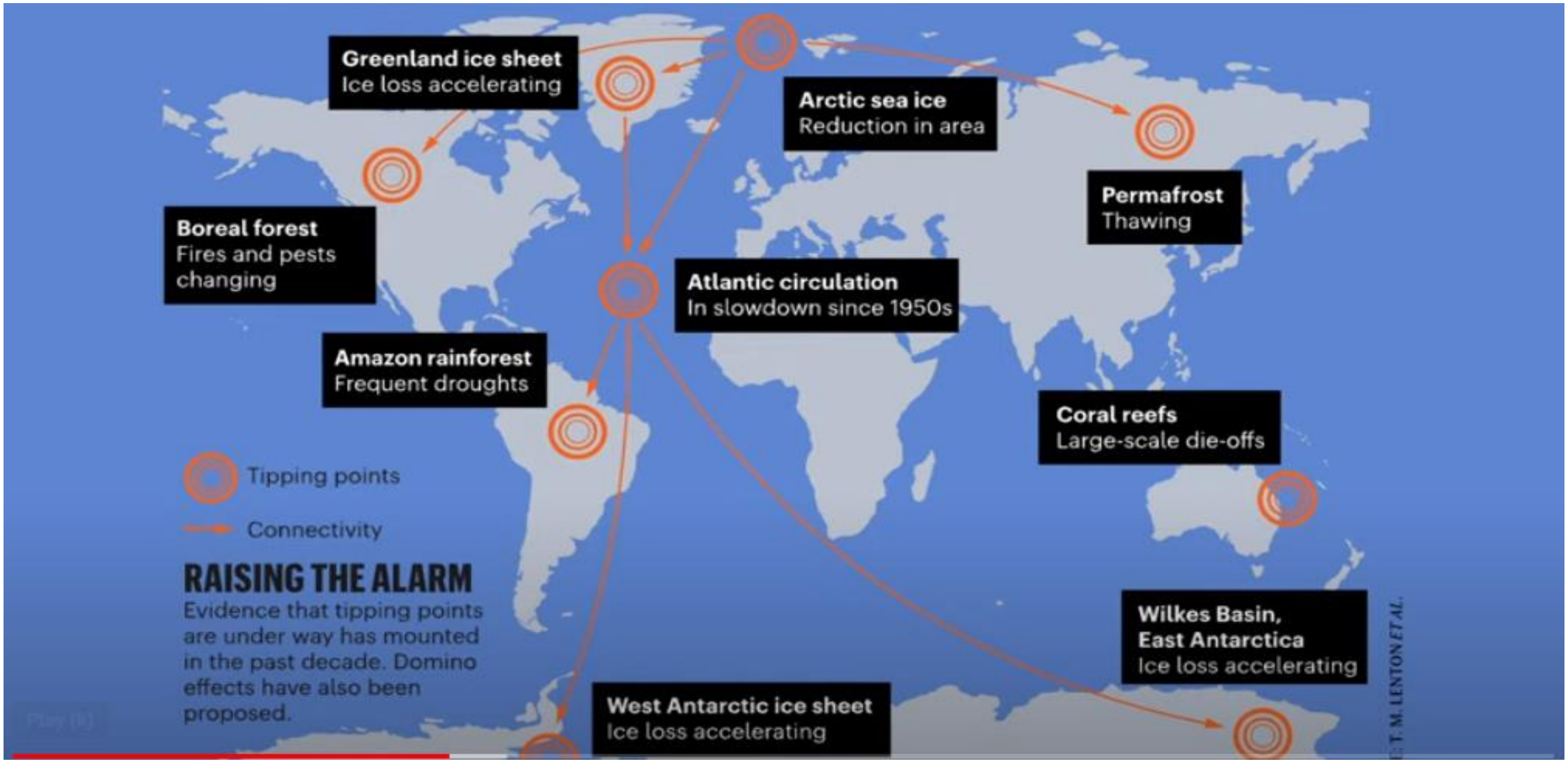
Green Industry Investment = $400B + $800B

US GOV PRIVATE

CLIMATE MODELLING & TIPPING POINTS

Accelerated climate change through a domino effect

Above a temperature Tipping Point the climate system flips into a new stable state



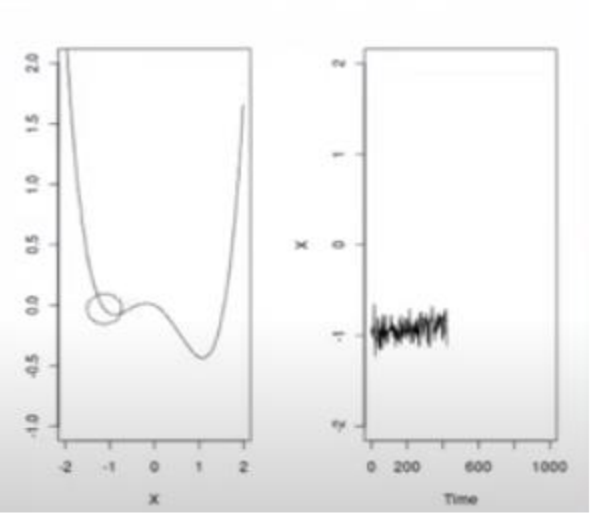
<u>Historical records & climate modelling</u> indicate there may be up to 20 tipping points

WHAT ARE TIPPING POINTS?

Complex systems can remain 'stable' for long periods resisting external change
Our climate has been relatively stable since last ice age 10k years ago

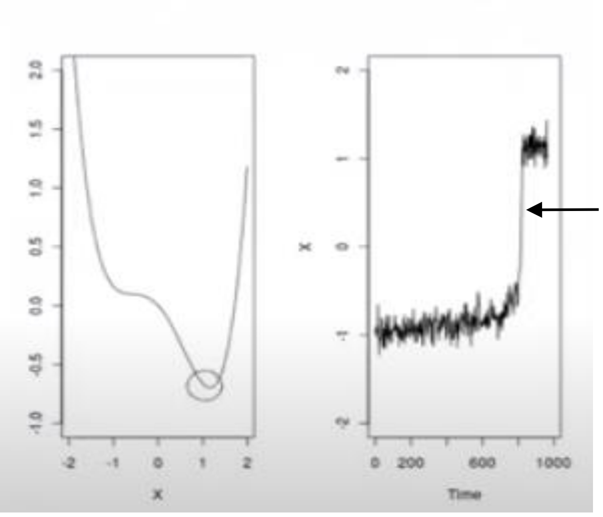
Complex system modelling
Positive & negative feedback loops keep the overall system 'stable'

Small Changes



INPUTS OUTPUTS

Large Changes



Tipping Point

INPUTS OUTPUTS

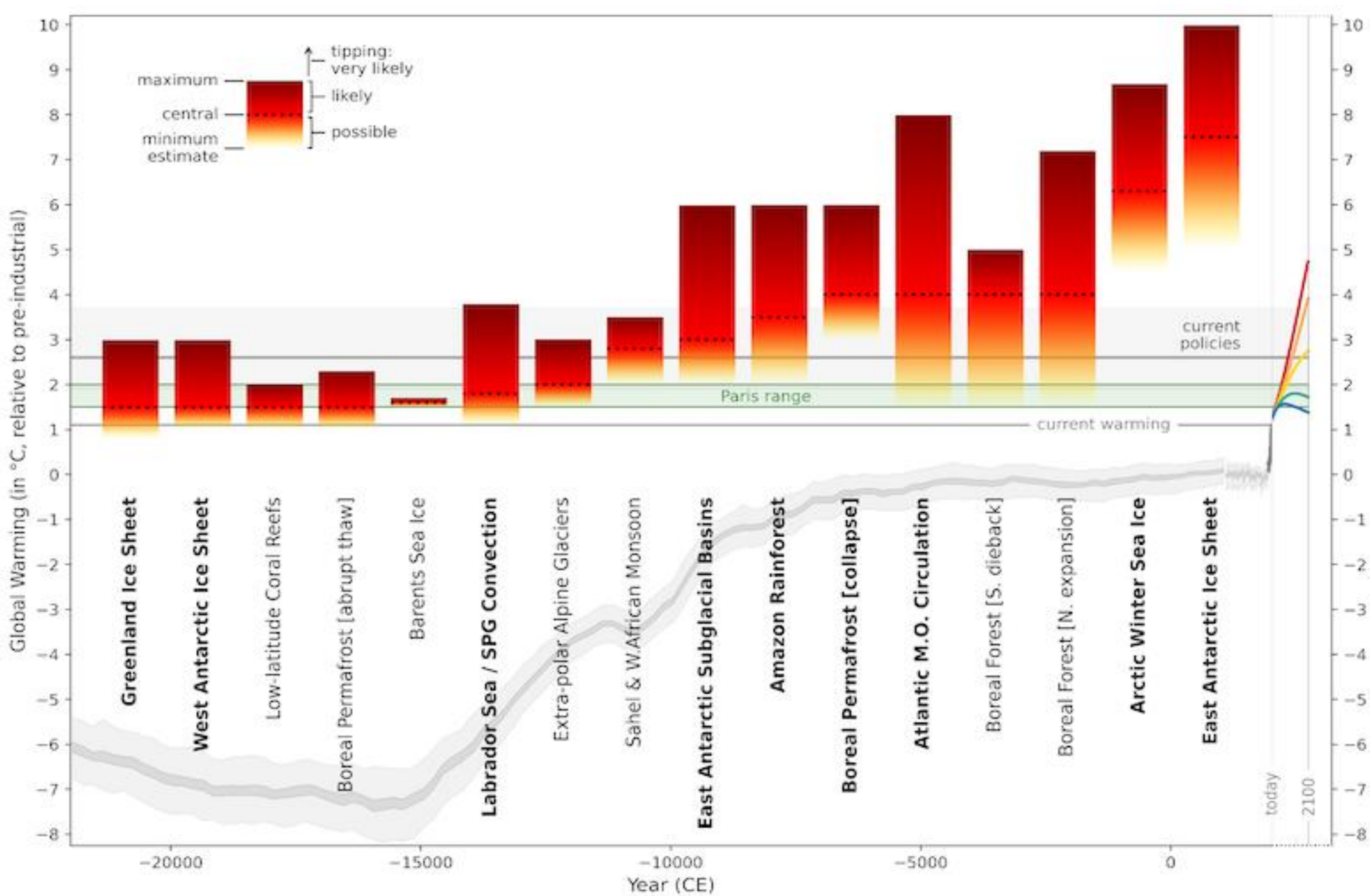
Large changes produce Tipping Points flipping the system into a new stable state

This will accelerate climate change

CLIMATE MODELLING & TIPPING POINTS

16 Known Tipping Points

Temp Rise



Human-caused warming of 1.2C has made passing 4 tipping points highly likely

Climate modelling indicates a 3C rise would trigger most of the remaining tipping points

PERMAFROST MELTING

More than 80% of the worlds subsea permafrost exist in the East Siberian Arctic shelf

Estimated 1400 Billion tonnes methane stored

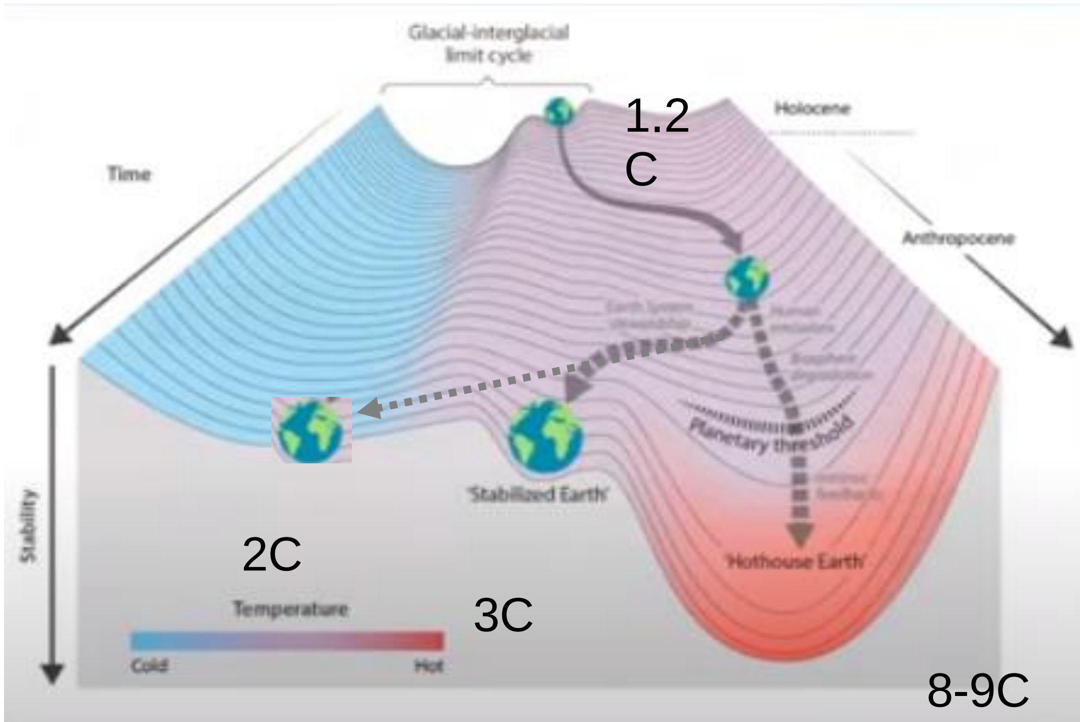
Methane escaping at ~ 17 million tons each year accelerating as temperatures rise

Over 5-10 years methane is 80x potent than CO_2 (x23 over 100 years)

Release of all this methane would generate a large temperature spike

COOL, WARM OR HOT HOUSE EARTH?

Cool House Earth requires strong mitigation of green house gas emissions



We are currently on track for Warm House Earth

Domino effect could lead to 'Hot House Earth'

GEOENGINEERING MODELLING

Geoengineering is the deliberate large-scale intervention in the Earth's natural systems

What do the climate models predict?

Excess carbon dioxide remains in the atmosphere for estimated 1-3 thousand years

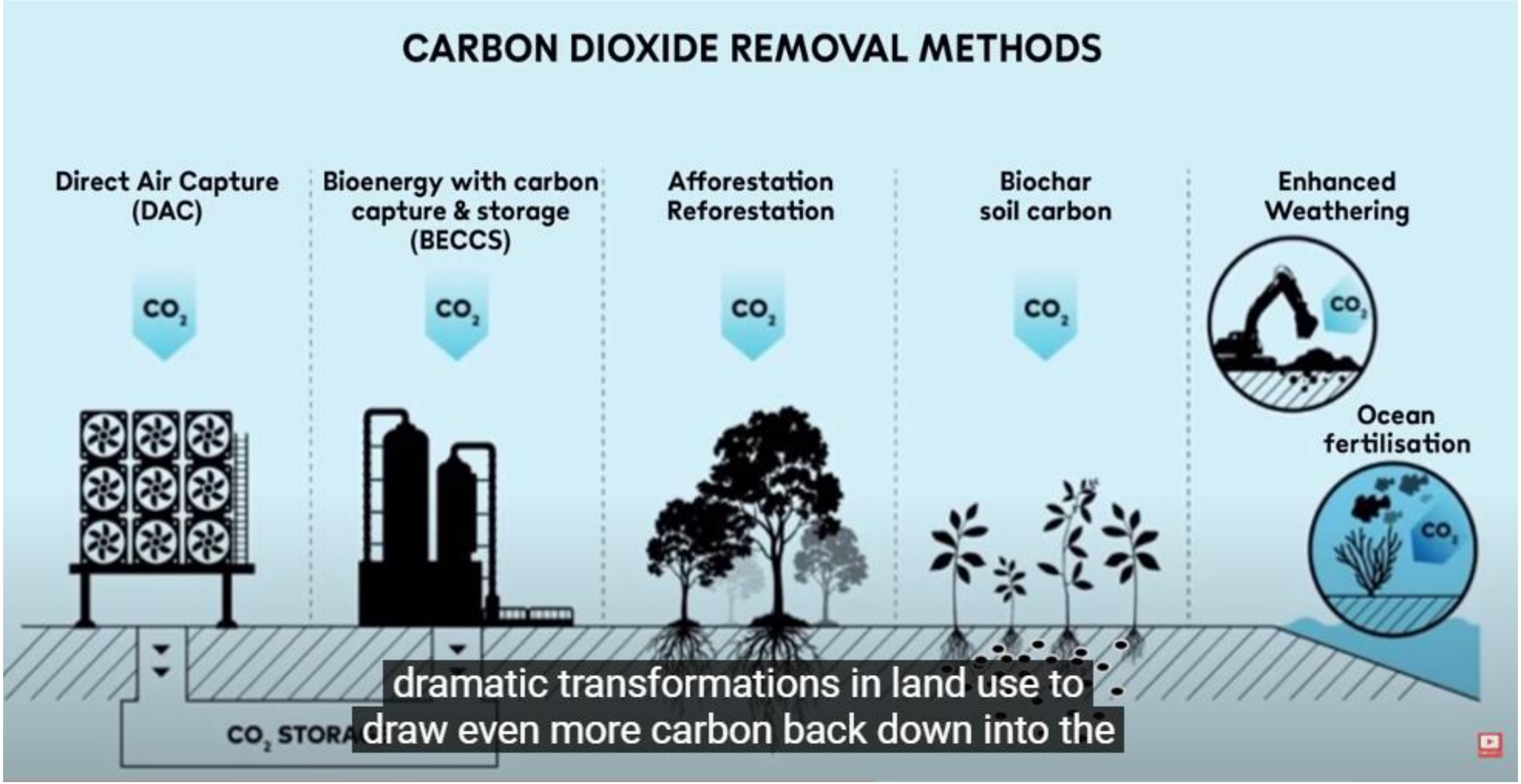
The two principle geoengineering methods are massive CO_2 removal & reflection of solar energy back into space

The risks & consequences of geo-engineering proposals not entirely understood

Geoengineering research has expanded significantly over the past 5 years
The White House has began a five-year research programme into “climate interventions”

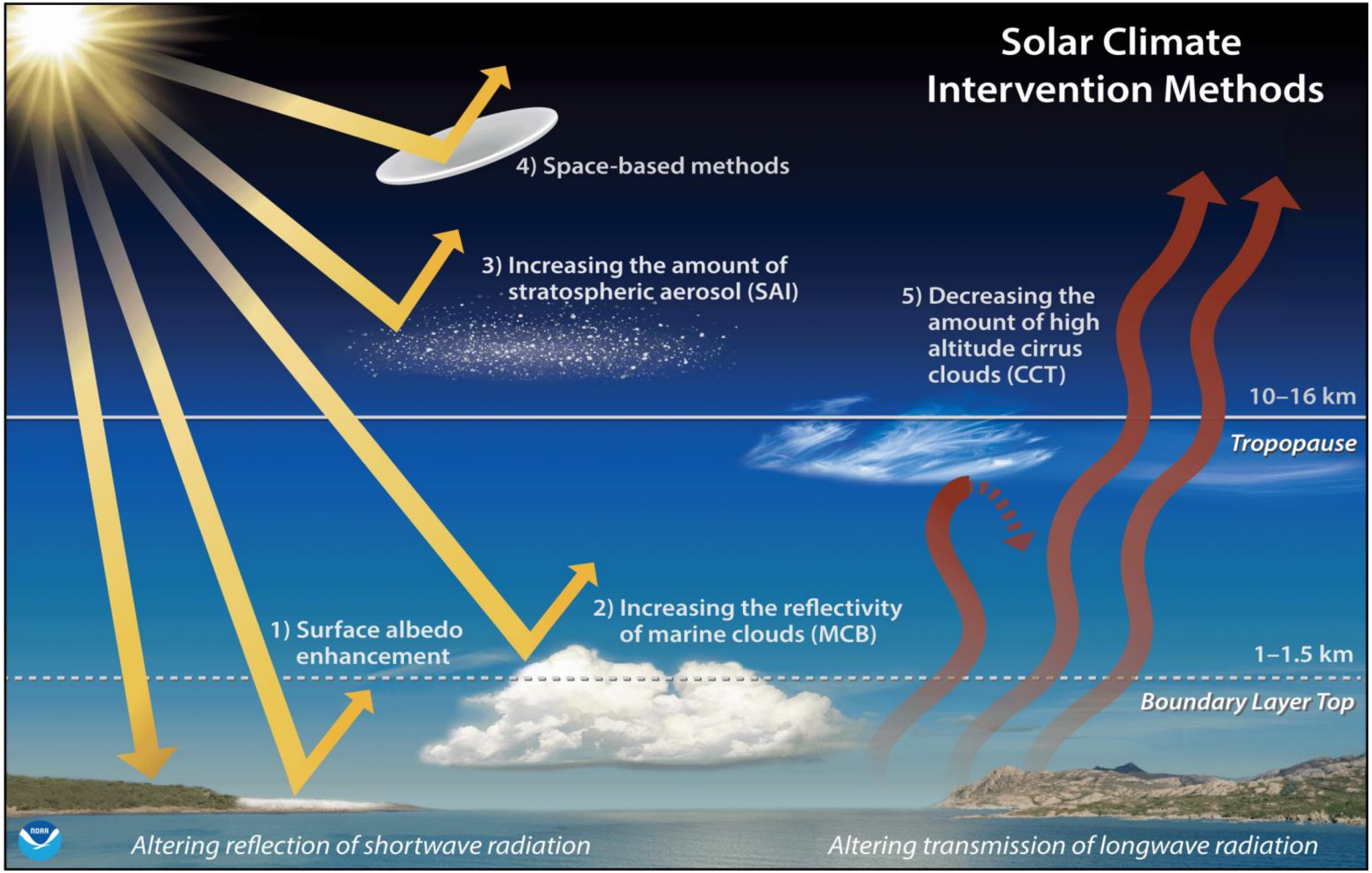
MASSIVE DEPLOYMENT OF CARBON CAPTURE TECHNOLOGY

x100,000



What is the impact on the balance of Earth systems?

SOLAR RADIATION MANAGEMENT



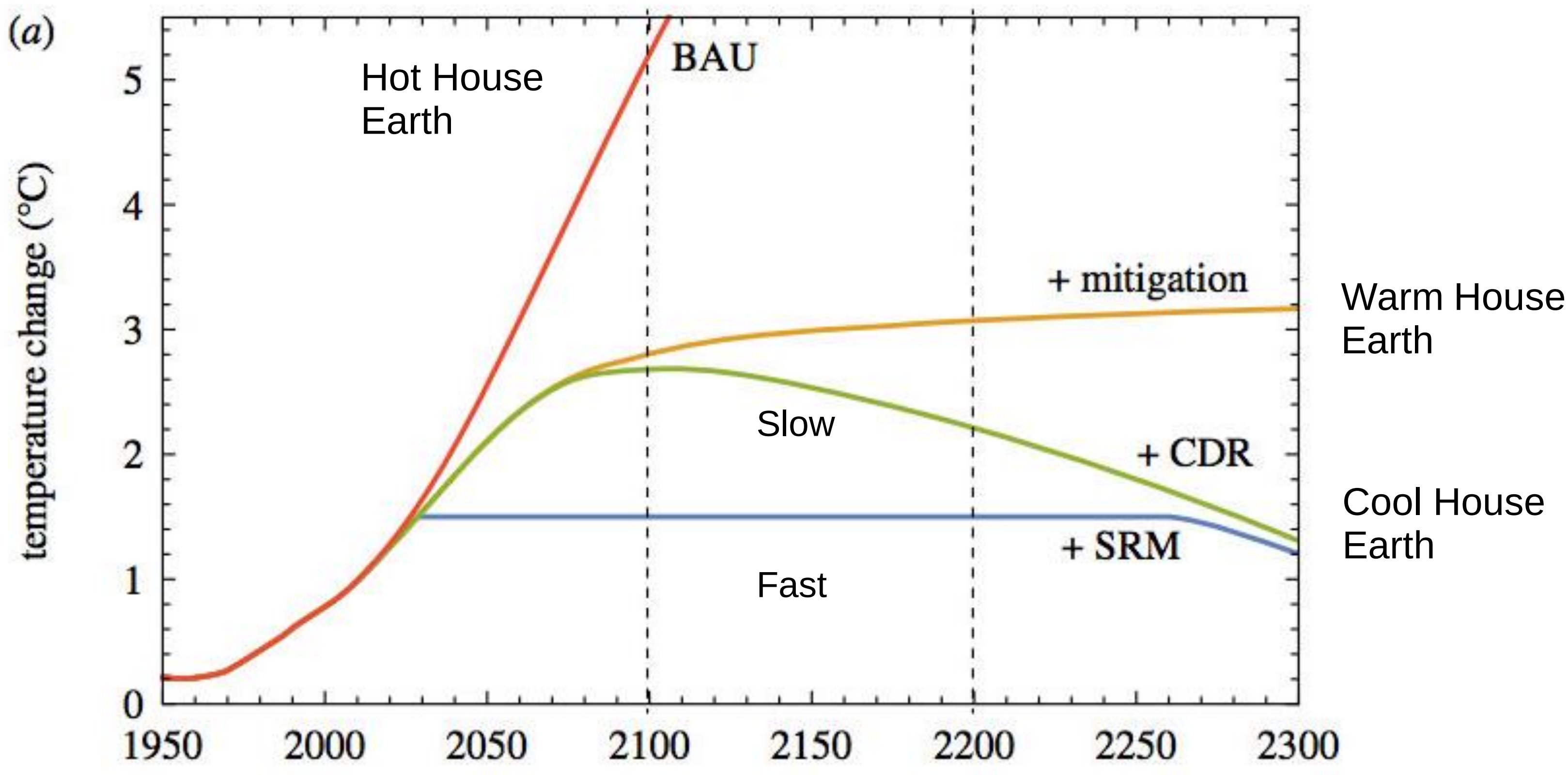
Model the effectiveness of different methods

Explore the consequences of SRM on weather patterns & climate

GEOENGINEERING MODELLING PREDICTIONS

Ideas at this stage

BAU = Do Nothing   CDR= Carbon Dioxide Removal   SRM= Solar Radiation Management



SRM is fastest but new technology carries risk until fully understood

CDR is slow but better understood

SUMMARY

Climate modelling is an essential tool in the fight against climate change

Computer models help us:
Understand the causes of climate change in greater detail
Predict future climate change
Assess the wider impacts of climate change

Climate models are not perfect but are becoming increasingly sophisticated & accurate over time

International climate agreements involve climate model predictions

Evaluate impact of climate adaptation strategies for sea level rise, extreme weather events, water supply...

Assess the financial risks of climate change for businesses and investors