



**The Actuarial Profession**

making financial sense of the future

# Climate Change and its Impacts

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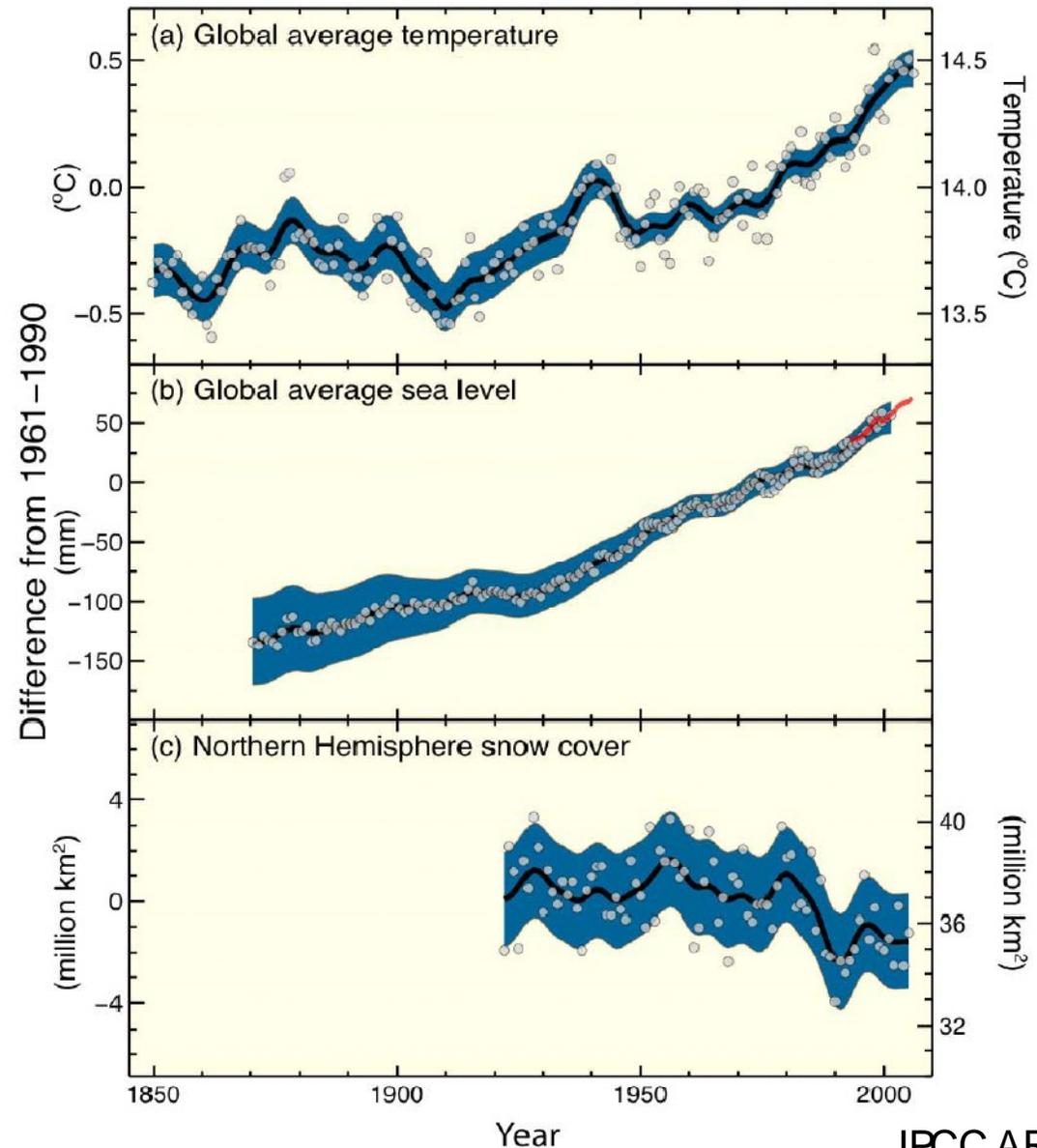
University of Reading

- What's happening to our climate and why we should believe in global warming
- Climate modelling and the attribution and prediction of climate change – Is it us and what will it mean?
- Big issues and uncertainties – Water, food and extreme weather.....
- Barriers to progress?

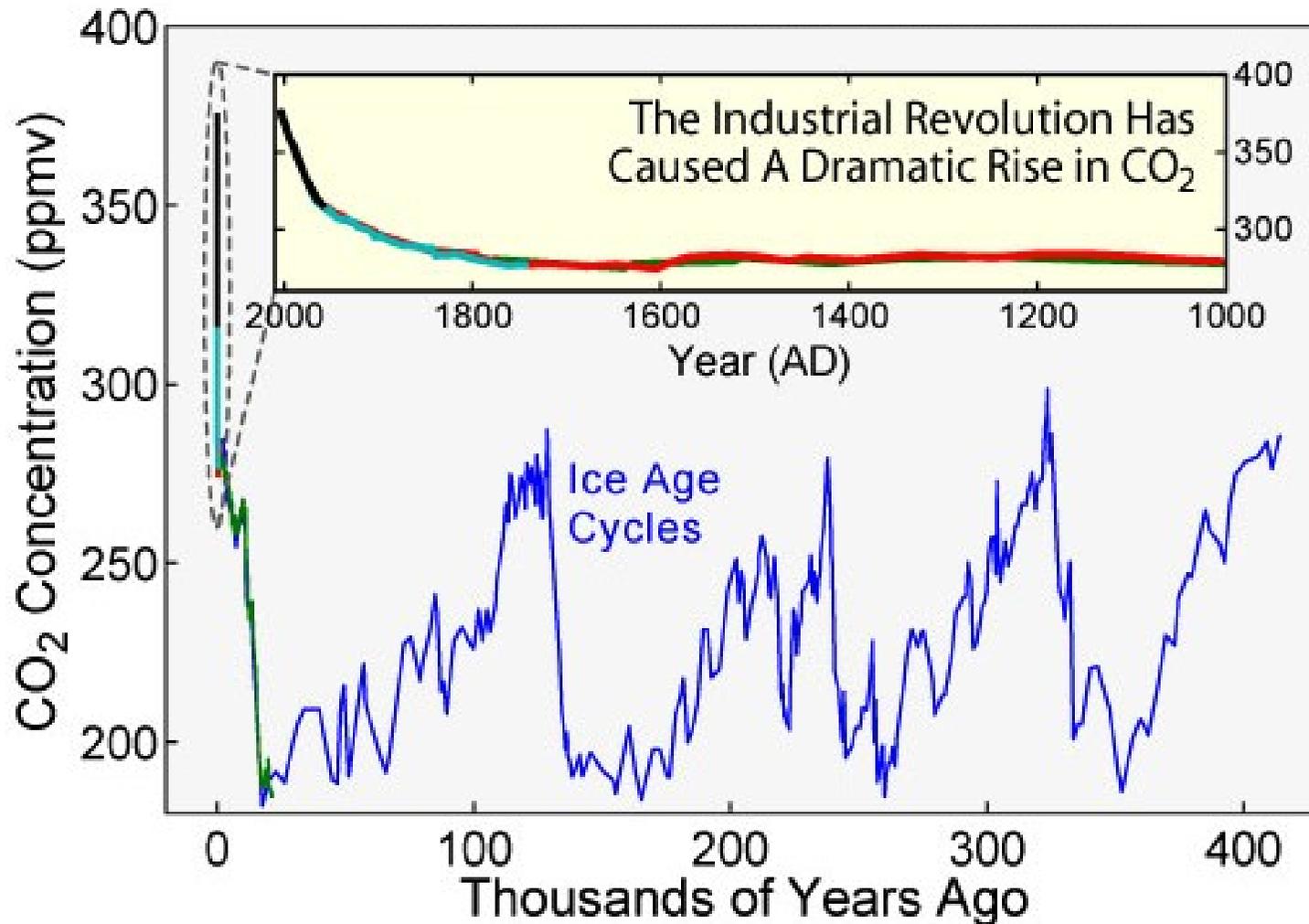
**‘Warming of the climate system is unequivocal’**

**– IPCC 4<sup>th</sup> Assessment Report**

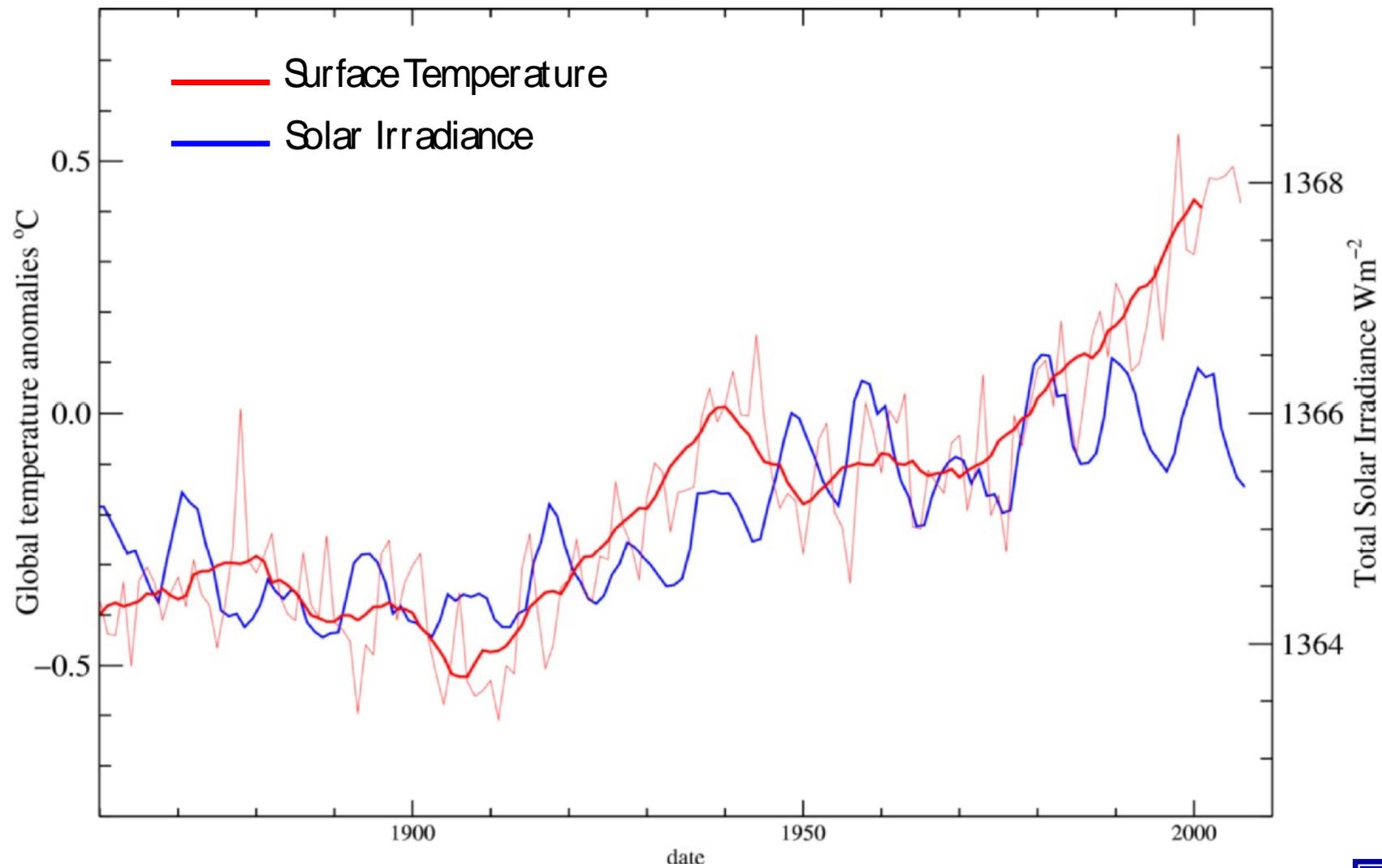
Eleven of the last 12 years rank among the 12 warmest years on record since 1850



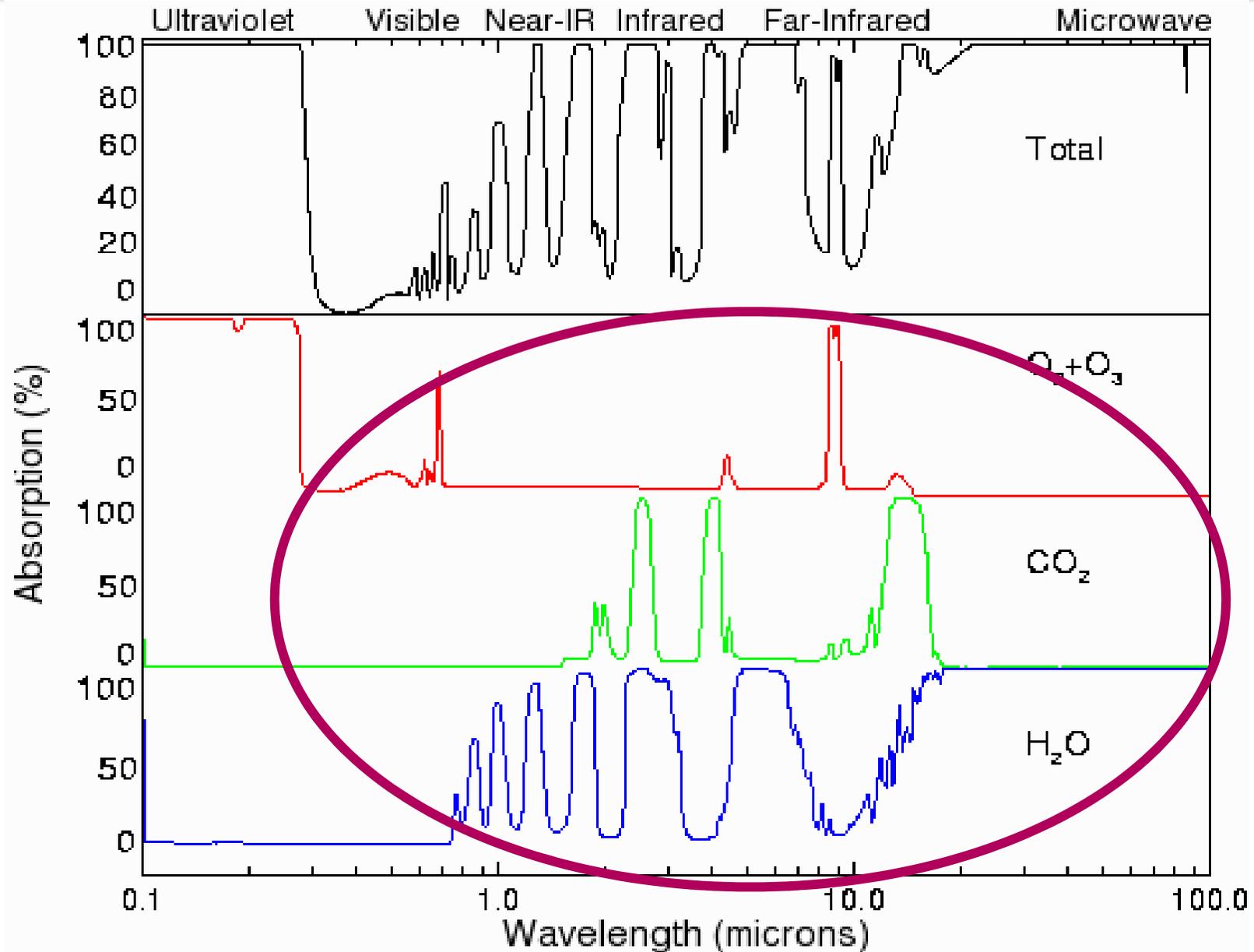
CO<sub>2</sub> levels are rising and are 27% higher than at any time over at least the last 650,000 years



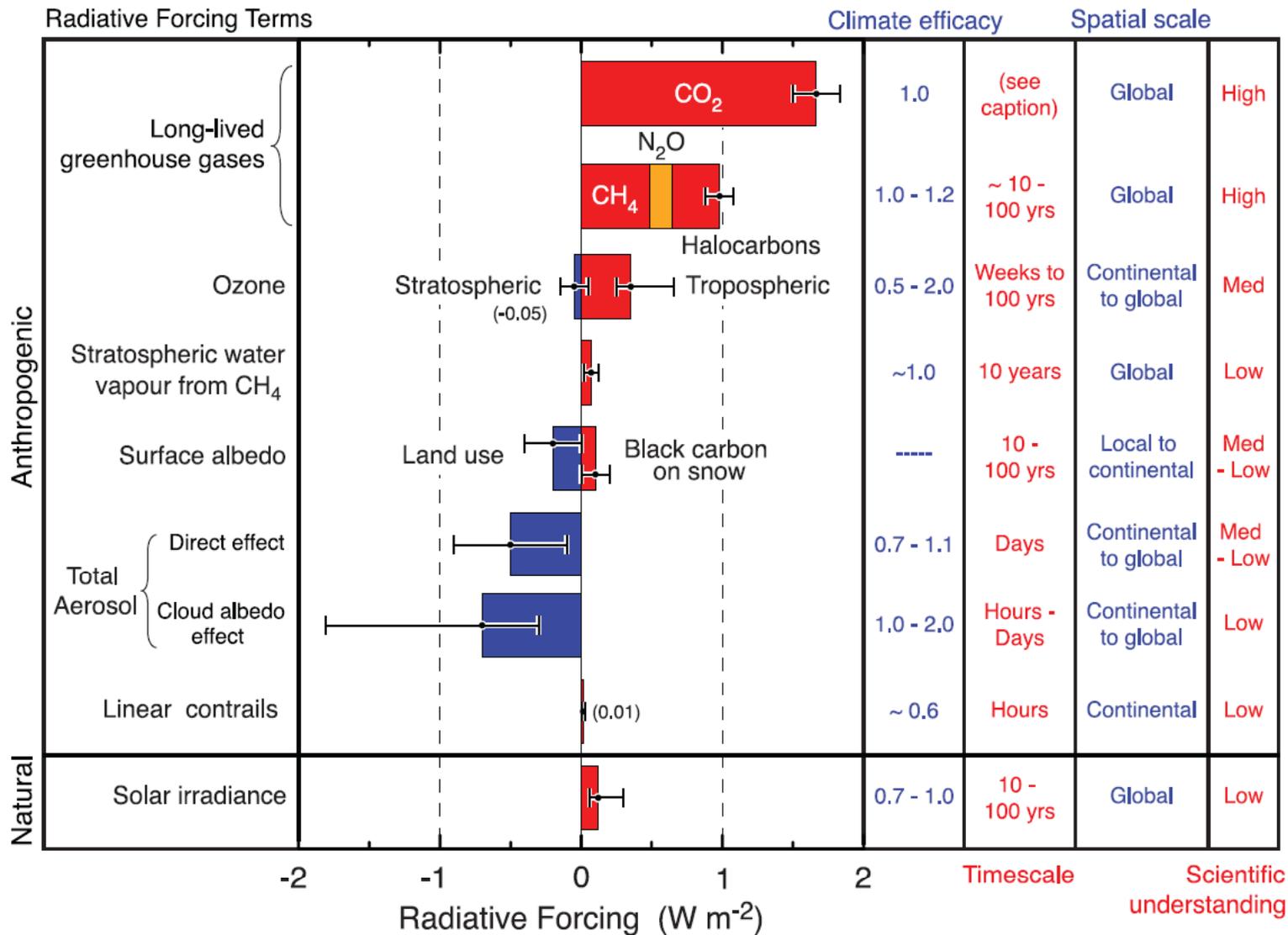
# Solar irradiance does not correlate with recent warming



# Greenhouse gases absorb infrared radiation in distinct spectral bands



# Effect of human activities since 1750 - positive radiative forcing



NB: Past trend in solar forcing since 1750 is estimated at ~ 0.12W m<sup>-2</sup>

# DETECTION & ATTRIBUTION of Climate Change: Is it us?

**DETECTION** is the process of demonstrating that climate has changed in some defined statistical sense, without providing a reason for that change.

**ATTRIBUTION** is the effort to scientifically ascertain mechanisms responsible for relatively recent changes observed in the Earth's climate.

Simple statistical correlations between forcing and response are not sufficient to distinguish between multiple potential forcings with similar trends.

Unequivocal attribution of climate change to anthropogenic causes (i.e., the isolation of cause and effect) would require controlled experimentation with the climate system!

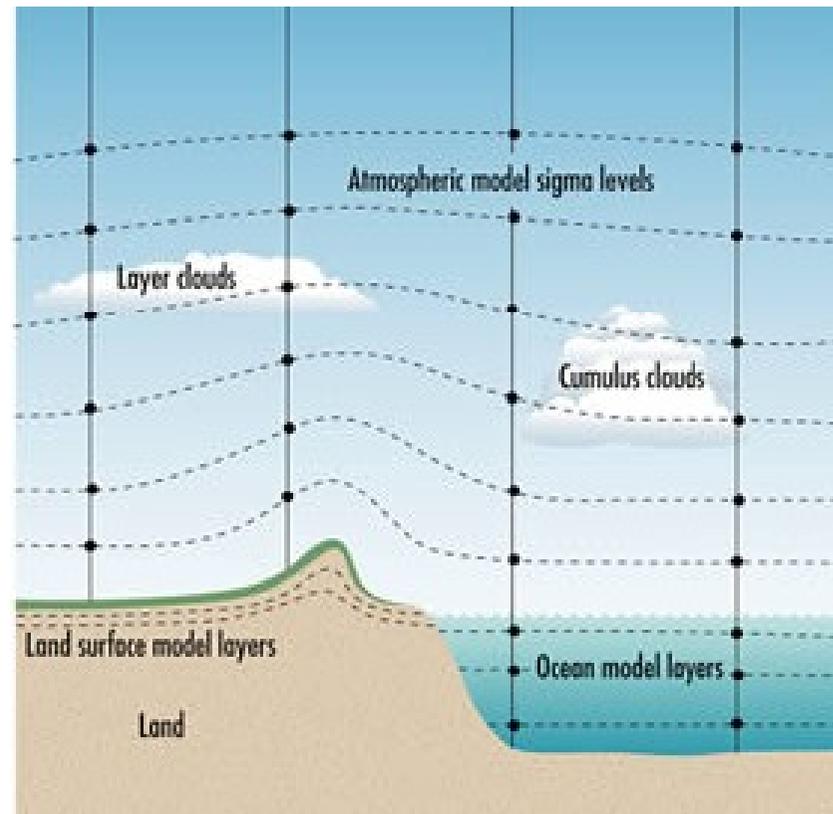
**Attribution of climate change can only be done using models of the climate system, which enable the links between cause and effect to be explored.**

**Climate Models** are huge computer codes based on **fundamental** mathematical equations of motion, thermodynamics and radiative transfer

*These govern:*

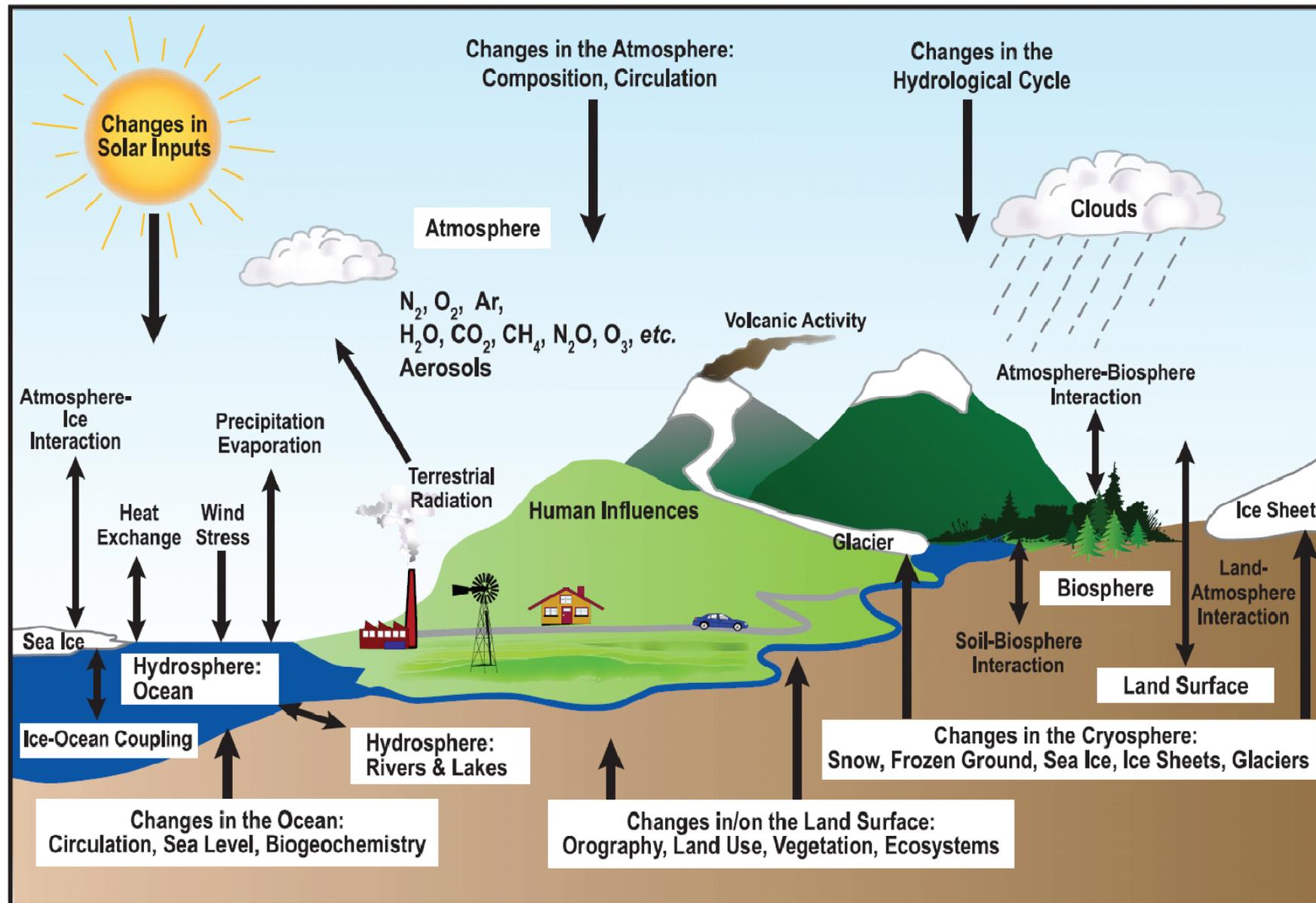
- Flow of air and water - winds in the atmosphere, currents in the ocean.
- Exchange of heat and water between the atmosphere and the earth's surface
- Release of latent heat in the atmosphere by condensation during the formation of clouds and raindrops
- Absorption of sunshine and emission of thermal (infra-red) radiation

**Climate models are extensions of weather forecast models and represent scientists' best understanding of how the climate system operates.**



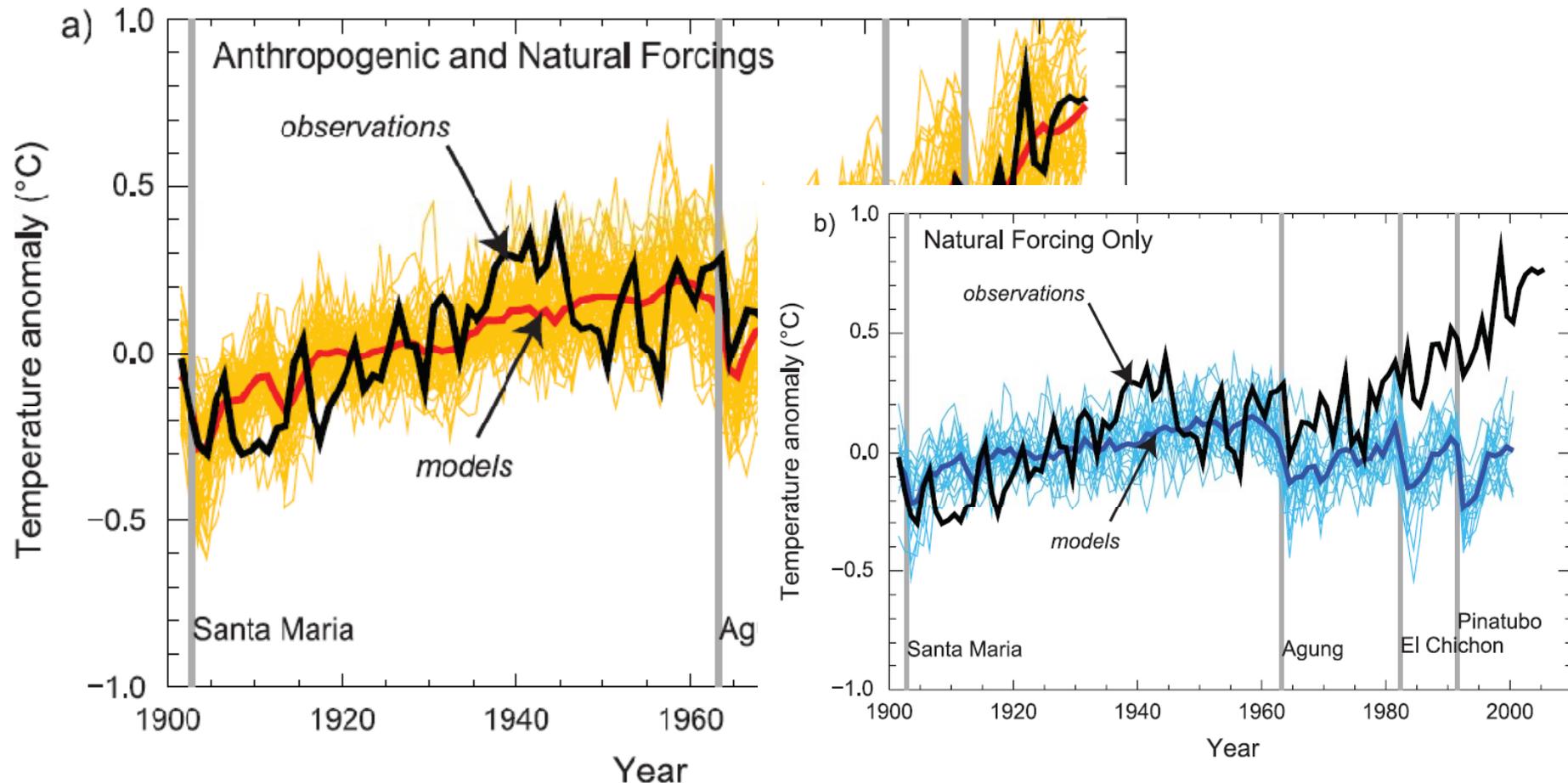
- To solve these equations we represent the earth by a grid of squares, typically of length 150 km or smaller.
- The atmosphere and oceans are divided into vertical slices of varying depths.
- This gives us a 3-dimensional picture of the circulation of the atmosphere and oceans.

# Processes & interactions in the climate system and increasingly included in models



# ATTRIBUTION of global climate change – It is us!

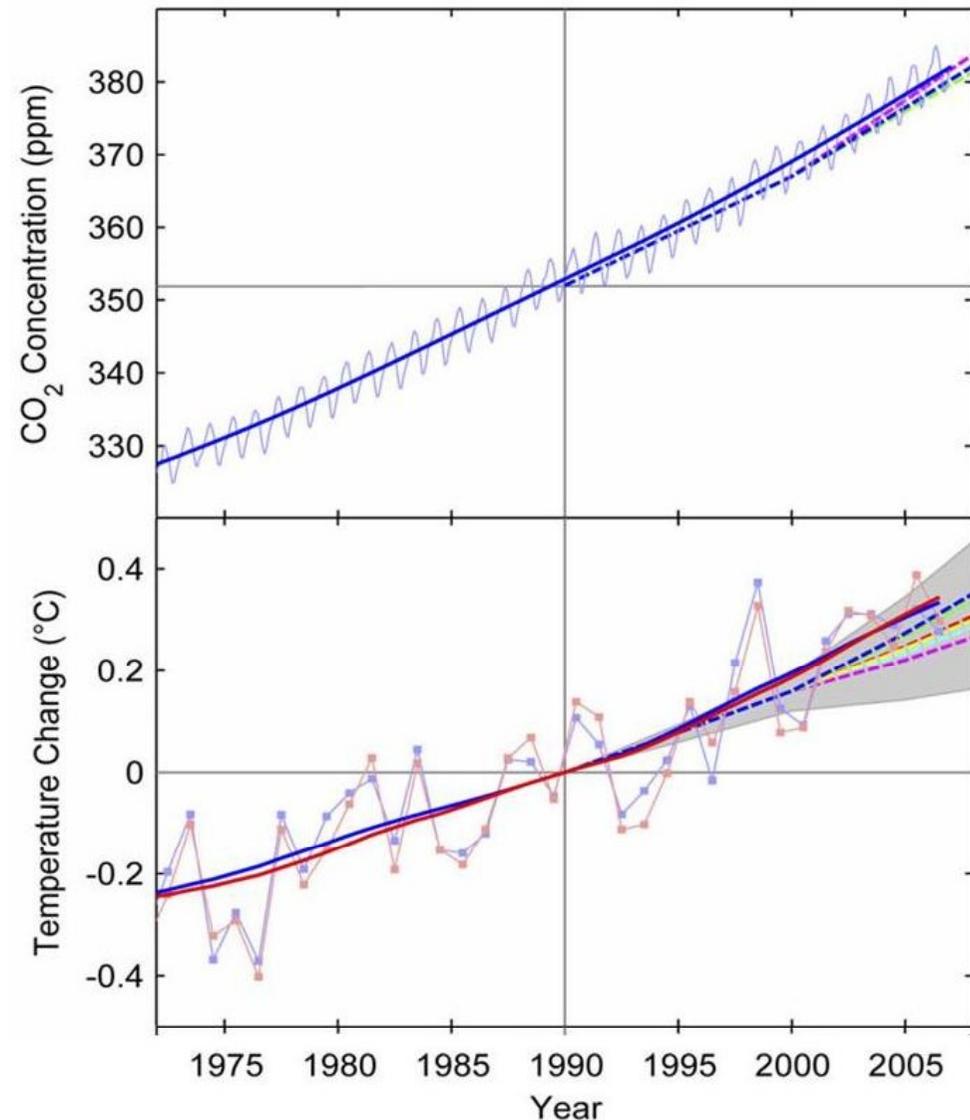
## GLOBAL MEAN SURFACE TEMPERATURE ANOMALIES



‘Most of the observed increase since the mid-20<sup>th</sup> century is **very likely** due to the observed increase in anthropogenic GHG concentrations.’ – IPCC 2007

## Predictions of CO<sub>2</sub> levels and global mean surface temperatures from 1991 (IPCC Third Assessment Report) vs. what actually happened

- Various emission scenarios slightly underestimated the actual CO<sub>2</sub> levels
- Temperature projections all gave warming but suggested less warming than observed
- Underestimate in warming due to improvements in air quality?



*From Rahmstorf et al. 2007*

How quickly the climate will change in the future depends on:

## **1. How much greenhouse gas emissions grow**

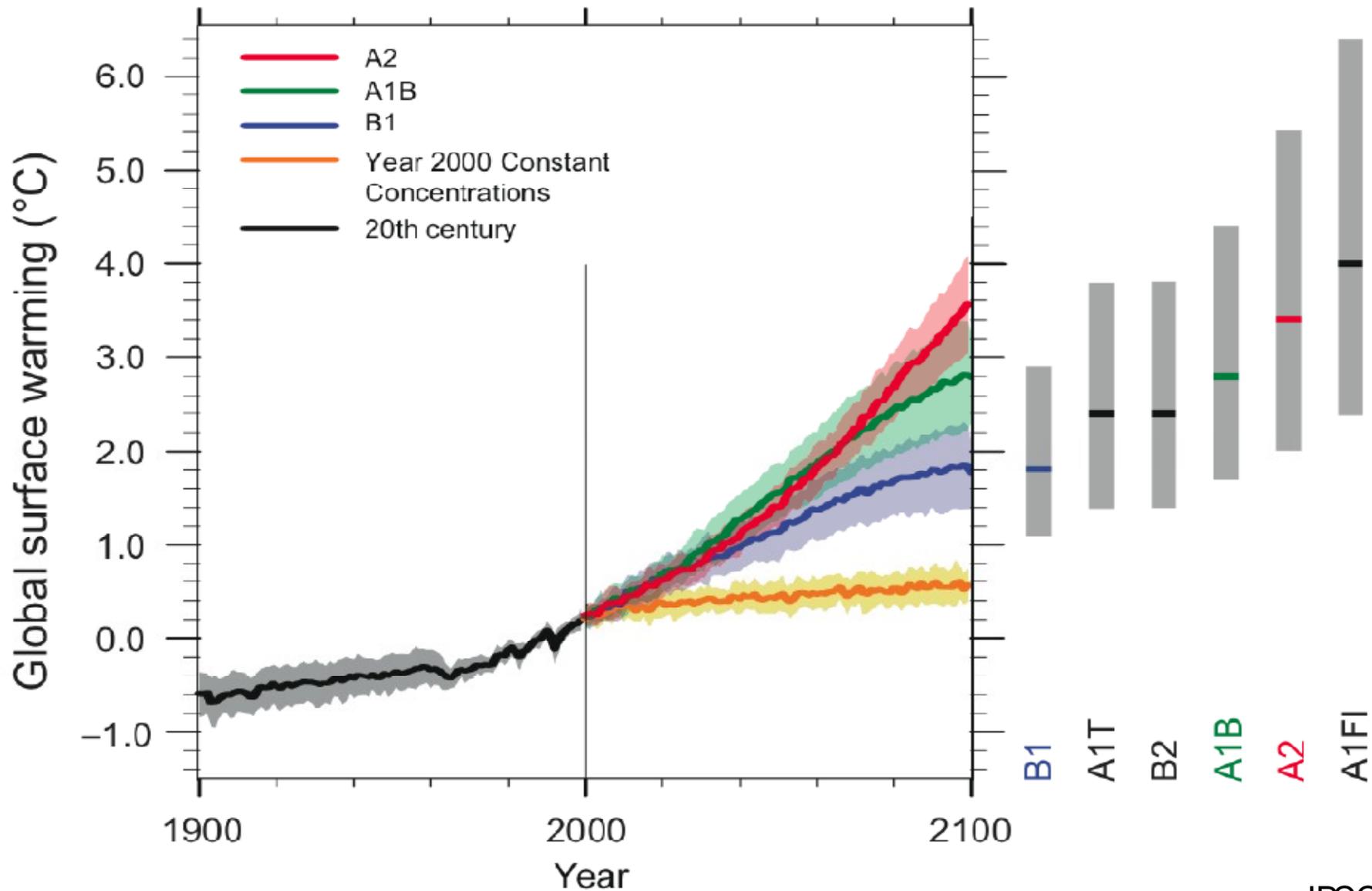
– depends on population growth, energy use, new technologies, etc

## **2. How sensitive the climate system is to those emissions**

- how clouds, ice, oceans etc respond to the extra heating

The same models that are used to attribute climate change are used to make projections

# FUTURE: Projections of 21<sup>st</sup> century climate



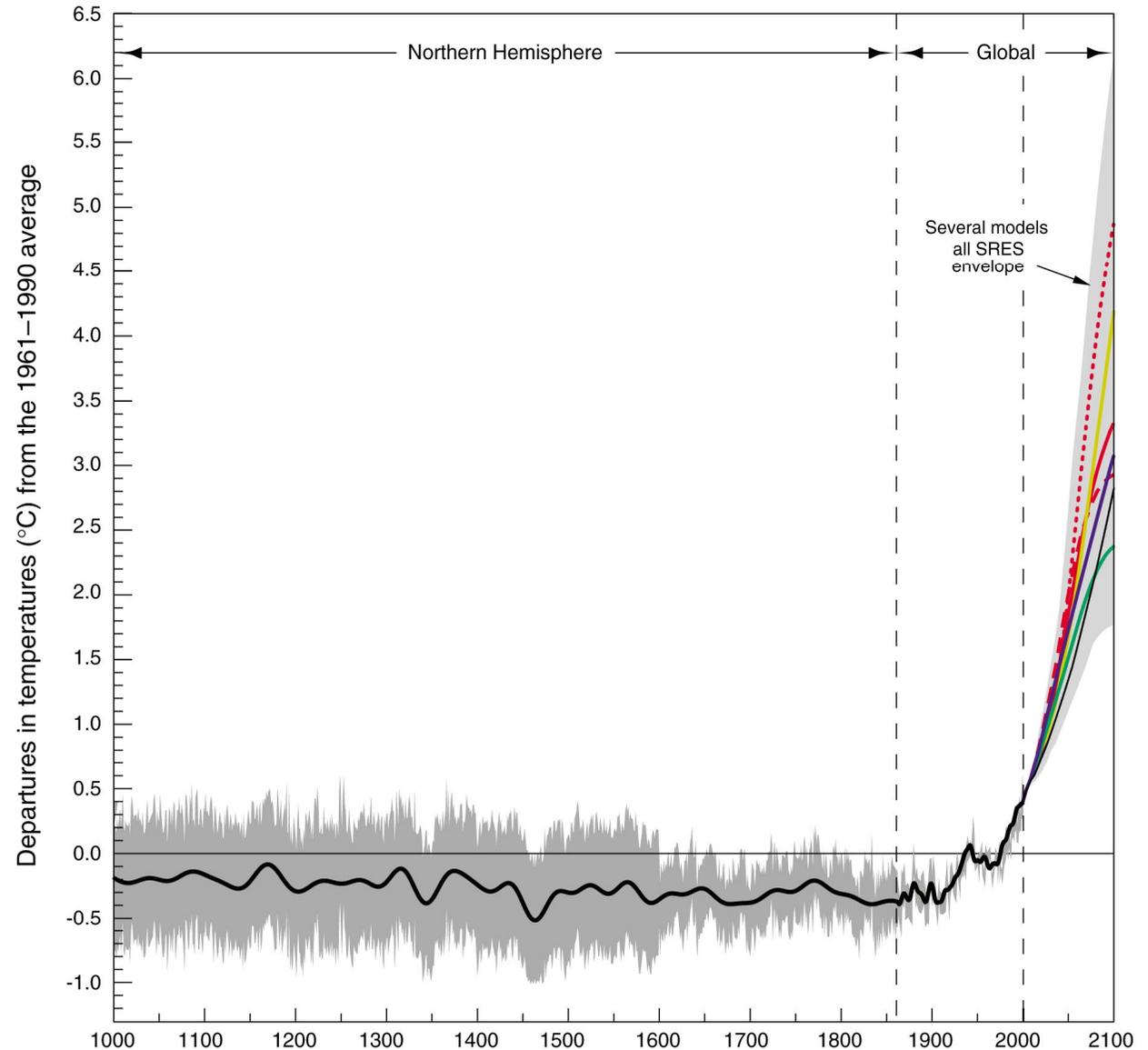
*+ Amplifying effect*

*- Damping effect*

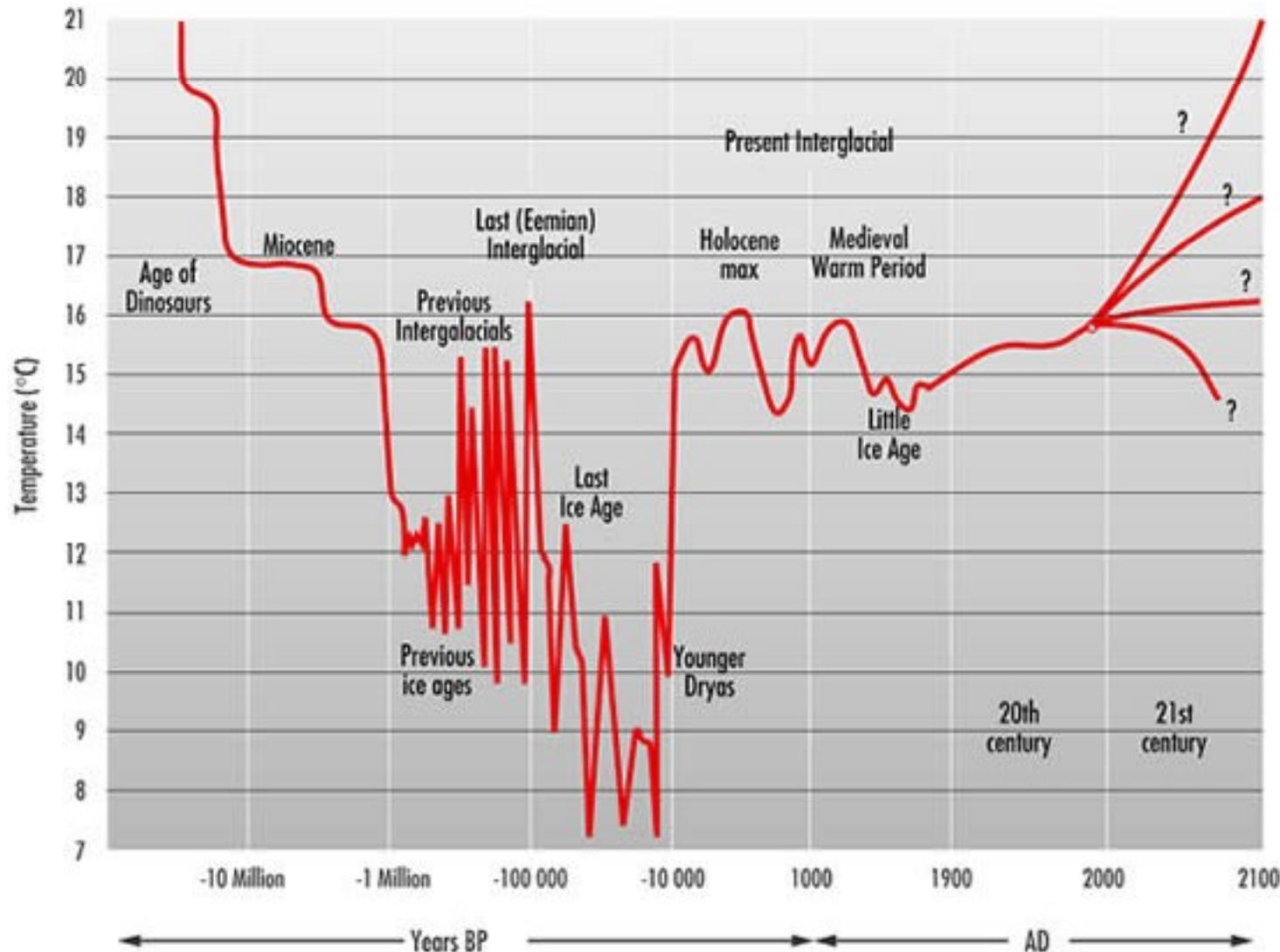
- 
- + (?) Clouds** – changes in cloud amount, height and radiative properties
  - ++ Water vapour** – Basis moist thermodynamics tells us that warmer air holds more water.
  - ++ Terrestrial carbon cycle** – Warmer soils release more carbon, changes in water availability threaten rainforests
  - + Ocean carbon cycle** – More acidic oceans inhibit growth of organisms that sequester carbon
  - ++ Snow and ice albedo** – Reduction in snow and ice cover leads to lower surface reflectivity and greater absorption of solar energy
  - +++ (?) Methane emissions from melting permafrost** – Potential to release very large amounts of methane, a potent greenhouse gas
  - (?) Slow-down of the Atlantic Thermohaline Circulation**

# Putting future changes in context

Future changes will be outside anything experienced over the last 1000 years



# Putting future changes in context: Climatic history of the Earth

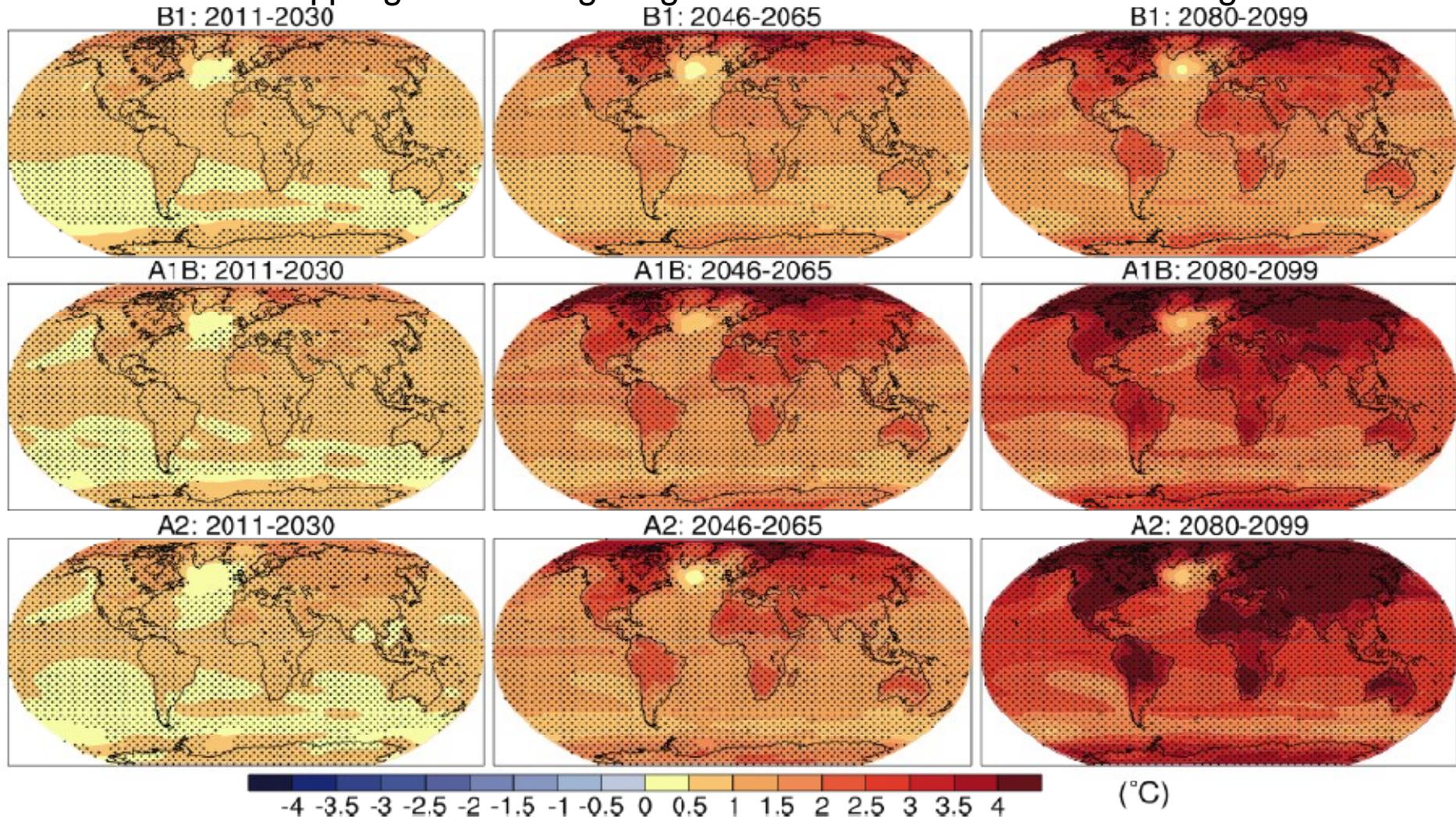


Earth is entering a period of unprecedented warmth, at least for over 10 million years.

Past rapid changes (Ice Ages) have always occurred in relatively cold periods.

# Distributions of warming for different scenarios and different lead times (IPCC AR4)

Stippling indicates high degree of confidence in level of warming

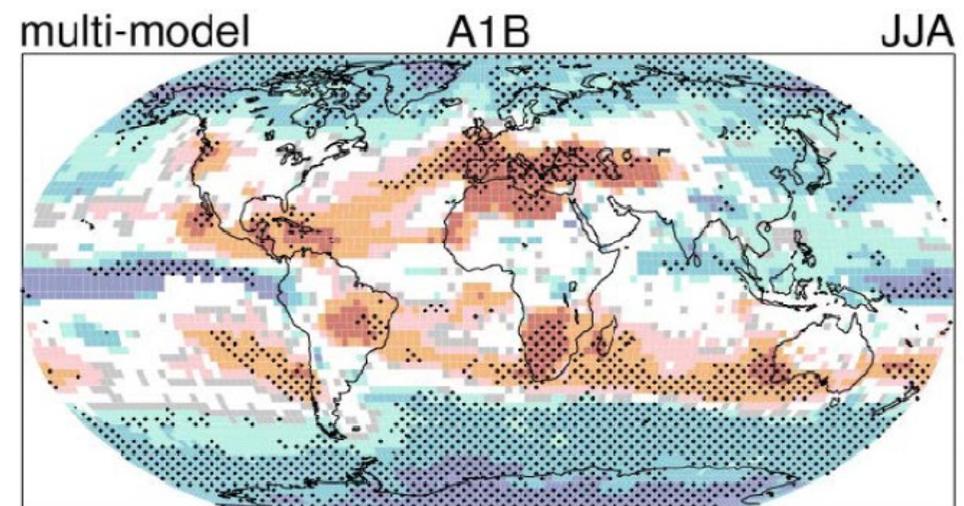
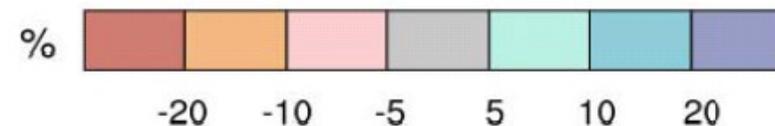
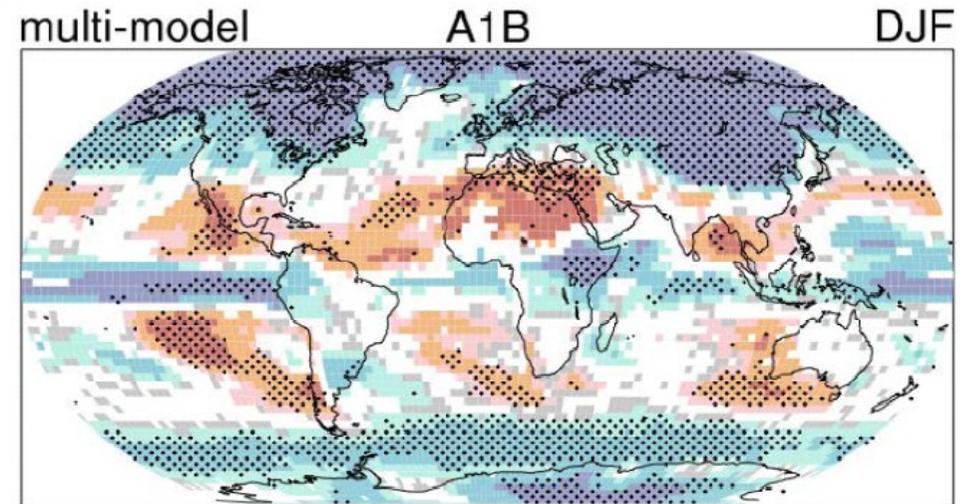


Note that the pattern of change is largely independent of scenario and lead time  
Can global mean temperature change be used as a proxy for regional changes?

# Global warming perturbs the water cycle very profoundly

## IPCC 4<sup>th</sup> Assessment Report: Projections of likely shifts in rainfall patterns

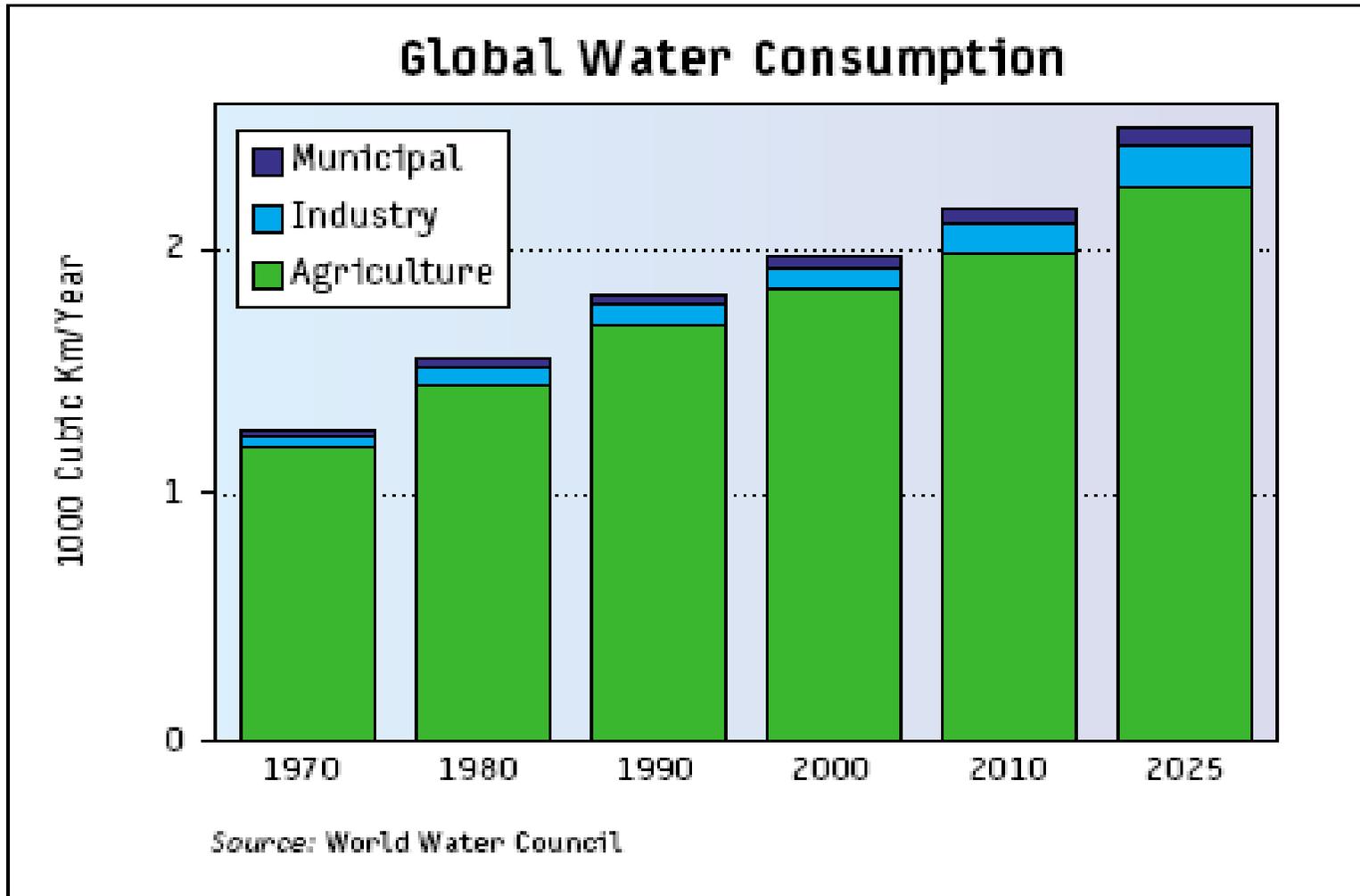
- ❖ % change in rainfall by end of 21<sup>st</sup> century, where more than 2/3 of the models agree on the sign of the change.
- ❖ White areas denote regions where no consistent signal is predicted e.g. Africa.



# Why the Water Cycle is at the heart of climate change

- Impacts of climate change on the quality of human life occur primarily through changes in the water cycle.
- Impacts of climate change on natural ecosystems directly involve precipitation.
- Regional changes in mean precipitation patterns have implications for desertification, flooding.
- Potential acceleration of the hydrological cycle has implications for the incidence of extreme events.
- Changes in the partitioning between fresh and salty water (e.g. melting ice-caps, river water extraction, accelerated hydrological cycle from global warming) could have major consequences for the Earth System.
- Water availability and water quality are fundamental issues for the 21st century, particularly in regions where water is already a precious commodity.

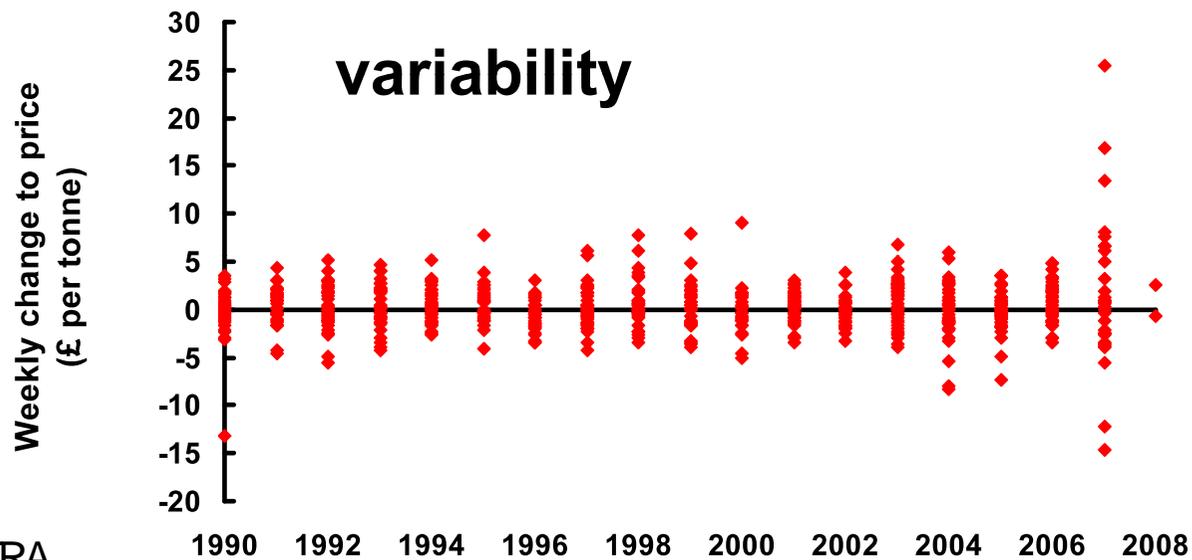
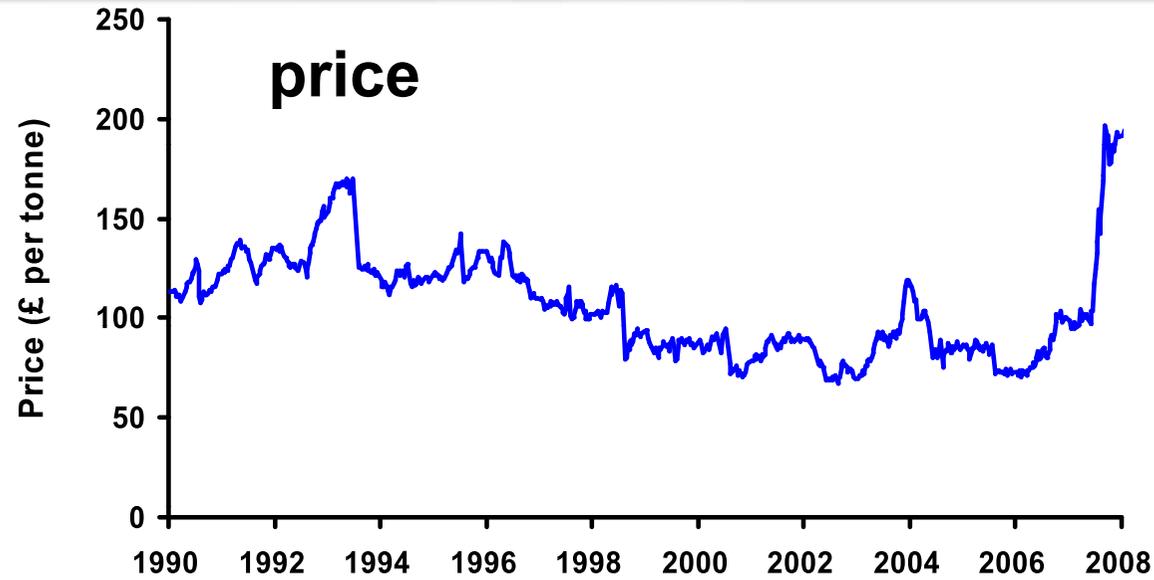
# Water uses by humans: Food, household, industry & energy



Currently equivalent to 0.3% of global precipitation,  
1.5% of that on land, 10% of that flowing to sea



# Price of wheat -UK



Data from DEFRA

- Food prices should drop slightly but remain high for the next 10 years
- Prices may become more volatile, with current grain stocks remaining low
- Climate change would affect crop production and supply “in unforeseen ways”
- High food prices will hit the poor and hungry hardest

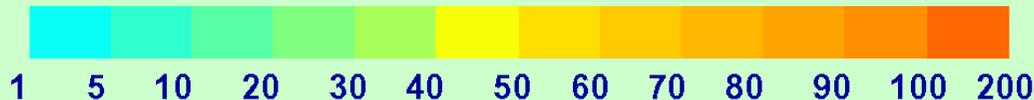
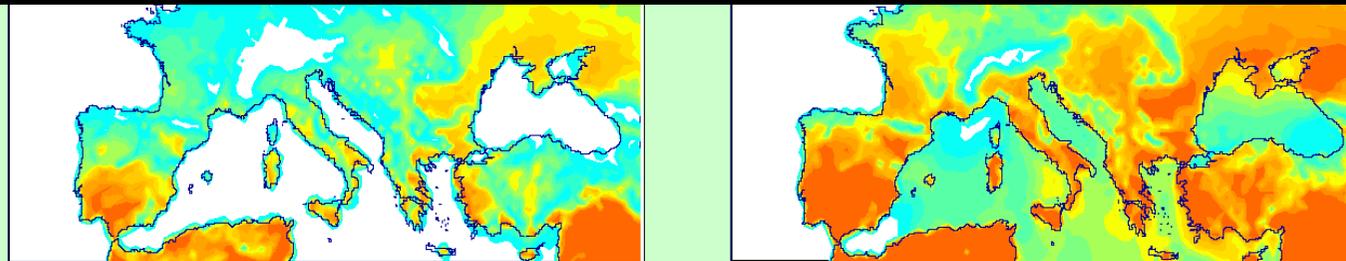
OECD-FAO Agricultural Outlook 2008-2017  
Published June 2008

# Europe – change in hot summers

Daily maximum temperatures  
Number of days per year above 30°C

UK Met. Office

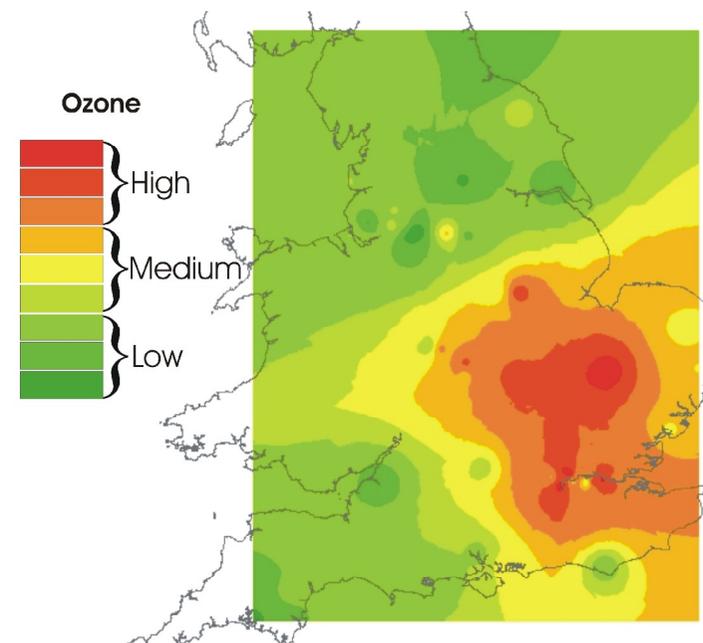
	Production M tonnes	Production 2003 (% change)	Yield 2003 (% change)
EU-15	101.1	-10.1	-8.0
Russia	43.1	-20.1	-7.8
Ukraine	14.6	-75.4	-42.5

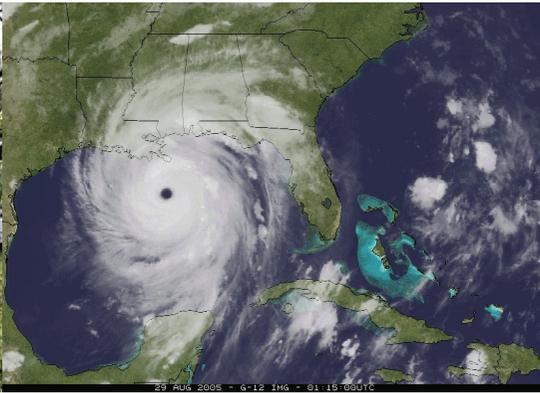




- Surface ozone is damaging to plants and humans by affecting 'lung function'.
- Future projections of air quality are uncertain
- New research at Reading suggests that 'ozone-friendly' weather (e.g. anticyclonic conditions) may be more prevalent in the future

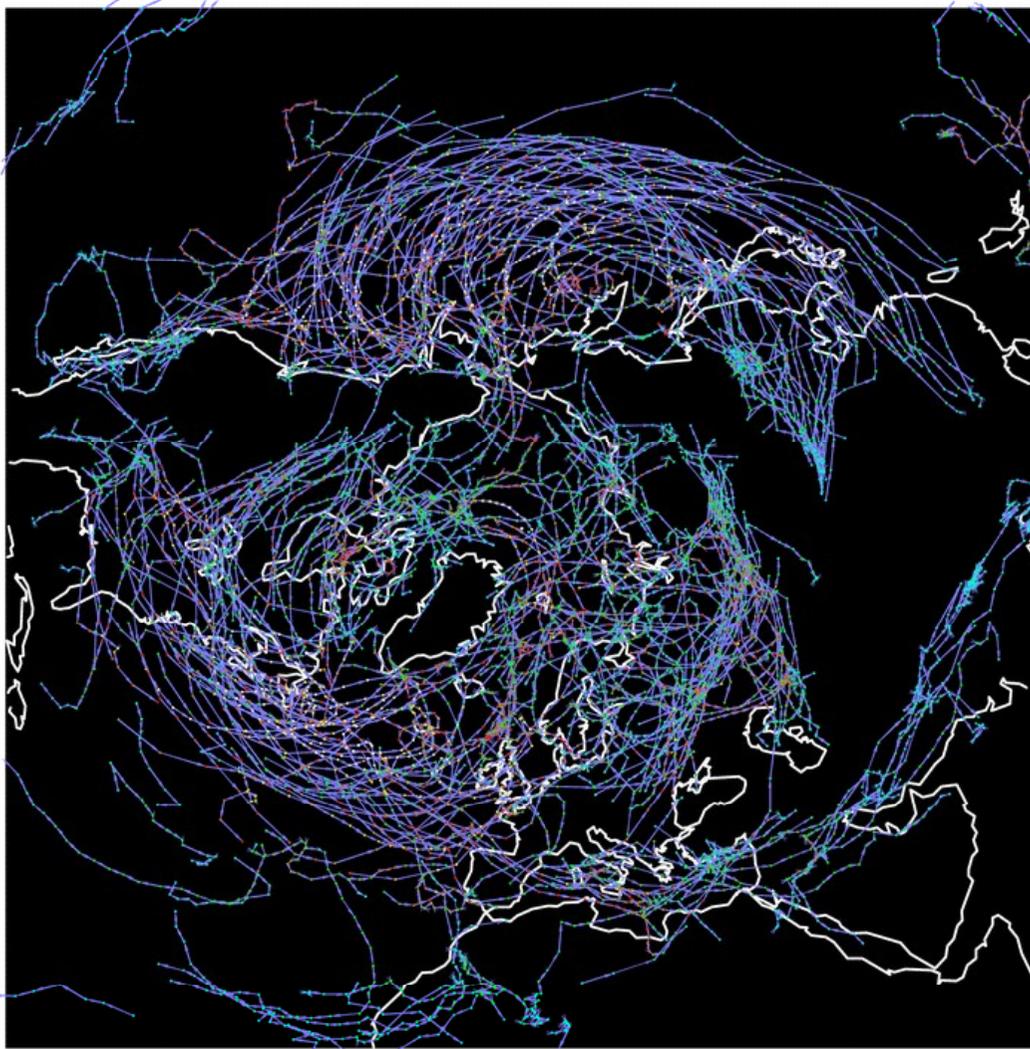
- Surface ozone levels at the height of the August 2003 heatwave.
- Thresholds considered dangerous to plants and humans were exceeded in many places.





# Hazardous weather in a changing climate

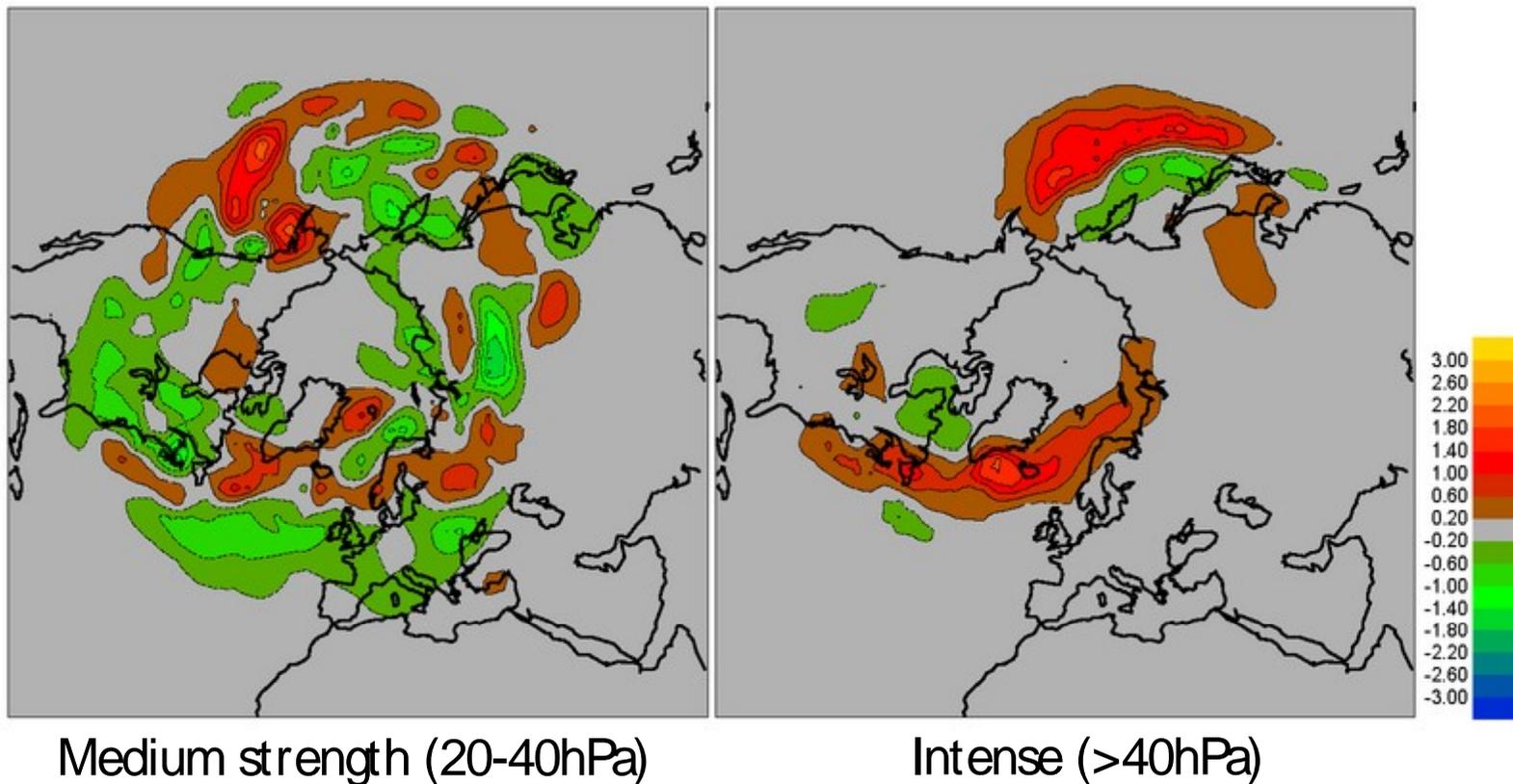
# Tracking weather systems to build better statistics



- Tracks of individual extratropical cyclones (low pressure systems) for a single winter season
- Individual dots represent position of the cyclone every 6 hours.
- Colour of the dots represents strength of the cyclone.

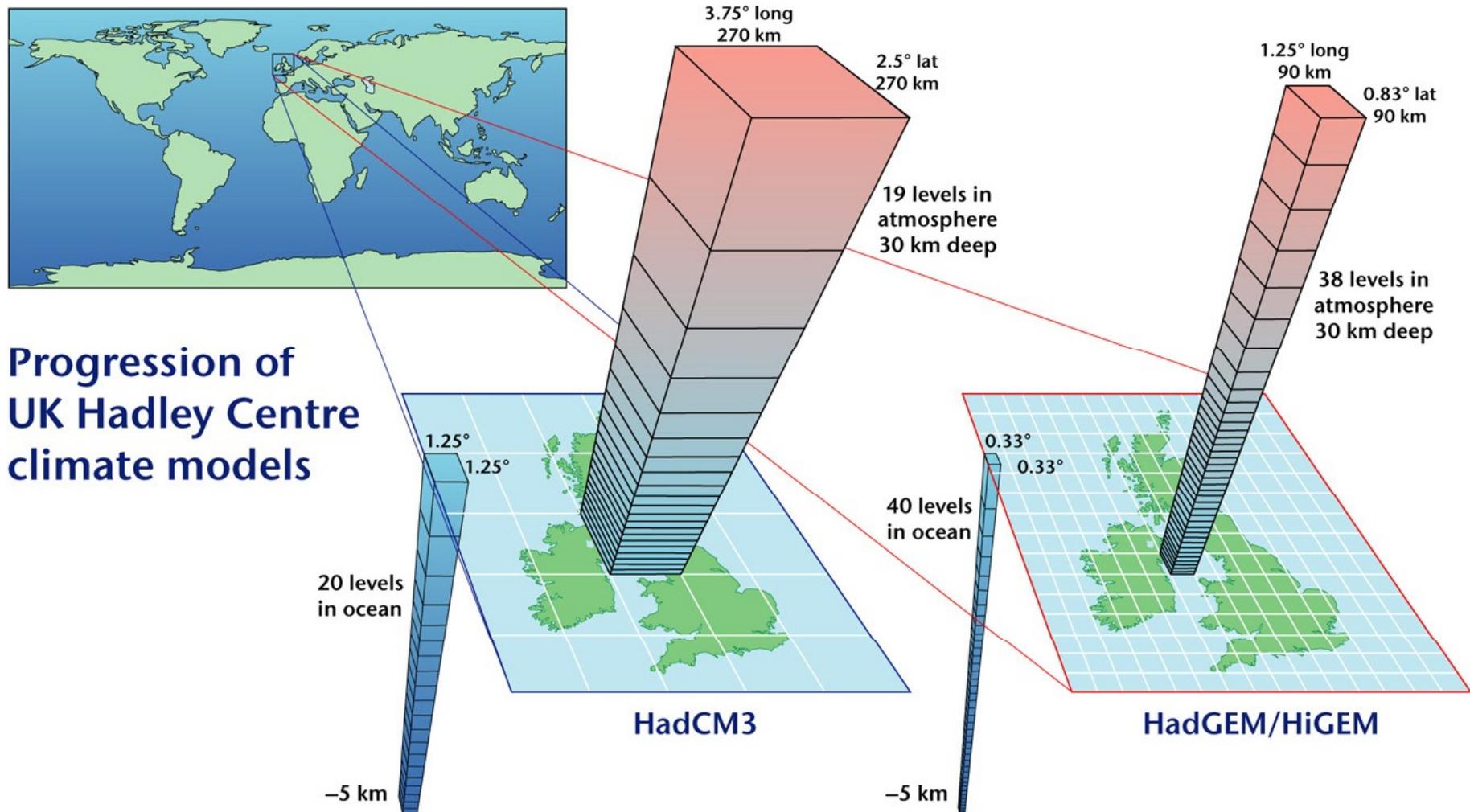
# Recent observed changes in mid-latitude storminess

Changes in the track density of mid-latitude storms  
1979 - 2003 minus 1958 - 1978

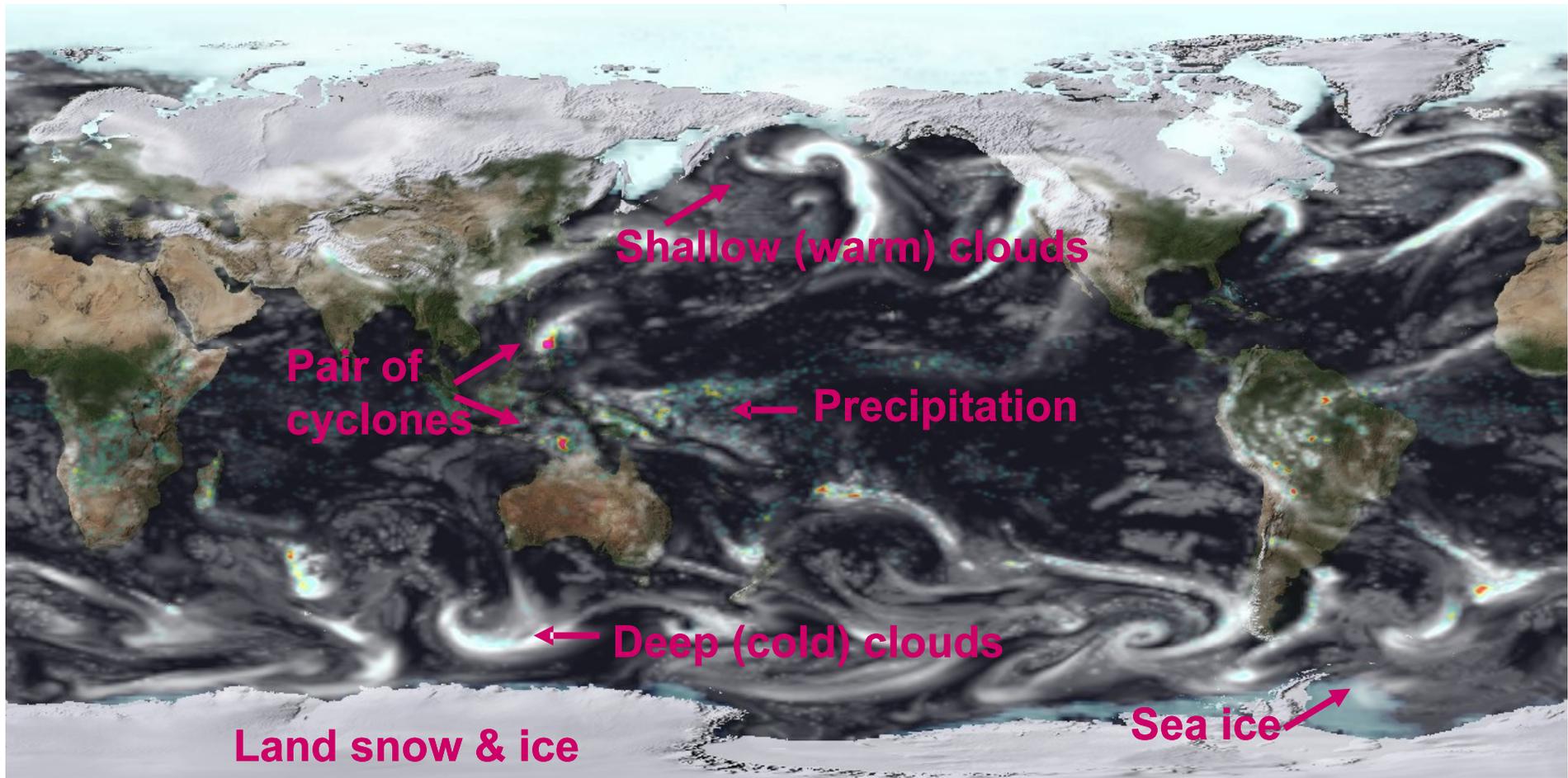


Is it associated with the Atlantic Multi-Decadal Oscillation and the NAO?  University of Reading

# UK in typical climate models



# Climate Modelling at Weather Resolution on the Earth Simulator



**NUGAM 60km climate model simulation snapshot**

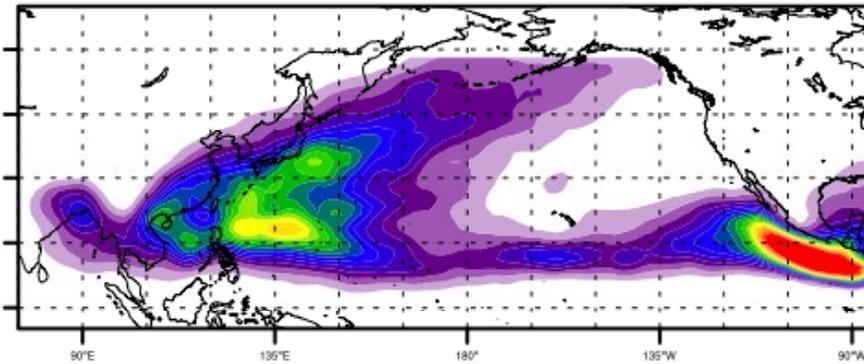
Visualisation produced by NASA Earth Observatory

White/grey represent clouds; colours represent rainfall

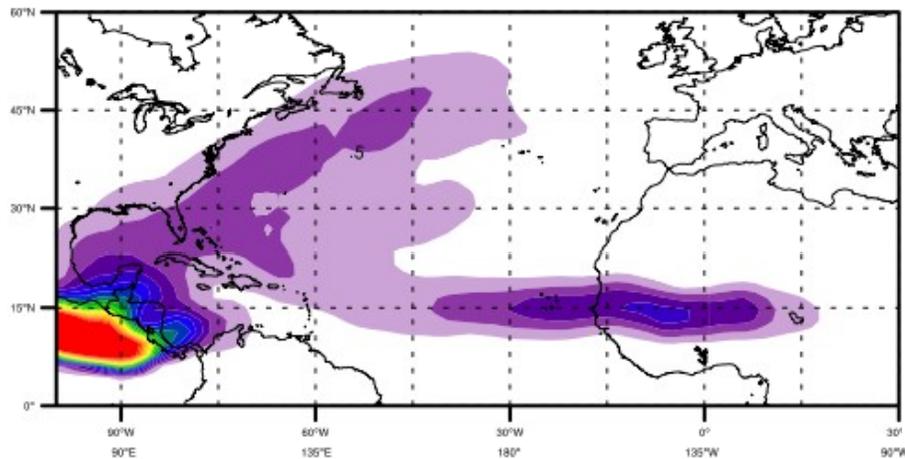
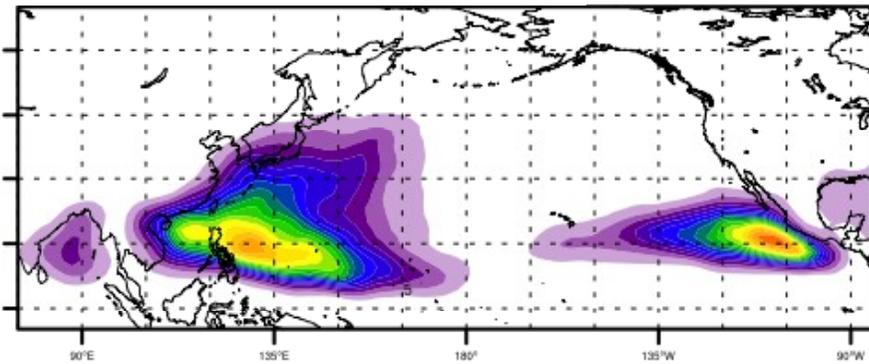
# Tropical Cyclone Multi-year Statistics in 60km Climate Model

## Density of storm tracks

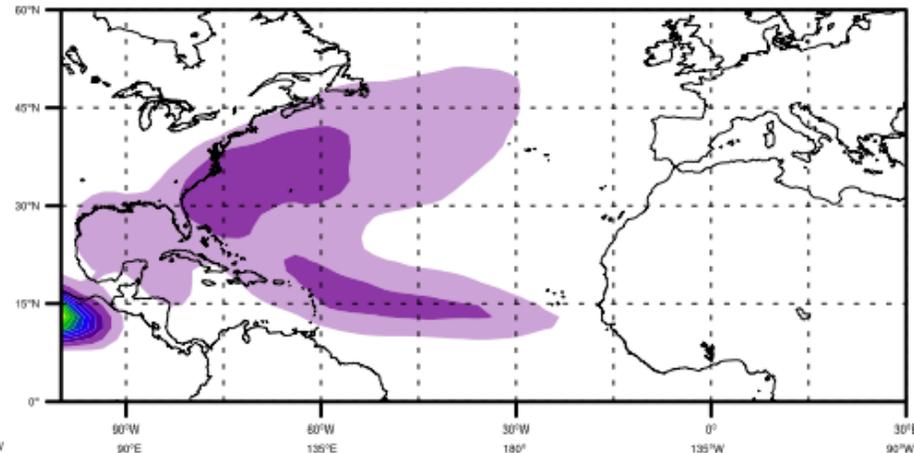
Model



Observations: Best Track

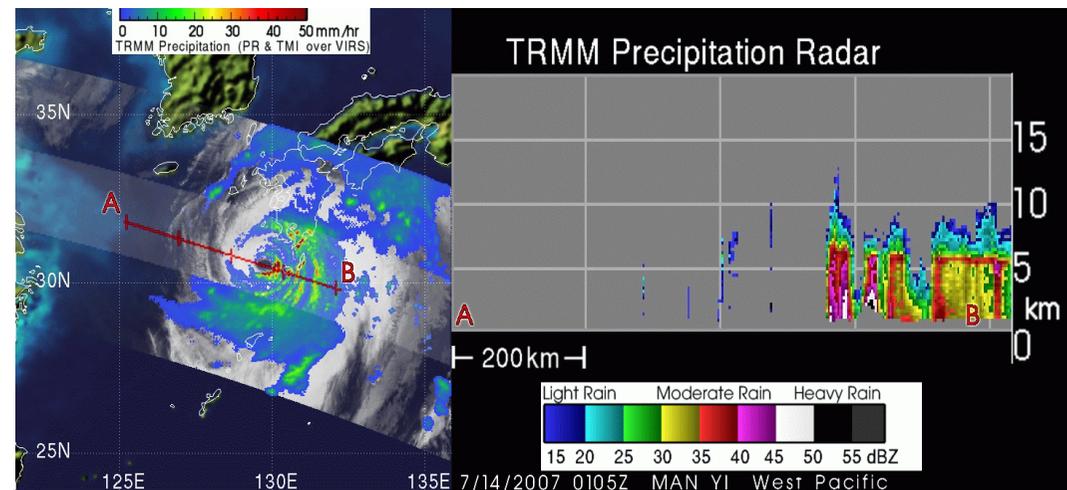
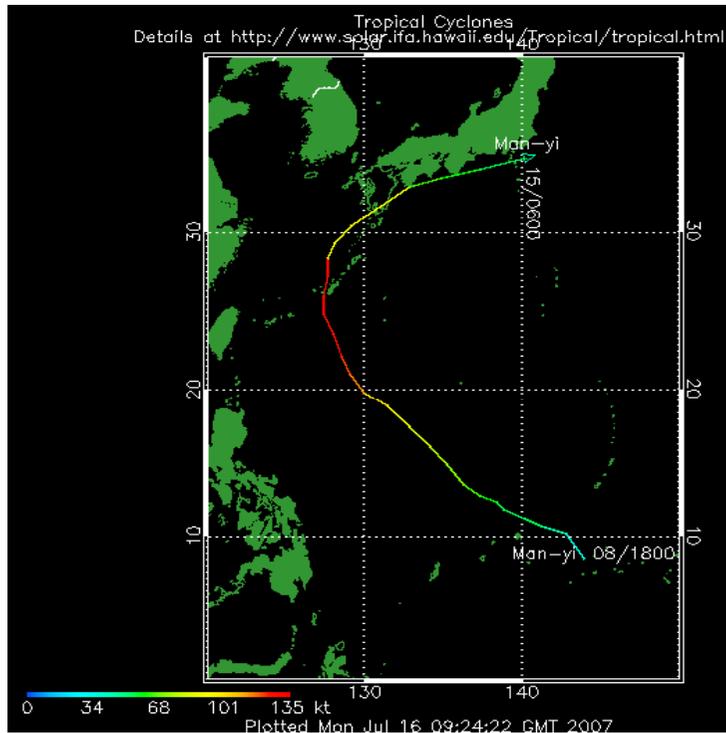
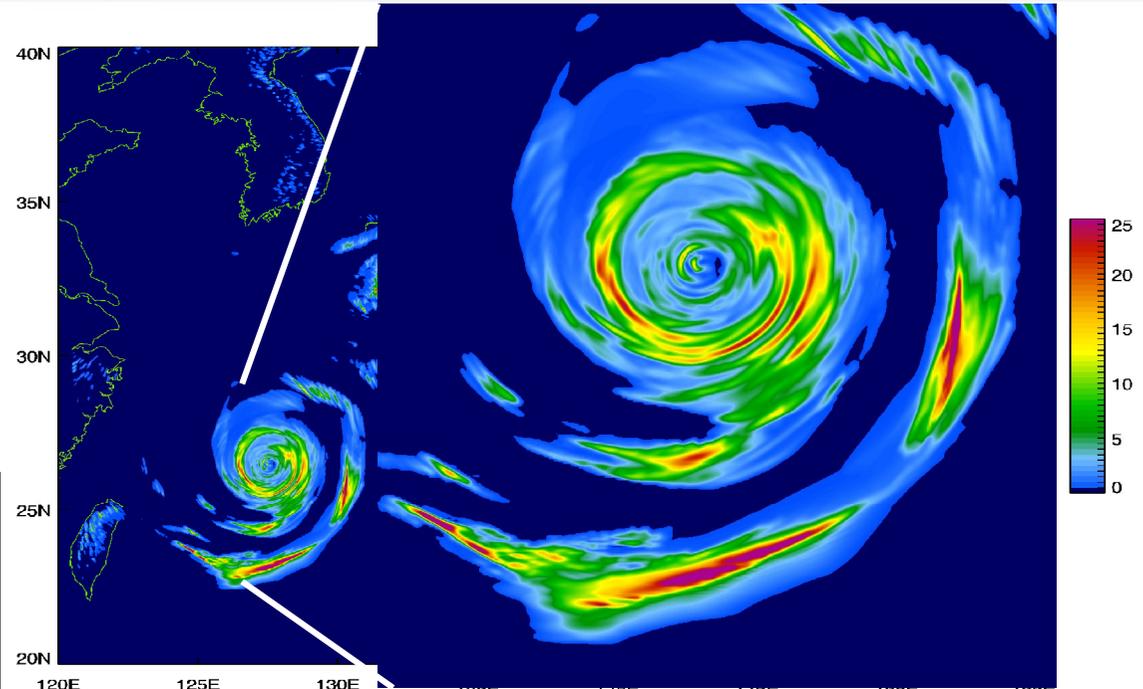


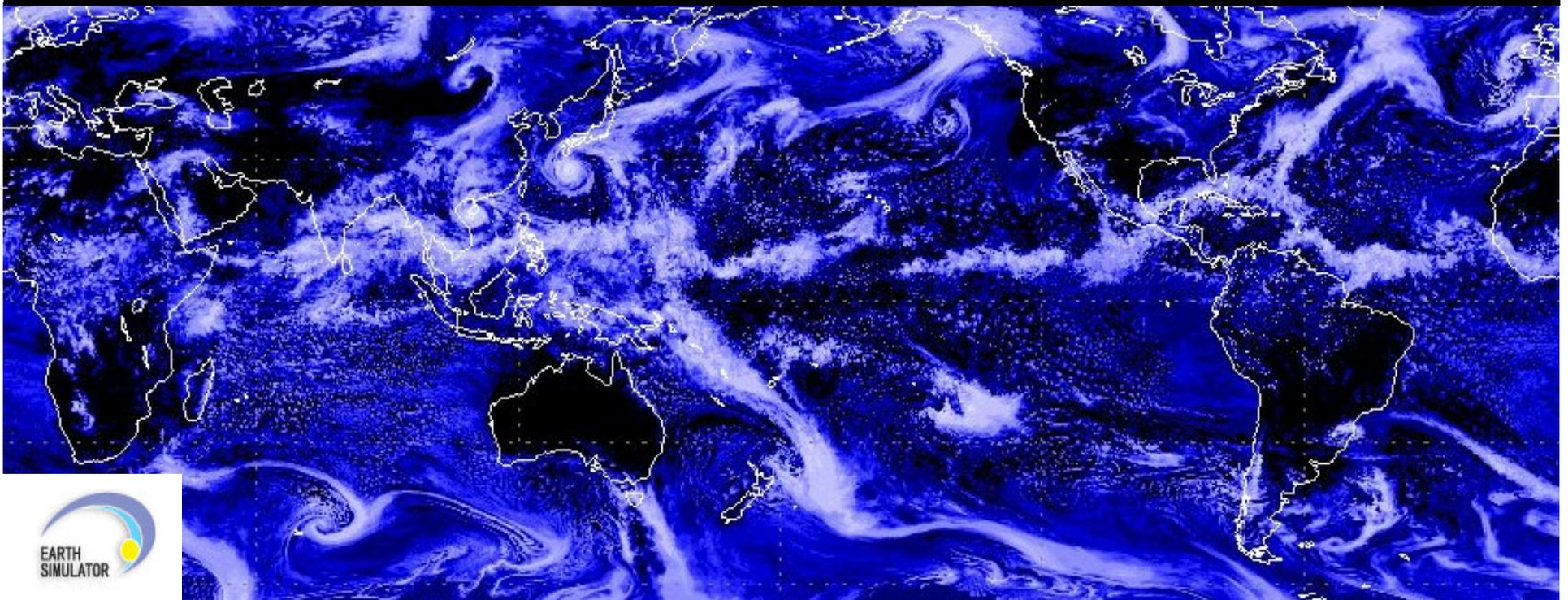
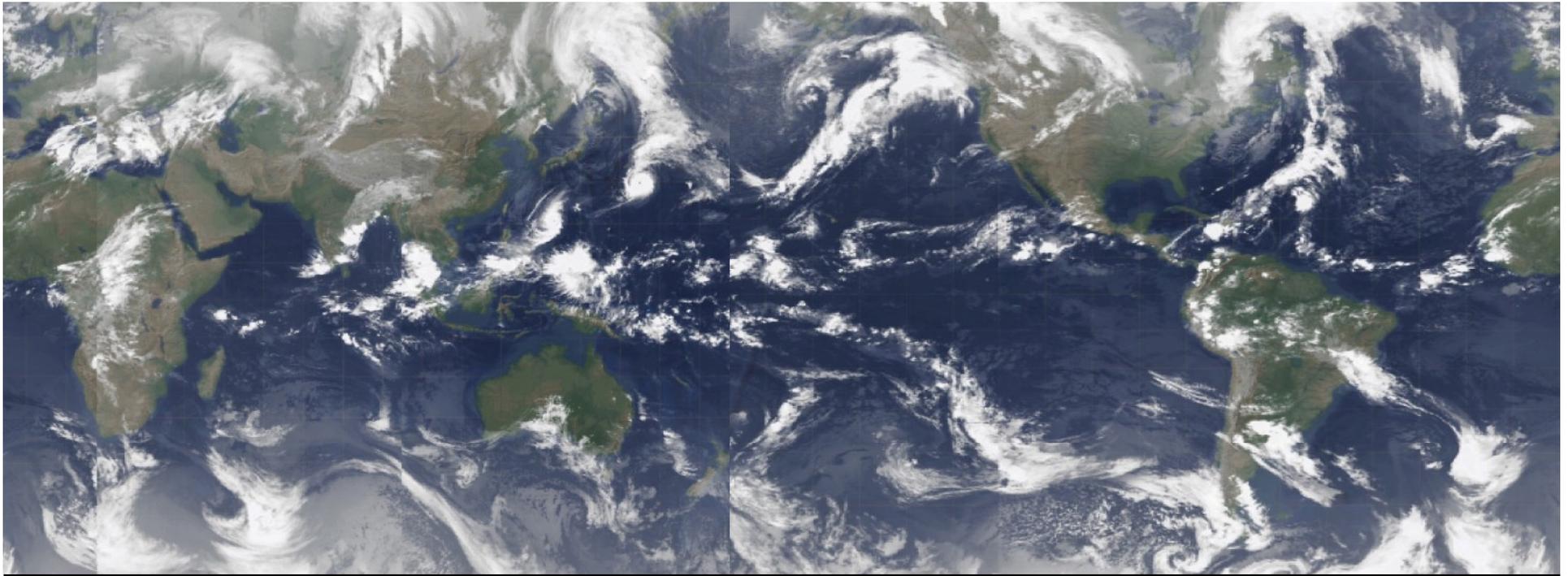
BestTrack



# Estimating Hazard Footprint of Land-falling Cyclones

Earth Simulator research group led by Keiko Takahashi  
**Multi-scale Simulator for the Geo-environment (MSSG)**  
Maximum resolution 2.8km





# Model Grid Size (km) & Computing Capability



Peak Rate:	10 TFLOPS	100 TFLOPS	1 PFLOPS	10 PFLOPS	100 PFLOPS
Cores	1,400 (2005)	12,000 (2007)	80-100,000 (2009)	300-800,000 (2011)	6,000,000? (20xx?)
Global NW P <sup>0</sup> : 5-10 days/hr	18 - 29	8.5 - 14	4.0 - 6.3	1.8 - 2.9	0.85 - 1.4
Seasonal <sup>1</sup> : 50-100 days/day	17 - 28	8.0 - 13	3.7 - 5.9	1.7 - 2.8	0.80 - 1.3
Decadal <sup>1</sup> : 5-10 yrs/day	57 - 91	27 - 42	12 - 20	5.7 - 9.1	2.7 - 4.2
Climate Change <sup>2</sup> : 20-50 yrs/day	120 - 200	57 - 91	27 - 42	12 - 20	5.7 - 9.1

Thanks to Jm Abeles (IBM)

Range: Assumed efficiency of 10-40%

0 - Atmospheric General Circulation Model (AGCM; 100 vertical levels)

1 - Coupled Ocean-Atmosphere-Land Model (CGCM; ~ 2X AGCM)

2 - Earth System Model (with biogeochemical cycles) (ESM; ~ 2X CGCM)



# World Modeling Summit for Climate Prediction: May 2008



The Summit was organized to develop a strategy to revolutionize prediction of the climate through the 21<sup>st</sup> century to help address the threat of global climate change.



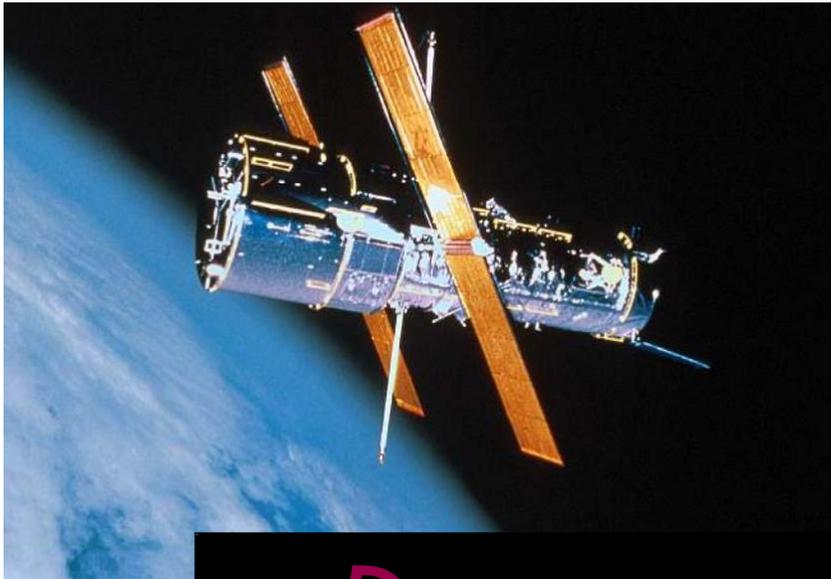
*Protecting our cities*



*Feeding the world*



*Managing our water*



**Hubble** cost \$1.5 billion to build and put into orbit. Hubble's annual operating budget is in the range \$230-250 million. Includes funds for scientific data analysis, as well as for the development of future hardware and its associated software.

c  
total

## *Do we need a World Climate Prediction Project?*

*World Modelling Summit, ECMWF, May 2008*



**Envisat** cost 2.3 BEuro (including 300 MEuro for 5 years operations) to develop and launch (launch price tag: 140 MEuro).



- Climate is changing and we are largely responsible
- The effects of climate change will impact many sectors of business and society
- The most profound effects are likely to be associated with changes in rainfall and hazardous weather
- Climate models are reaching a level of sophistication where they can be used to guide decision-making at the regional and local level
- Major investment in computing power is required to provide confident assessments of the risks associated with climate change

Thank you!

