

# Global Warming:

The known, the unknown,  
and the unknowable

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*January, 2008, George Mason University*



# George Mason University

## Department of Climate Dynamics

### Understanding and Predicting Climate and it's Variability

- PhD in Climate Dynamics
- Some key research components:

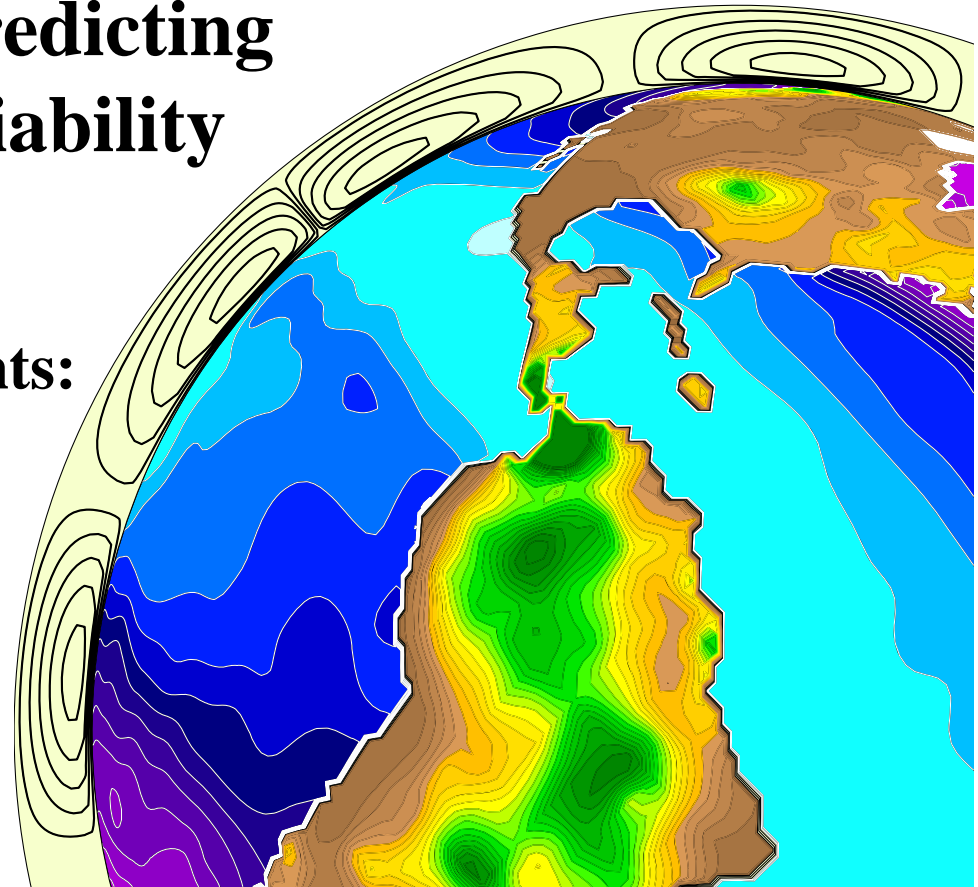
Atmospheric Dynamics

Physical Oceanography

Land-Air Interactions

Predictability

Climate Modeling



[www.climate.gmu.edu](http://www.climate.gmu.edu)



**Want to explore more?**

**Climate Dynamics classes  
include...**

**This semester: CLIM 759 Climate Change**

(graduate course – 14 week version of today's lecture)

*7:20-10:00pm, Tue, Innovation Hall rm 338*

**Fall 2008: NEW COURSE**

**CLIM 101: Weather, Climate, and Global Society**

- Open to all undergraduates
- Satisfies General Education Requirement for Science (non-lab)

# Intergovernmental Panel on Climate Change (IPCC)

IPCC established by WMO and UNEP to assess scientific, technical and socio-economic information for understanding climate change, its impacts and options for adaptation and mitigation.

**Working Group I: The Physical Science Basis**

**Working Group II: Impacts, Adaptation and Vulnerability**

**Working Group III: Mitigation of Climate Change**

- Largest number of U.S. scientists: nominated by the U.S. Govt.
- Highest skepticism : “U.S. Govt.”





# CLIMATE CHANGE 2007

## THE PHYSICAL SCIENCE BASIS



Working Group I Contribution to the Fourth Assessment  
Report of the Intergovernmental Panel on Climate Change



Center of Ocean-Land-  
Atmosphere studies



**CREW**  
Center for Research on  
Environment and Water



# Some things we know about global warming:

- Observations



<http://www.pmel.noaa.gov/tao/>

- Mechanisms



<http://en.wikipedia.org/wiki/Greenhouse>

- Models

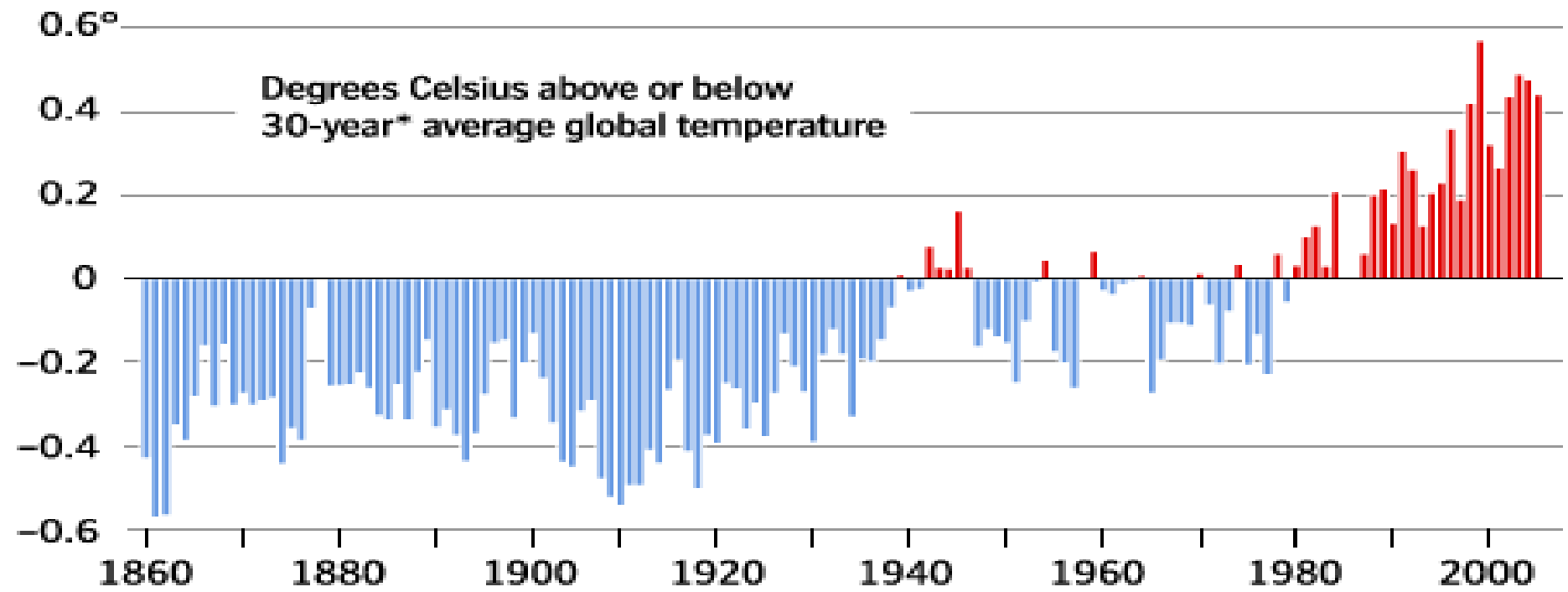
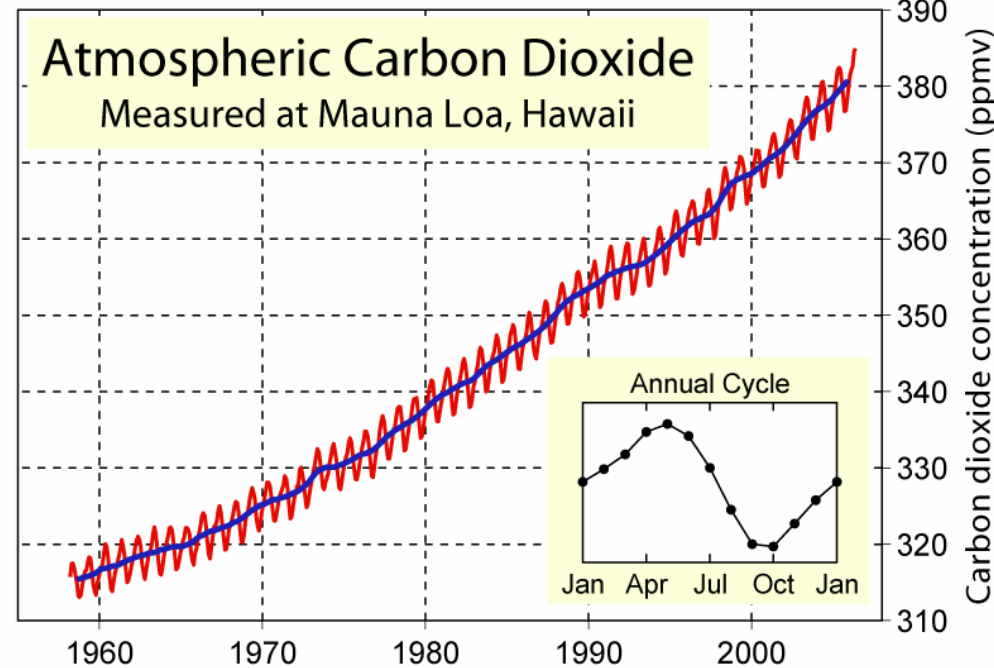


<http://www.cisl.ucar.edu/main/computers.html>

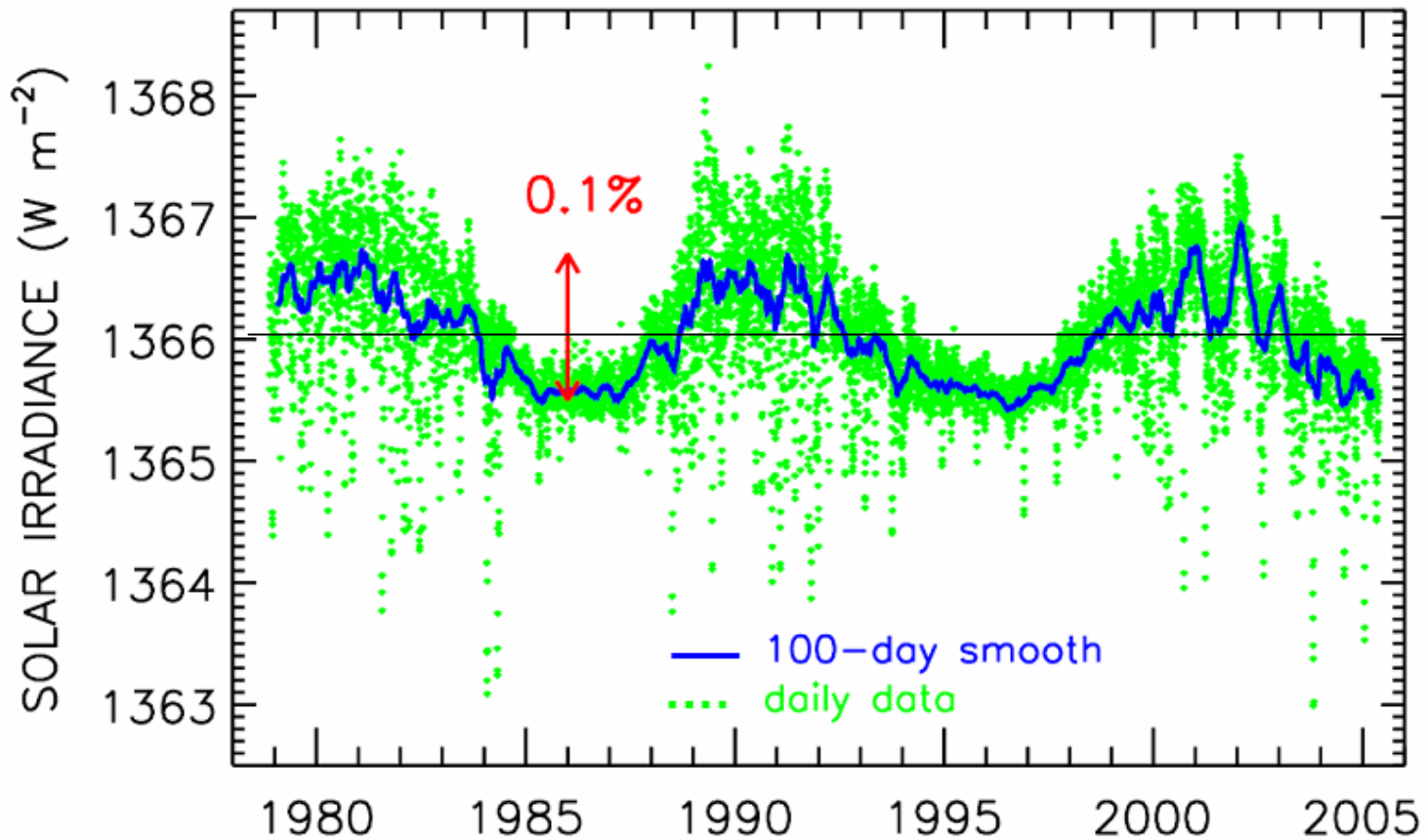
## Direct measurements:

CO<sub>2</sub> and other trace gases are increasing

Global mean surface temperature increasing



Natural forcings that *could* cause warming do not seem to have correct strength/pattern



Frohlich and Lean (2005)



# Air and sea warming are widespread

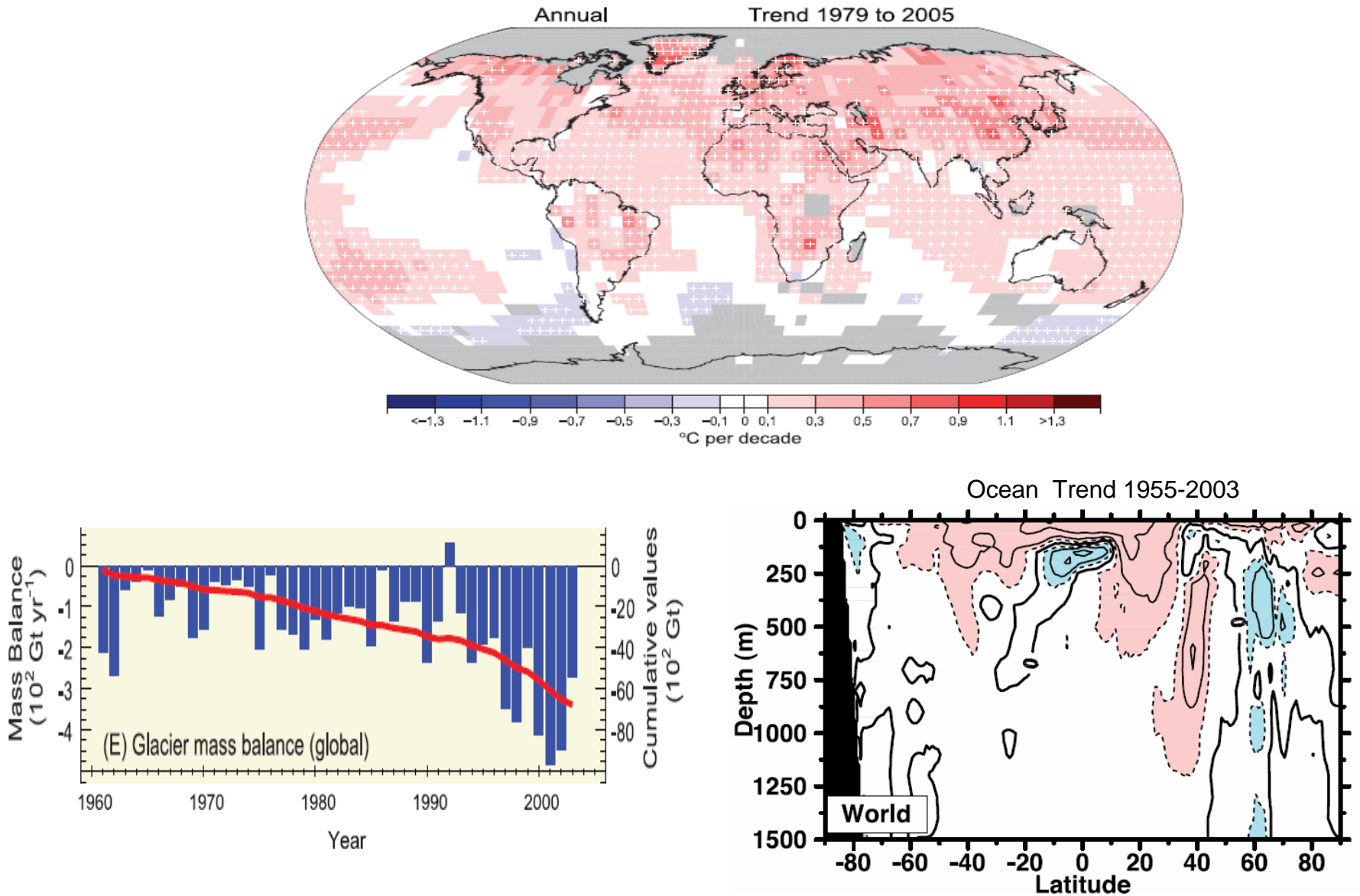
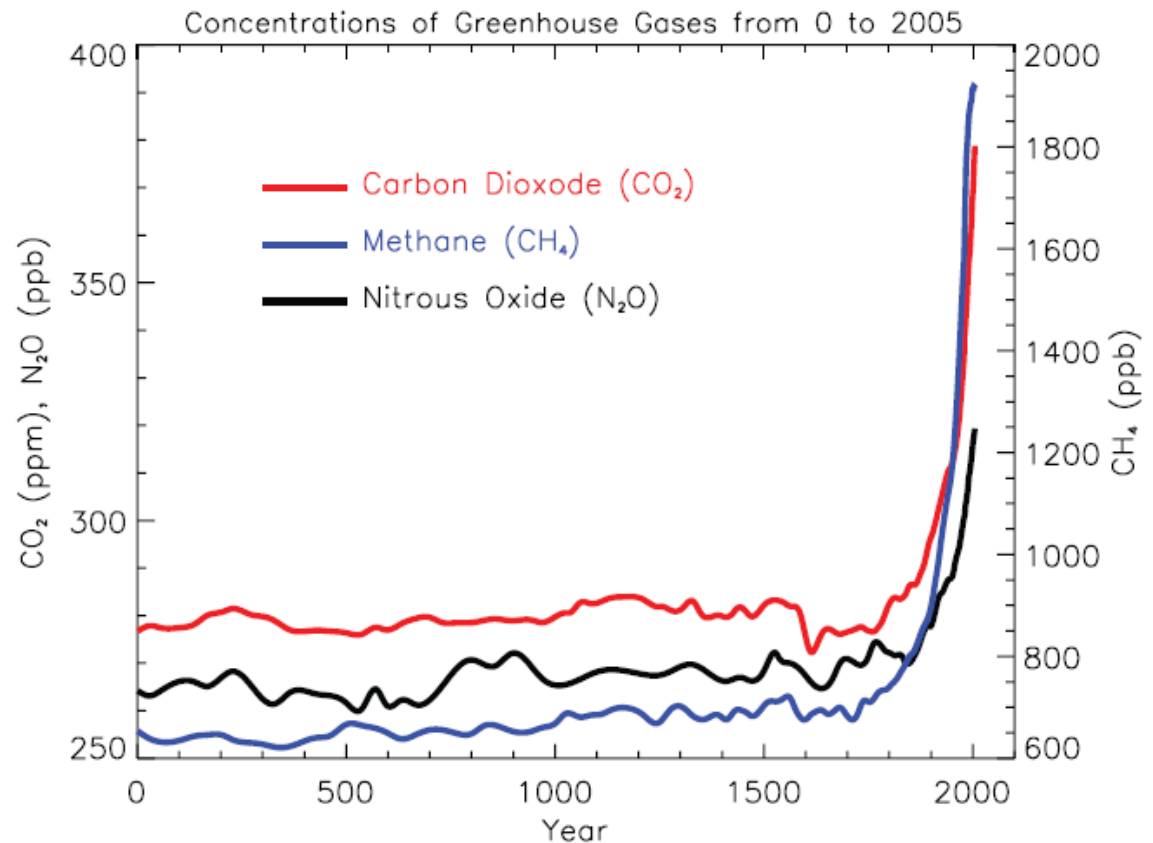
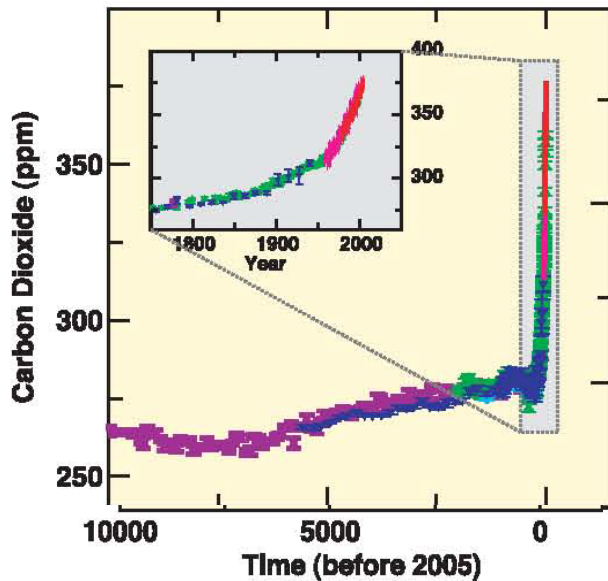


Fig 3.9, FAQ 4.1 Fig 1, and 5.3

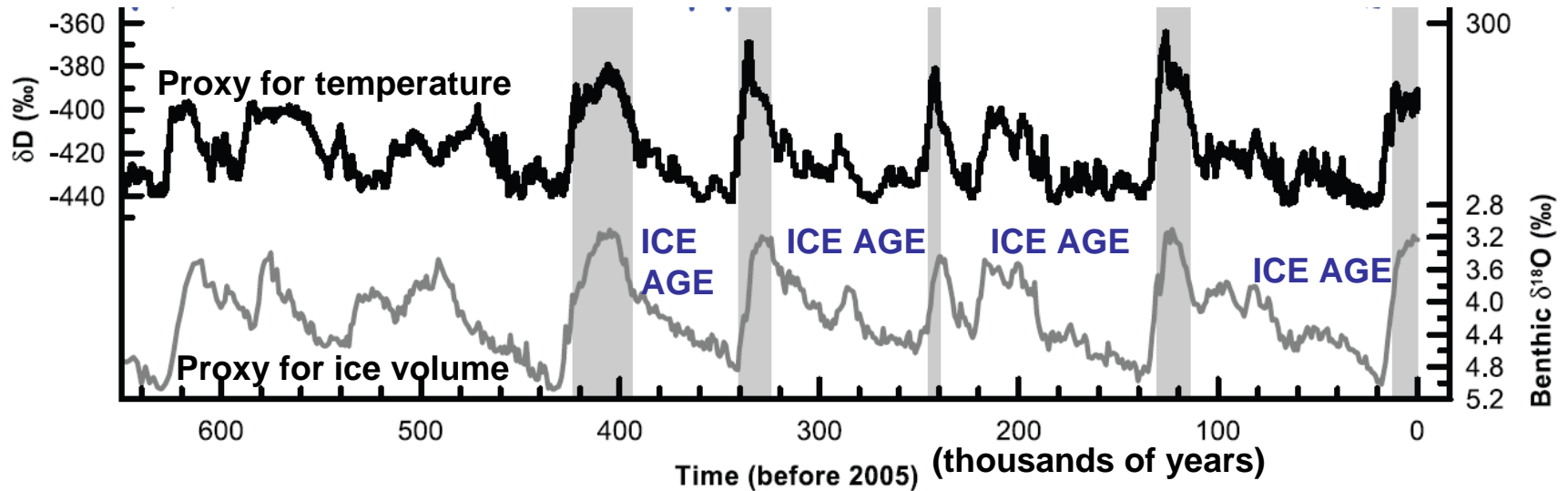
# Proxy measurements:

Recent increases are unprecedented, at least since end of the last Ice Age (around 10,000 yr ago)

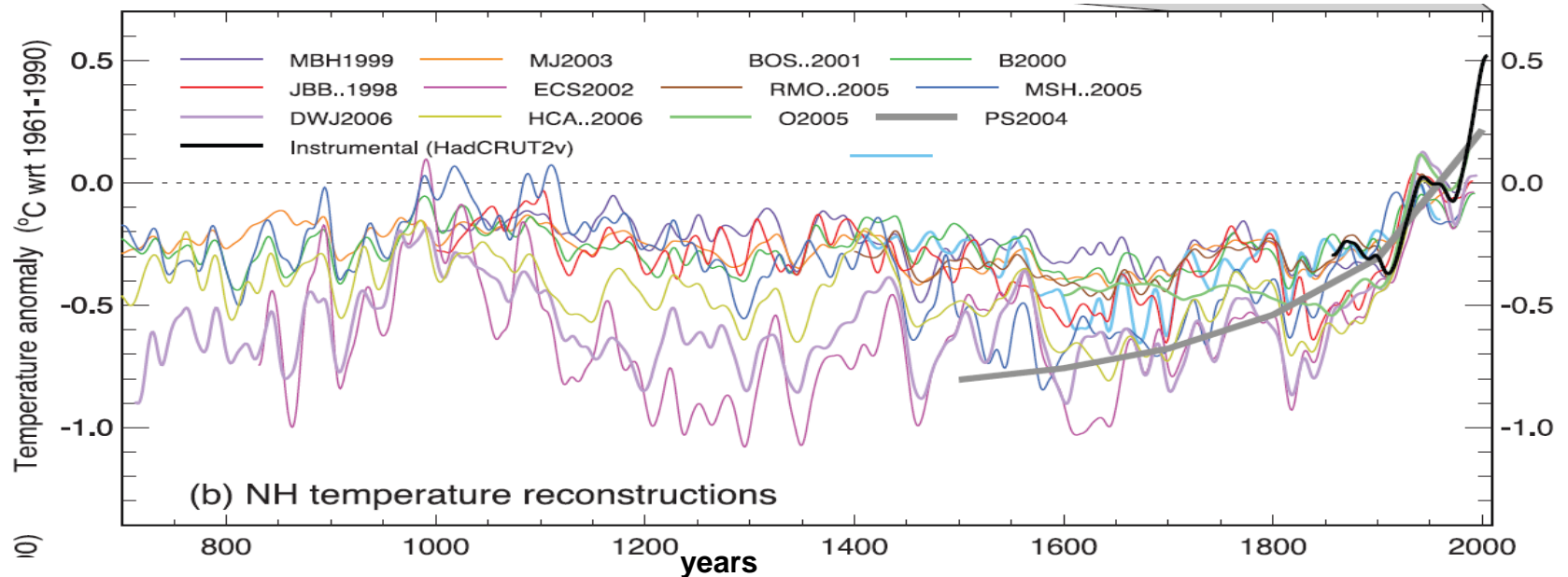


From FAQ 2.1, Fig 1

## Evidence that since last ice age, temperatures were stable...



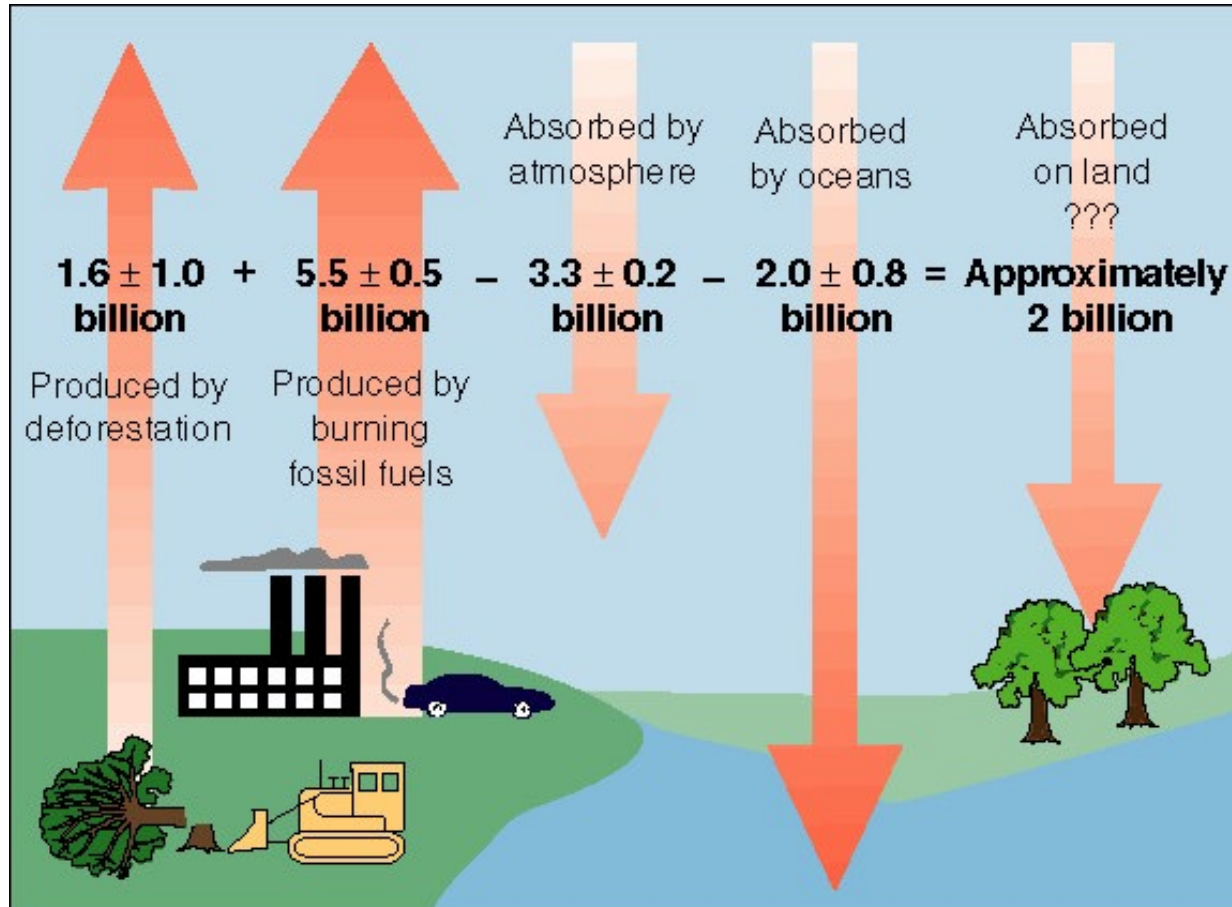
## ...and that northern hemisphere temperature is hitting record values



From Figs. 6.4 and 6.10

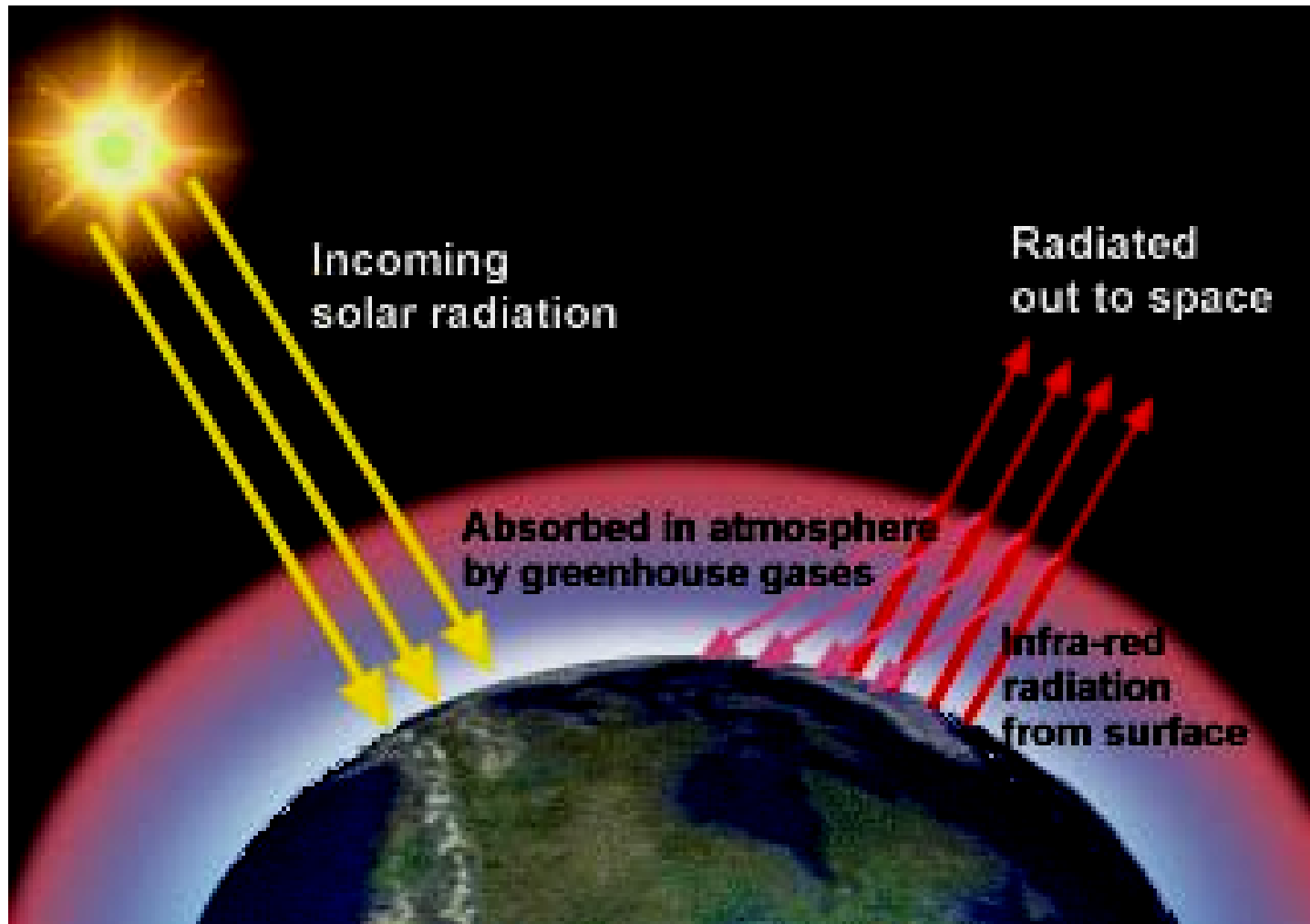
# Mechanism

for increasing CO<sub>2</sub> and other gases in atmosphere: PEOPLE



CO<sub>2</sub> emissions (Gigatons of Carbon, Gt C), *IPCC 2007*

**Mechanism for gases to raise temperature: “greenhouse effect”:** carbon dioxide, methane, etc., absorb outgoing radiation, make atmosphere warmer for given solar radiation.





**Influence of greenhouse gases on radiation: “*direct effects*”  
But *indirect effects* are just as important:**

**Water vapor is the main greenhouse gas.  
Warmer air holds more water vapor.**

**Warming from CO<sub>2</sub> etc → more water vapor  
→ more greenhouse effect → more warming**

**Warming → less ice → less sunlight reflected into space  
→ More sunlight absorbed by Earth → more warming**

**Warming → changes in atmospheric circulation → ??**

**Changes in atmospheric circulation →**

**changes in evaporation and precipitation → ??**

**changes in clouds → ??**

**Warming → changes in ocean circulation**

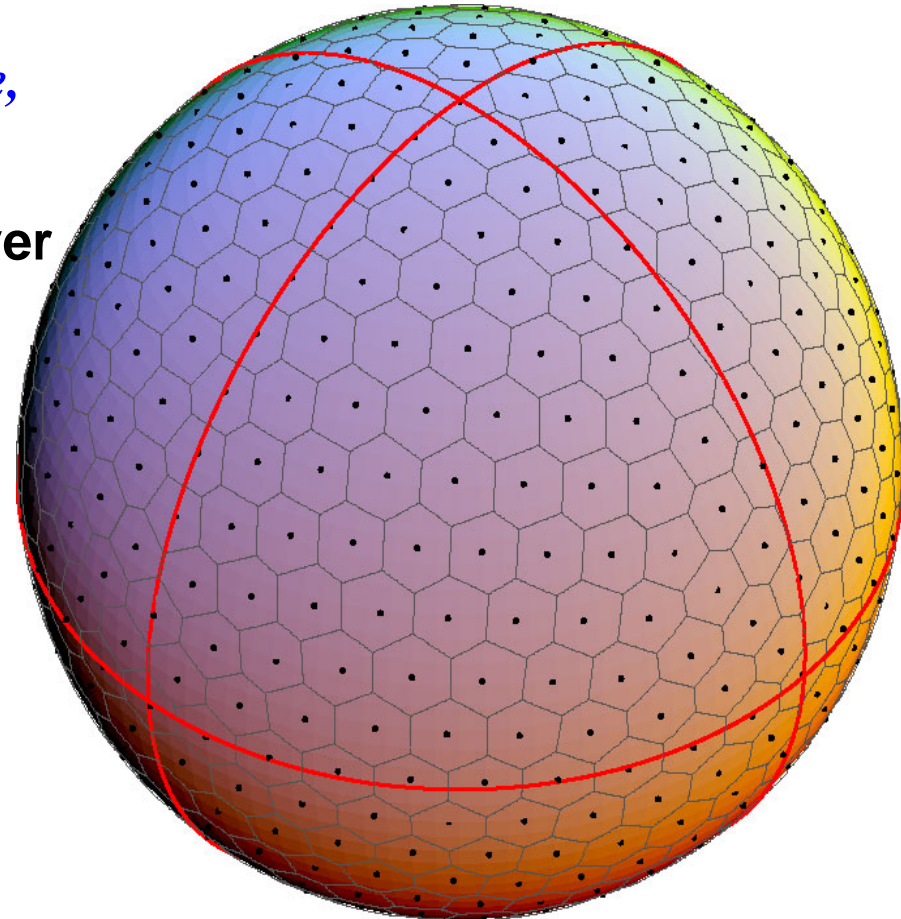
**→ Changes in heat transport from equator to poles → ??**

**Warming → changes in chemistry and ecosystems → ??**

**Use numerical models to understand/predict**

# What is a Climate Model?

- Divide atmosphere, ocean, and land surface into a 3-D grid (latitude, longitude, height)
- At each gridpoint, equations describing physical laws predict rate of change of: *Temperature, velocity, humidity, etc*
- Calculate how quantities change over time (hours for weather, years to centuries for climate)
- With Time Steps of: ~ 10 Minutes
- Use Supercomputers



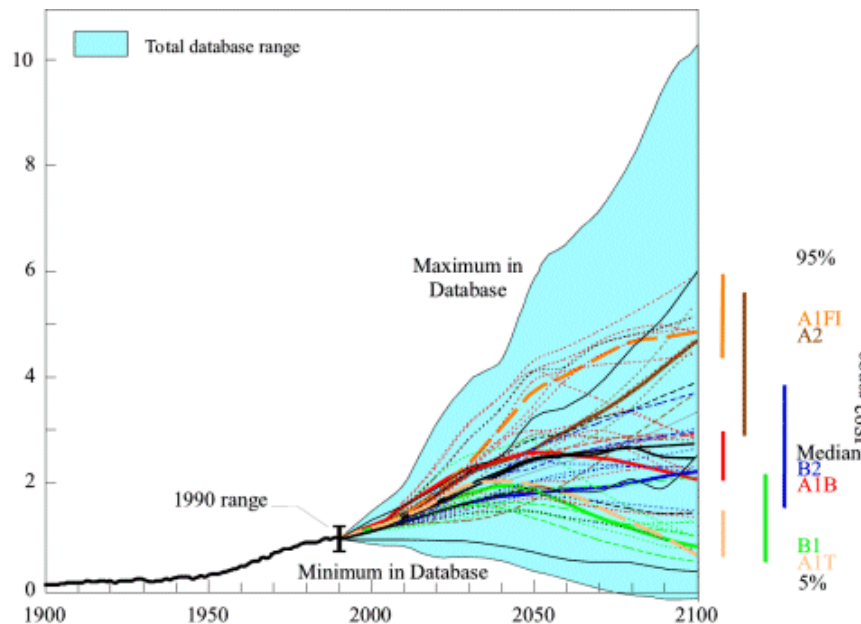
**Models give insight into “Climate Sensitivity”  
(how climate responds to a given forcing)**

**Future greenhouse forcing can only be guessed at:  
Depends on what you, me, and billions of other people do**

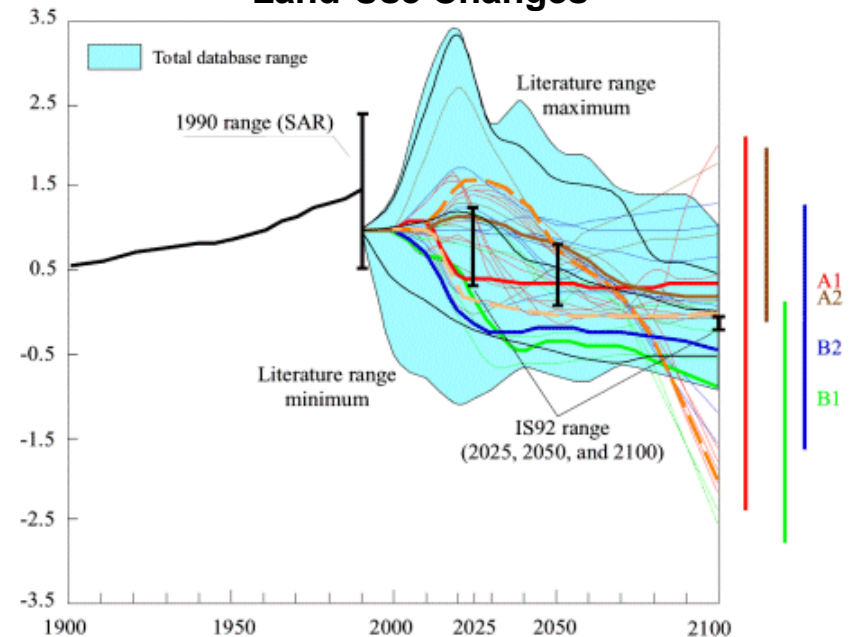
**A few forcing “scenarios” are used to drive models.**

### CO2 Emissions Scenarios / (1990 Emissions)

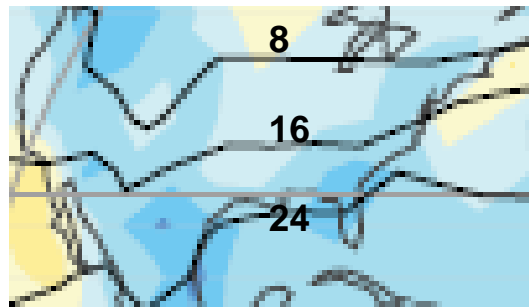
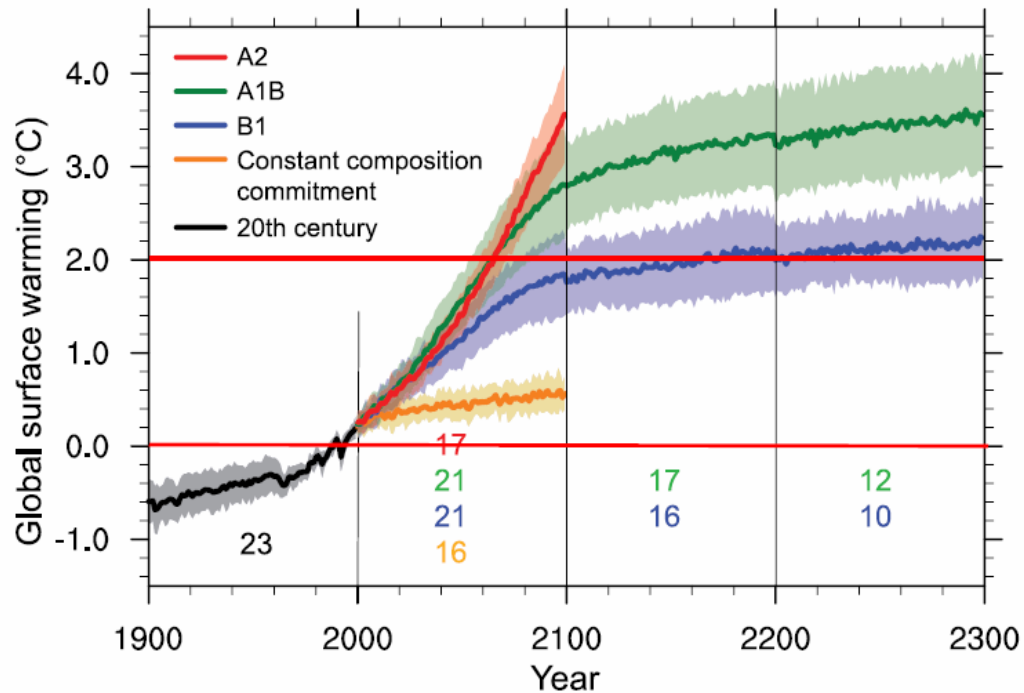
#### SRES Fossil-Fuel Scenarios



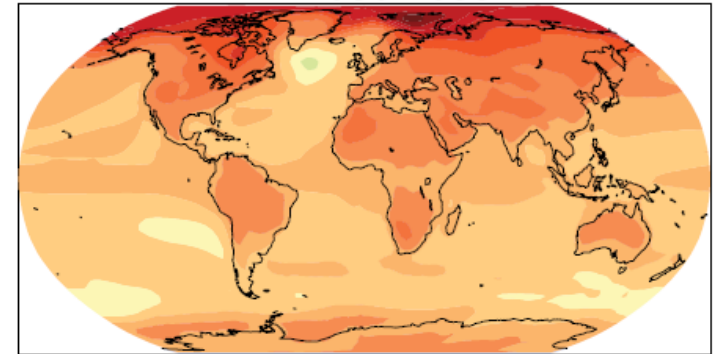
#### Land-Use Changes



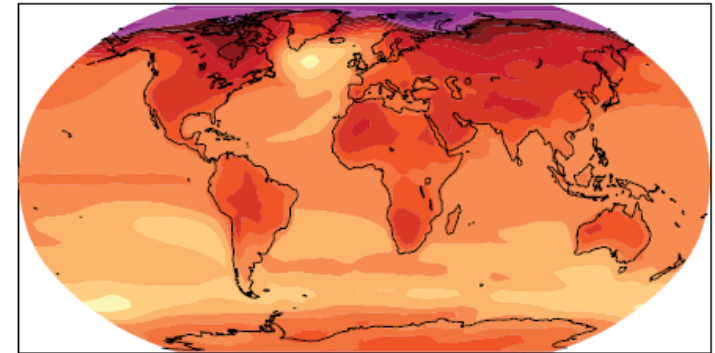
# Global Warming: Model Predictions for 21<sup>st</sup> Century



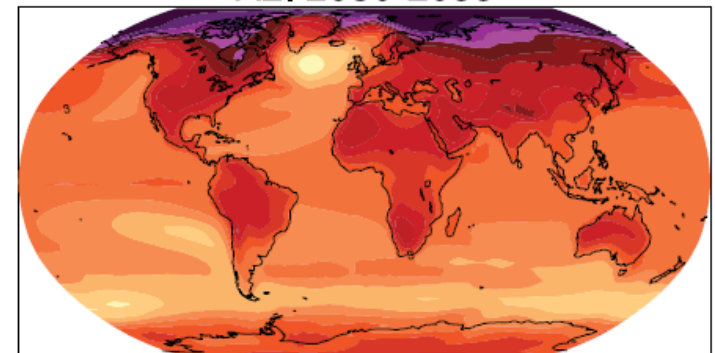
B1: 2080-2099



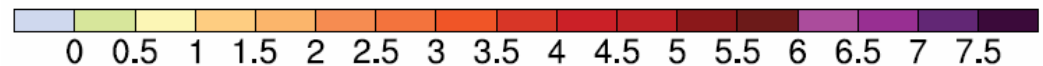
A1B: 2080-2099



A2: 2080-2099



Figs 10.4 and 10.8



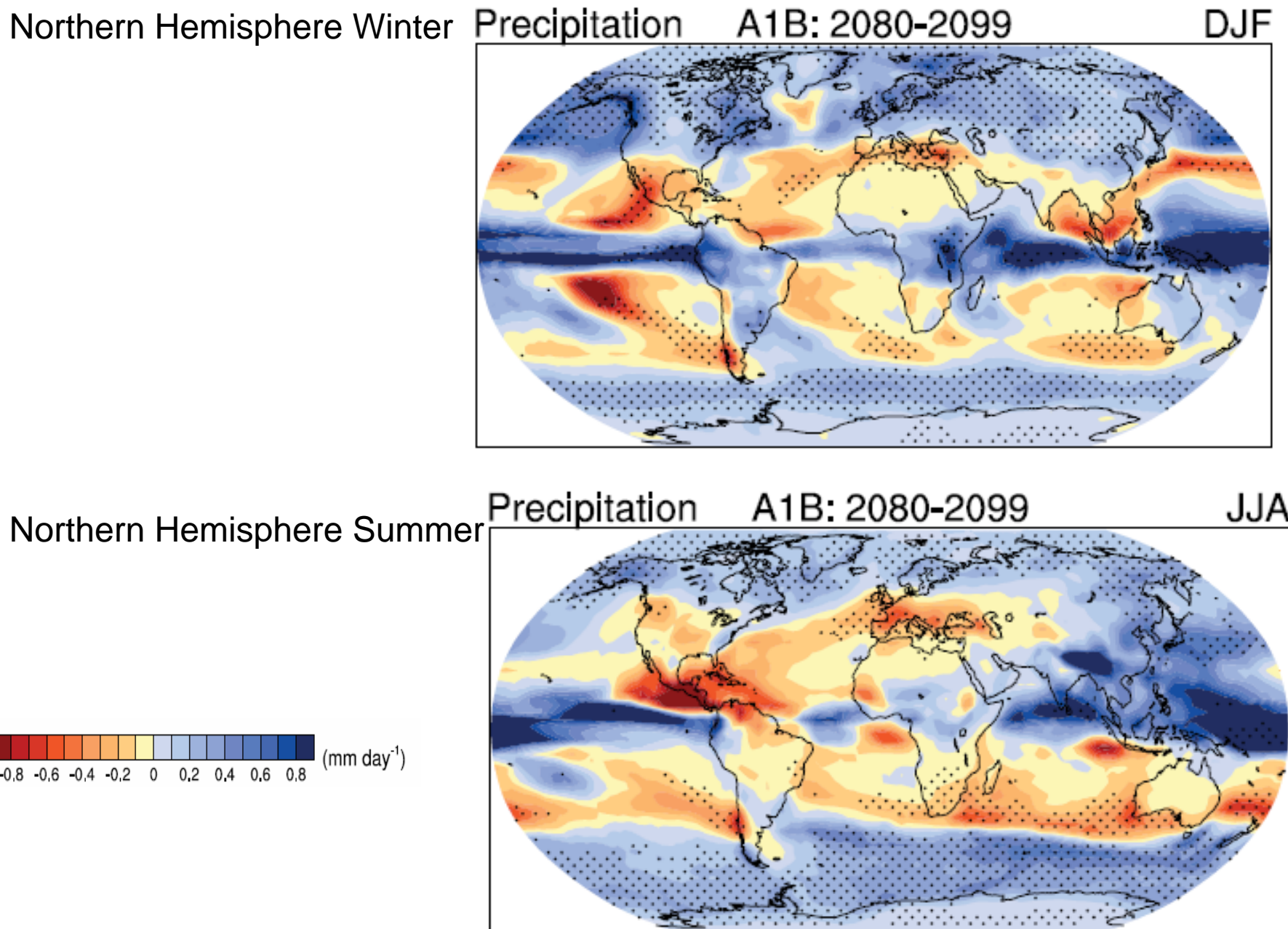
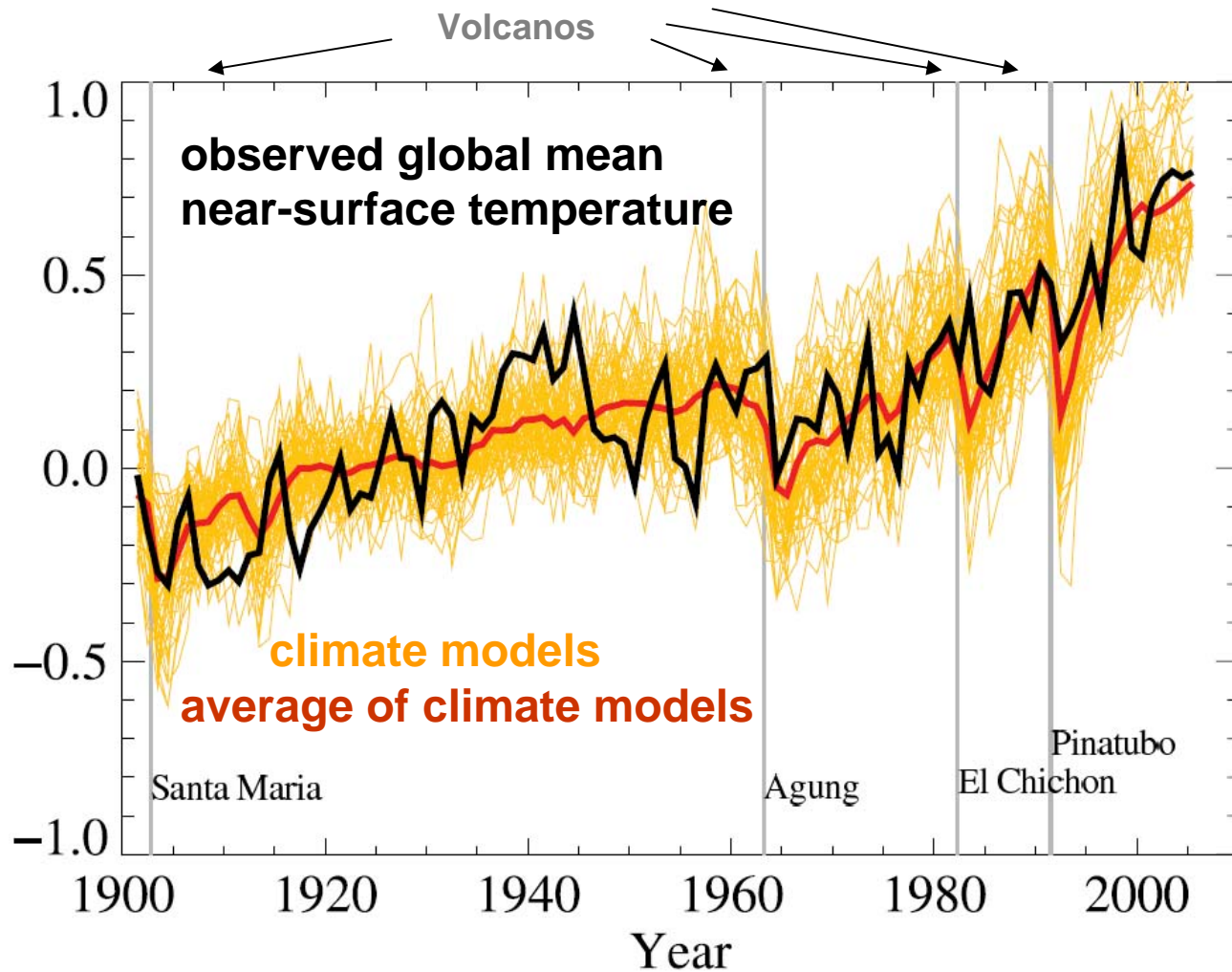


Fig 10.9



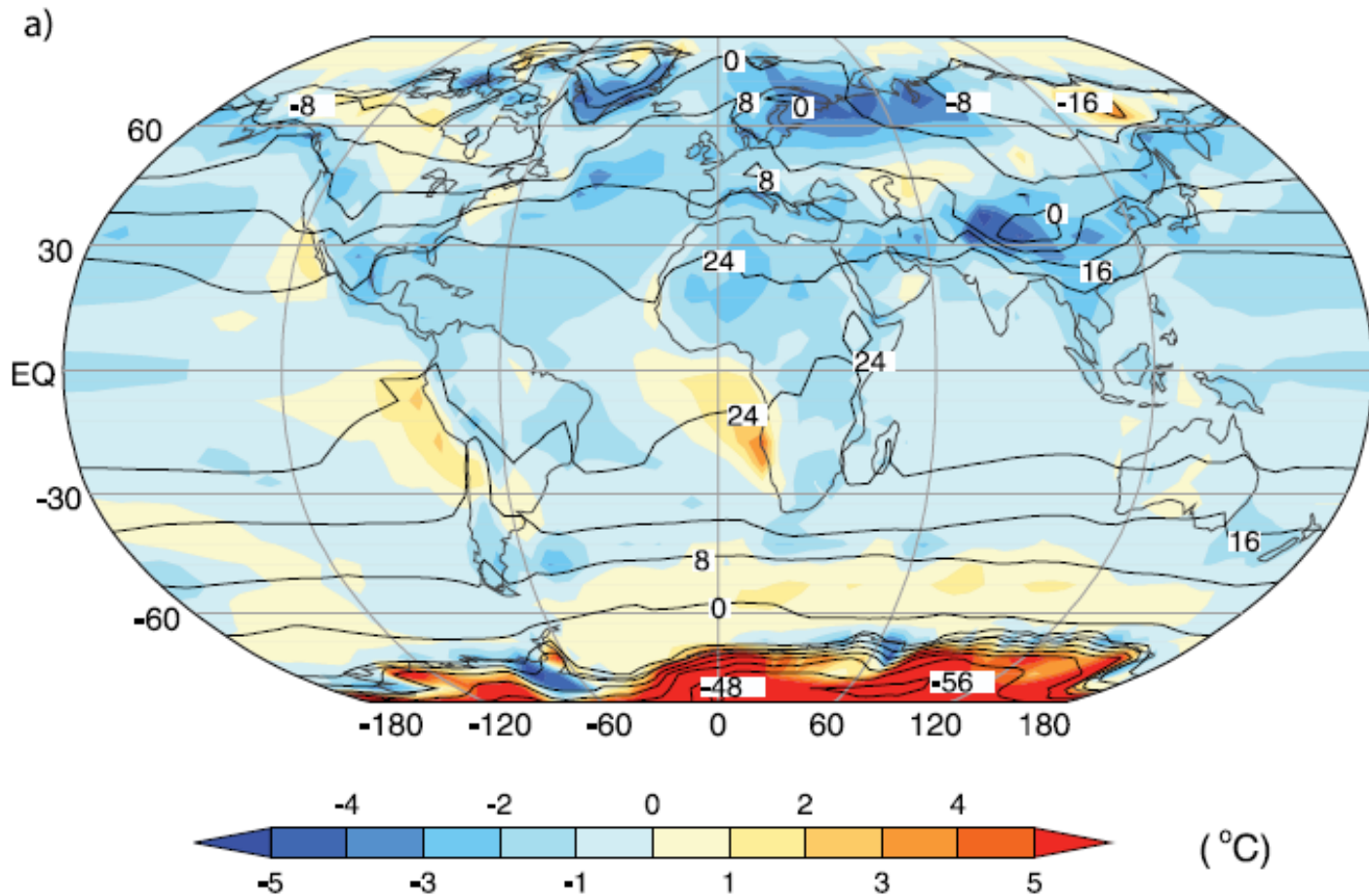
# Should we trust model results?

## A Test: Can reproduce recent climate?



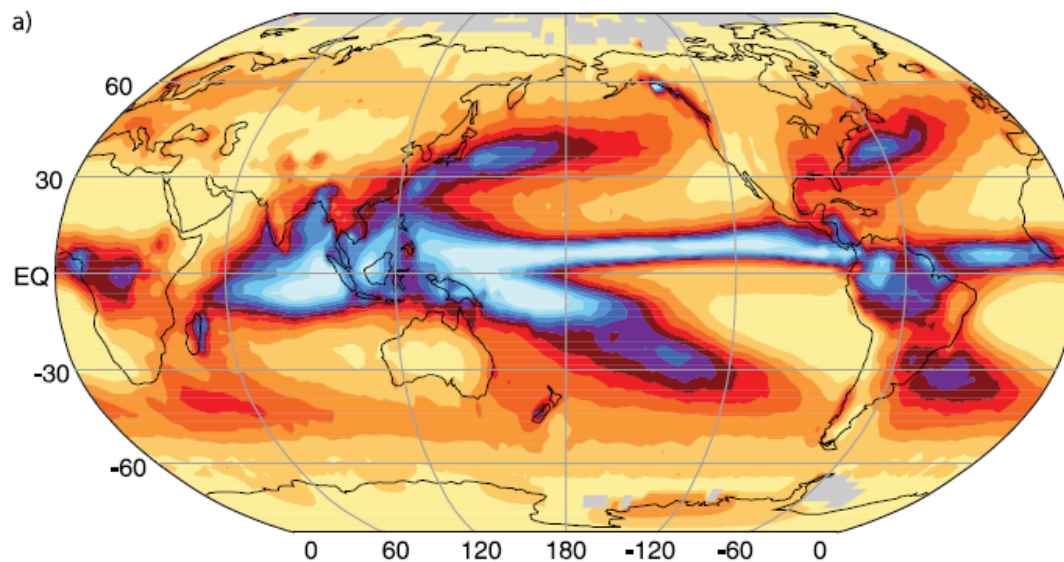
FAQ 8.1, Fig. 1

**Contours: observed annual mean  
surface (sea) or near-surface (land) Temperature**  
**Colors: Difference between model average and observations**



# Annual Average Precipitation

Observed



Multi-Model Average

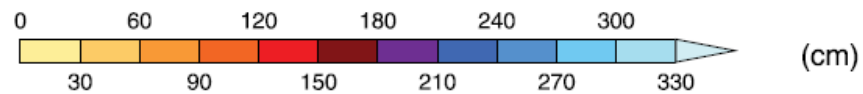
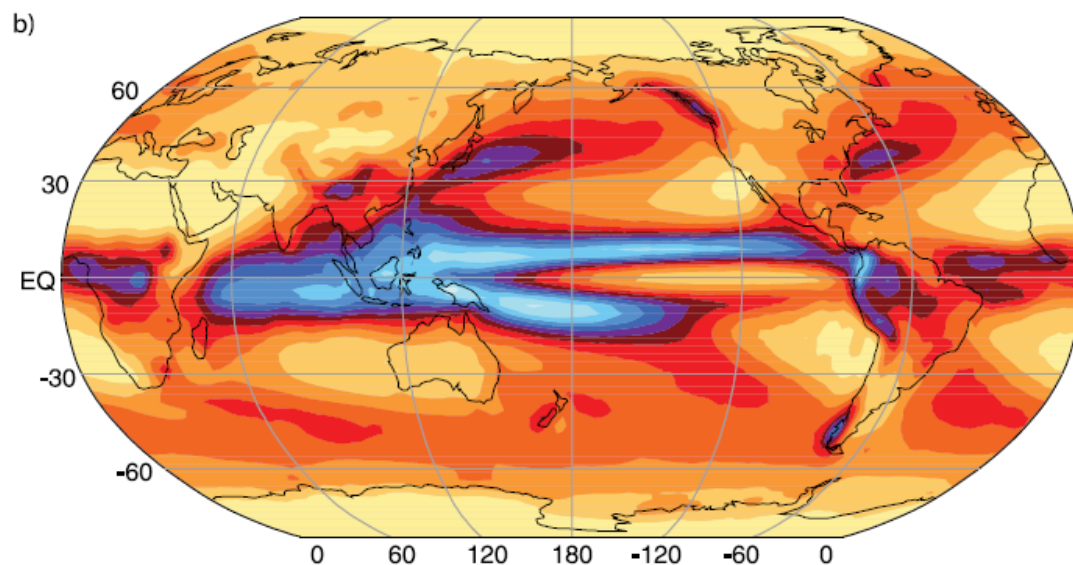
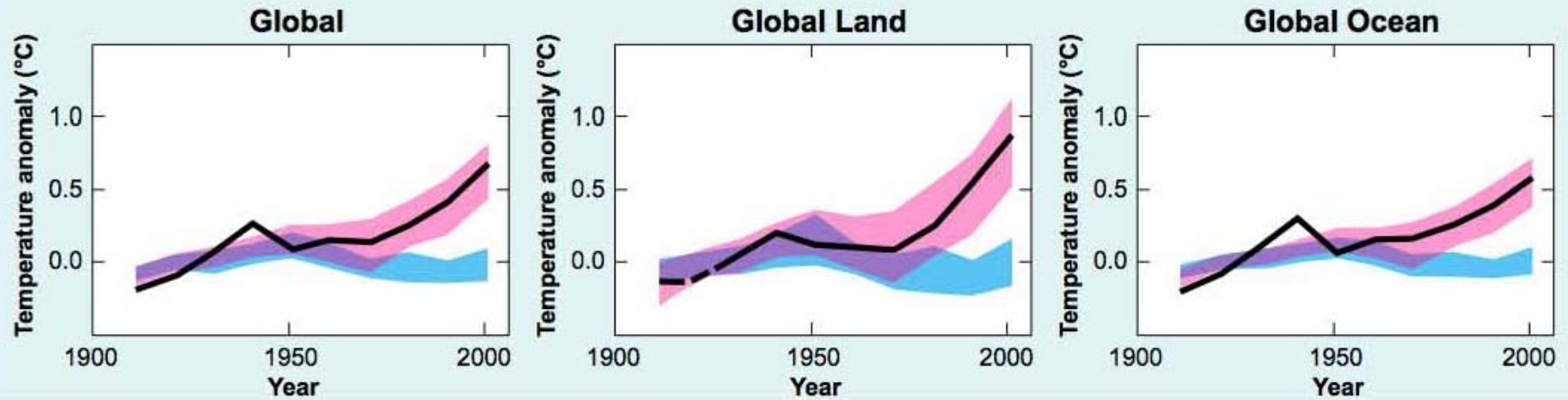


Fig 8.5

# Observed Decadal-Mean Surface Temperature

5-95% Range of model simulations, solar & volcano forcing only

Including greenhouse gas changes

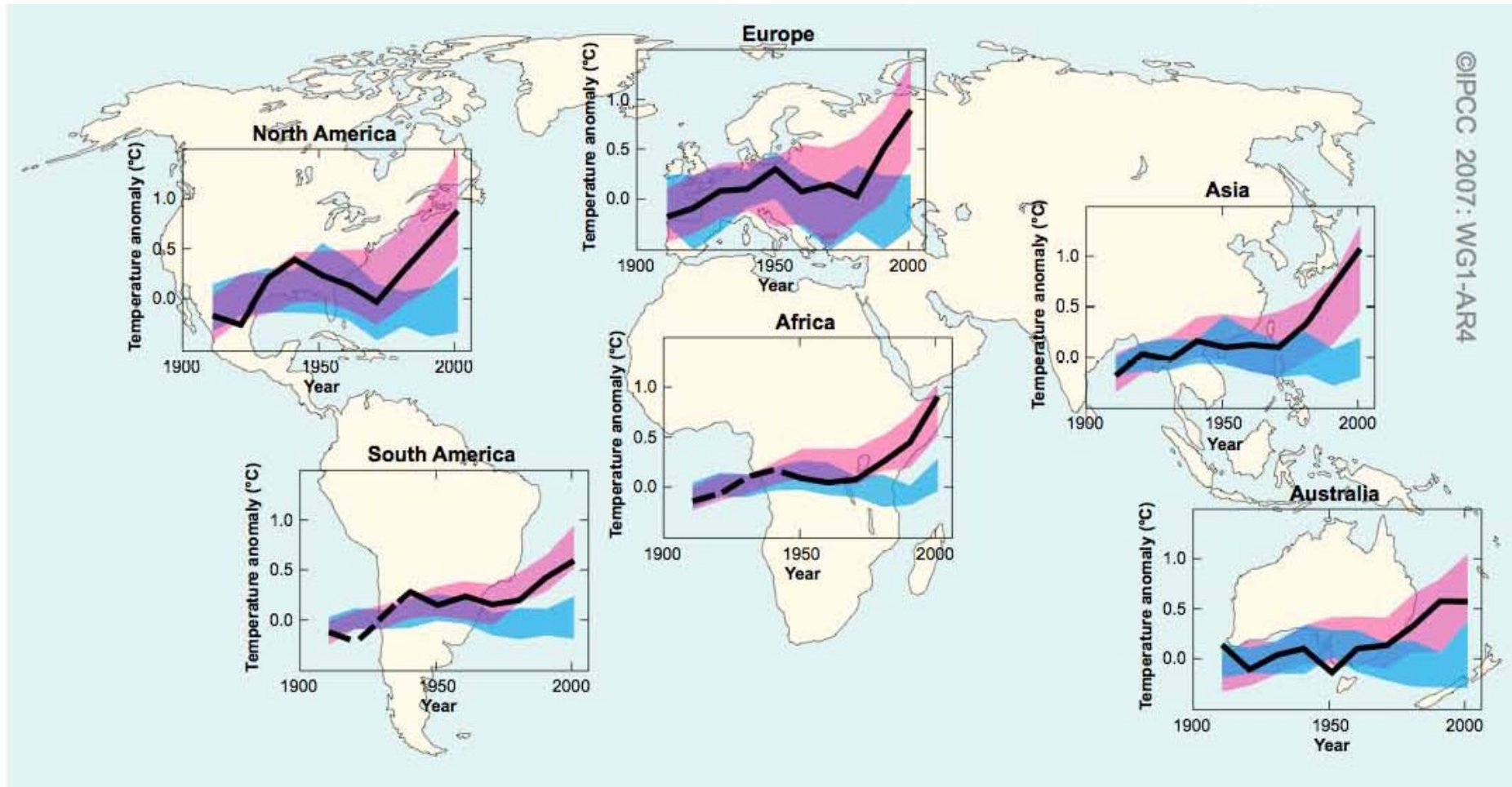




# Observed Decadal-Mean Surface Temperature

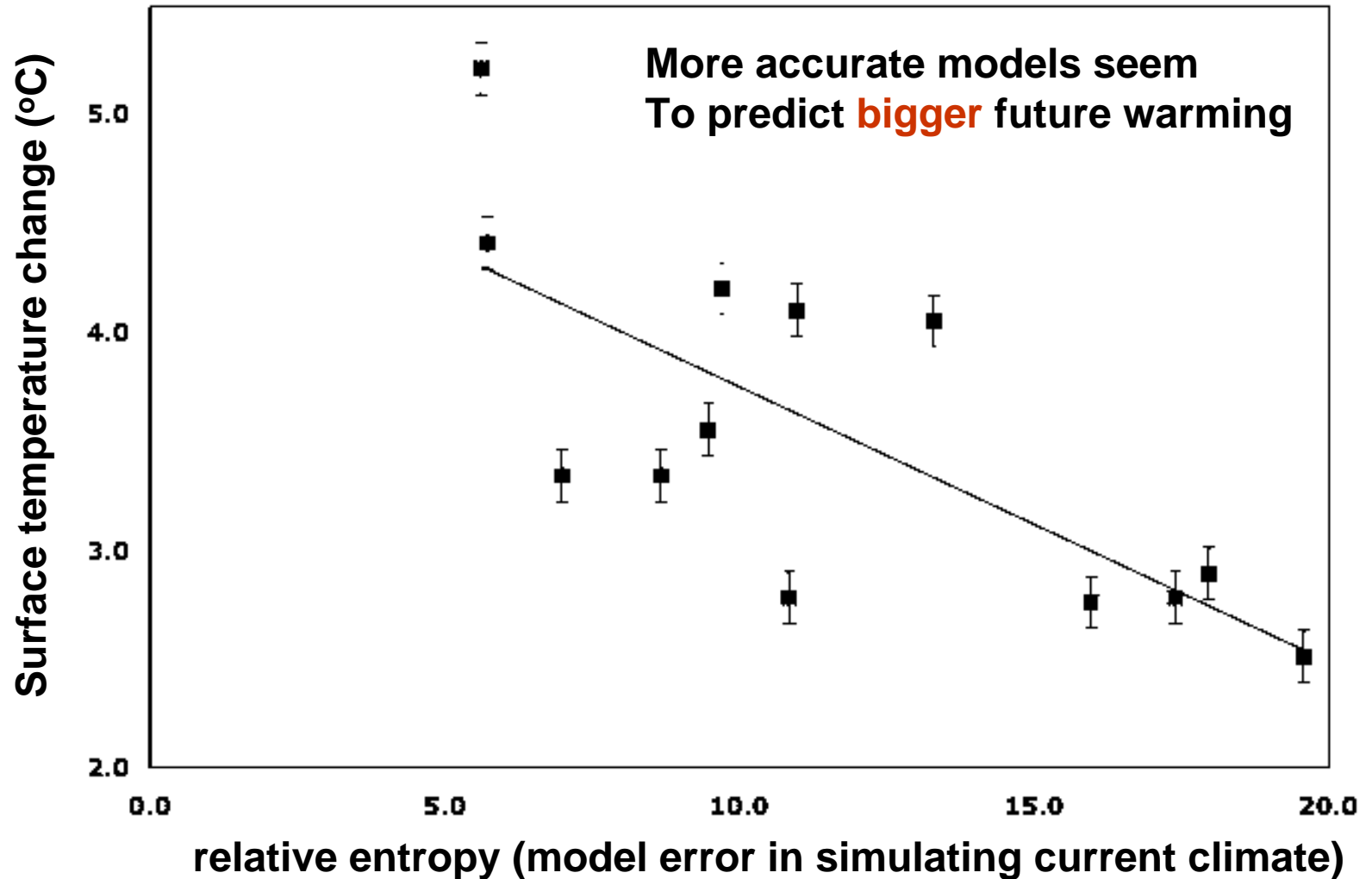
5-95% Range of model simulations, solar & volcano forcing only

Including greenhouse gas changes





Differences between models can be revealing...  
We are still improving models



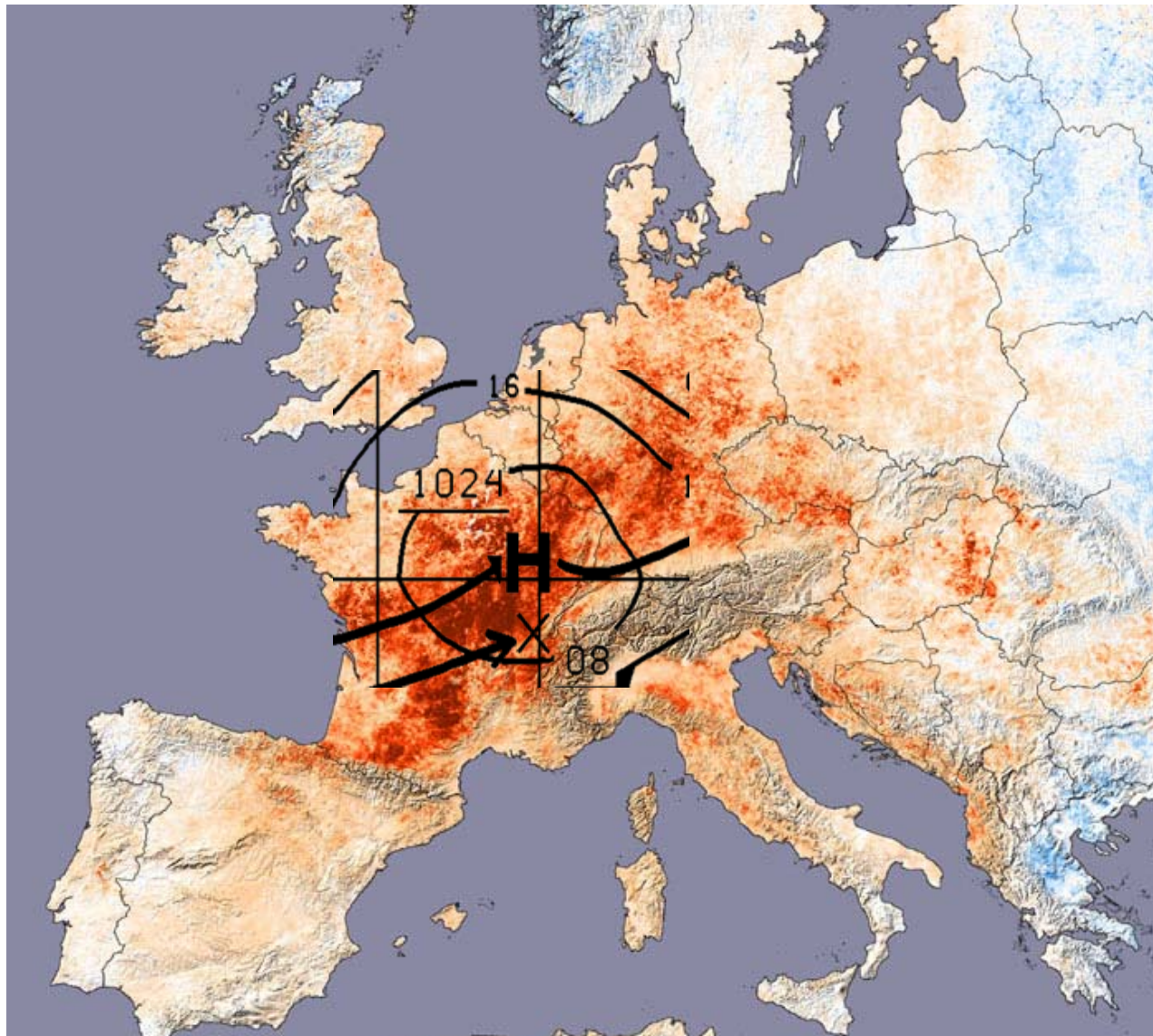
*J. Shukla, T. DelSole, M. Fennessy, J. Kinter and D. Paolino  
Geophys. Research Letters, 33, 2006*

# The Unknowns

- Predictability of models for small regions and extreme events.
- Change in the frequency and intensity of tropical cyclones.
- Timing for complete elimination of the Greenland ice sheet.  
(sea level will rise by 7 meters)
- Antarctic ice sheet : too cold?, gain mass due to more snowfall?
- The probability of large abrupt climate change.
- Level of warming for extinction of species  
( 1.5 – 2.5°C: 20 - 30% ; > 4°C: > 40% )
- Carbon uptake by the oceans.

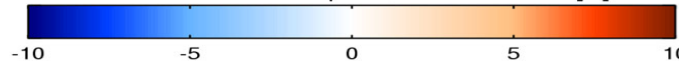
# Summer 2003 European Heat Wave:

## Result of Global Warming?



Summer 2003 temperatures relative  
to 2000-2004

Land Surface Temperature difference [K]

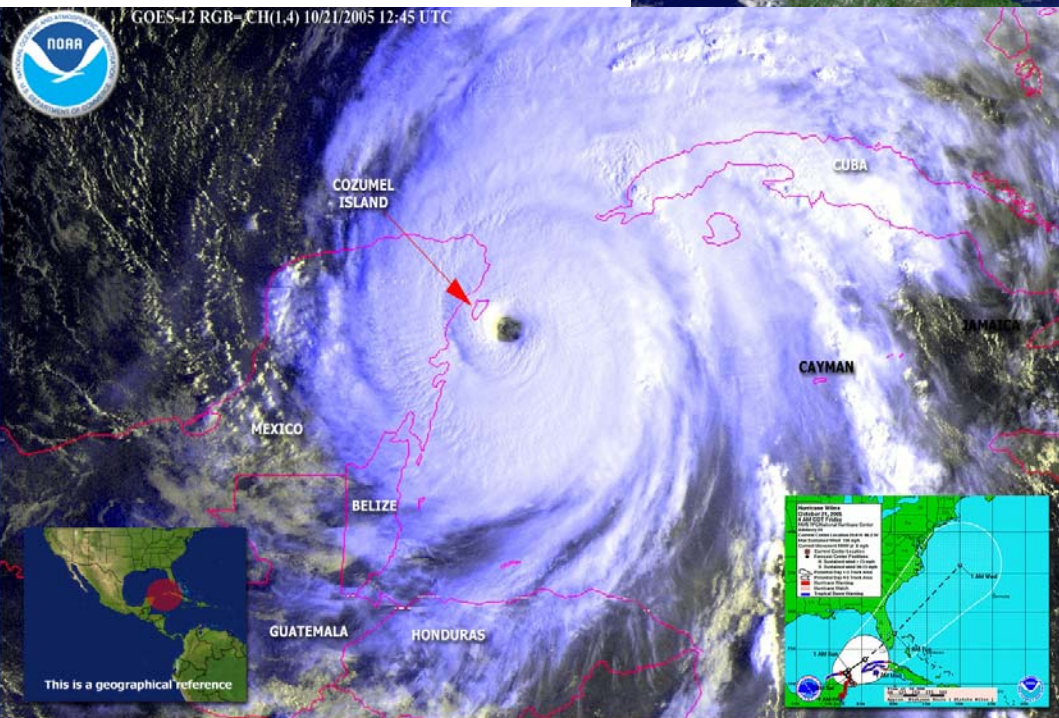


- The immediate cause of the heat-wave was a persistent high pressure center over Northwest Europe.
- There is **currently no evidence** that human influence on climate makes such circulation patterns more likely.

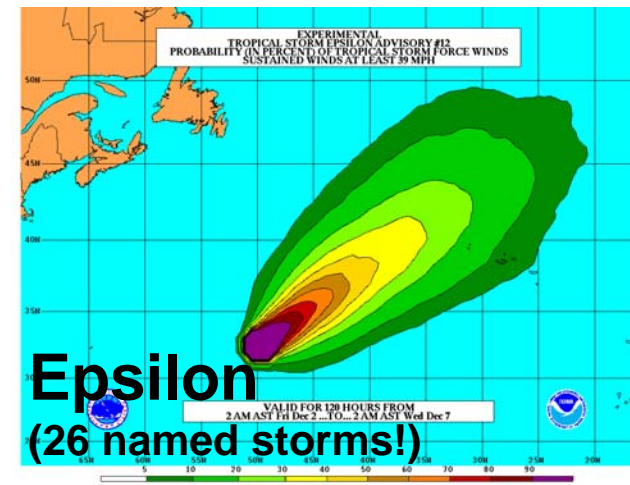


# 2005 Hurricane Season: Result of Global Warming?

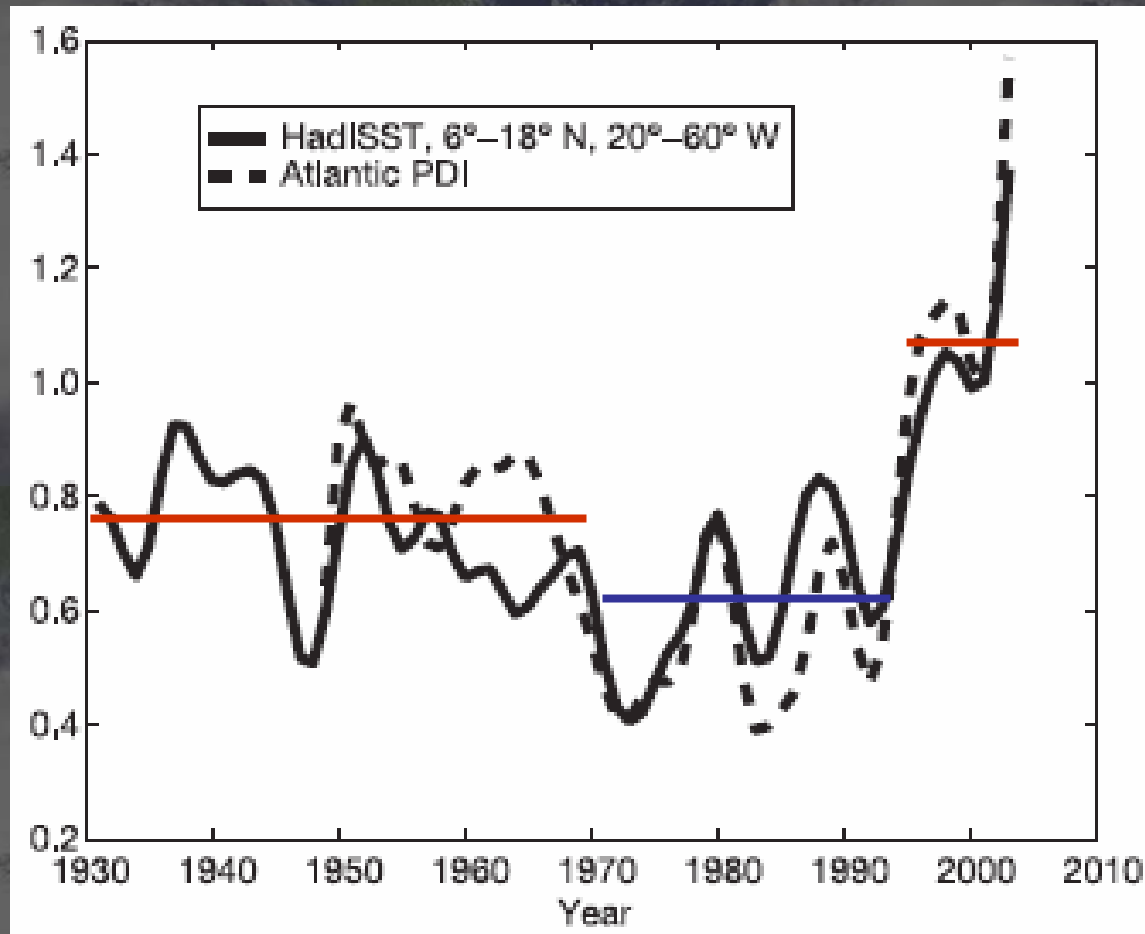
## Wilma



## Katrina



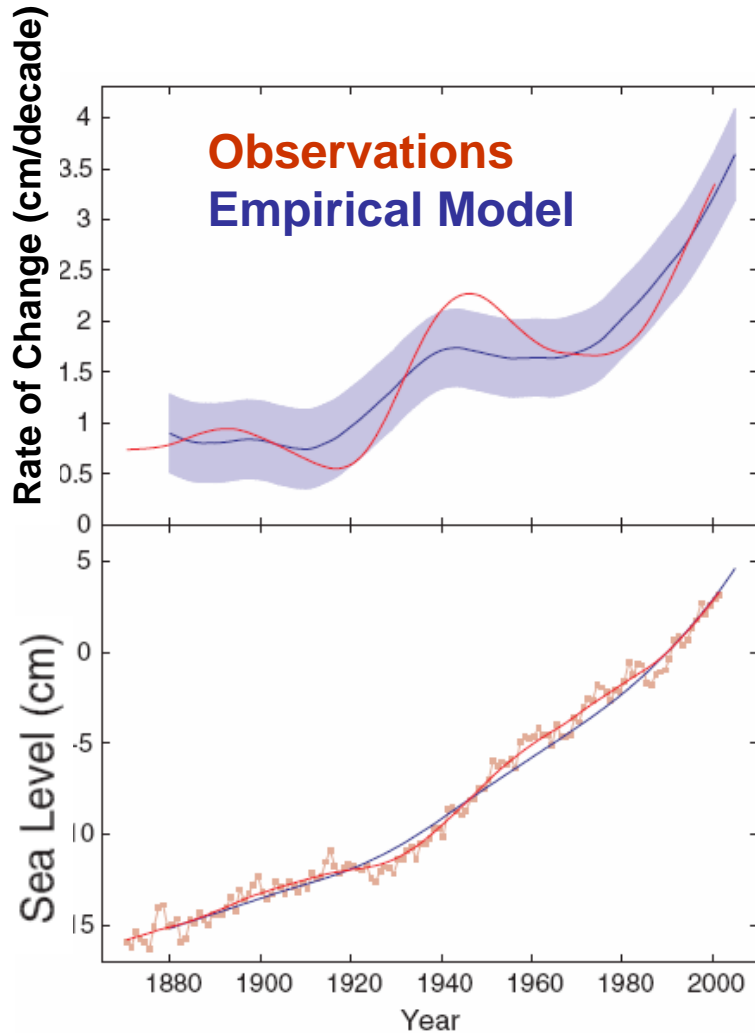
# Probability Shifting Toward Stronger Tropical Cyclones



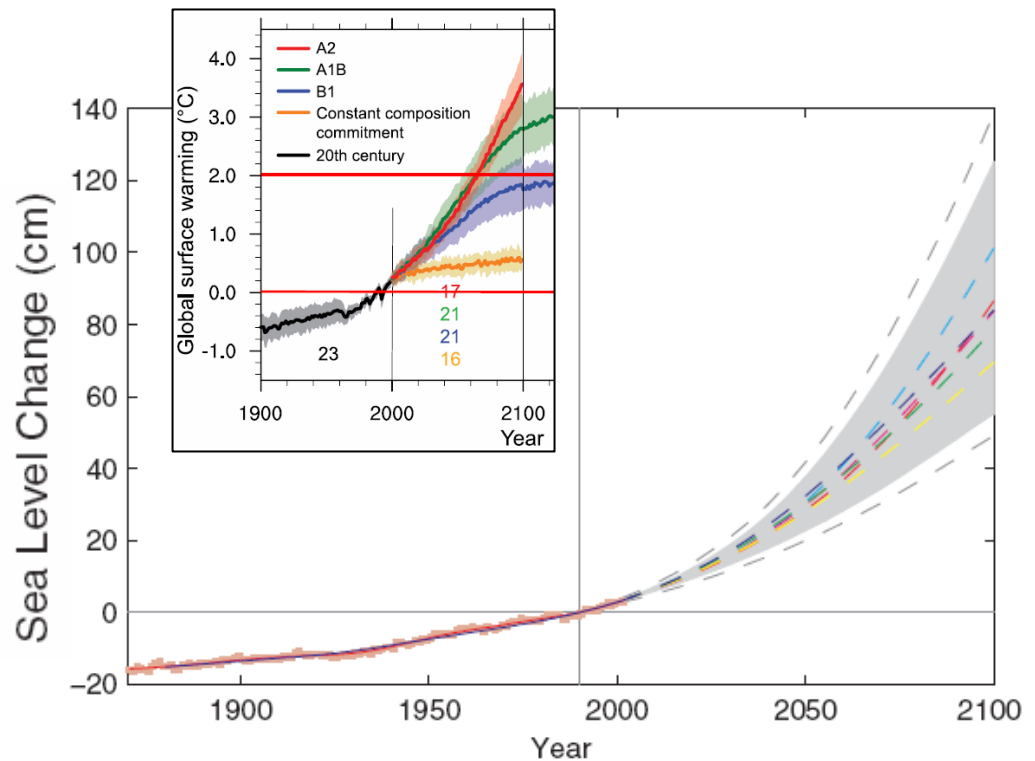
PDI : Total power dissipated annually by tropical cyclones.



# Sea Level Rise from Global Warming

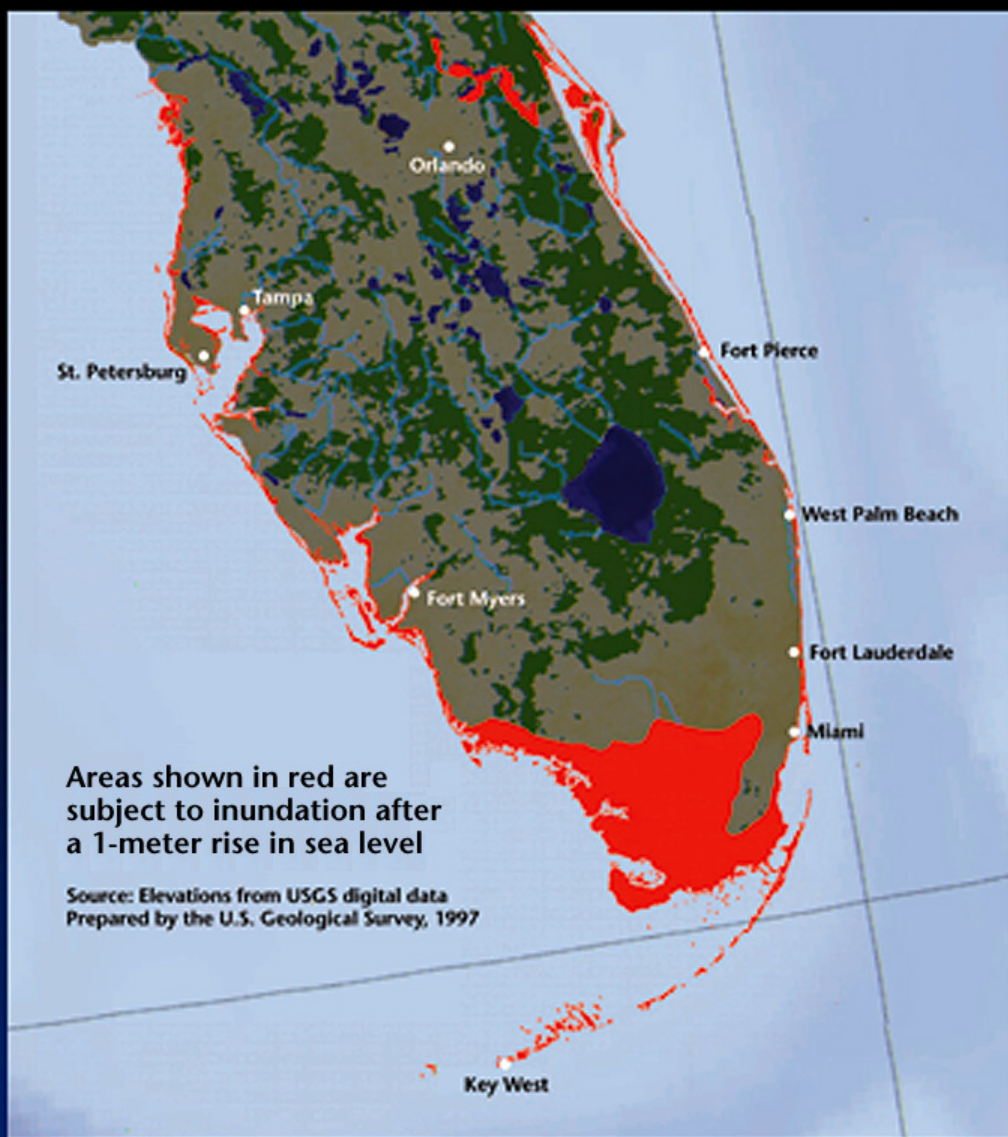


**IPCC: 18-51 cm during 21<sup>st</sup> Century**  
**May be underestimate.**  
**Ice dynamics poorly understood.**  
**Projection not compatible with obs?**



**Rahmstorf (2007)**

# South Florida Shoreline Change after a 1-Meter Rise in Sea Level



## Potential impact of sea-level rise on Bangladesh



**Today**

Total population: 112 Million

Total land area: 134,000 km<sup>2</sup>



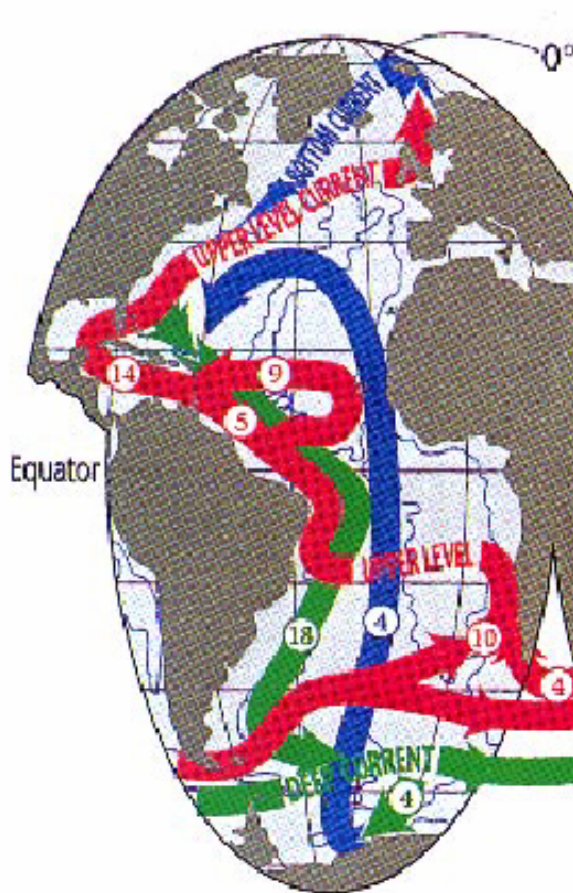
**1.5 m - Impact**

Total population affected: 17 Million (15%)

Total land area affected: 22,000 km<sup>2</sup> (16%)



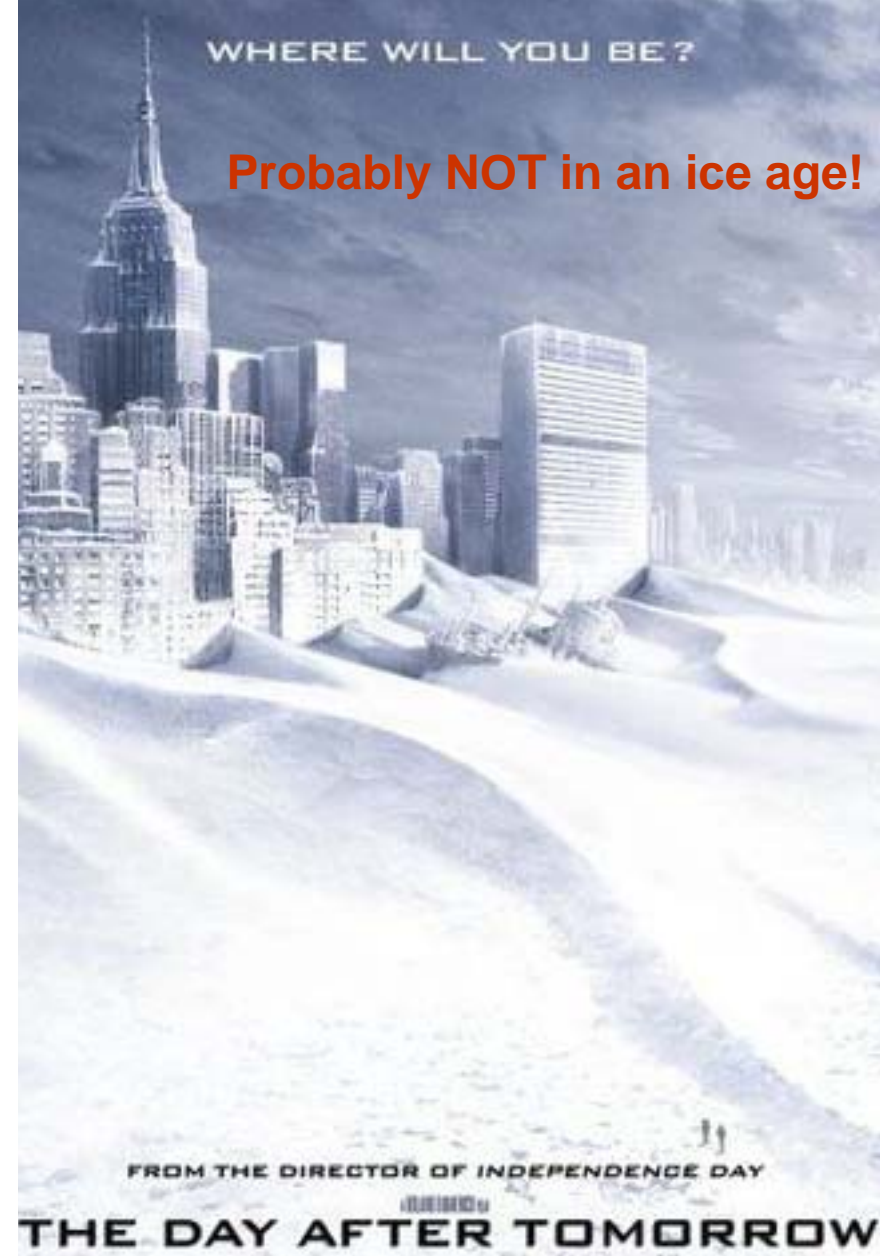
# Will the ocean's overturning circulation change?



**Overturning → warms high latitudes**  
**Weakening overturning → cooler high latitudes**

Overturning MITIGATES global warming:

Real risk may be NOT ENOUGH weakening of overturning...



[http://en.wikipedia.org/wiki/The\\_Day\\_After\\_Tomorrow](http://en.wikipedia.org/wiki/The_Day_After_Tomorrow)

**We know:**

- **Modest 20<sup>th</sup> century climate change**
- **Due to human greenhouse gases.**
- **21<sup>st</sup> century climate change will be much bigger  
(unless—perhaps—strong action is taken)**

**We suspect but don't know for sure that:**

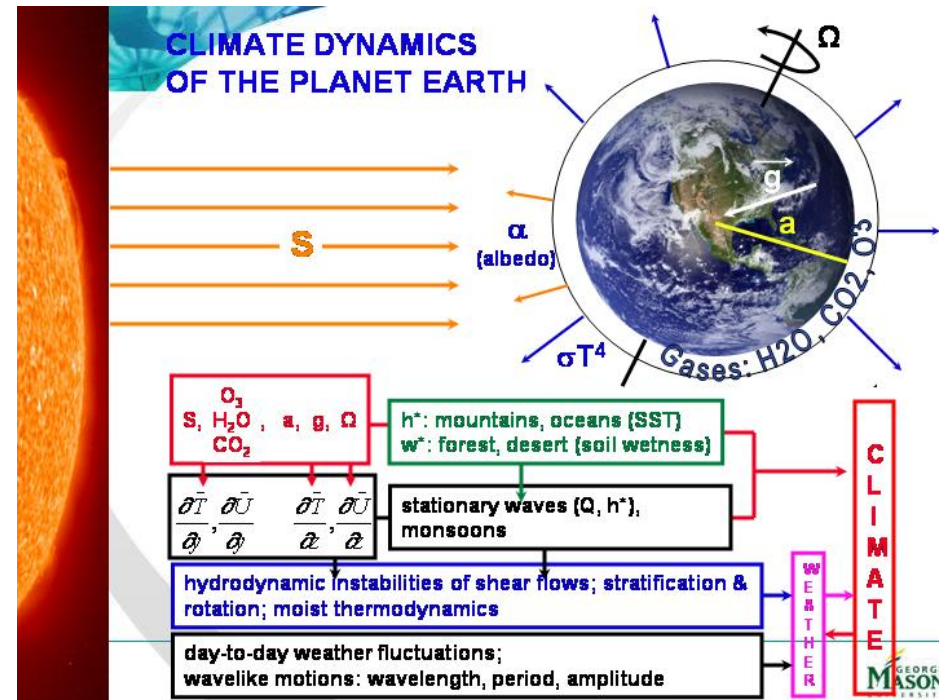
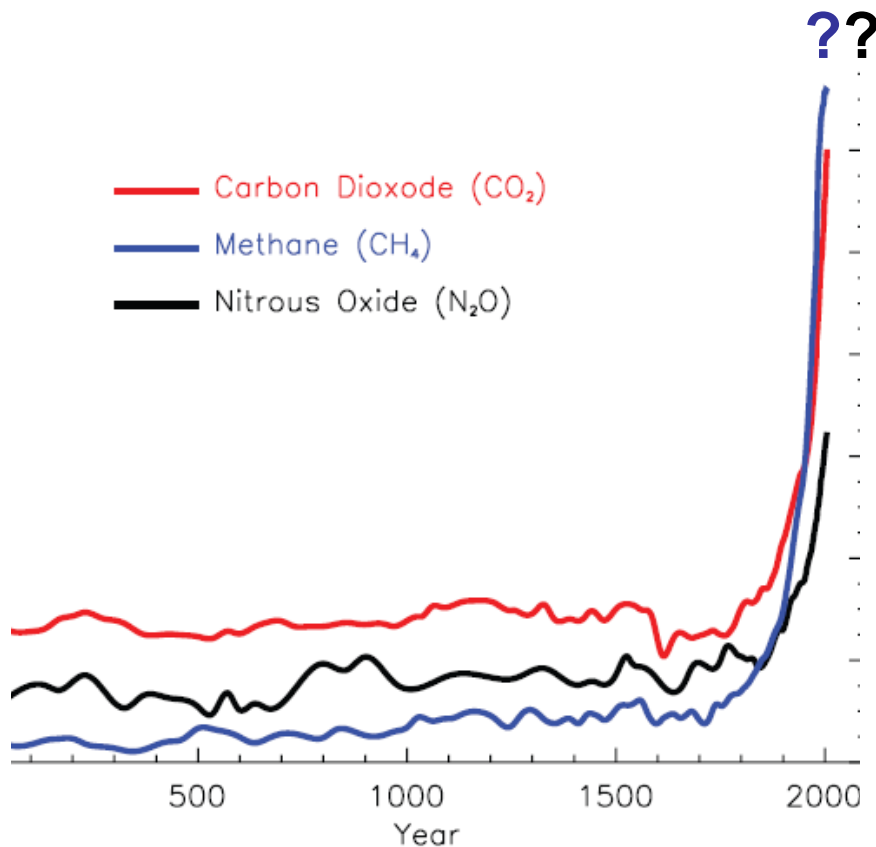
- **Climate change will have some negative impacts:**
  - **More strong hurricanes**
  - **Loss of low-lying coastal areas to ocean**
  - **Changes to rainfall patterns expanding some deserts**

**We don't know if**

- **will be much stronger/faster changes than expected**
  - **Ice sheet collapse?**



This is a very exciting time to be doing climate research...



...as humanity performs an unprecedented experiment on our planet!