

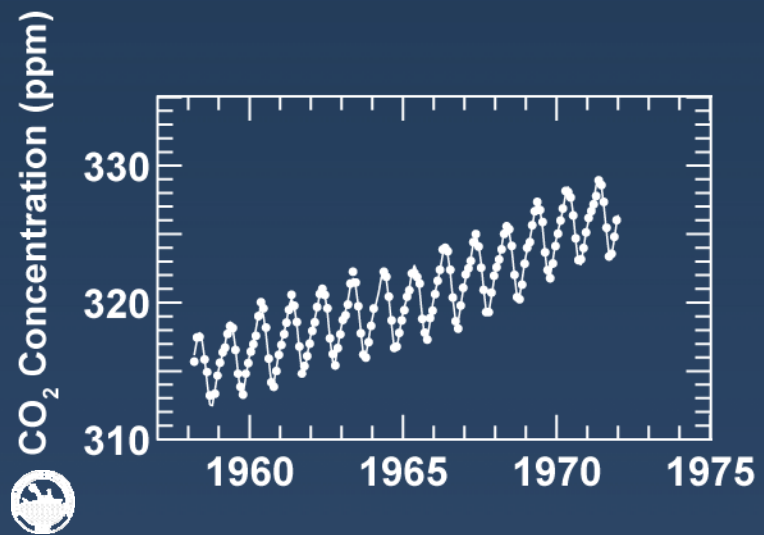
Geoengineering Options and Their Potential for Climate Cooling

Ralph F. Keeling

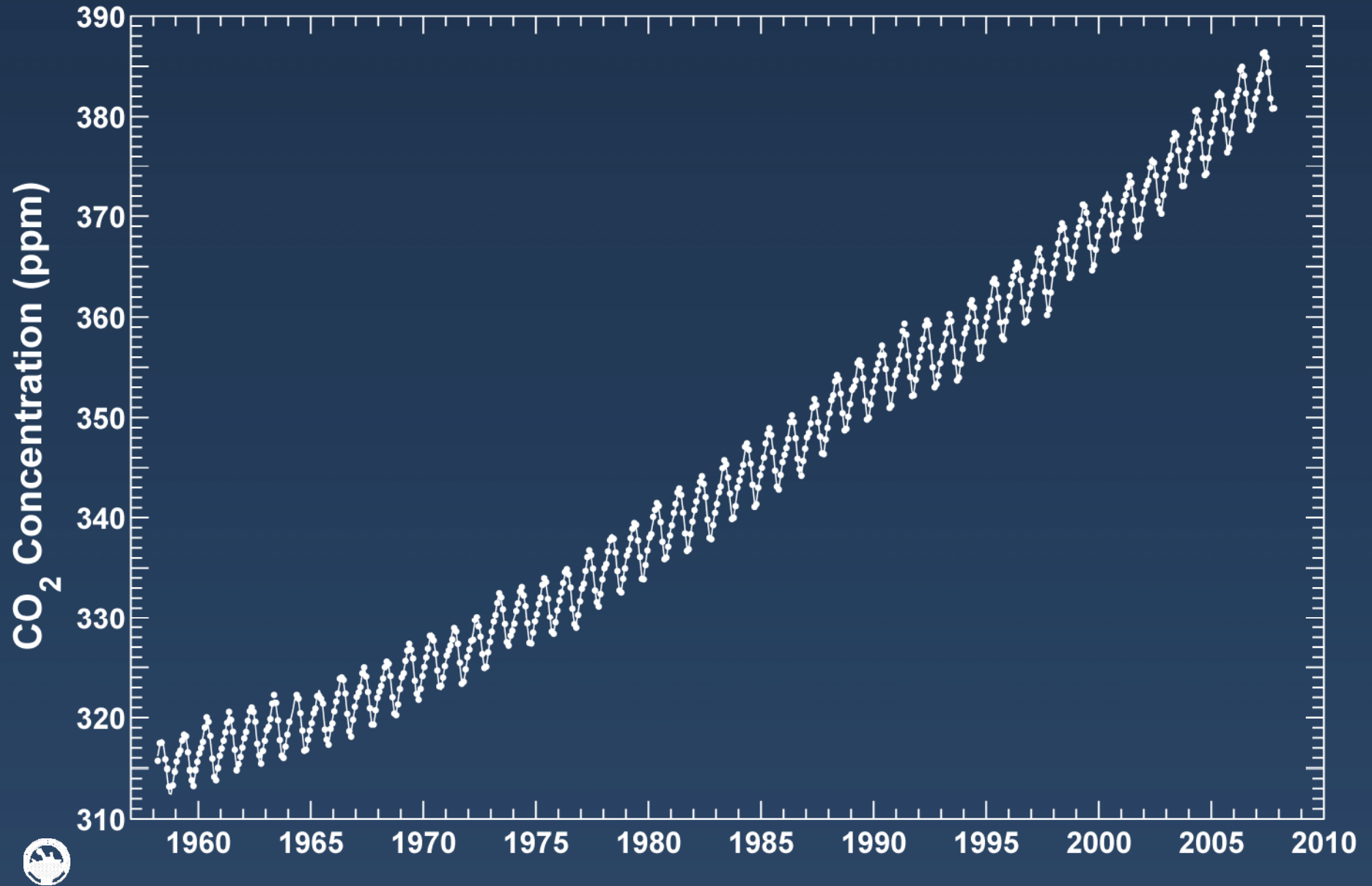
Visiting
IFM-GEOMAR

from
Scripps Institution of Oceanography

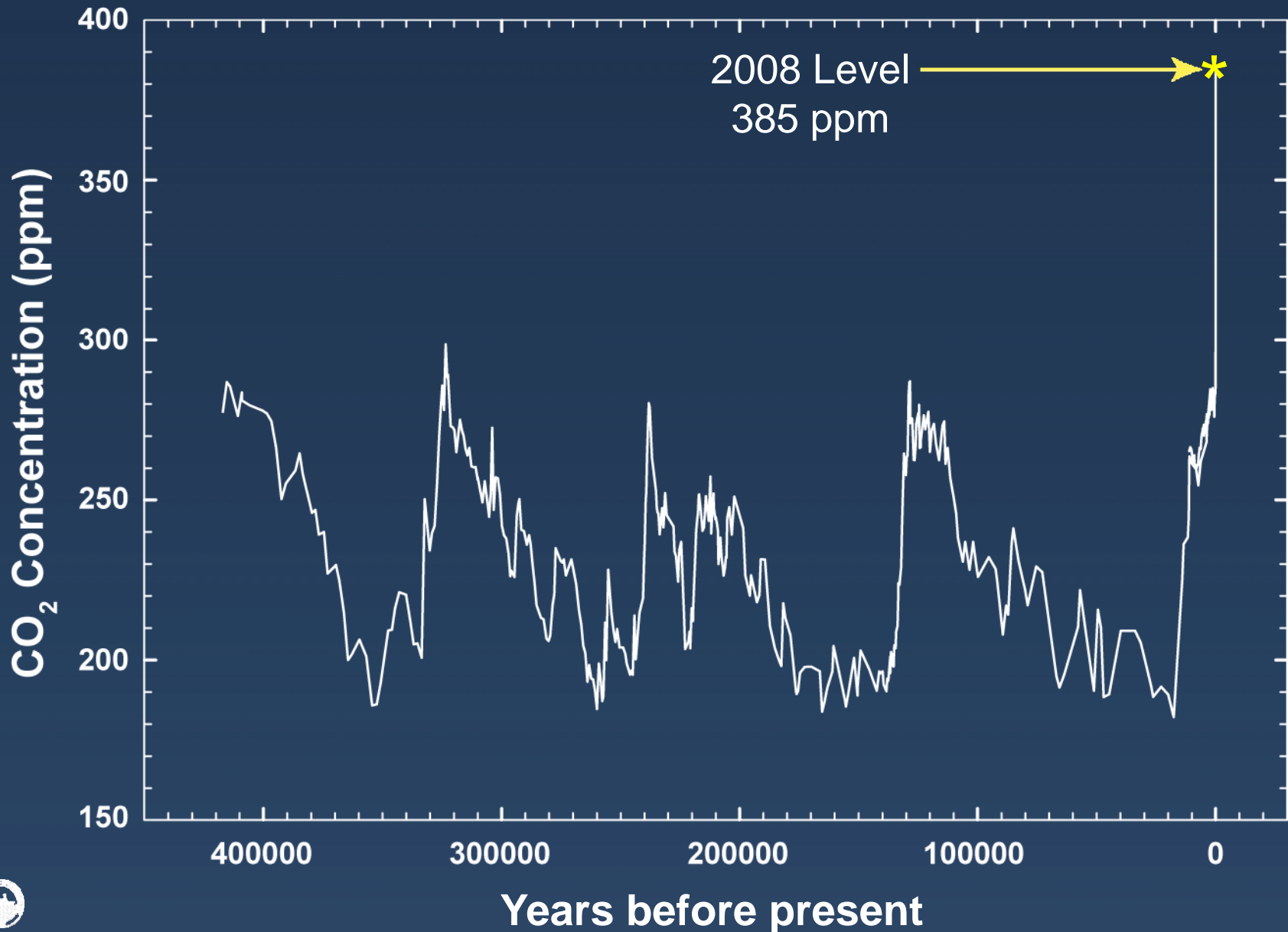
Mauna Loa Record



Mauna Loa Record

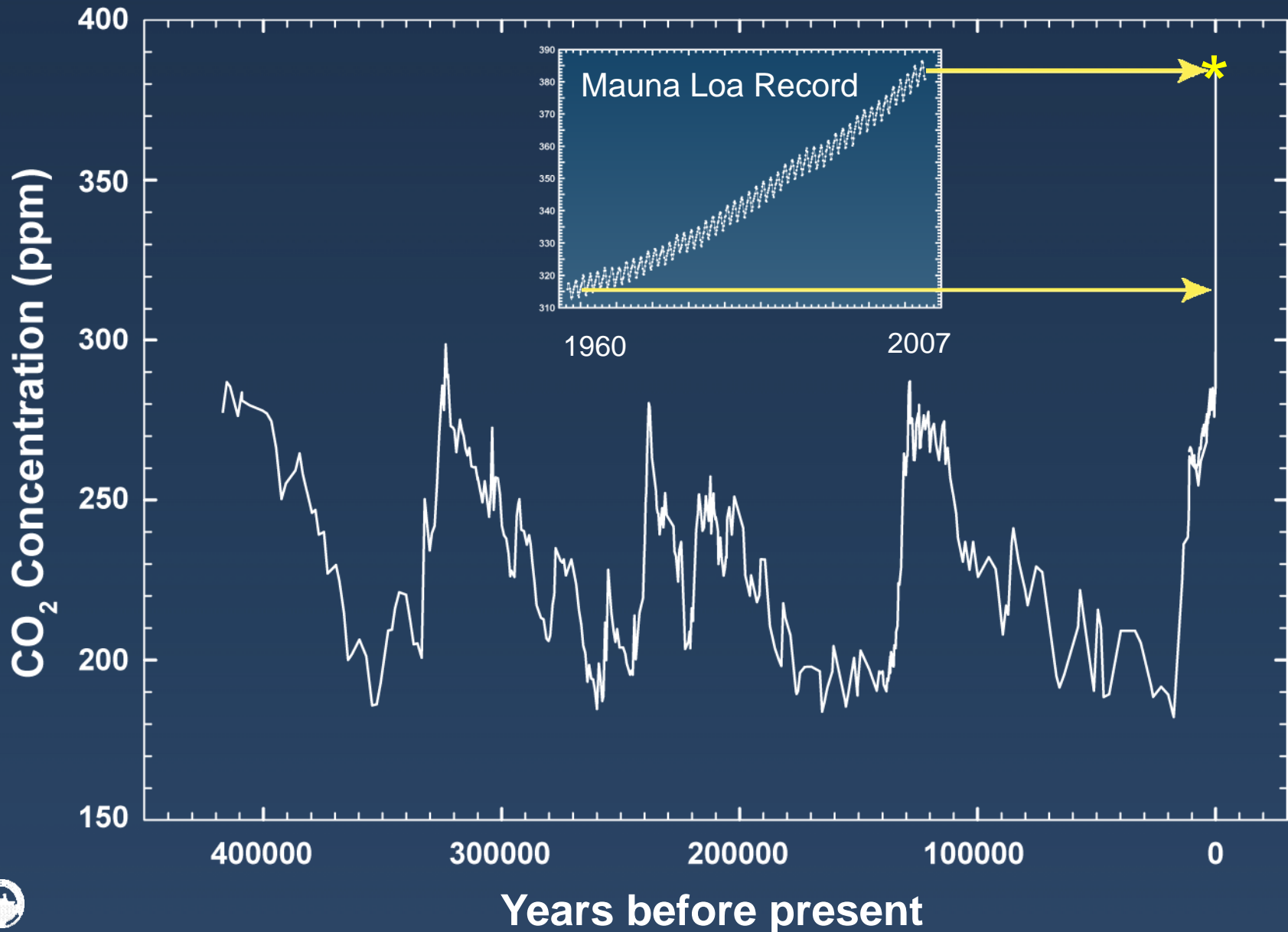


CO₂ over past 420 thousand years

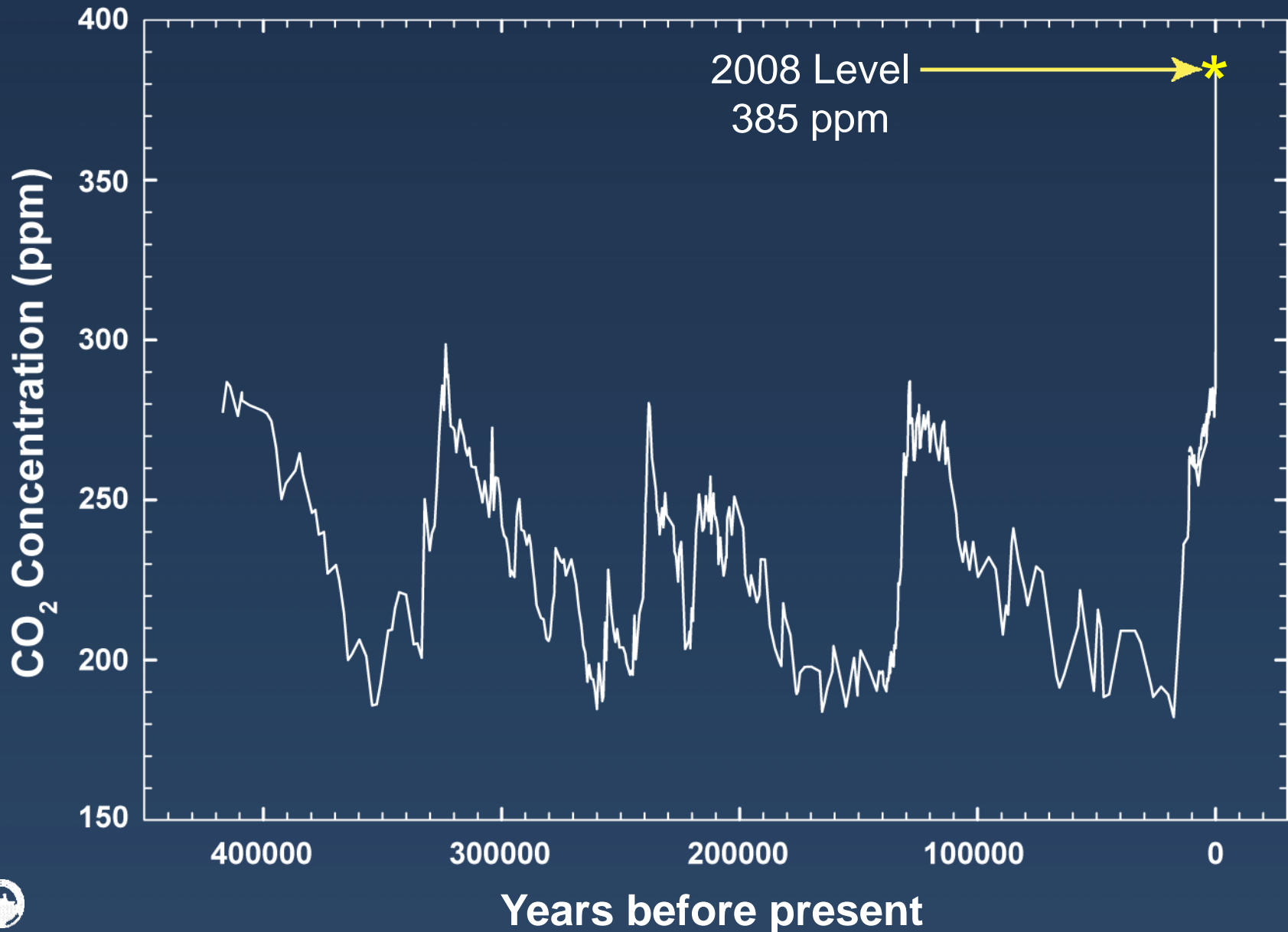


Source: Petit et al., Nature 399, 429-236, 1999.

CO₂ over past 420 thousand years

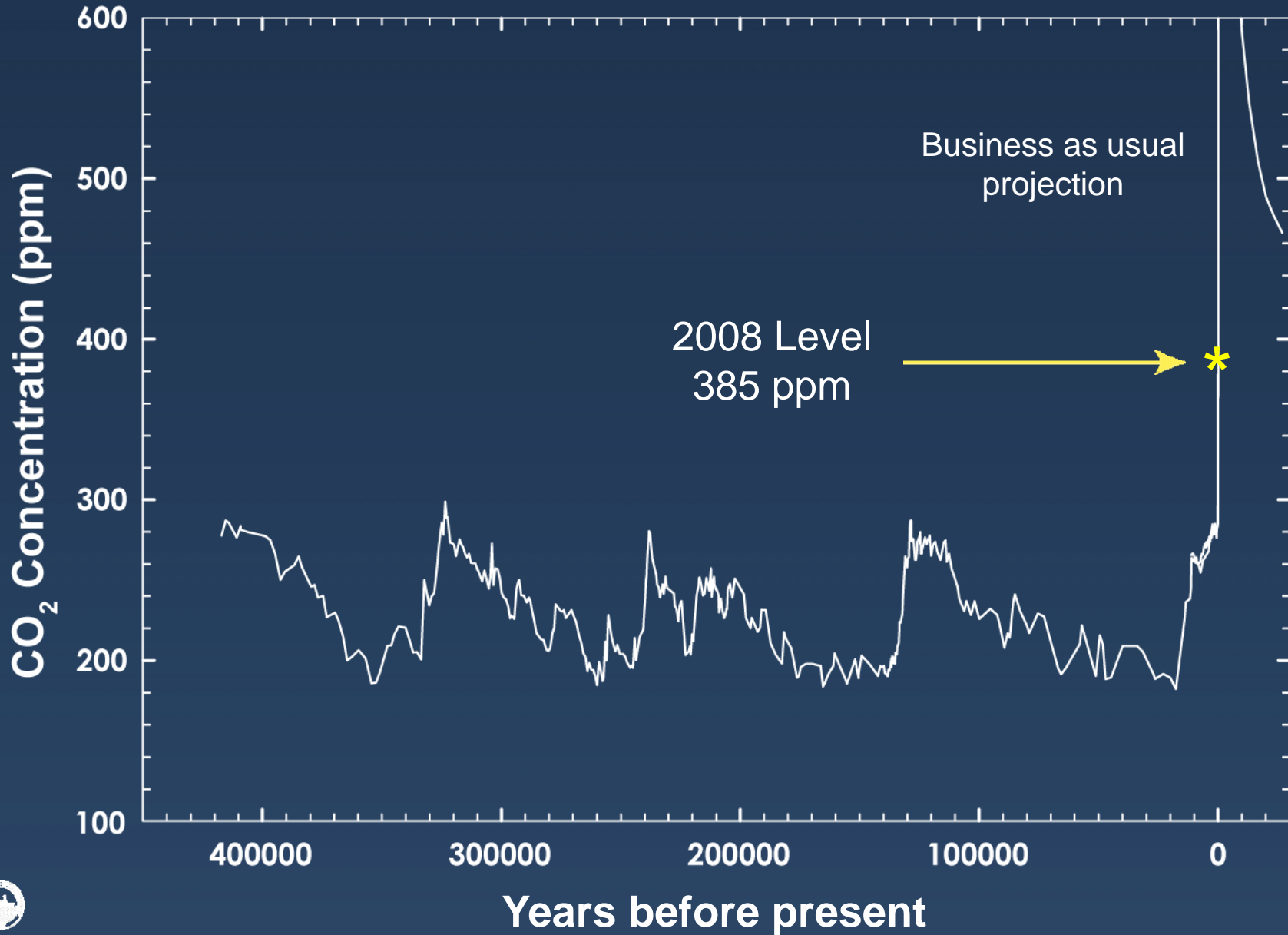


CO₂ over past 420 thousand years

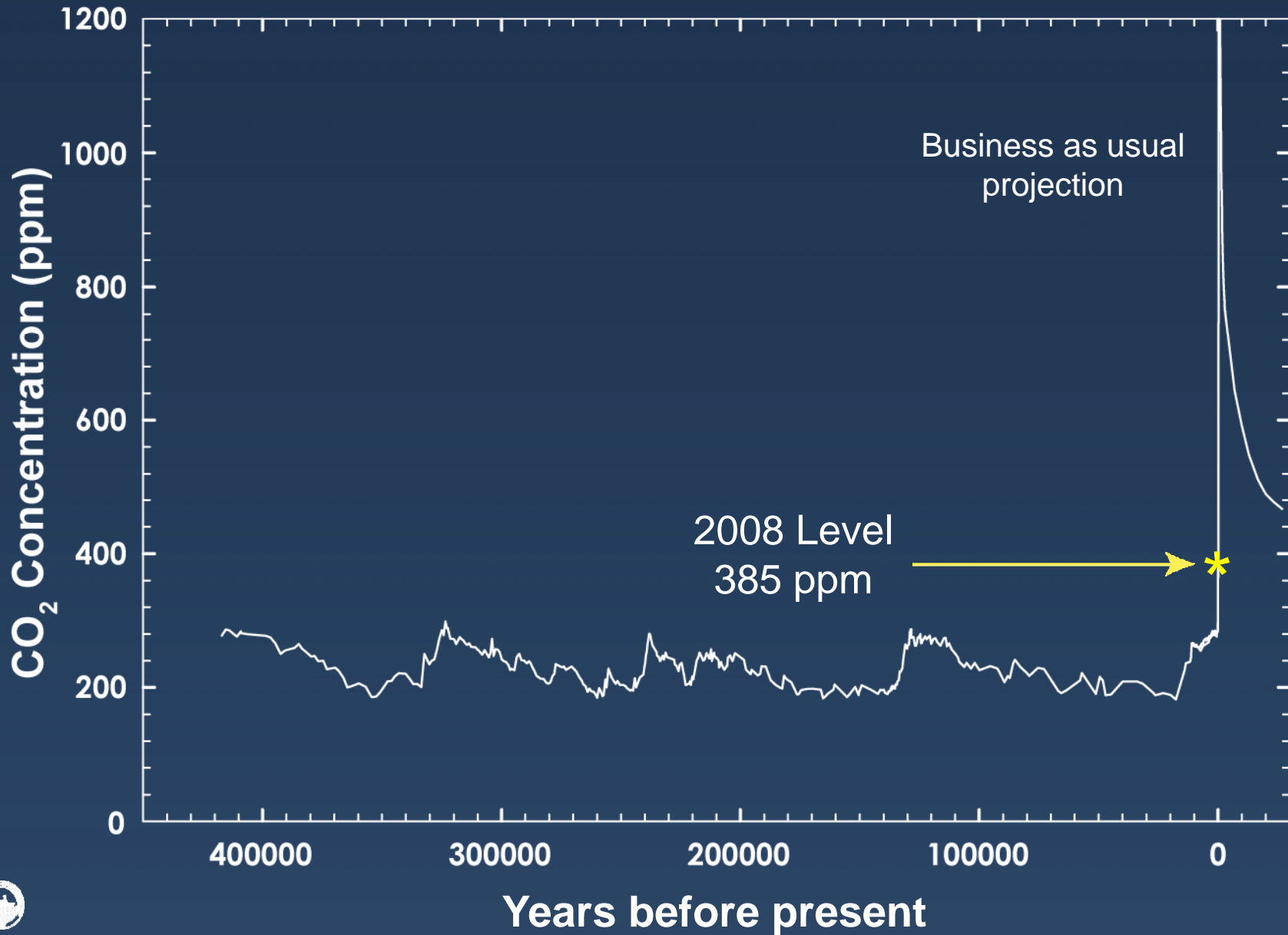


Source: Petit et al., Nature 399, 429-236, 1999.

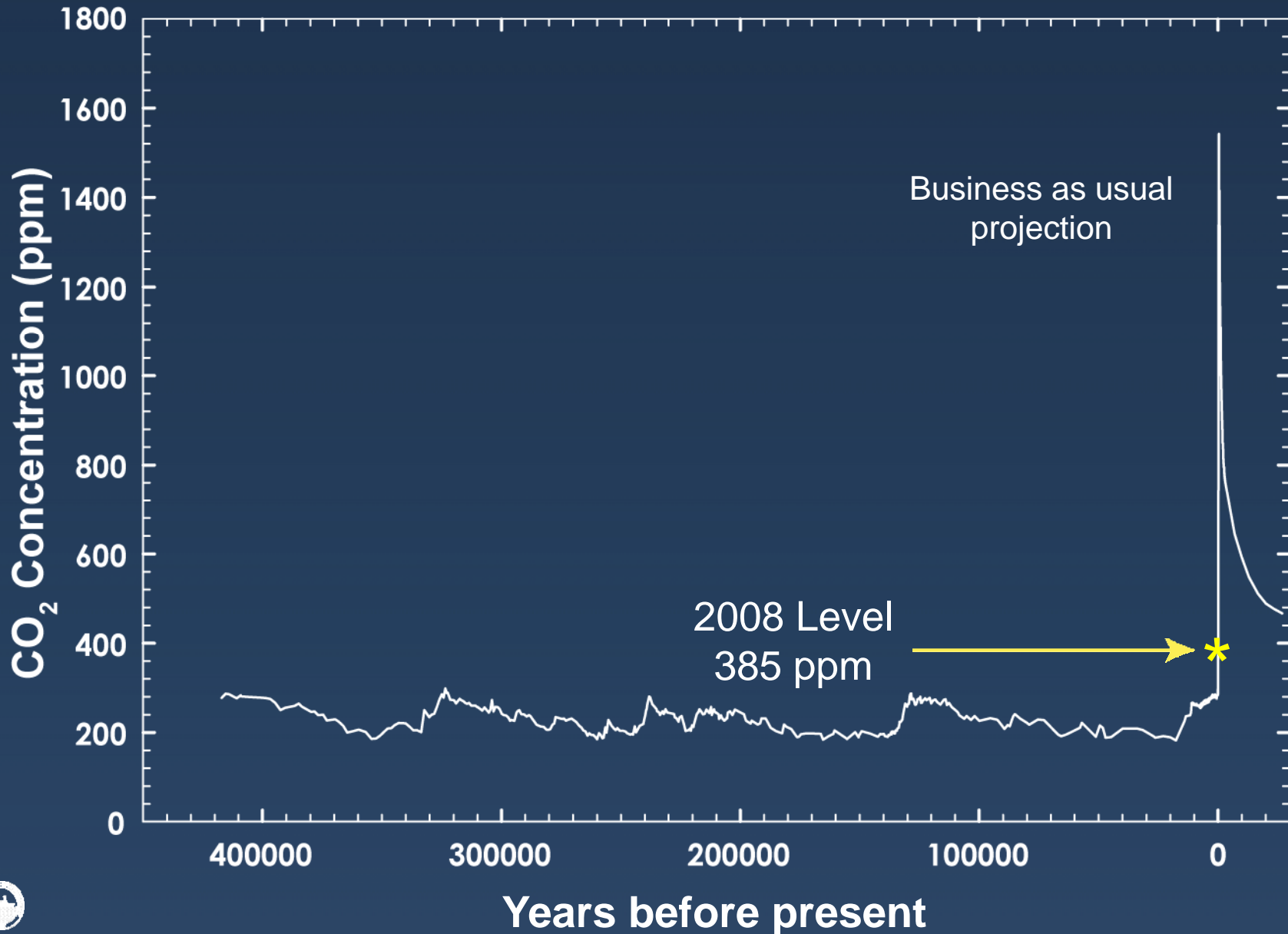
Past and future CO₂ levels



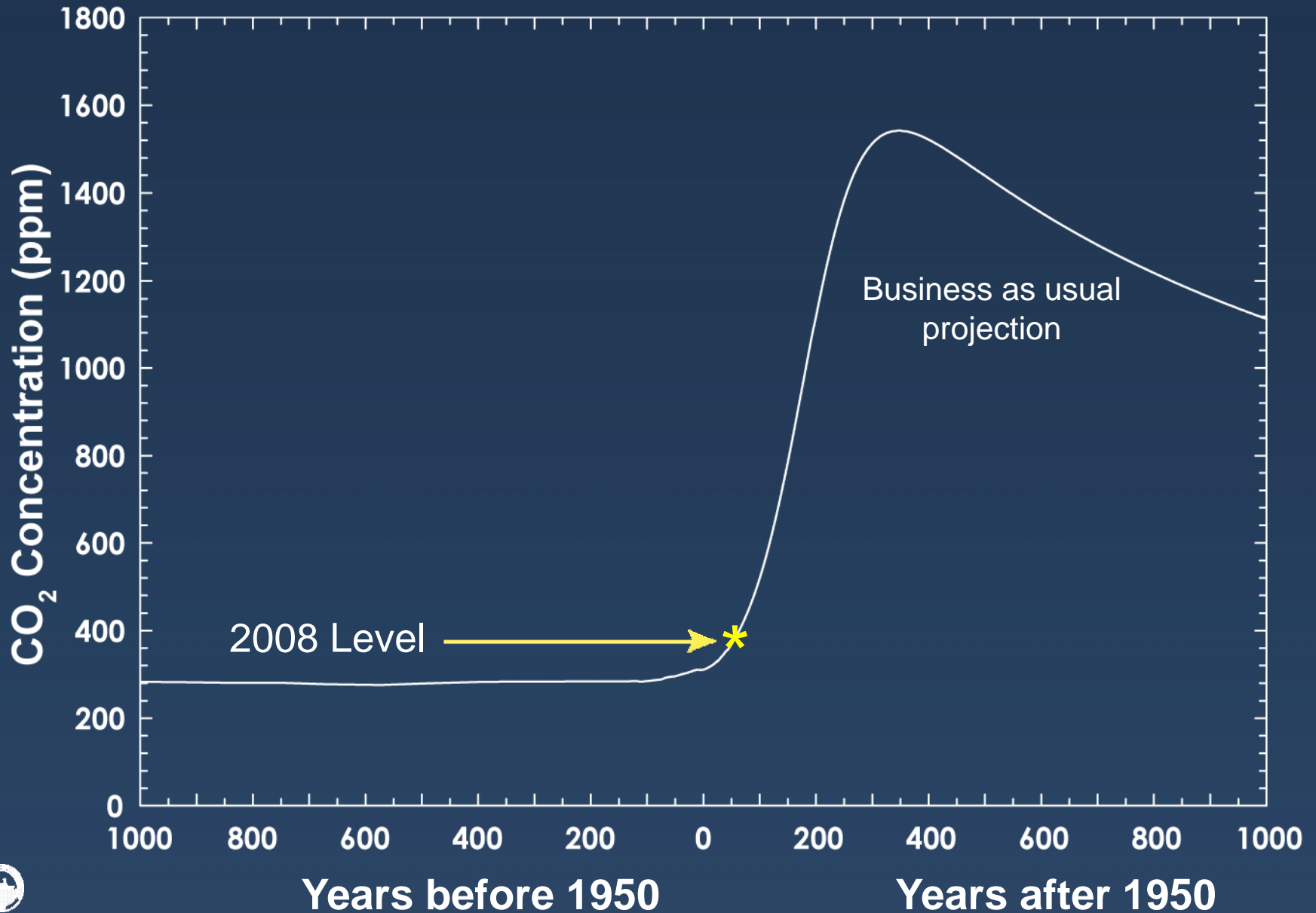
Past and future CO₂ levels



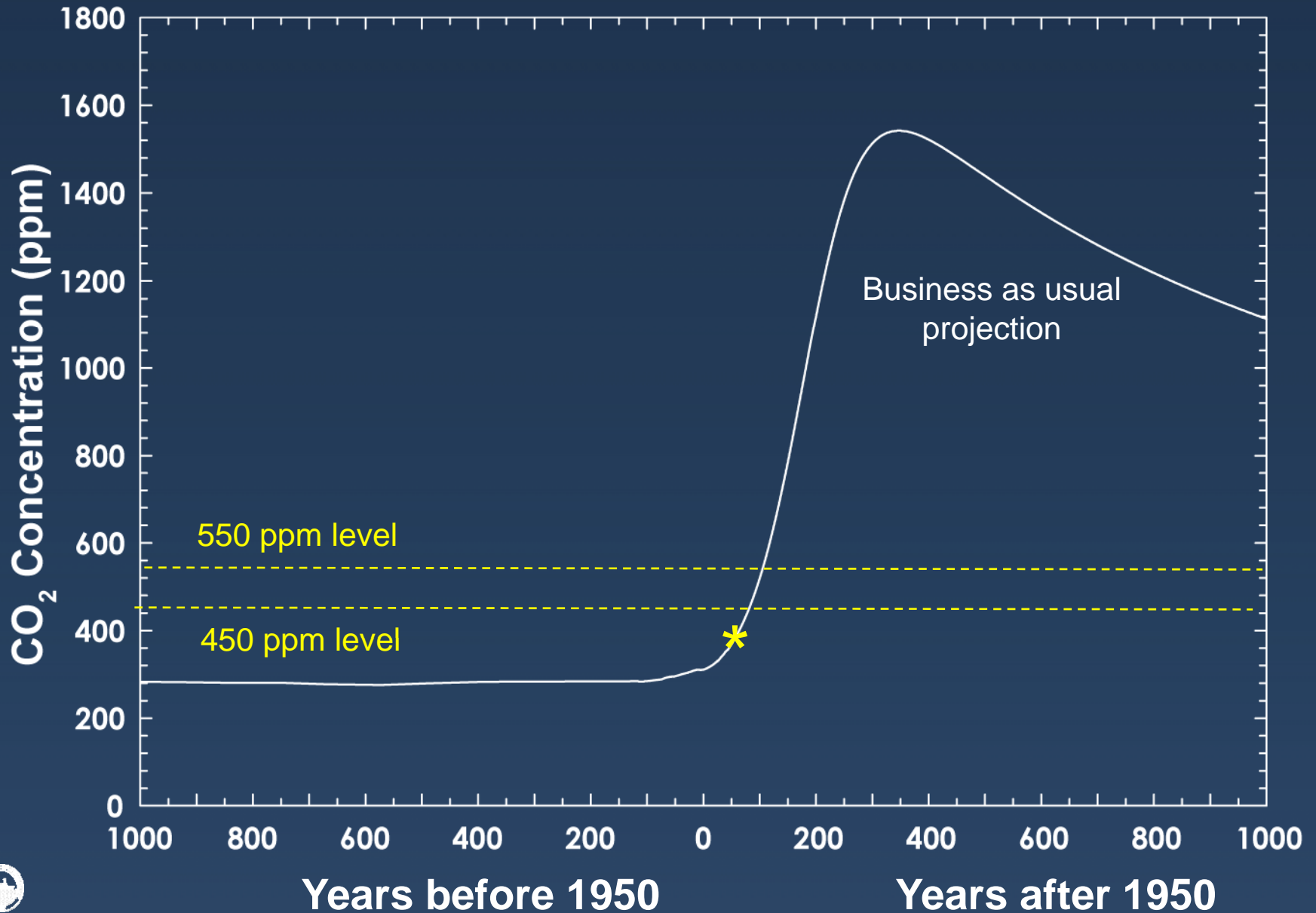
Past and future CO₂ levels



Past and future CO₂ levels

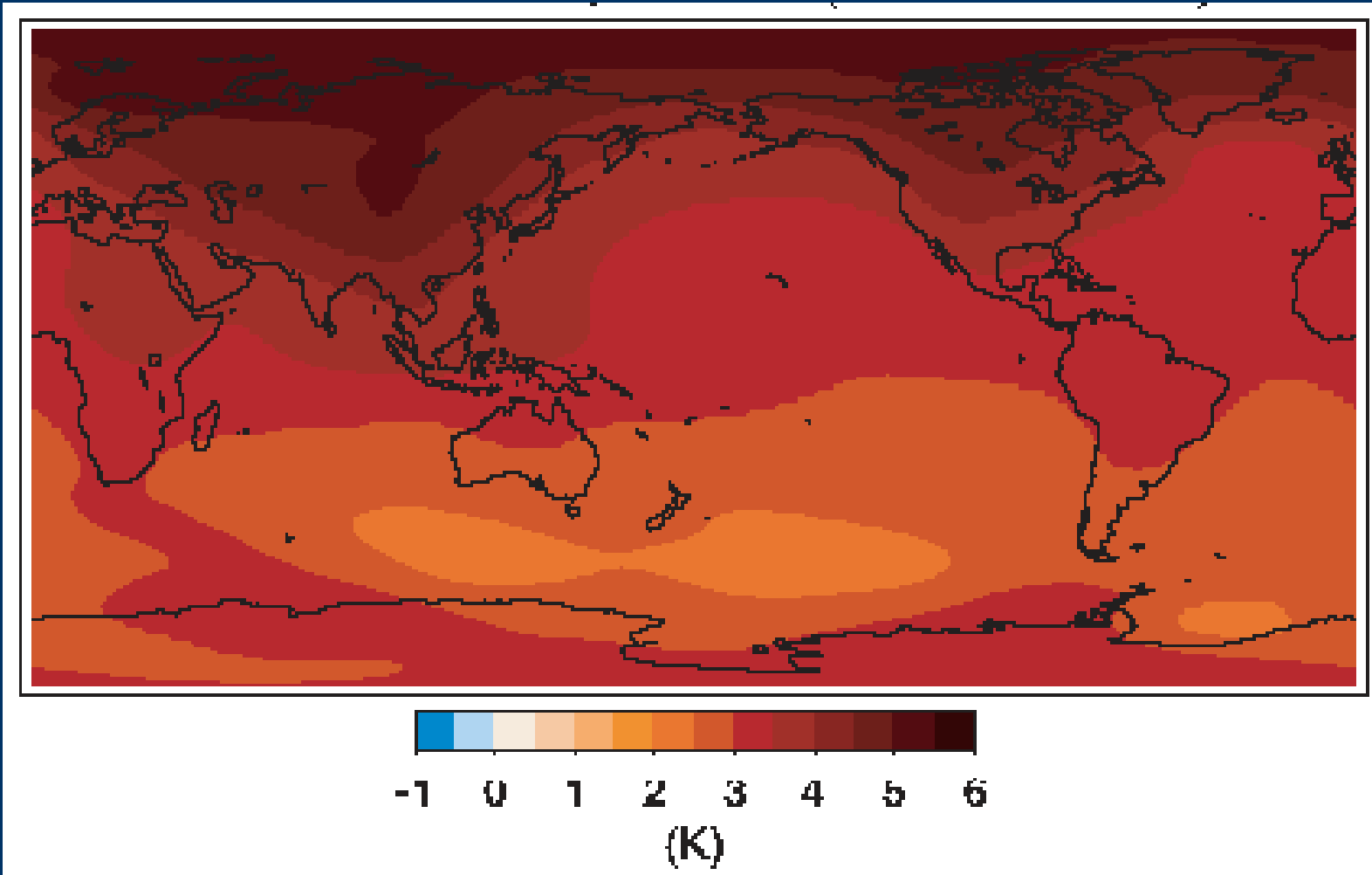


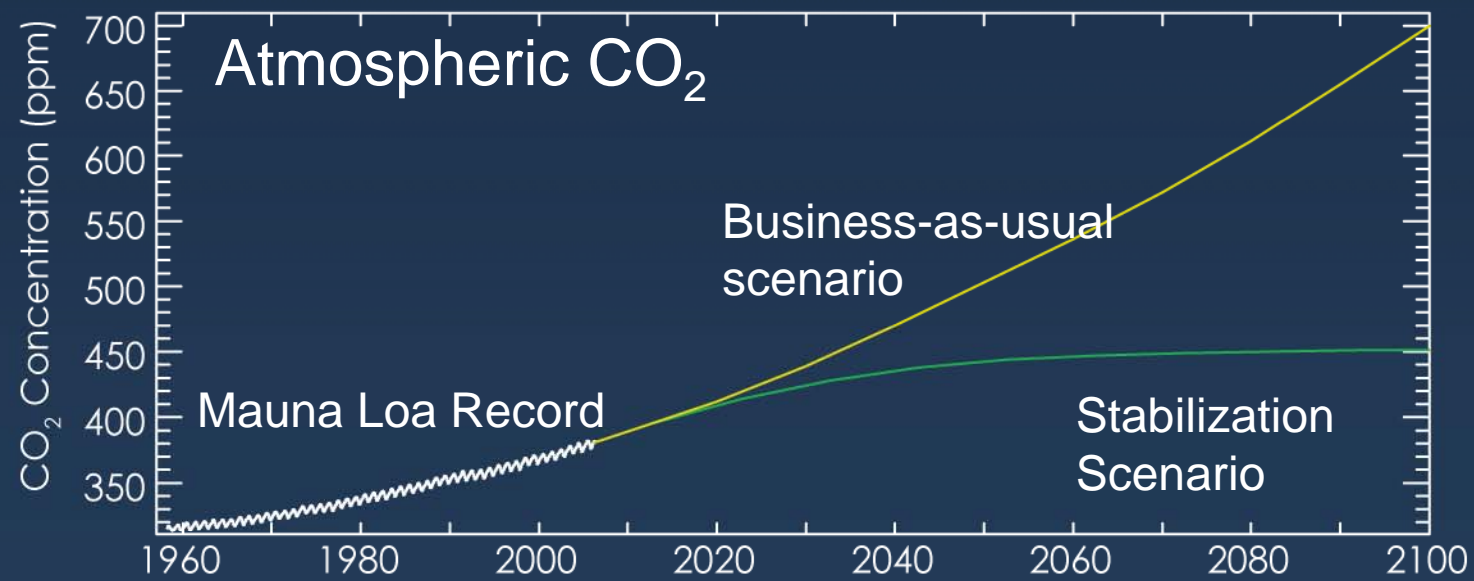
Past and future CO₂ levels

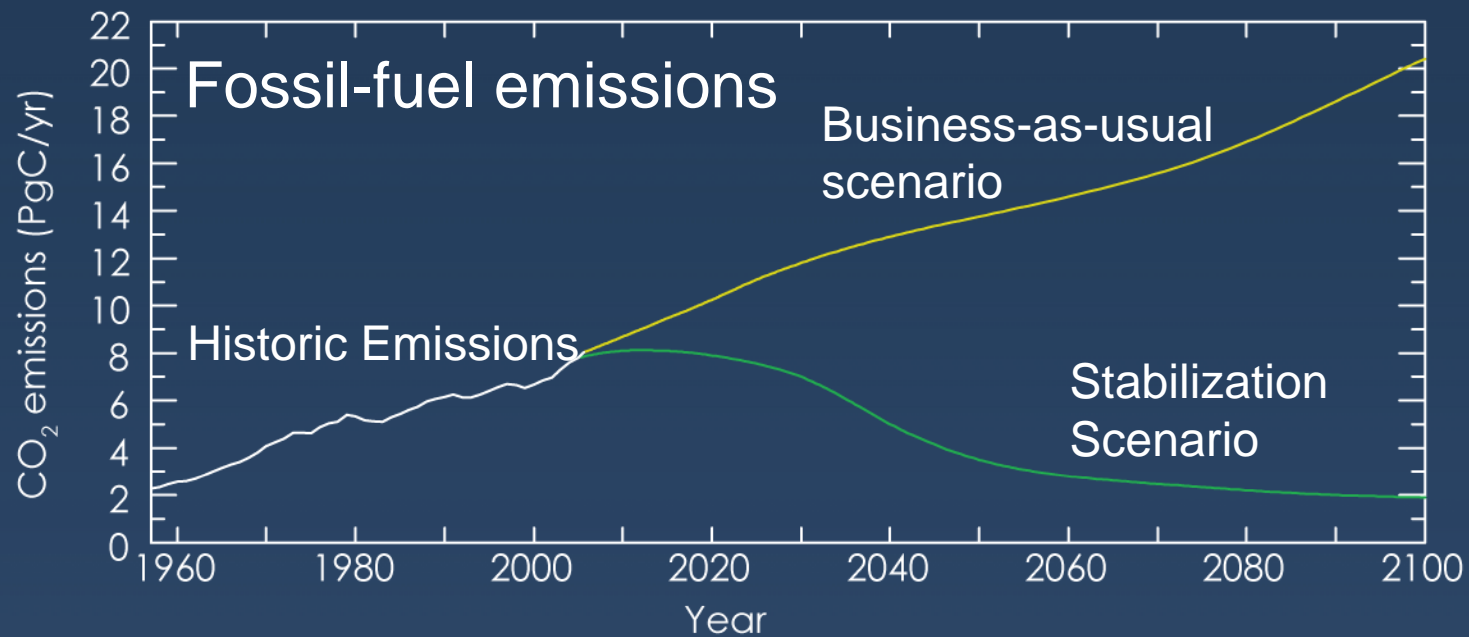
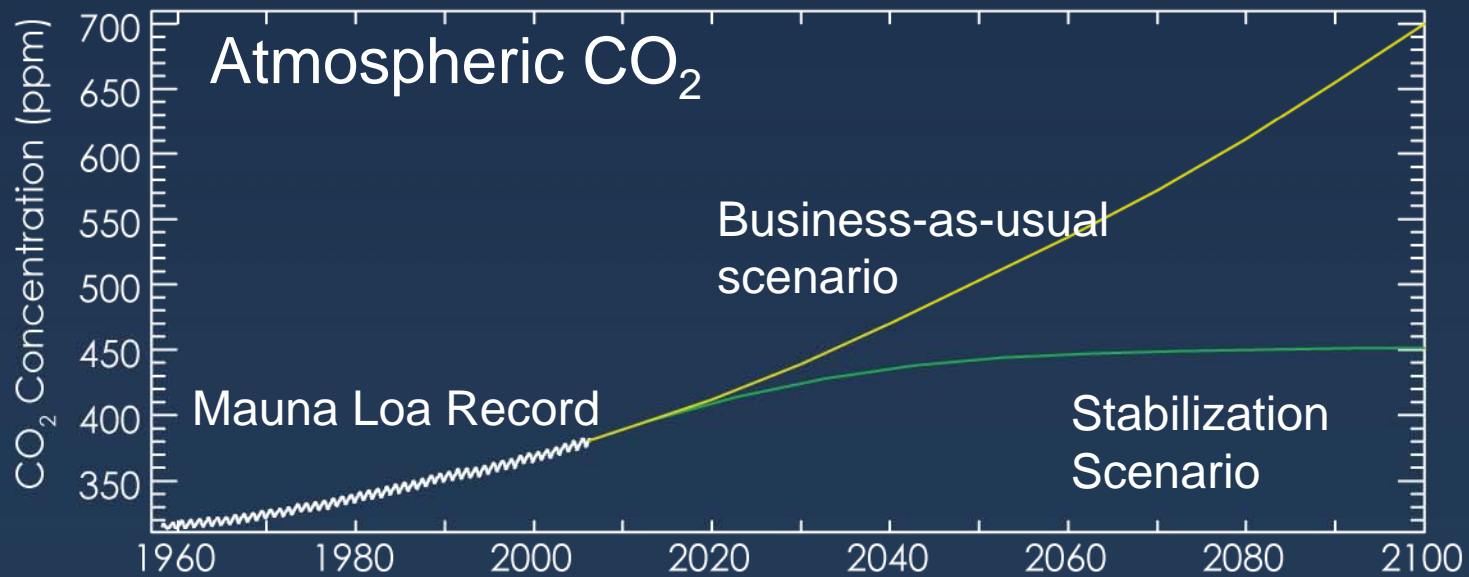


Climate forecast

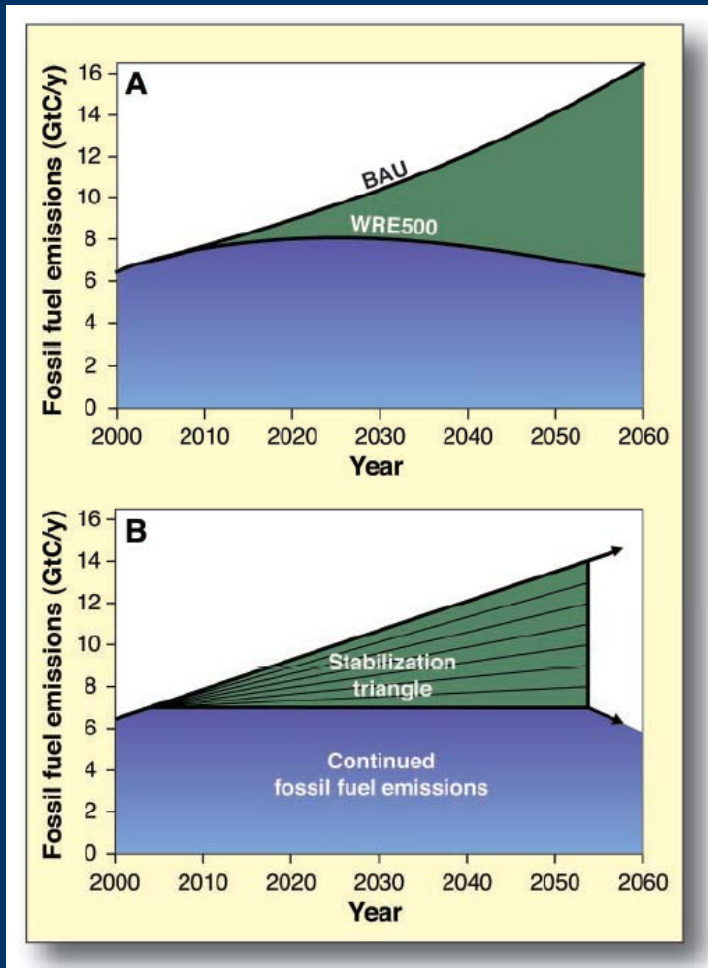
Surface air temperature change from 1900 to 2100







Mitigating climate change



Options

Conservation

Improved Efficiency

Solar

Wind

Nuclear

Biofuels

Carbon Capture &
Storage

Etc.

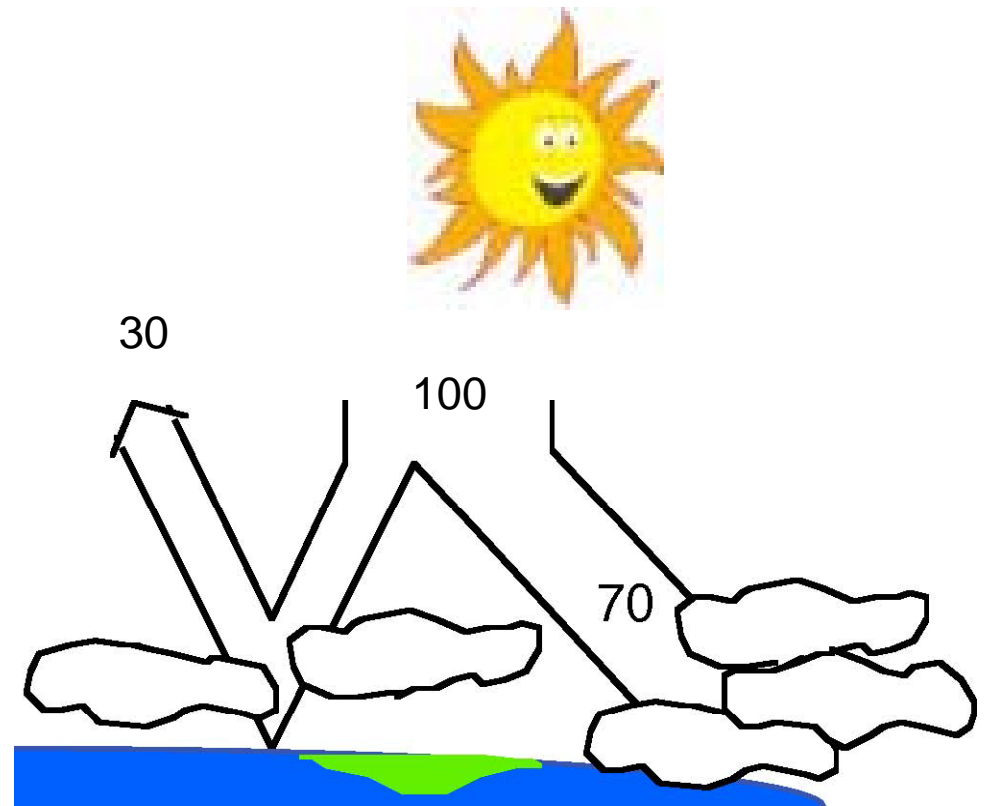
1 "wedge" = A triangle of averted emissions that grows from zero today to 1 Pg C/yr in 50 years. (Socolow and Pacala, 2002)

Sun-earth system

About 30% of the energy that comes to the earth from the sun is immediately reflected back into space...

...and about 70% is absorbed by the atmosphere and the ground where it becomes heat.

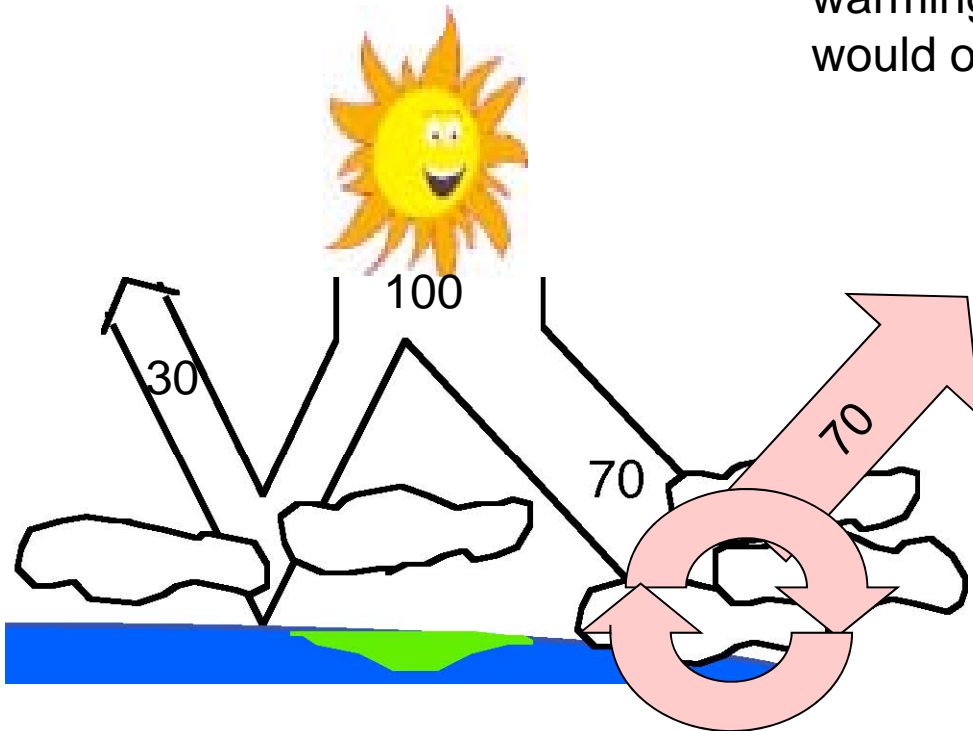
To stay in balance that heat energy has to get radiated back into space.



BUT, while the atmosphere is transparent to visible light, it is opaque to heat because infrared is absorbed by water vapor, carbon dioxide (CO₂) and other "greenhouse gases." So heat energy gets trapped and the planet warms. This is termed the "greenhouse effect."

Sun-earth system

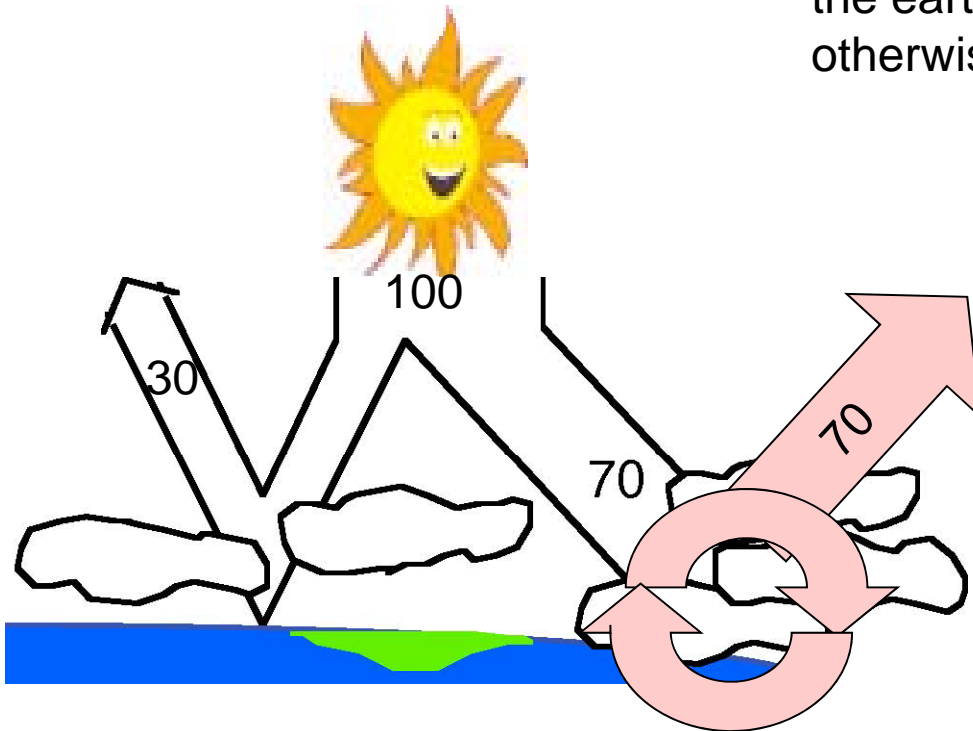
Because of this "greenhouse" warming the earth is 33°C warmer* than it would otherwise be.



At that warmer temperature, an equilibrium is reached and the same amount of energy is radiated back to space from the top of the atmosphere.

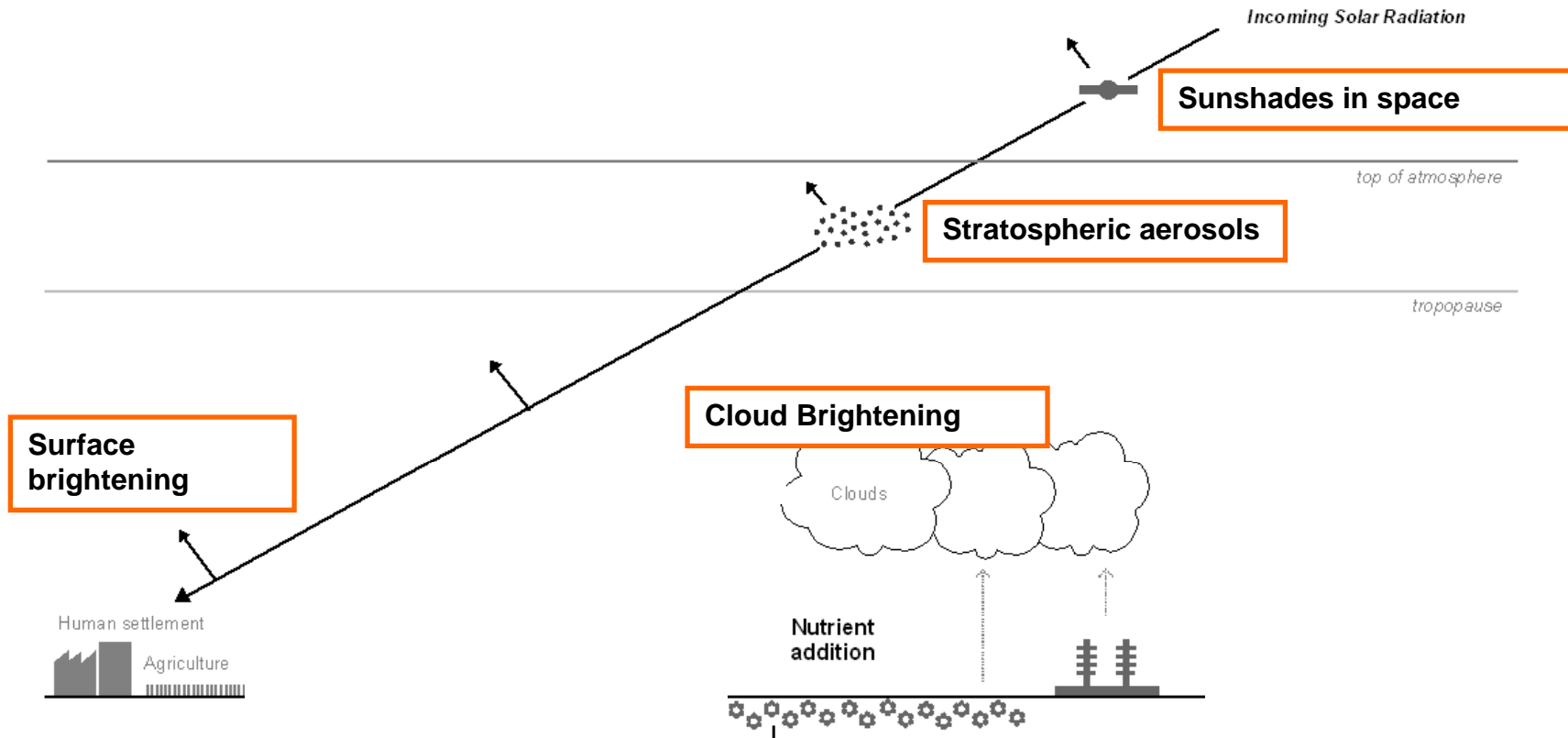
Sun-earth system

Because of this "greenhouse,, warming, the earth is 33°C warmer than it would otherwise be.



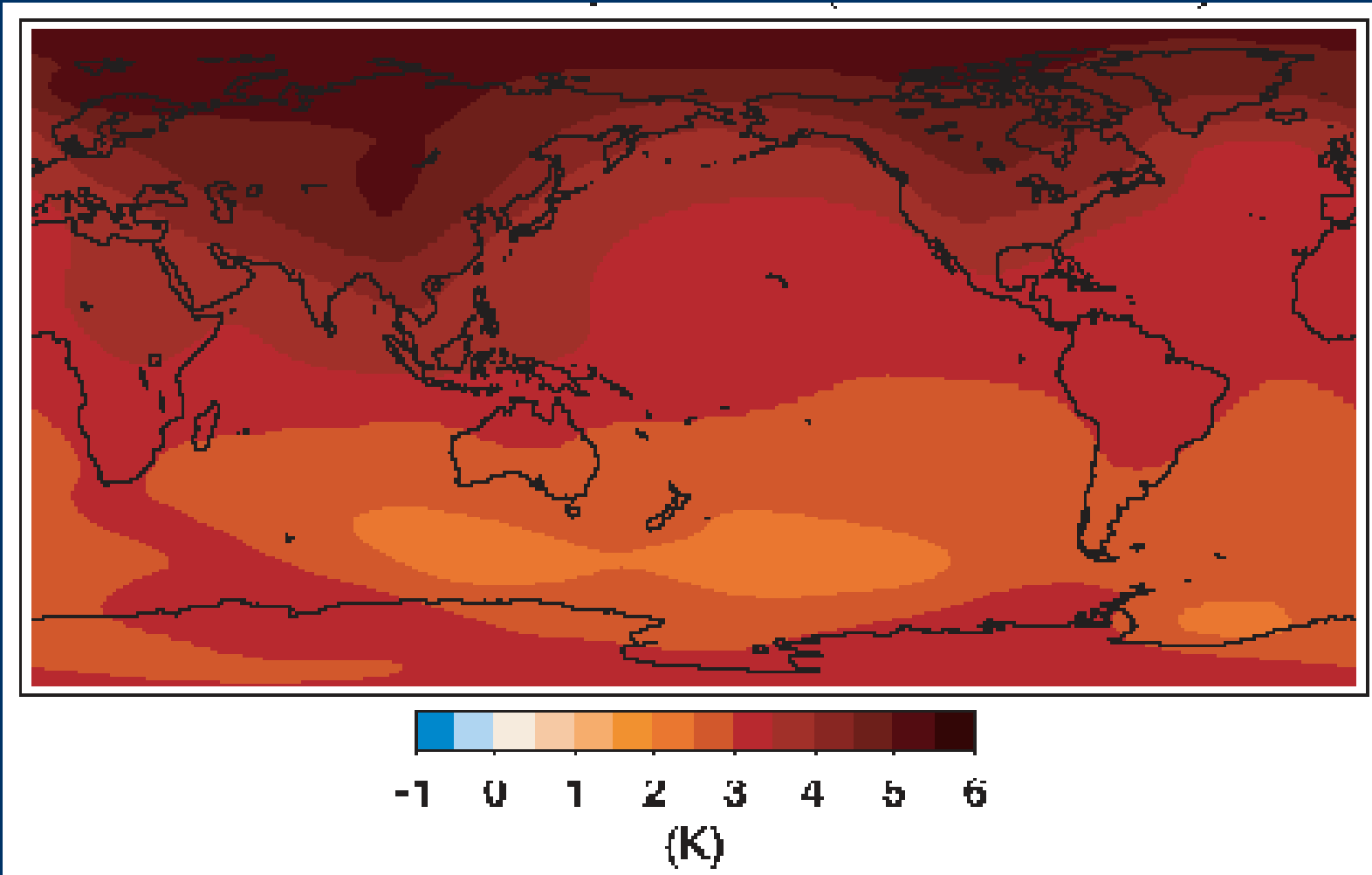
At that warmer temperature, an equilibrium is reached and the same amount of energy is radiated back to space from the top of the atmosphere.

Solar Radiation Management



Climate forecast

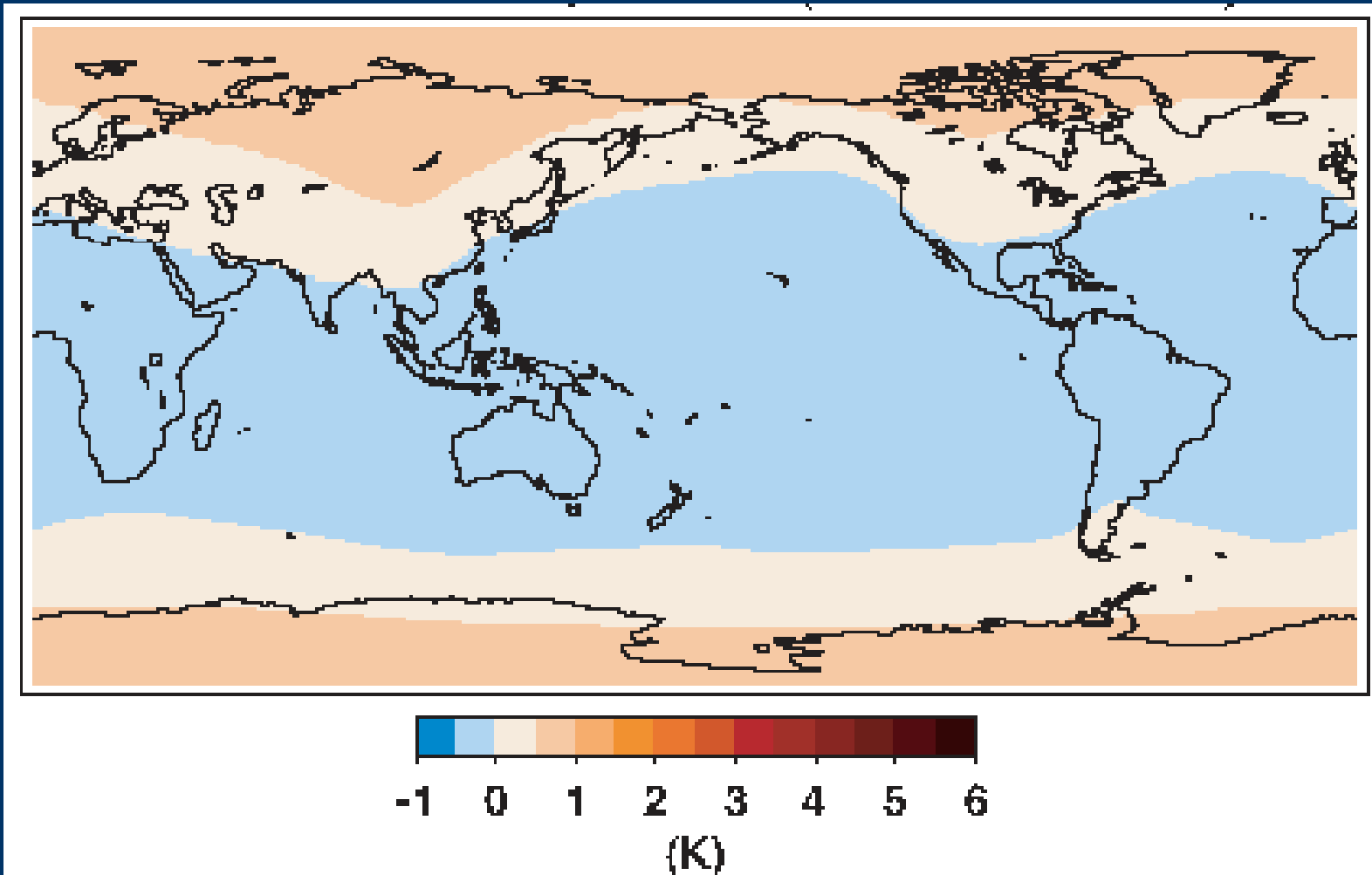
Surface air temperature change from 1900 to 2100



Matthews and Caldeira, PNAS 2007

Climate forecast with stratospheric treatment

Surface air temperature change from 1900 to 2100



Matthews and Caldeira, PNAS 2007

Solar Radiation Management – Effectiveness

Stratospheric aerosol injection

- Low cost

- Can cool whole planet (e.g. volcanic eruptions)

- Fast acting

- Can be quickly reversed

Other radiation treatment options

- More costly (sunshades in space)

- Or only partially effective (cloud or surface)

Solar Radiation Management – Side Effects

CO₂ buildup would continue

CO₂ effect on land plants

Ocean acidification

Changes in local climate (e.g. precipitation)

Stratospheric ozone depletion

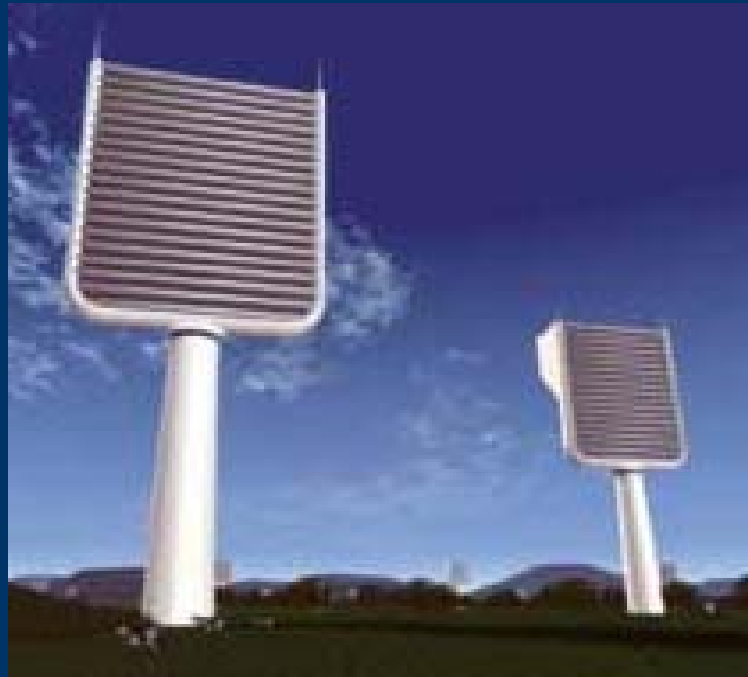
Solar Radiation Management – Side Effects

Reduces direct sunlight (less efficient solar power generation)

Increases diffuse sunlight (influences on plant growth, sunsets, etc.)

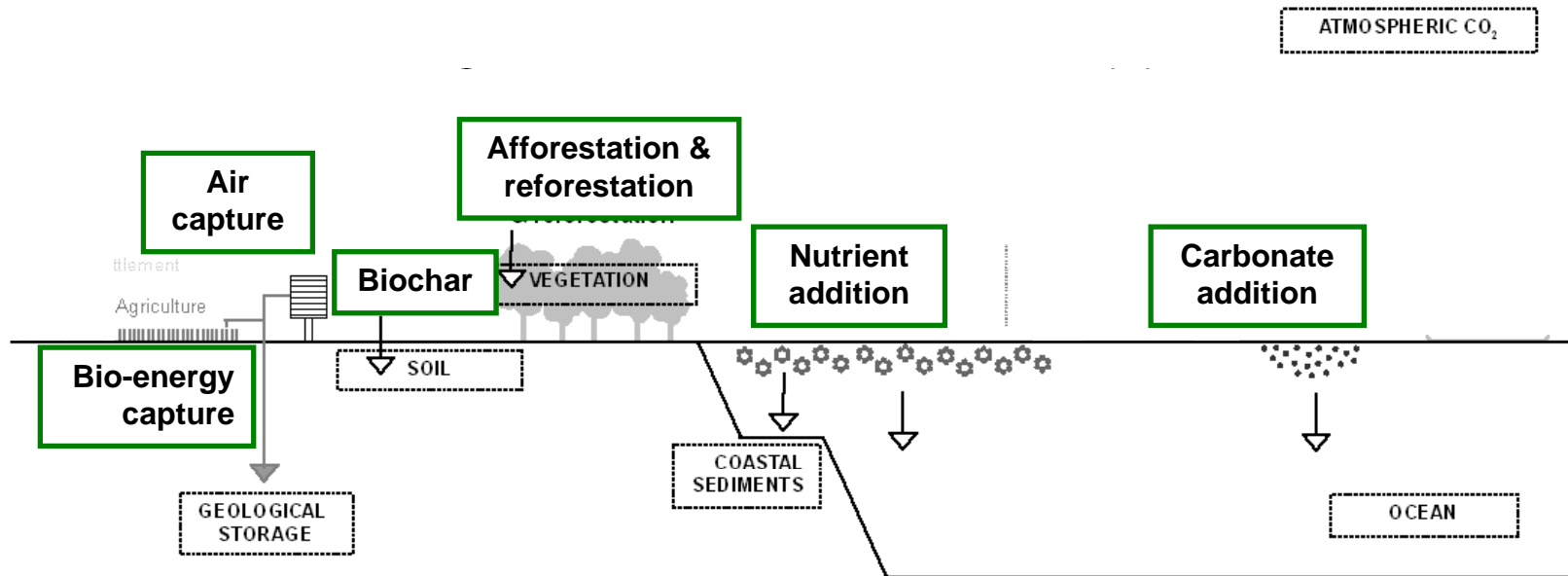
Potential for very rapid warming if injections are suddenly discontinued. May overwhelm ability to adapt.

Carbon Capture from Air



Direct air capture
– Klaus Lackner's artificial trees

Removal of CO₂ from Carbon Capture from Air



Carbon Capture from Air -effectiveness

Treats root cause of climate change, not just one symptom, i.e. deals also with acidification, etc.

All options would be slow acting and costly

Some options have capacity limits

(e.g. iron fertilization, afforestation, reforestation, char formation)

Verification may be challenging for iron fertilization

Scrubbing CO₂ from Air -side effects

Iron fertilization:

nutrient depletion and deoxygenation

Char, afforestation, etc.:

land albedo (brightness) effects

Direct capture & below-ground CO₂ storage:

minimal side effects?

Combining geoengineering & mitigation

Most global geoengineering options are as costly as mitigation options. The main exception is stratospheric aerosol injection.

Stratospheric aerosols might be used temporarily, to reduce peak impacts of CO₂, thereby buying time to allow mitigation and approaches to be developed.

Geoengineering as planetary medicine

Treatment

Symptom versus
cause

Side effect

Malpractice

Hippocratic oath

Geoengineering as planetary medicine

Hippocratic oath: “above all do no harm”

~~Stratosphere aerosol injection~~

~~Ocean iron fertilization~~

Direct carbon capture from air

Coastal Dams

Protecting ice sheets

Thank You

Major Carbon Pools

