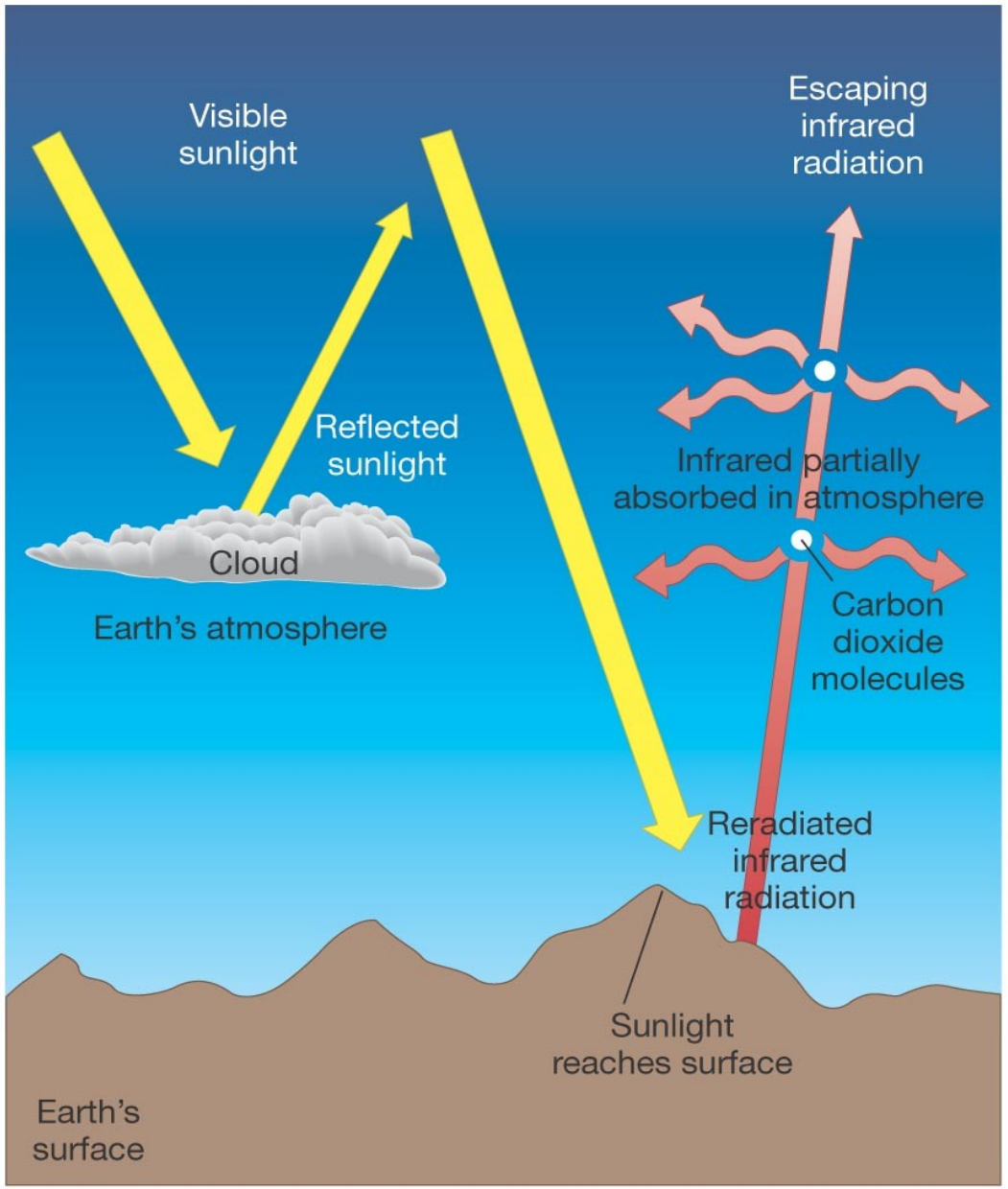
The greenhouse effect



Visible light arrives

About half reflected, half is absorbed by the ground.

This absorbed energy is then re-radiated, but NOT in the visible (would just go out again anyway); in the infrared

Greenhouse gases in the atmosphere efficiently absorb the re-emitted IR radiation, keeping the heat energy near Earth's surface

This causes surface to be warmer than without gases

Equilibrium T *with* atmosphere

Table 10.2 The Greenhouse Effect on the Terrestrial Worlds

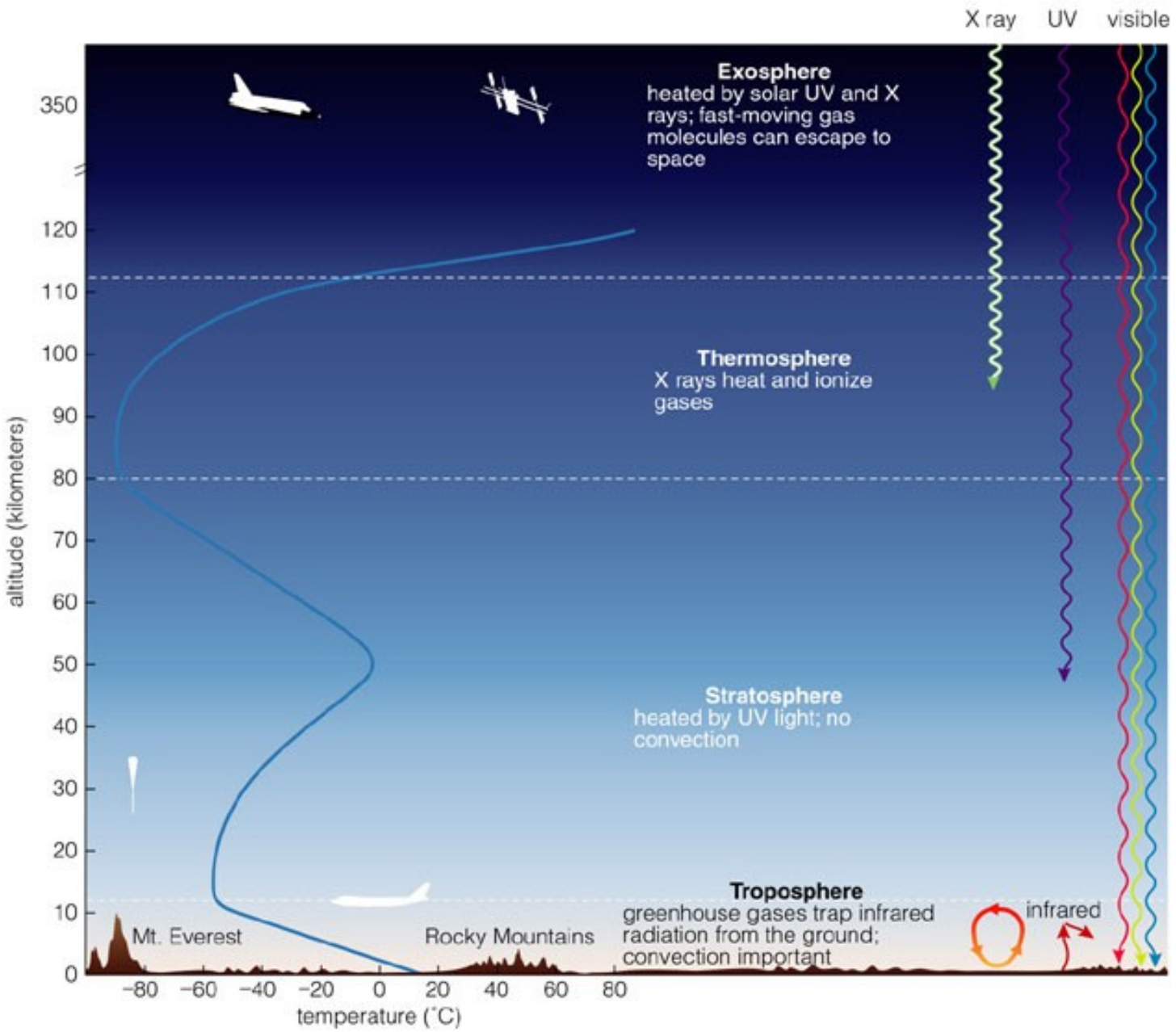
World	Average Distance from Sun (AU)	Reflectivity	"No Greenhouse" Average Surface Temperature*	Actual Average Surface Temperature	Greenhouse Warming (actual temperature minus "no greenhouse" temperature)
Mercury	0.387	12%	163°C	425°C (day), −175°C (night)	—
Venus	0.723	75%	−40°C	470°C	510°C
Earth	1.00	29%	−16°C	15°C	31°C
Moon	1.00	12%	−2°C	125°C (day), −175°C (night)	—
Mars	1.524	16%	−56°C	−50°C	6°C

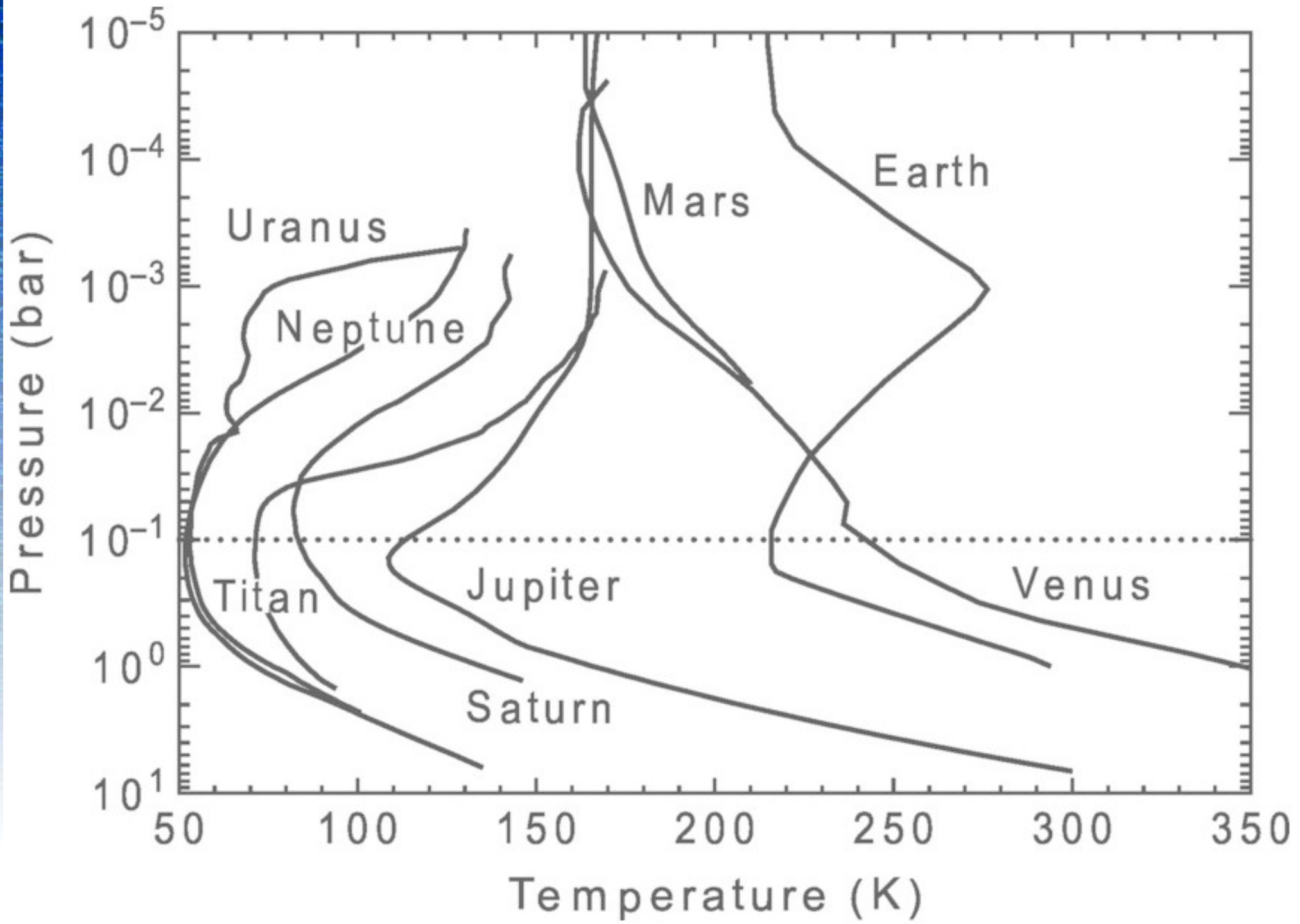
* The "no greenhouse" temperature is calculated by assuming no change to the atmosphere other than lack of greenhouse warming. Thus, for example, Venus ends up with a lower "no greenhouse" temperature than Earth even though it is closer to the Sun, because the high reflectivity of its bright clouds means that it absorbs less sunlight than Earth.

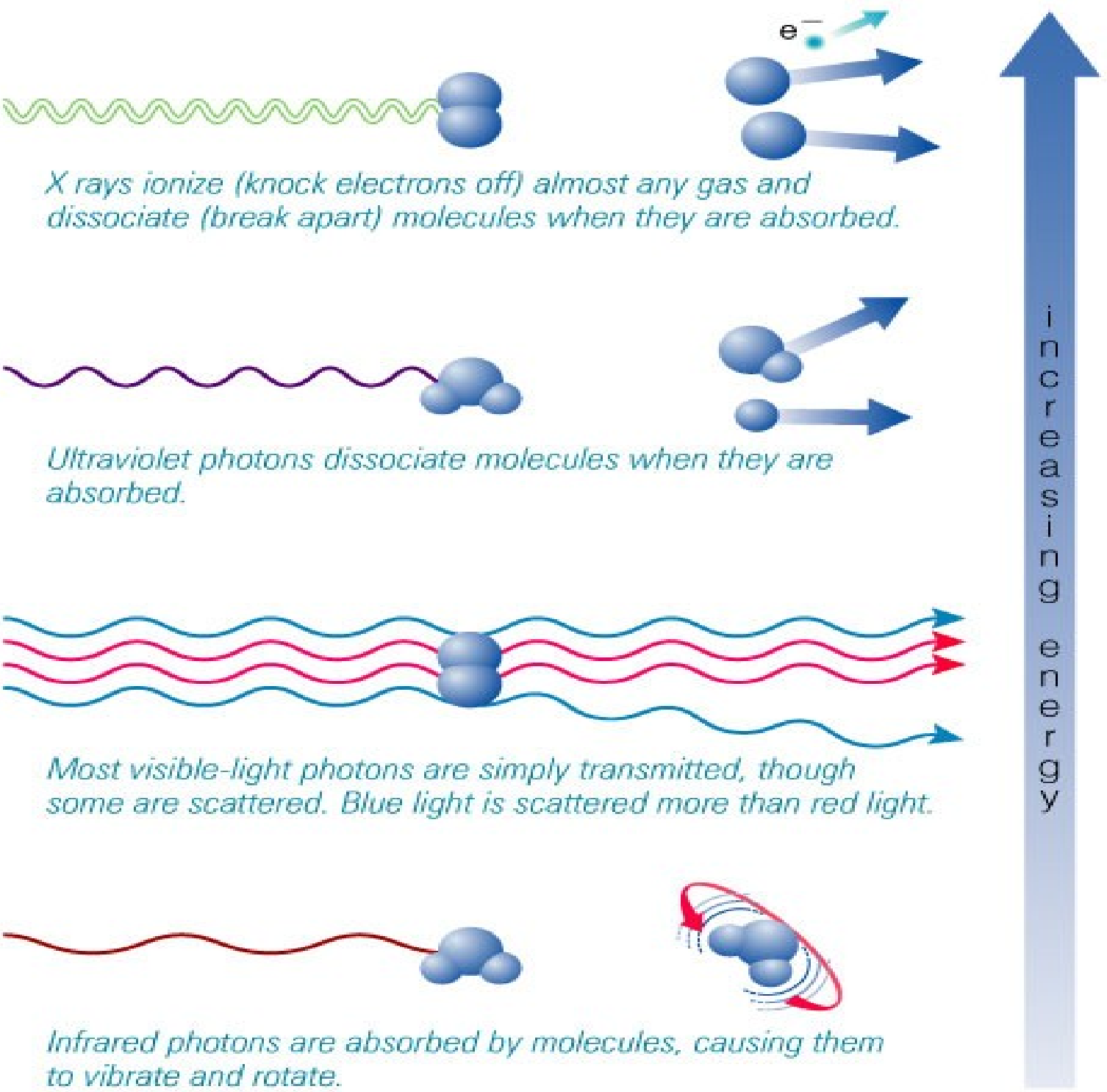
Mercury and Moon : Why is their actual average surface T different than the 'No Greenhouse' temperature? (hint: rotation)

Atmospheric structure

T structure determined by complex balance of density and heat input and output




Pressure (bar)
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^{0}
10^{1}
Uranus
Neptune
Titan
Mars
Earth
Jupiter
Venus
Saturn
50
100
150
200
250
300
350
Temperature (K)



X rays ionize (knock electrons off) almost any gas and dissociate (break apart) molecules when they are absorbed.

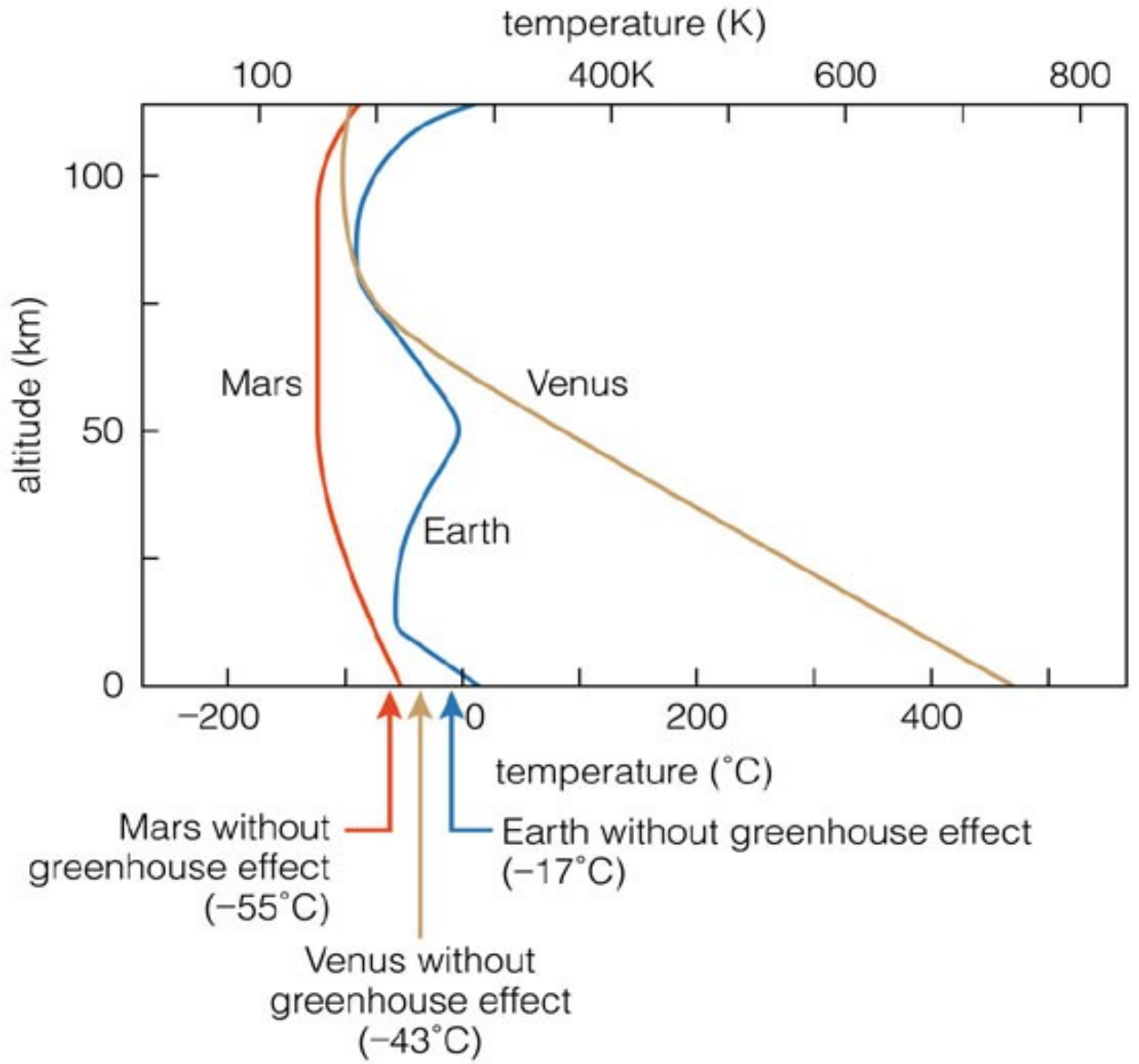
Ultraviolet photons dissociate molecules when they are absorbed.

Most visible-light photons are simply transmitted, though some are scattered. Blue light is scattered more than red light.

Infrared photons are absorbed by molecules, causing them to vibrate and rotate.

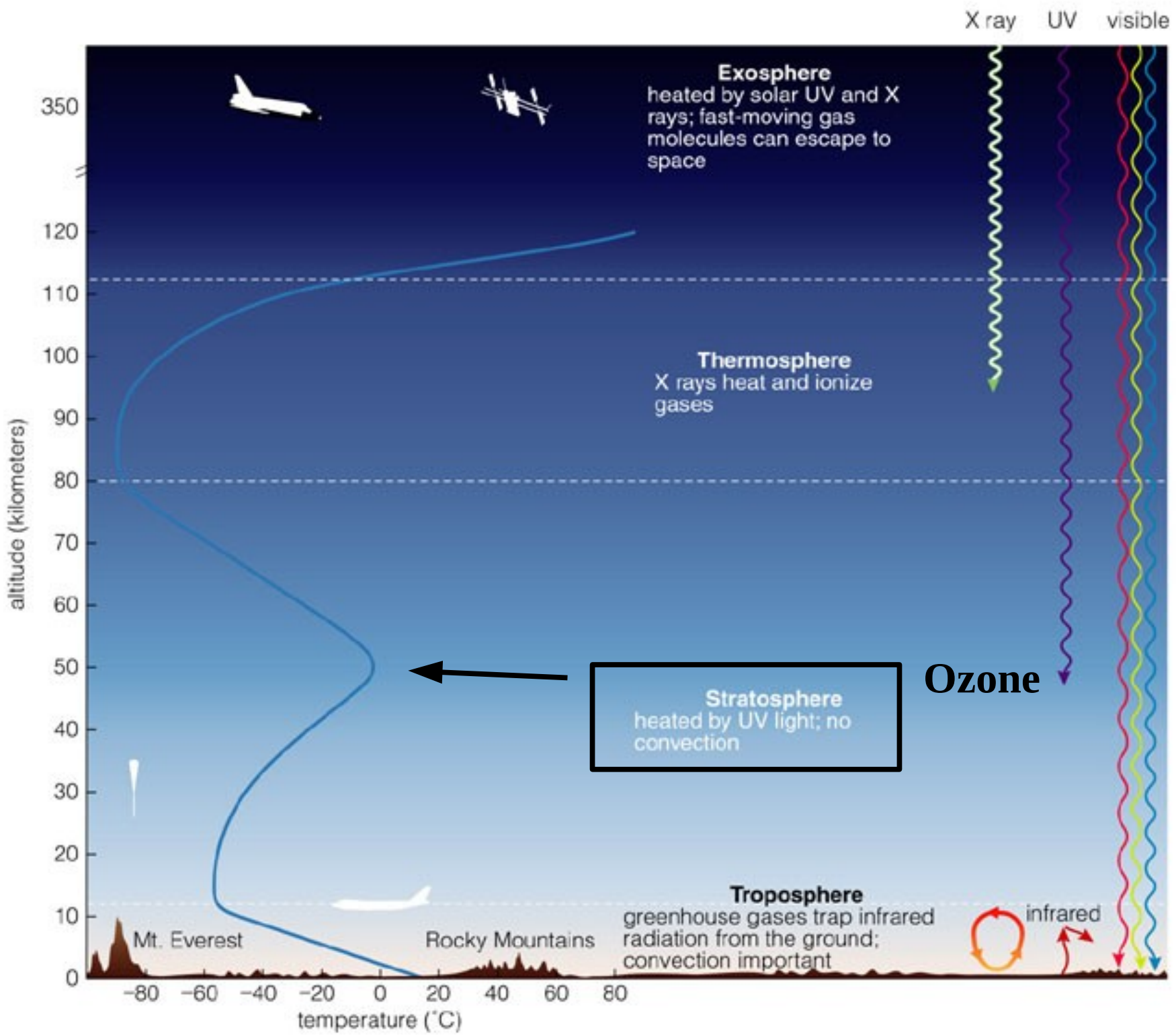
Atmospheric structure

Temperature profiles on Mars/Earth/Venus all drop initially as altitude increases. Only Earth has stratospheric bump.



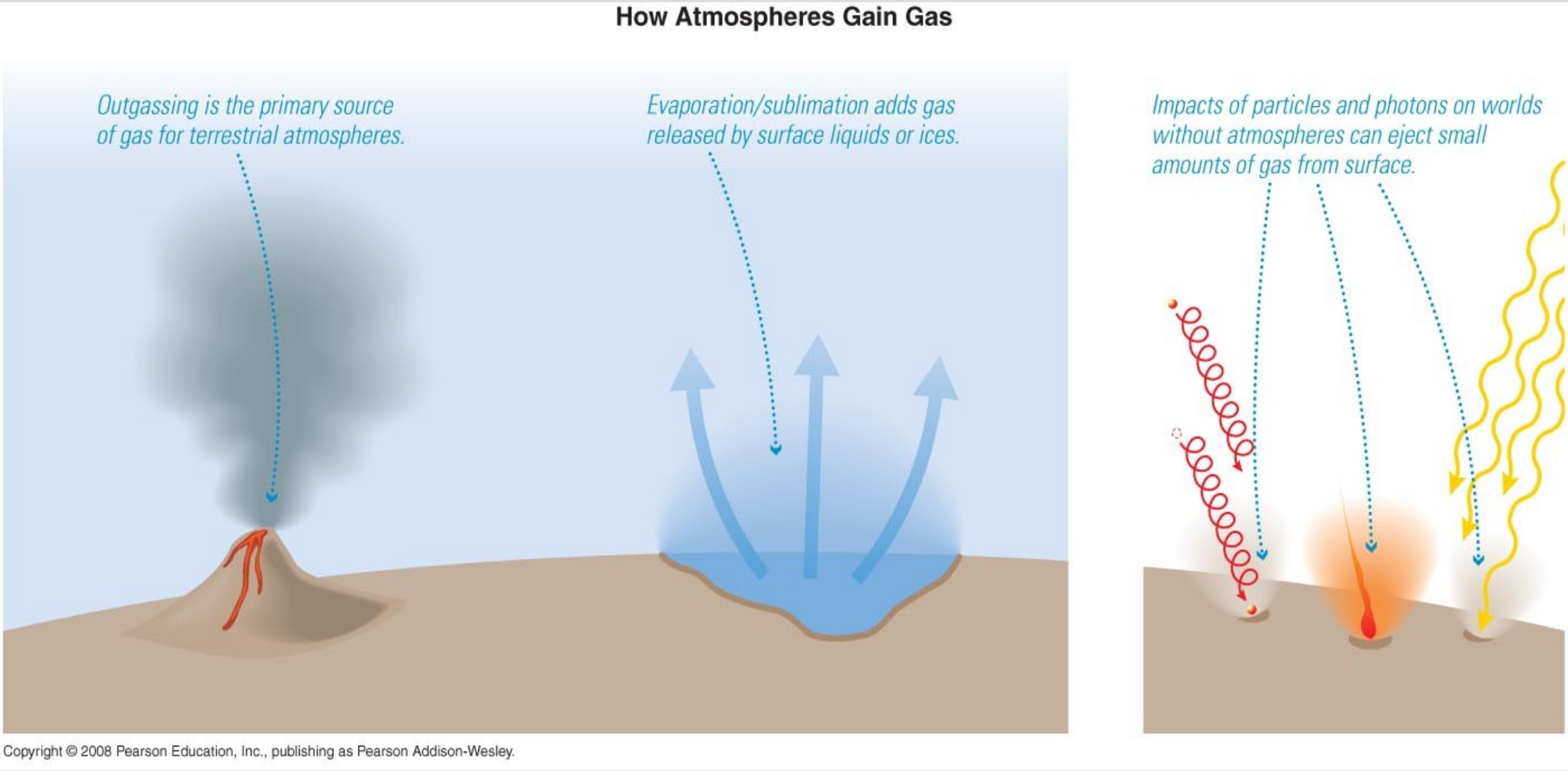
All have some temperature inversion in thermosphere (about 80 km altitude).

Why does only Earth have a second inversion (at 20-50 km up)?


X ray
UV
visible
Exosphere
heated by solar UV and X rays; fast-moving gas molecules can escape to space
Thermosphere
X rays heat and ionize gases
Stratosphere
heated by UV light; no convection
Ozone
Troposphere
greenhouse gases trap infrared radiation from the ground; convection important
infrared
Mt. Everest
Rocky Mountains
altitude (kilometers)
temperature (˚C)
350
120
110
100
90
80
70
60
50
40
30
20
10
0
−80
−60
−40
−20
0
20
40
60
80

Origin of terrestrial atmospheres

How do gases come into a planetary atmosphere?



Outgassing on Earth

From the Kilauea volcano (Hawaii) (deep mantle outgassing)

~50%	H20
~20%	CO2
~10%	N2
<1%	SO2
Tiny	Ar, Ne, Kr
None	O2

Current atmosphere

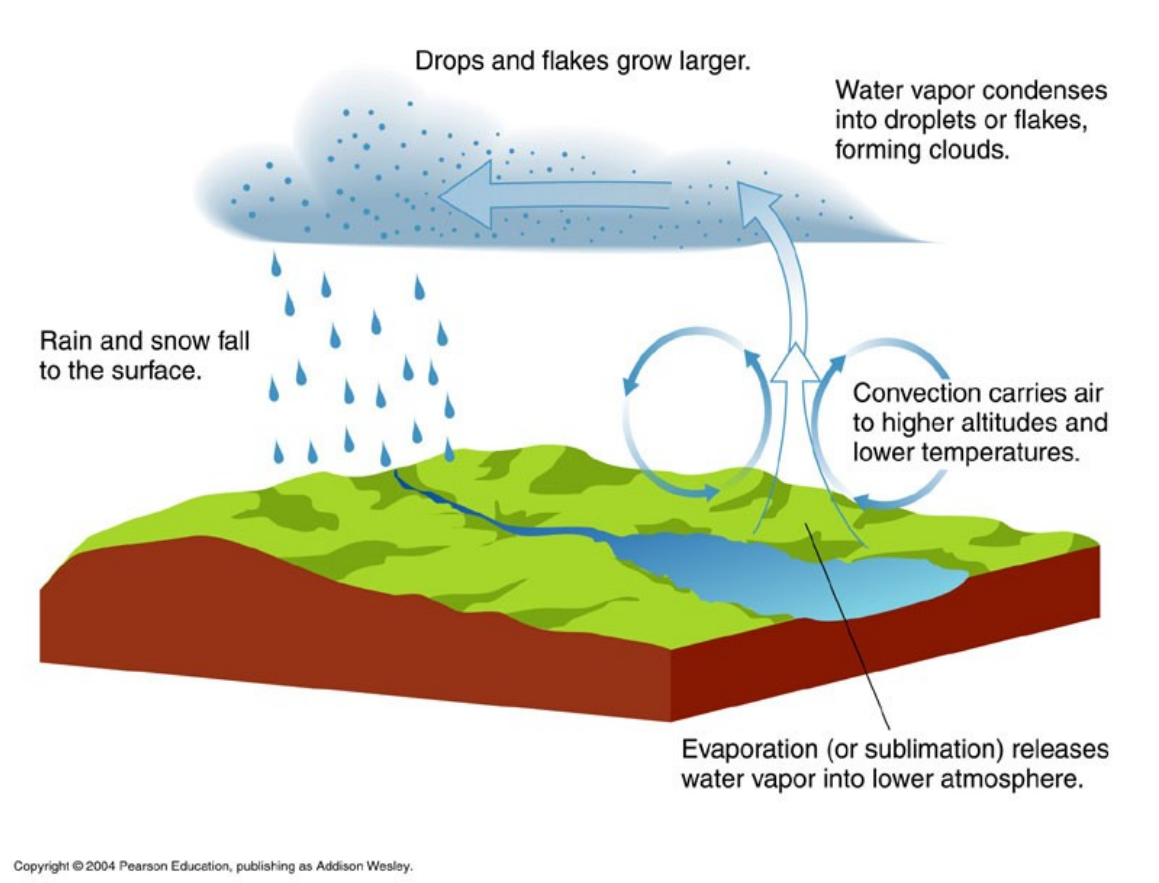
78.1%	N2
21.0%	O2
0.93%	Ar
0.03%	CO2
.002%	Ne
.0001%	Kr
.001-1.0%	H20 (variable)

Atmospheric Cycles: Earth

Water is a VOLATILE on Earth (easily changes from solid/liquid to gas)

The water cycle processes H_20 from the surface into the atmosphere and back.

Atmosphere contains only a small fraction of Earth's water at any one time.



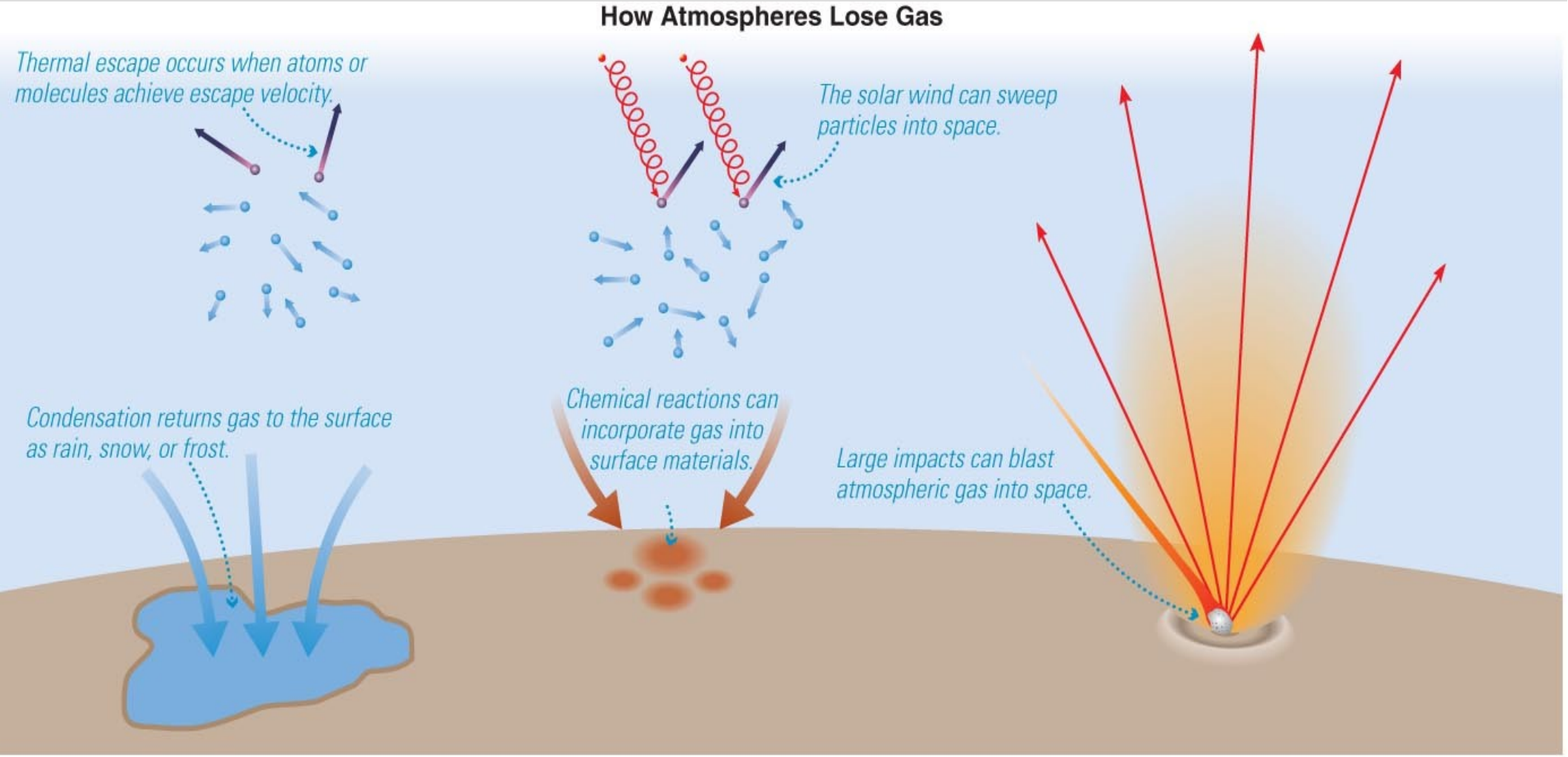
Outgassing on other worlds

Outgassing dominates the supply of gases which are the origin of terrestrial planet atmospheres

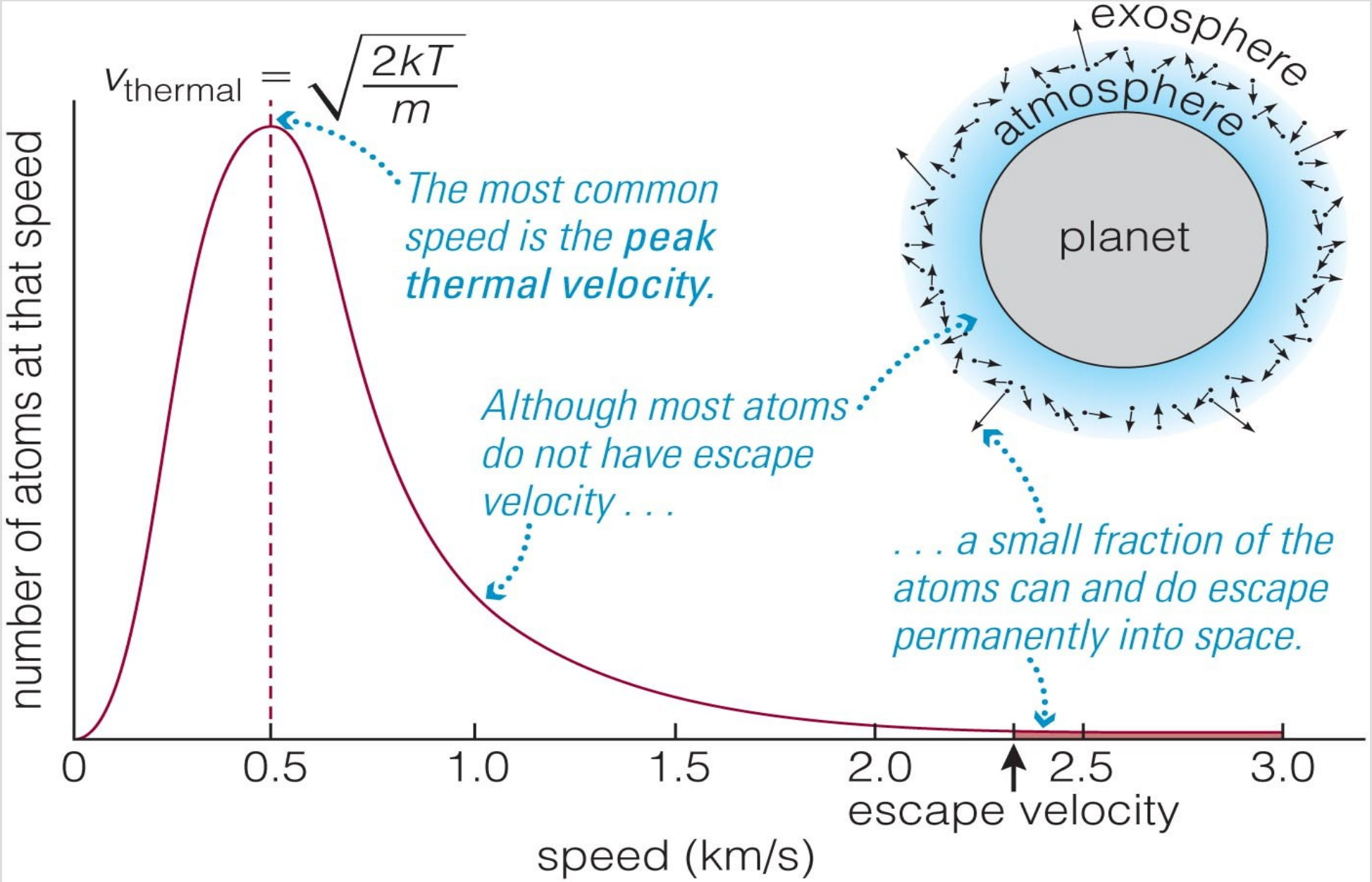
Planetary scientists believe that the outgassing from Earth's interior is likely very similar to that which came out of the other terrestrial planets

So the differences between the planetary atmospheres are due to different climate systems, not due to origin...

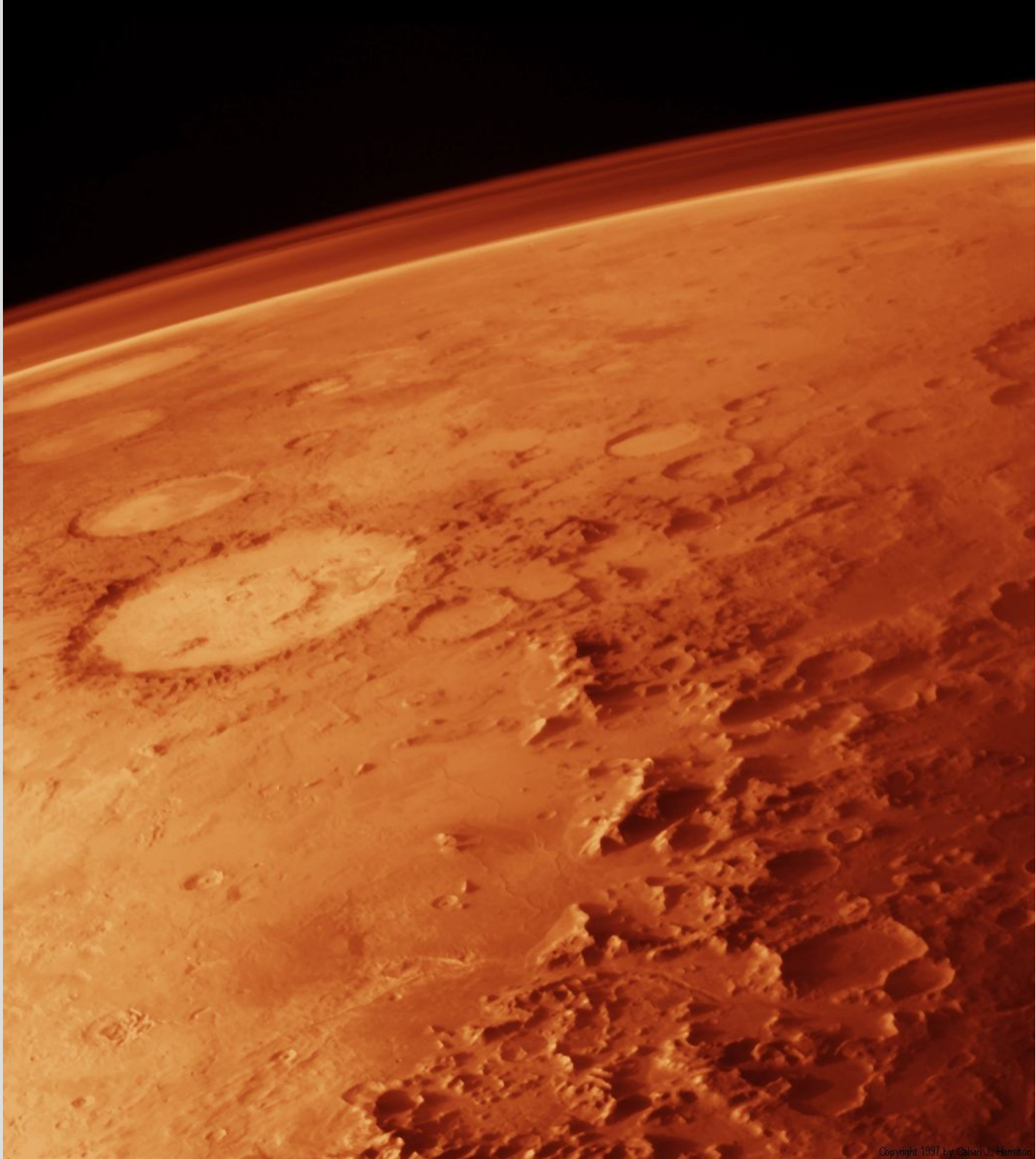
How do gases leave a planetary atmosphere?



Lighter gases escape to space over millions to billions of years



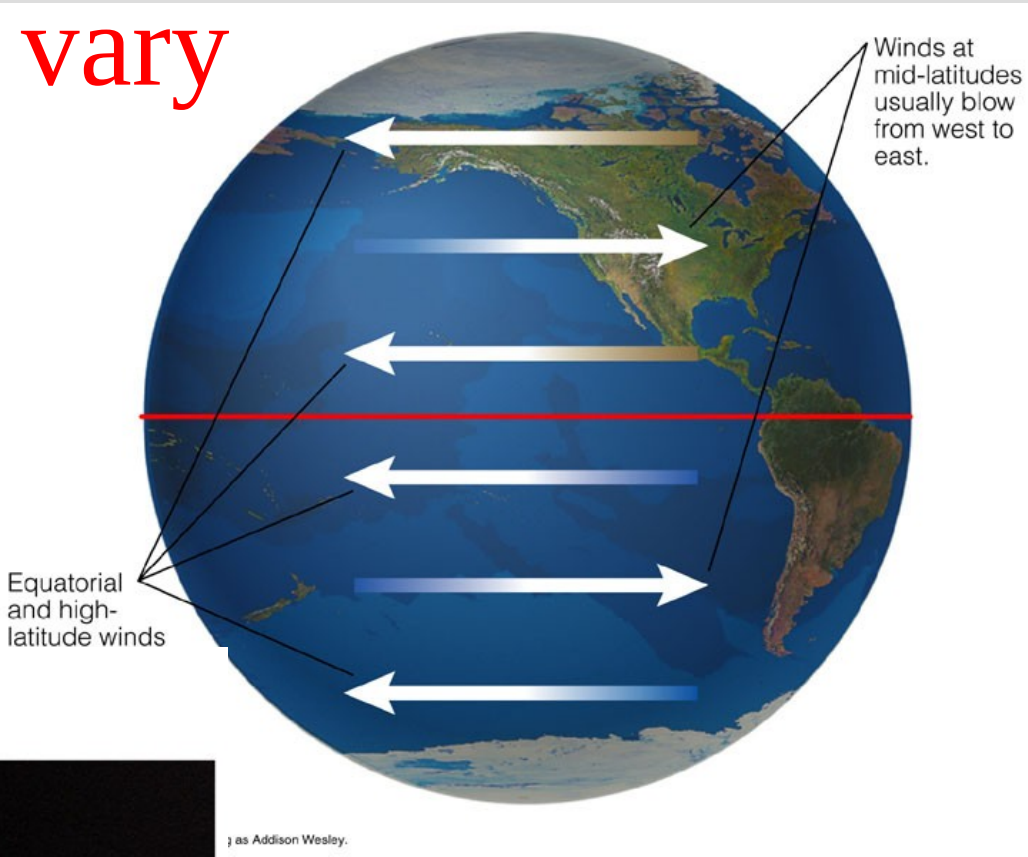
The martian atmosphere

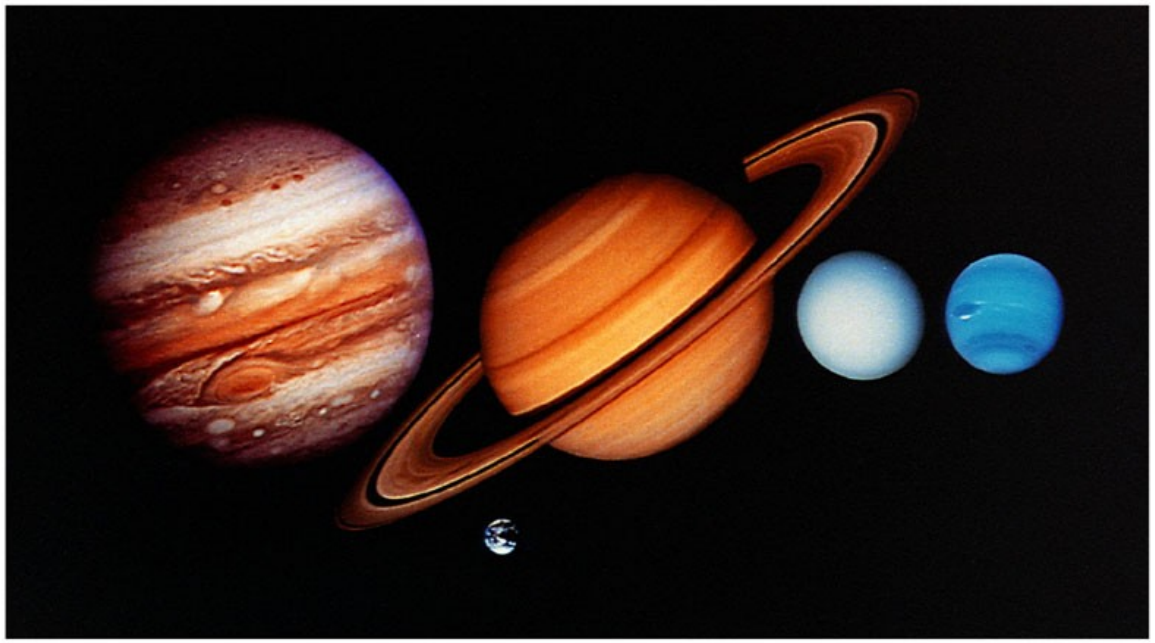


Atmospheres are dynamic

Many atmospheres vary with latitude

Banding at lines of constant latitude caused by parallel prevailing winds

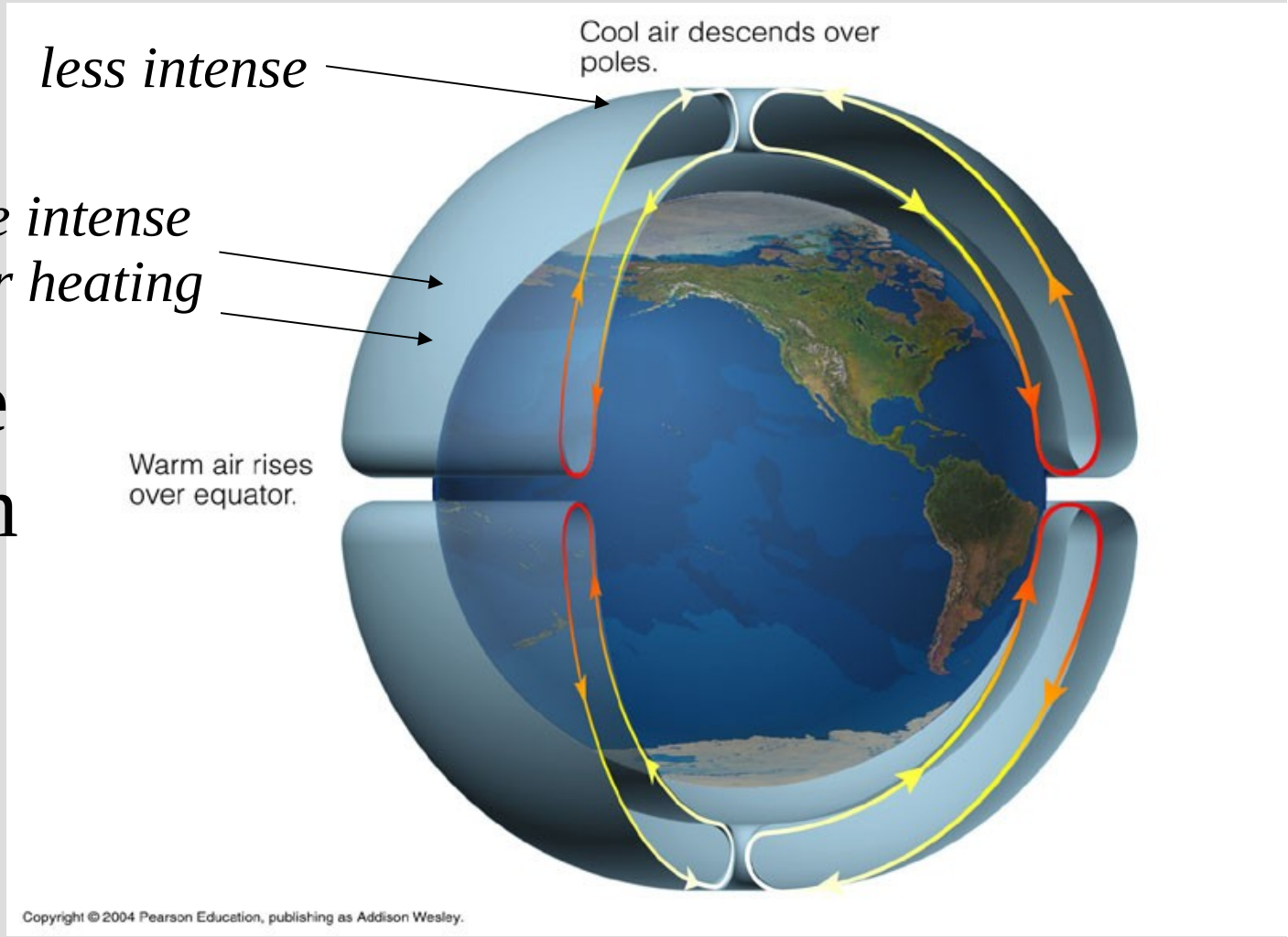




Why does this happen?

1. Differential heat input

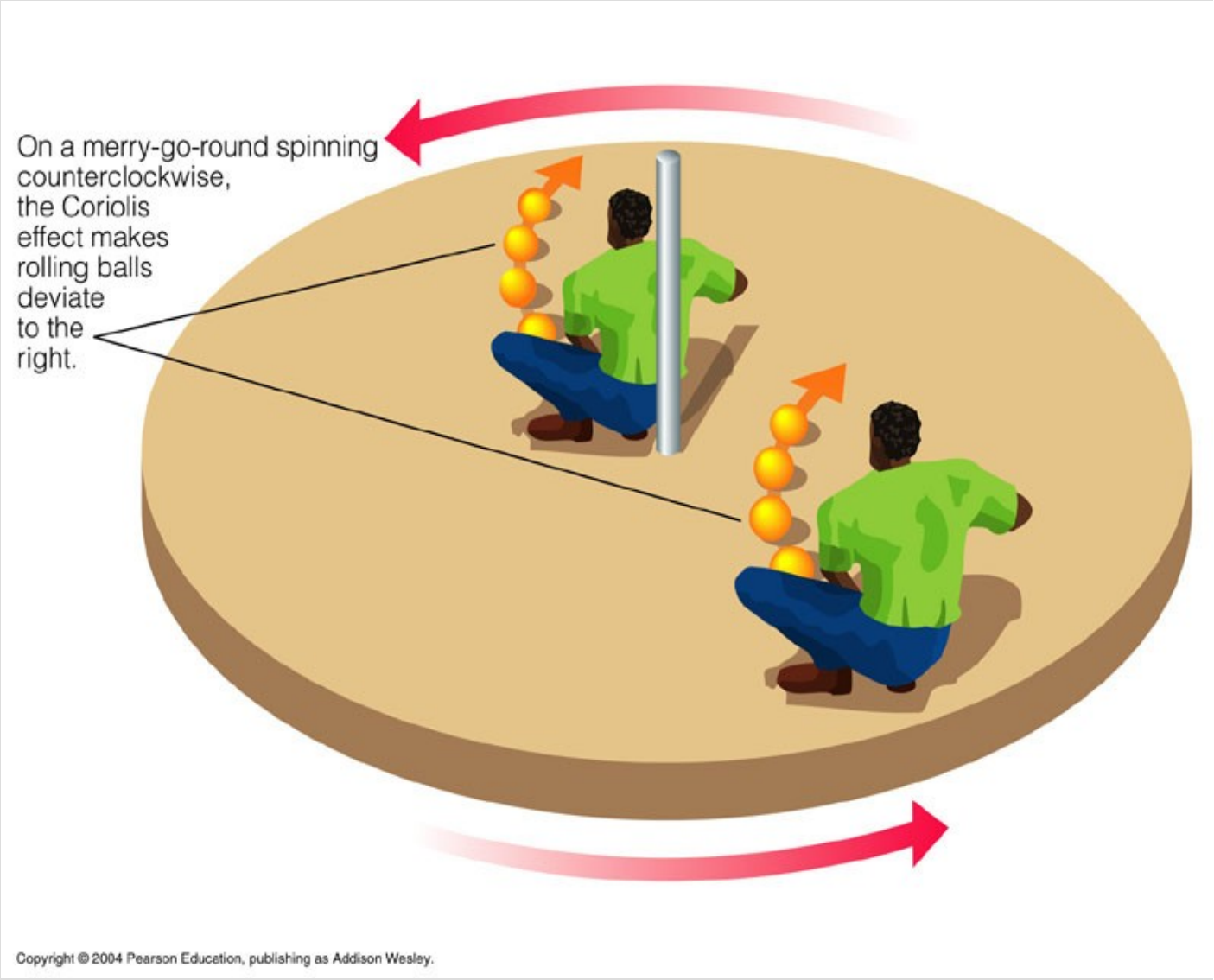
Sunlight heats the equator more than the poles (more direct...think summer)



Atmosphere tries to 'redistribute' heat by circulating hot air to poles. 'Hadley cells'

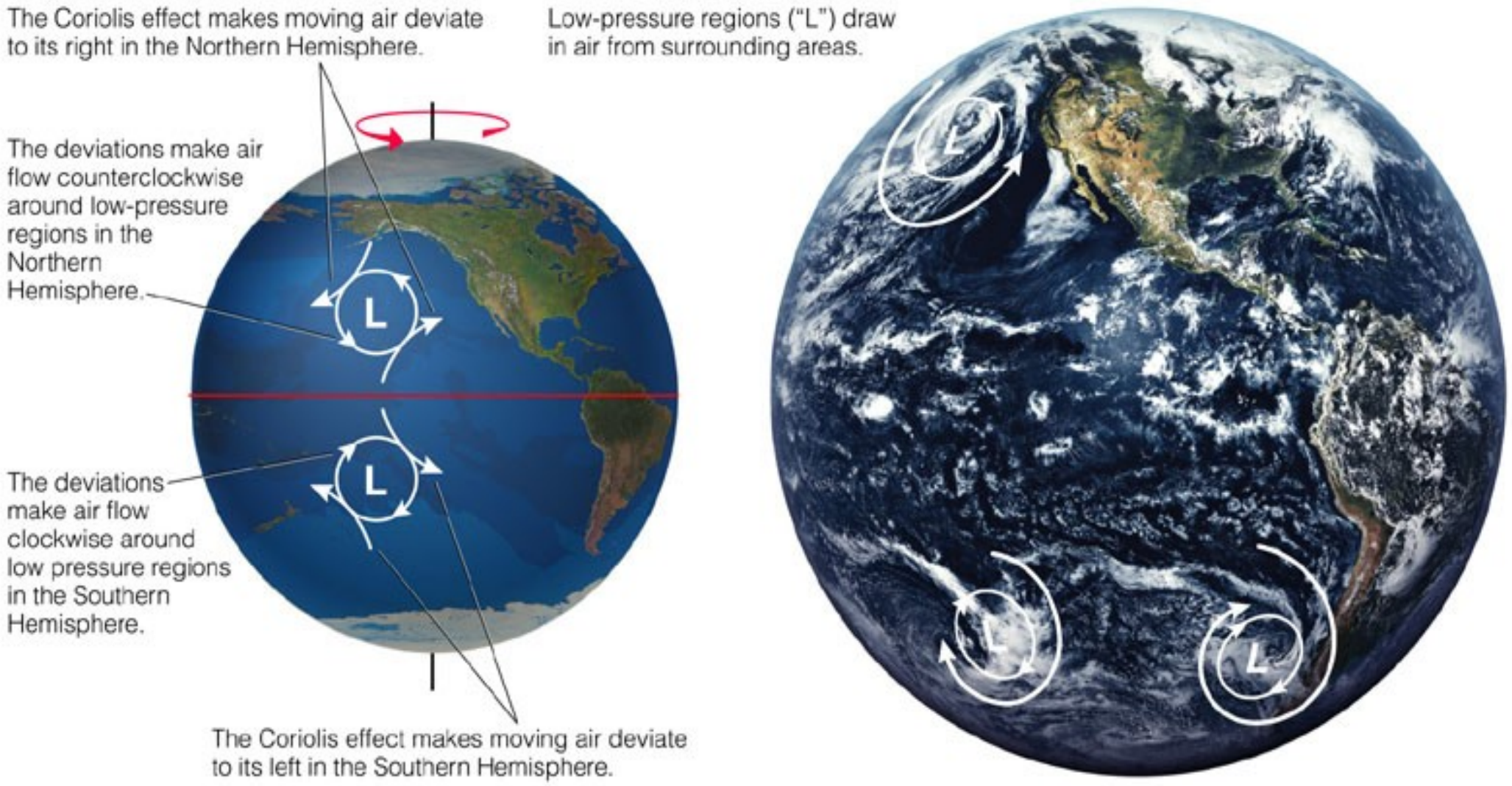
2. The coriolis effect

Forces produced in a rotating reference frame.



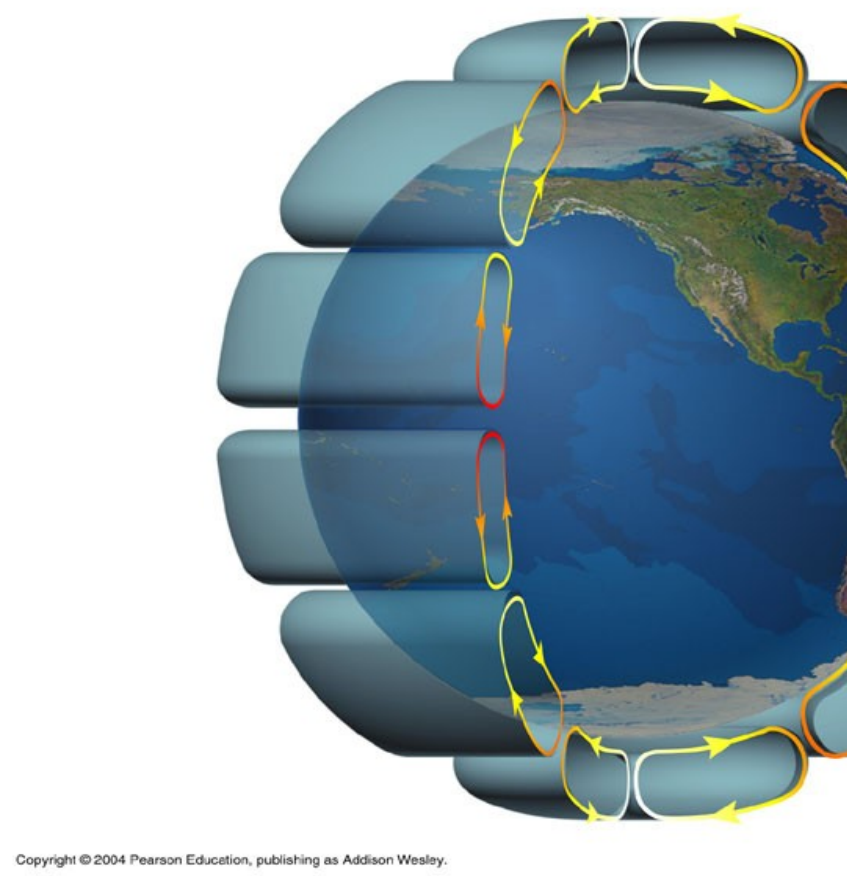
Causes linear motion to appear to curve.

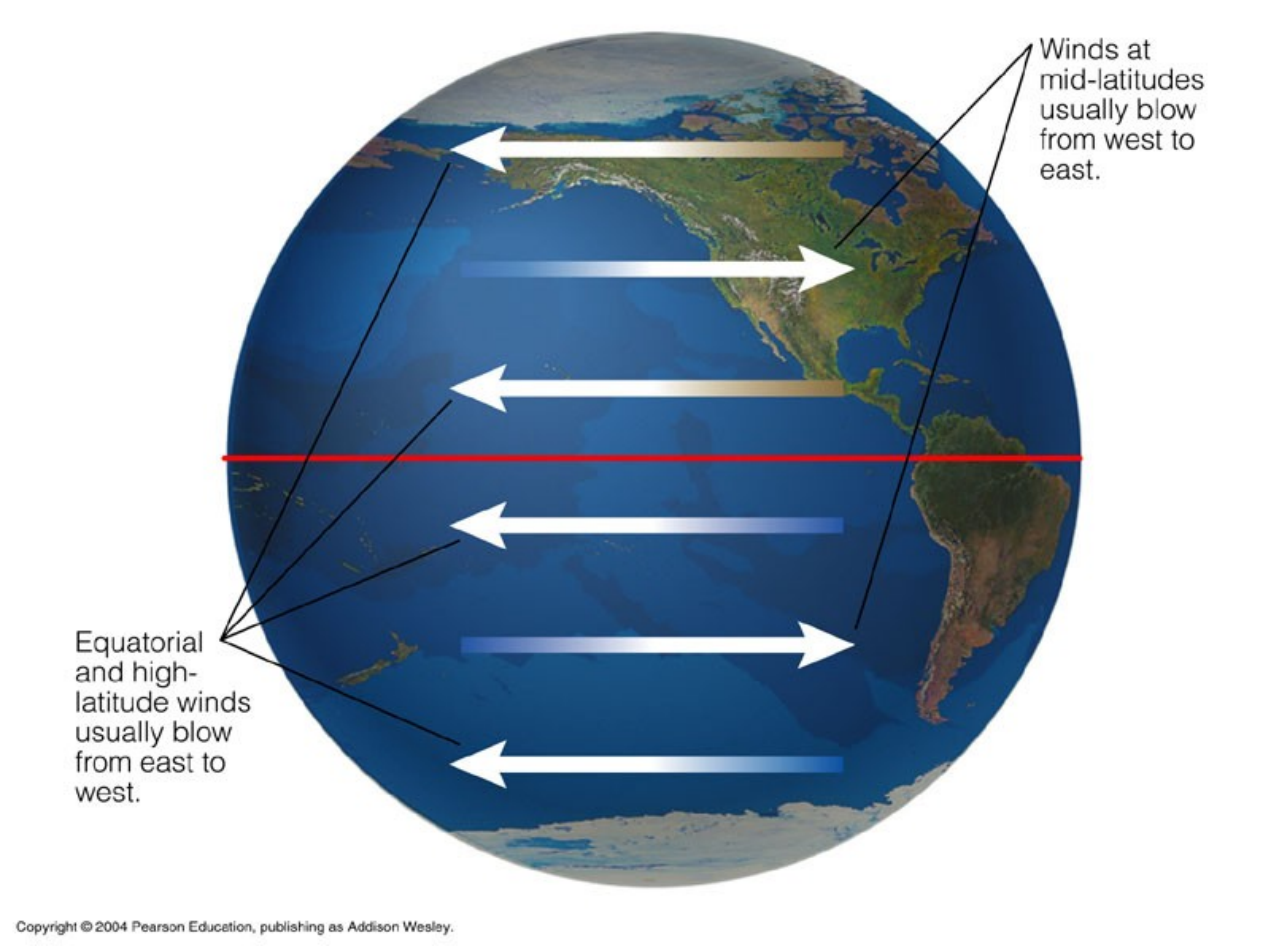
3. Causes local circulatory motion



Produces familiar counter-clockwise rotation around a low-pressure system in N. hemisphere

of bands depends on spin rate



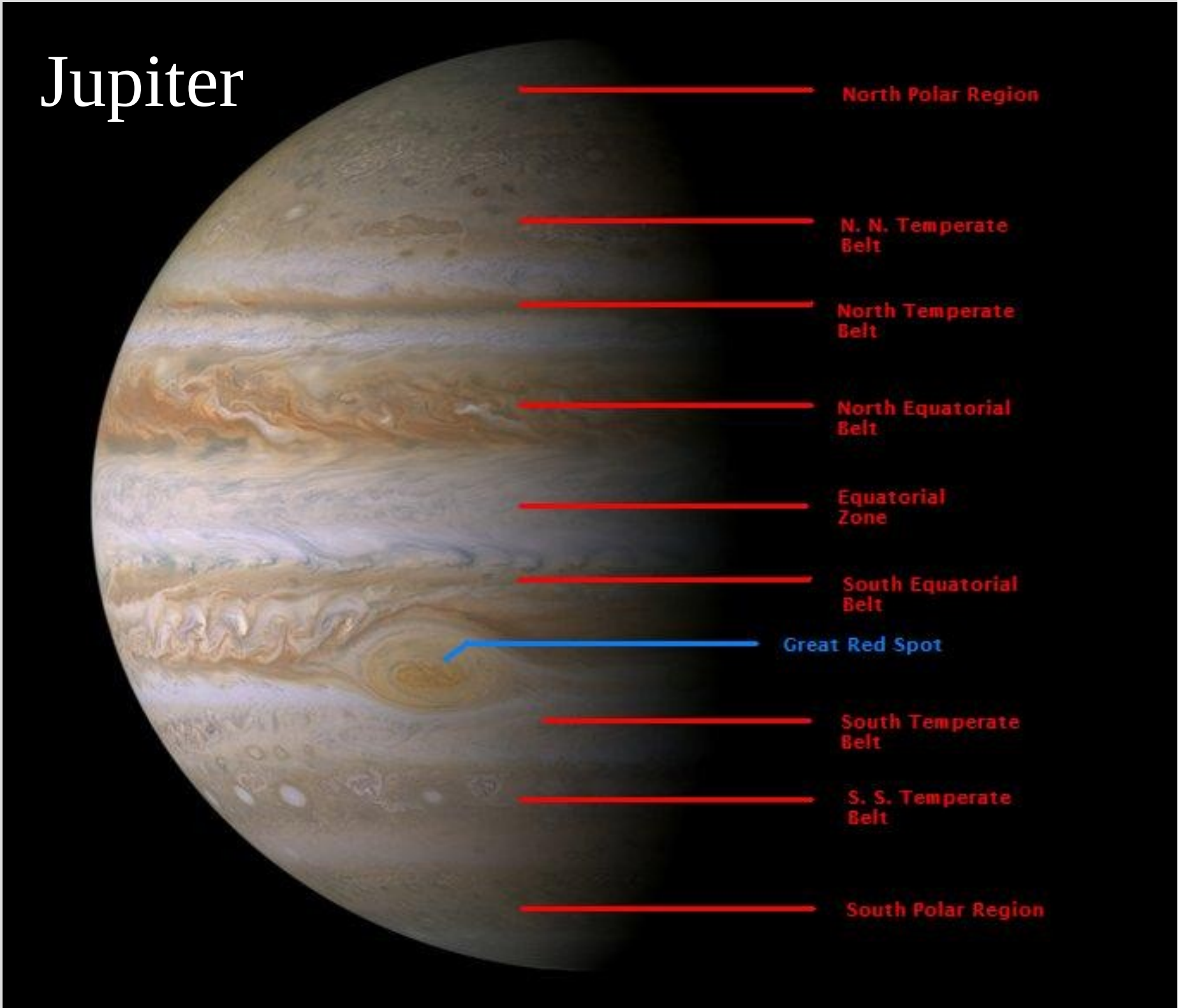


On Earth there are 3 bands per hemisphere

There ARE local modifications (eg. Gulf stream)

Jupiter (eg.) spins faster --> Many bands

Jupiter


North Polar Region
N. N. Temperate Belt
North Temperate Belt
North Equatorial Belt
Equatorial Zone
South Equatorial Belt
Great Red Spot
South Temperate Belt
S. S. Temperate Belt
South Polar Region

Planetary Atmospheres and climate

- Atmosphere of the Earth
- Climate
- Long-term changes

Outgassing on Earth

From the Kilauea volcano (Hawaii) (deep mantle outgassing)

~50% H_20

~20% CO_2

~10% N_2

<1% SO_2

Tiny Ar, Ne, Kr

None O_2

Current atmosphere

78.1% N_2

21.0% O_2

0.93% Ar

0.03% CO_2

.002% Ne

.0001% Kr

.001-1.0% H_20 (variable)

If Venus outgassed the same...

Where did all the water go?

If outgassed TODAY: Too hot...water goes to steam immediately

UV in upper atmosphere breaks up water into:

Oxygen : Goes into H_2S0_4 sulfuric acid

Hydrogen : some escapes, rest to H_2S0_4

Deuterium (H with neutron) stays longer because heavier

But the outgassed CO_2 stays in the atmosphere

So Earth's atmosphere, which has the water extracted into the oceans, should have lots of carbon dioxide, right??

So Earth's atmosphere, which has the water extracted into the oceans, should have lots of carbon dioxide, right??

Wrong.

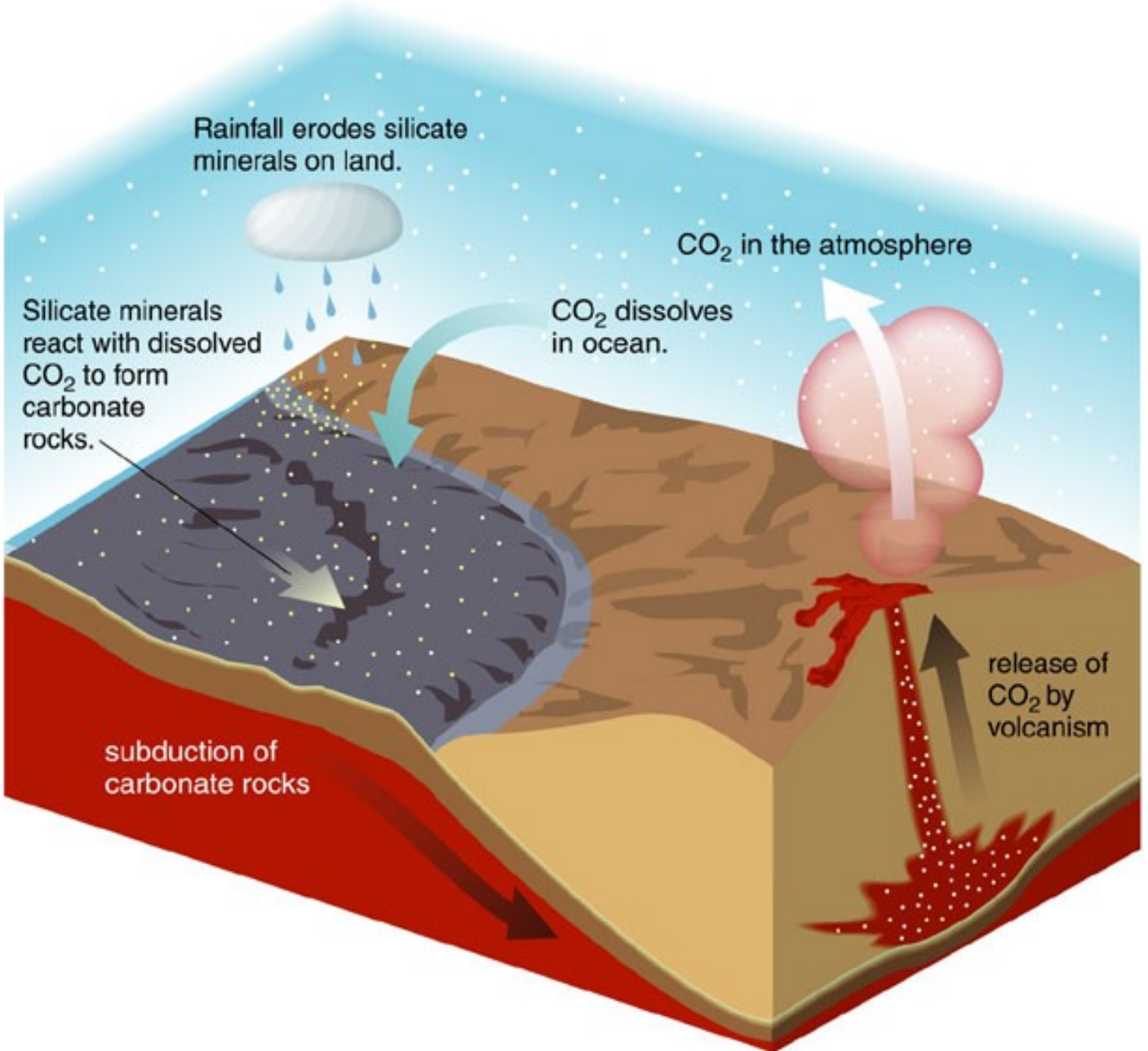
There is little CO2 in Earth's atmosphere.

Where did it go???

The CO_2 cycle on Earth: a critical atmospheric regulator

When carbon dioxide is outgassed on Earth, it gets 'locked up' in silicate rocks in the oceans.

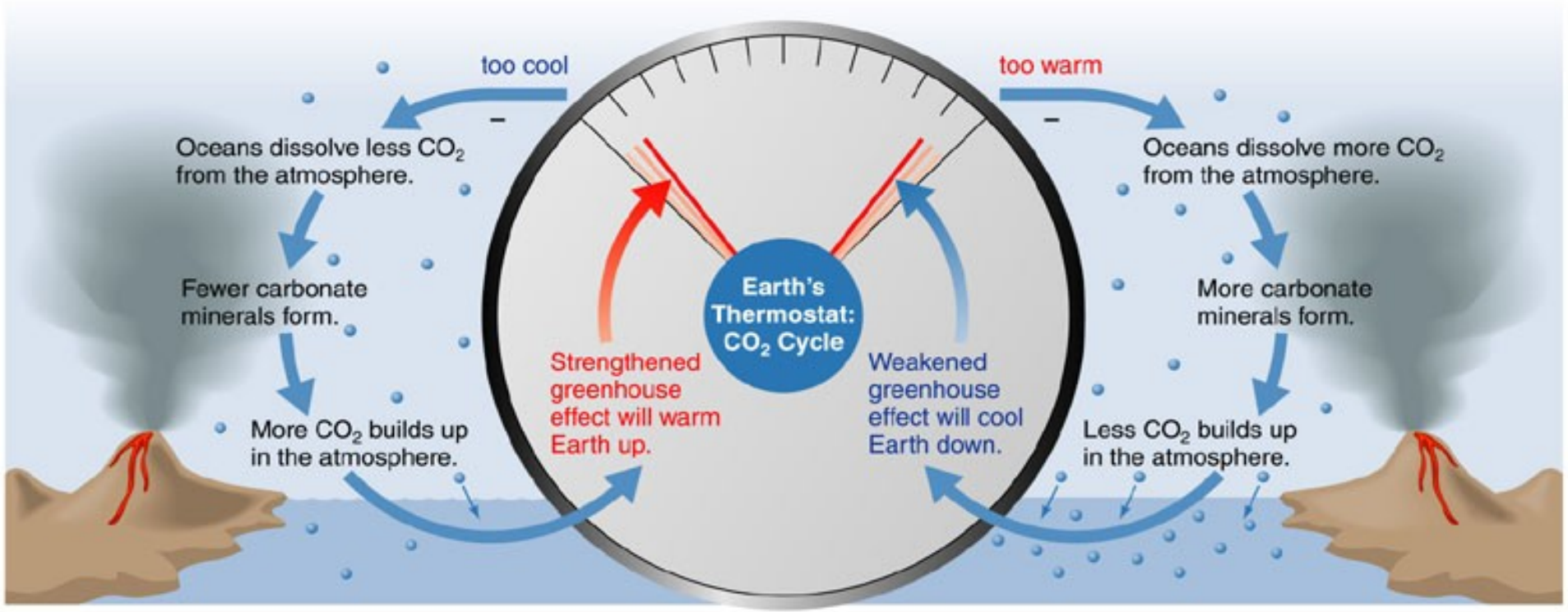
Some is recycled at subduction zones, returning to atmosphere



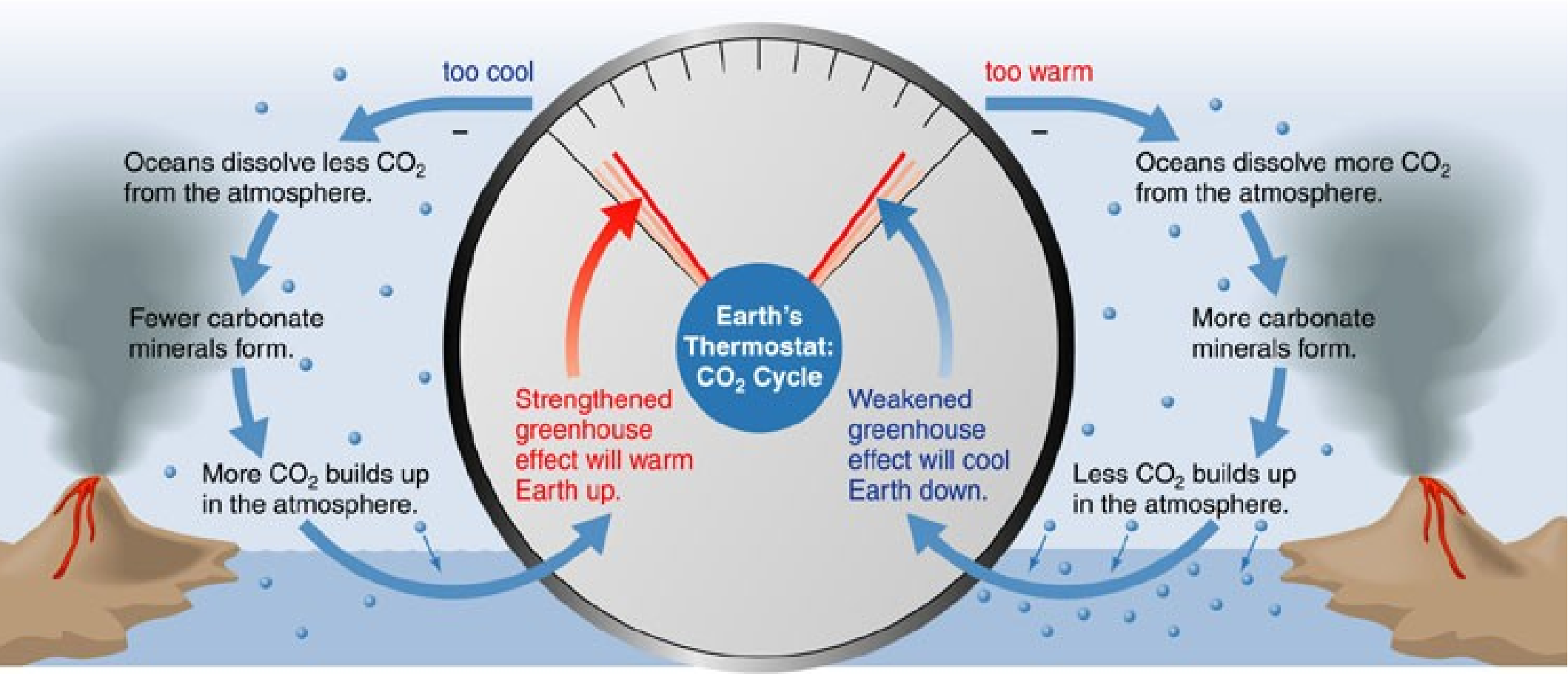
The CO_2 cycle on Earth: a critical atmospheric regulator

A negative feedback process

Works because the ability of the oceans to absorb CO_2 *increases with temperature*



The CO_2 cycle on Earth: a critical atmospheric regulator



Because return to atmosphere is via volcanoes/plate tectonics, this regulator works on GEOLOGIC time scales

So...on Earth...

The outgassed water is extracted into the oceans because the T and P are right to have liquid water on its surface

This T is of course *due* to greenhouse gases warming the planet...

The outgassed CO_2 is trapped in carbonate rocks on the sea floor.

What does this leave???

Outgassing on Earth

From the Kilauea volcano (Hawaii) (deep mantle outgassing)

~50% H_20

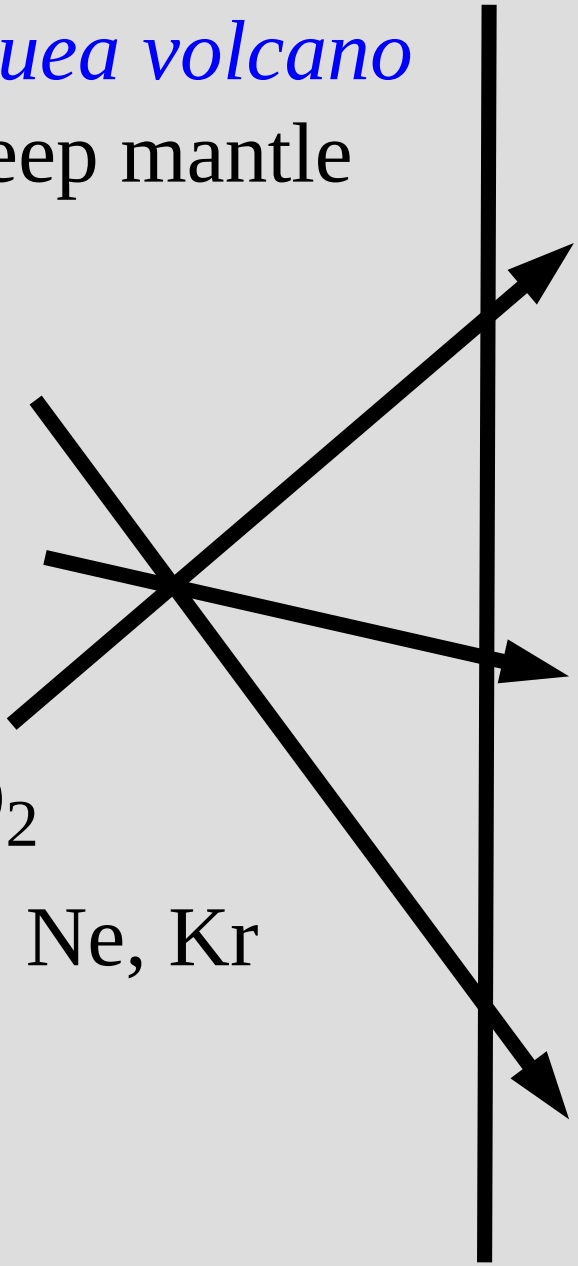
~20% CO_2

~10% N_2

<1% SO_2

Tiny Ar, Ne, Kr

None O_2



Current atmosphere

78.1% N_2

21.0% O_2

0.93% Ar

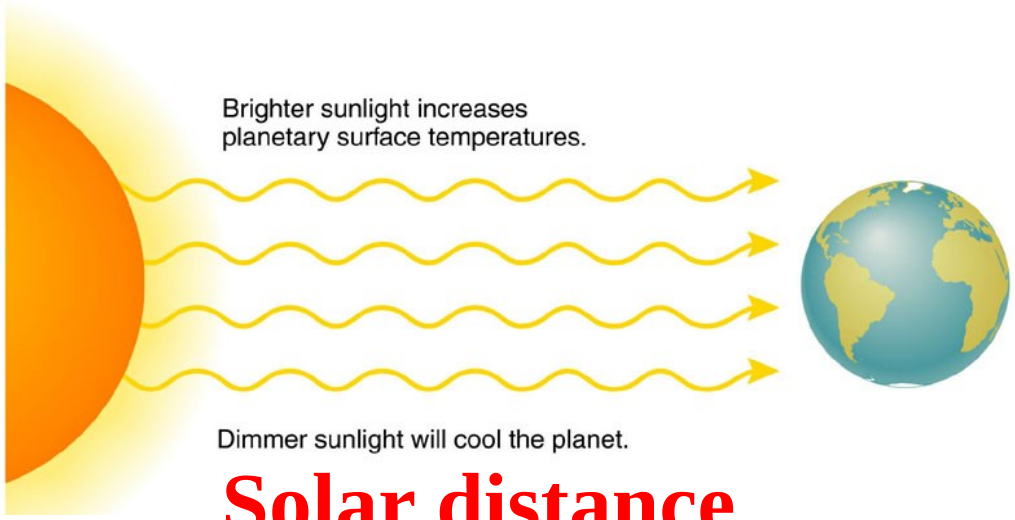
0.03% CO_2

.002% Ne

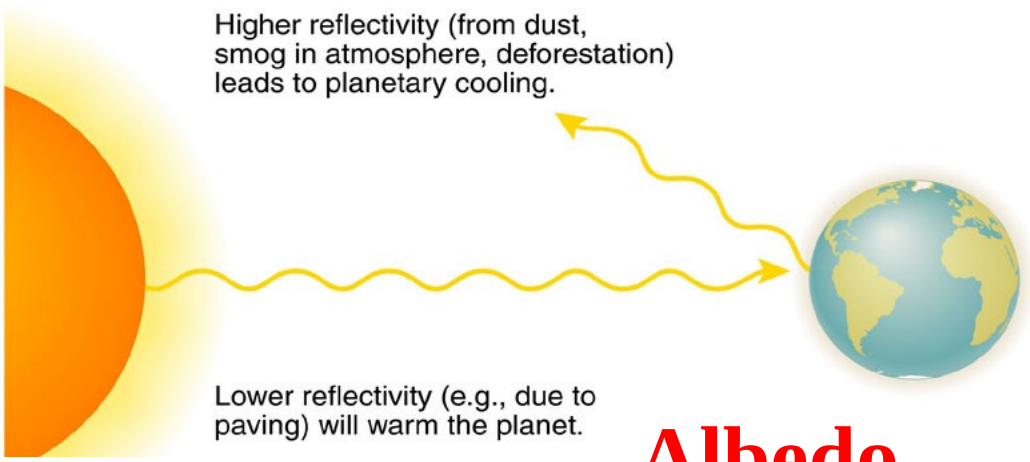
.0001% Kr

.001-1.0% H_20 (variable)

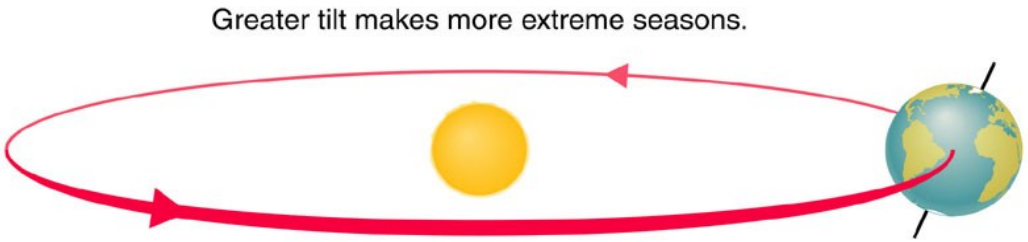
Four factors affecting climate



Solar distance

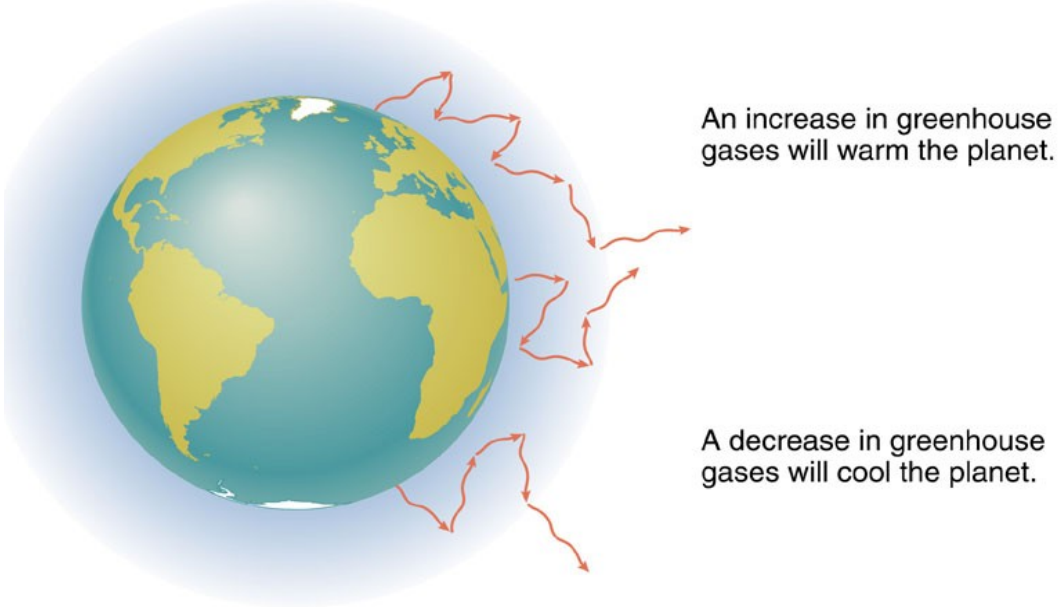


Albedo



spin

obliquity/tilt

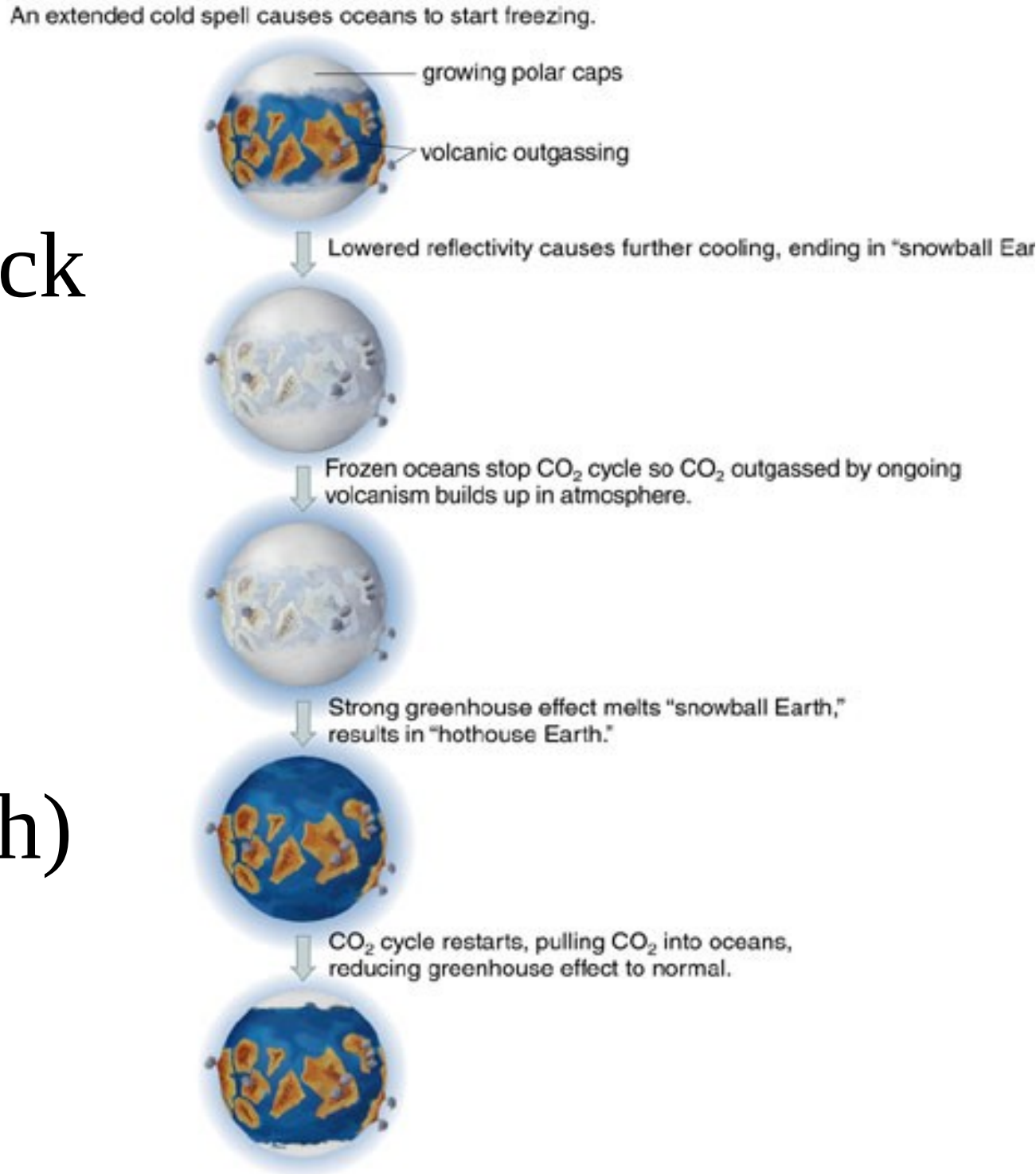


greenhouse effect

Another feedback loop

Reflectivity

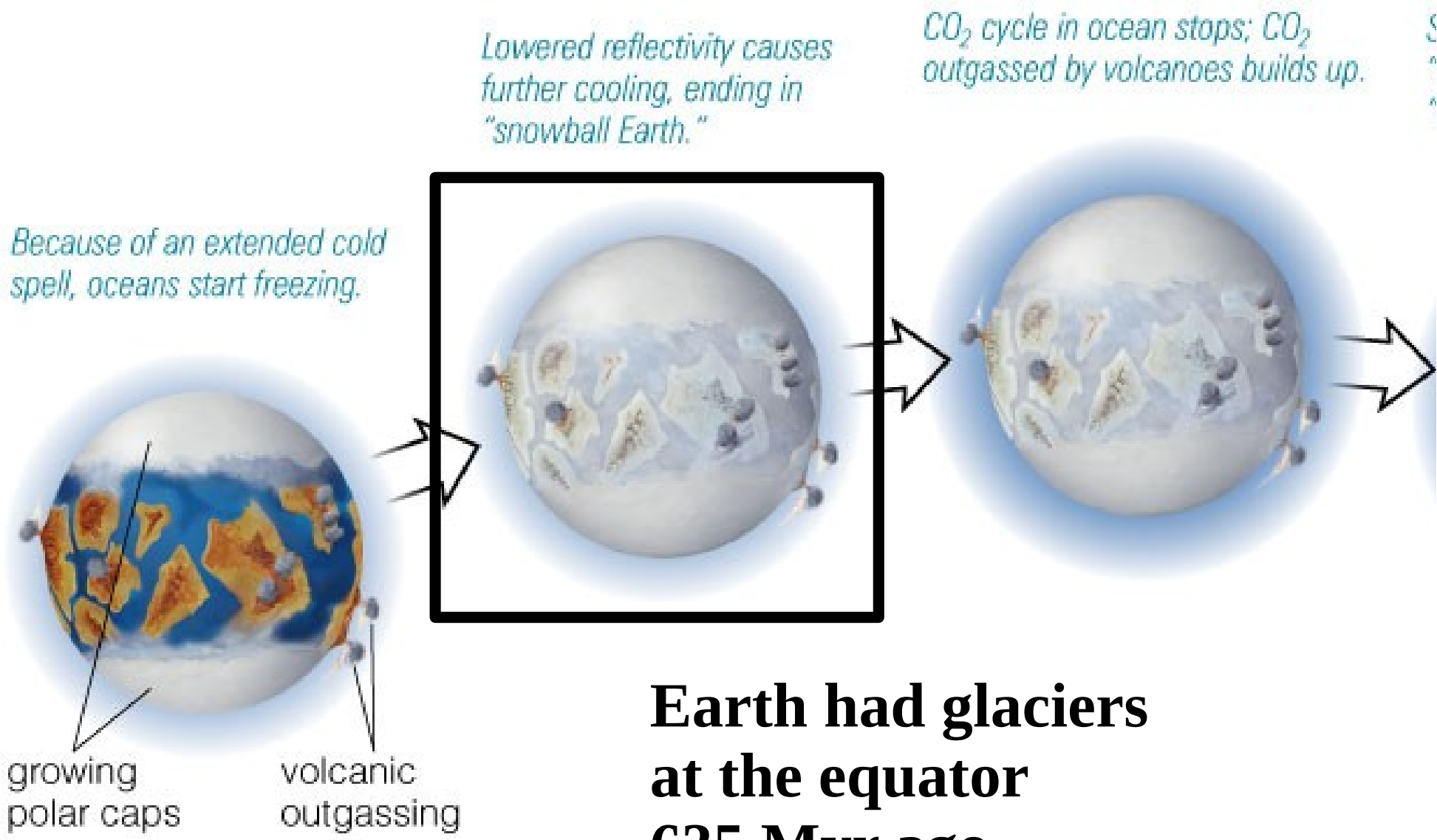
(Snowball Earth)



How does this *positive* loop work?

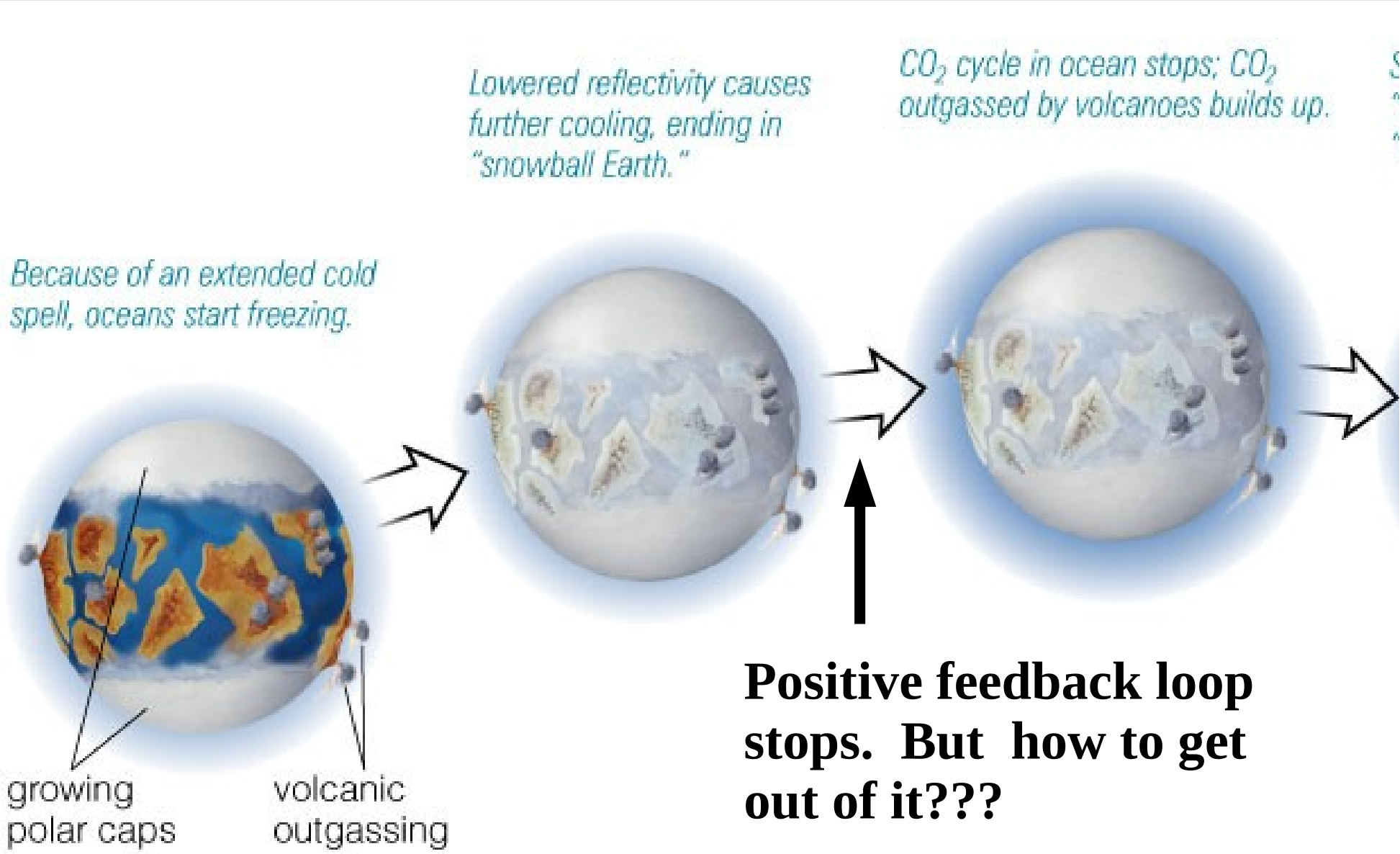
1. **Suppose ice caps grow bigger**
2. **Ice is white...reflectivity (albedo) goes up**
3. **Less solar light absorbed by Earth**
4. **Temperature at poles drops**
5. **Encourages ice formation; return to (1) !**

Snowball Earth



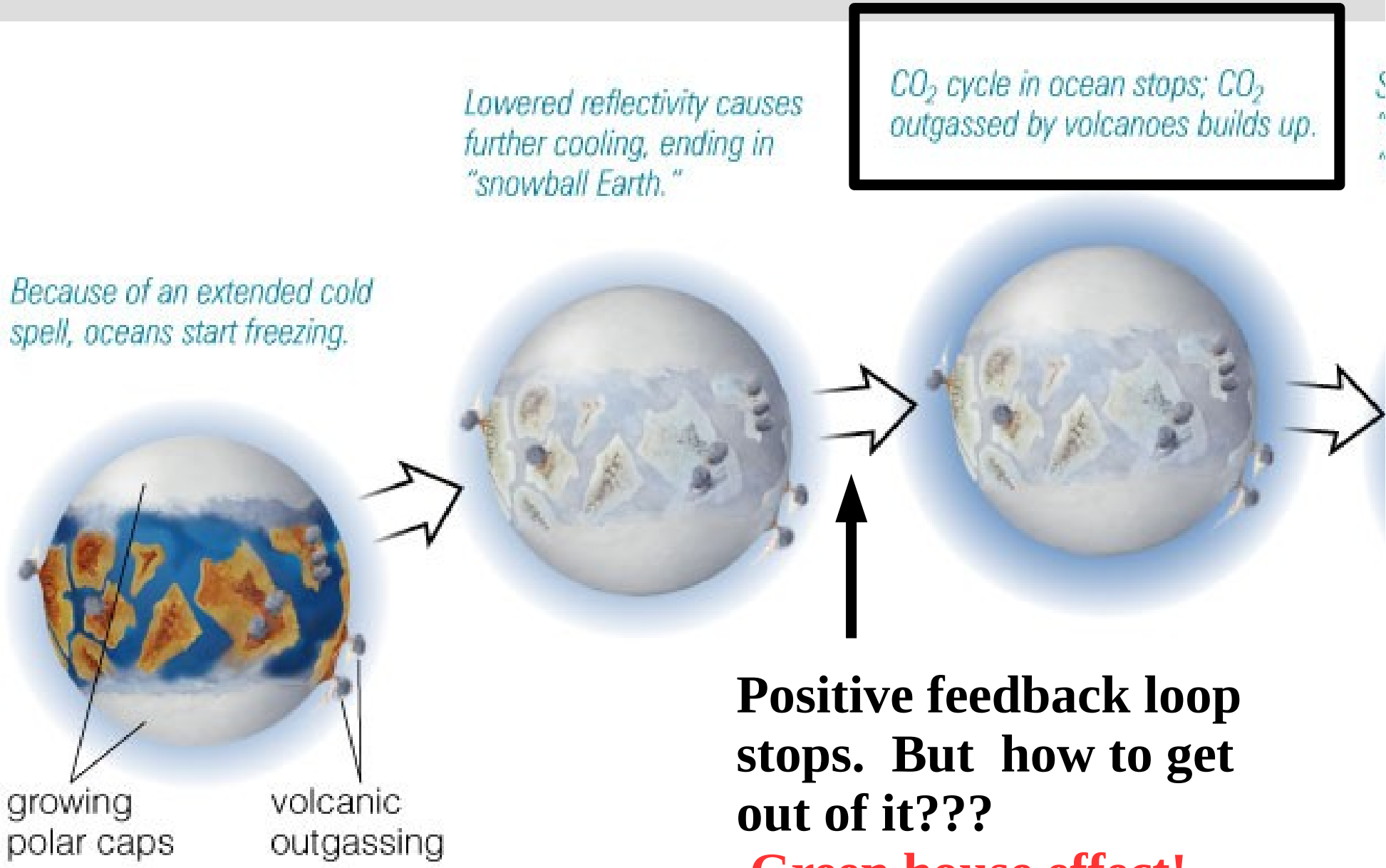
Earth had glaciers at the equator 635 Myr ago

Snowball Earth



Positive feedback loop stops. But how to get out of it???

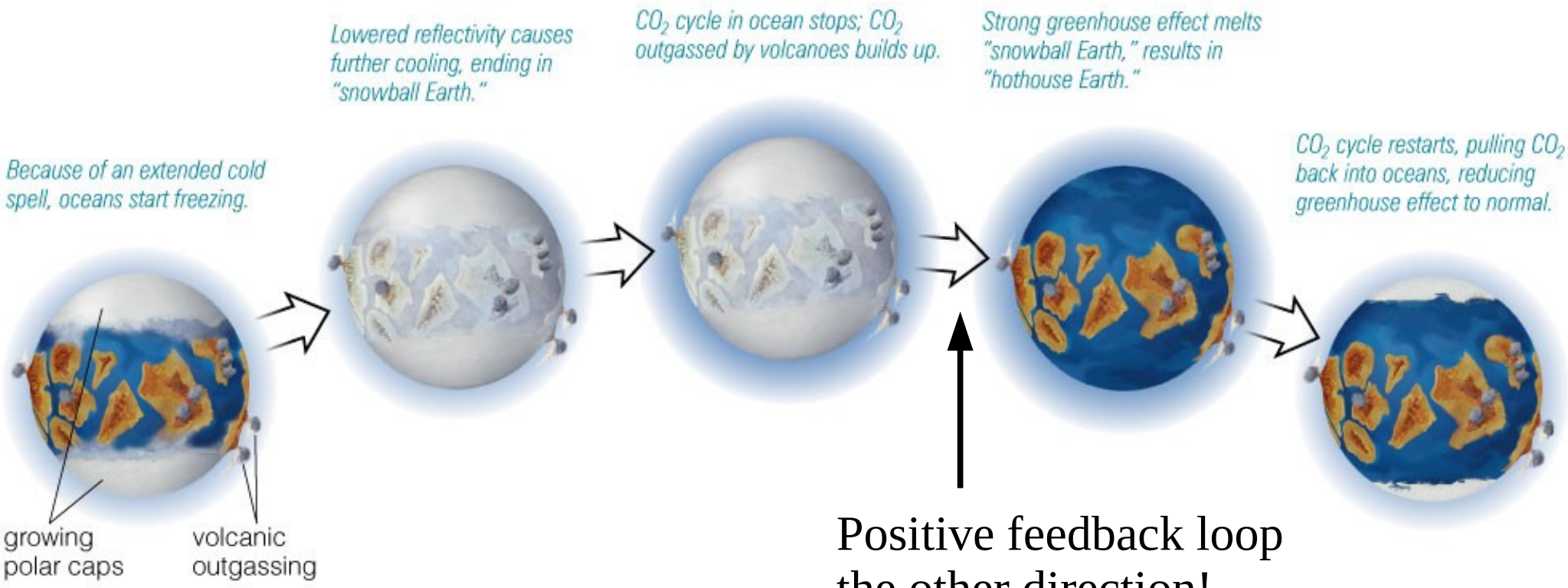
Snowball Earth



Positive feedback loop stops. But how to get out of it???

Green house effect!

Snowball Earth / Hothouse Earth



Positive feedback loop the other direction!
Ice melted in only 10,000 years!

The positive feedback loop about arctic sea ice

In the news recently

CBC news | Canada

IN THE NEWS
- Occupy opinion
- Black Friday sh

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Canada | North | Photo Galleries

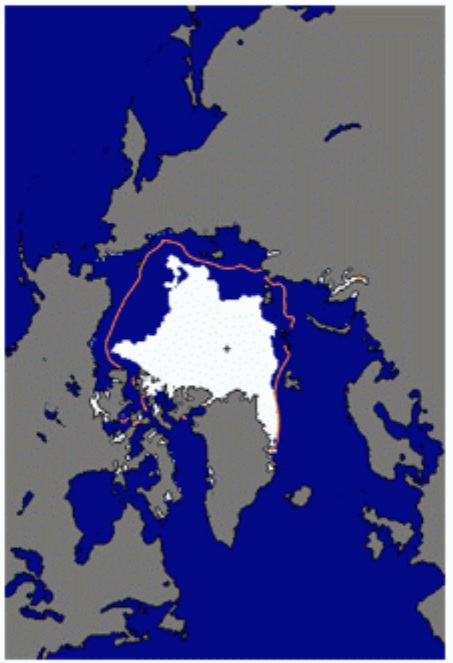
Arctic ice near all-time low, 2nd study confirms

The Canadian Press Posted: Sep 15, 2011 4:54 PM CT | Last Updated: Sep 15, 2011 5:03 PM CT 244

A second major scientific body has said Arctic sea ice is about as low as it's ever been since satellites began monitoring it.

And a researcher at the U.S.-based National Snow and Ice Data Center said that open water at the top of the globe may already be affecting weather in more southern reaches of North America.

The amount of ice in the North is almost at the all-time low of 2007 and could drop further in coming weeks, the centre said Thursday. That assessment came days after German researchers concluded ice cover is already less than it was four years ago, which was the lowest since satellite monitoring began in 1979.



Arctic sea ice on Sept. 9, seen by satellite, had retreated 35 per cent from its median 1979-to- 2000 low (indicated by the orange line), U.S. data says. National Snow and Ice Data Center

There is now about one-third less ice in the Arctic than the 1979-2000 average.

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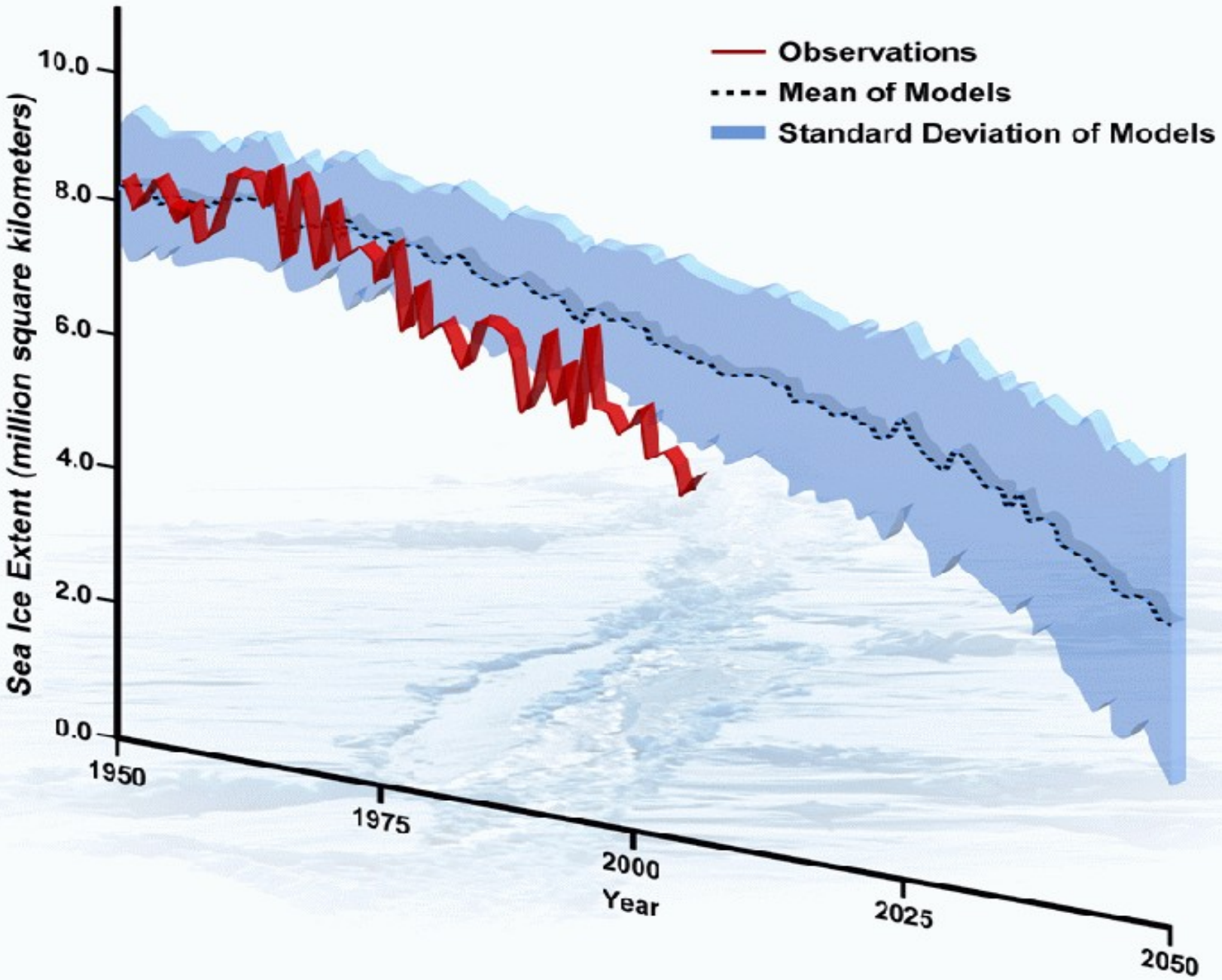
Mobile Facebook

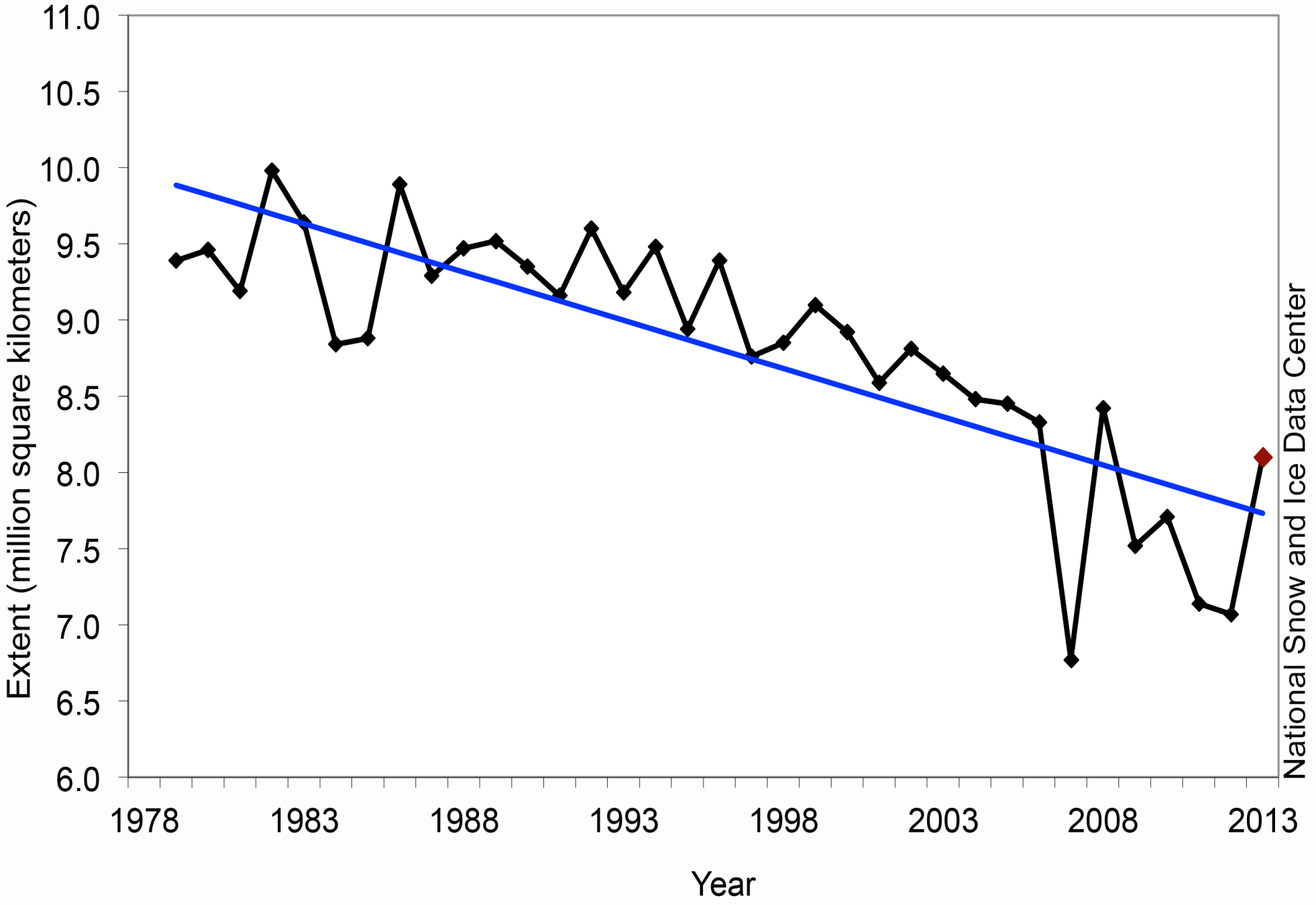
Latest North

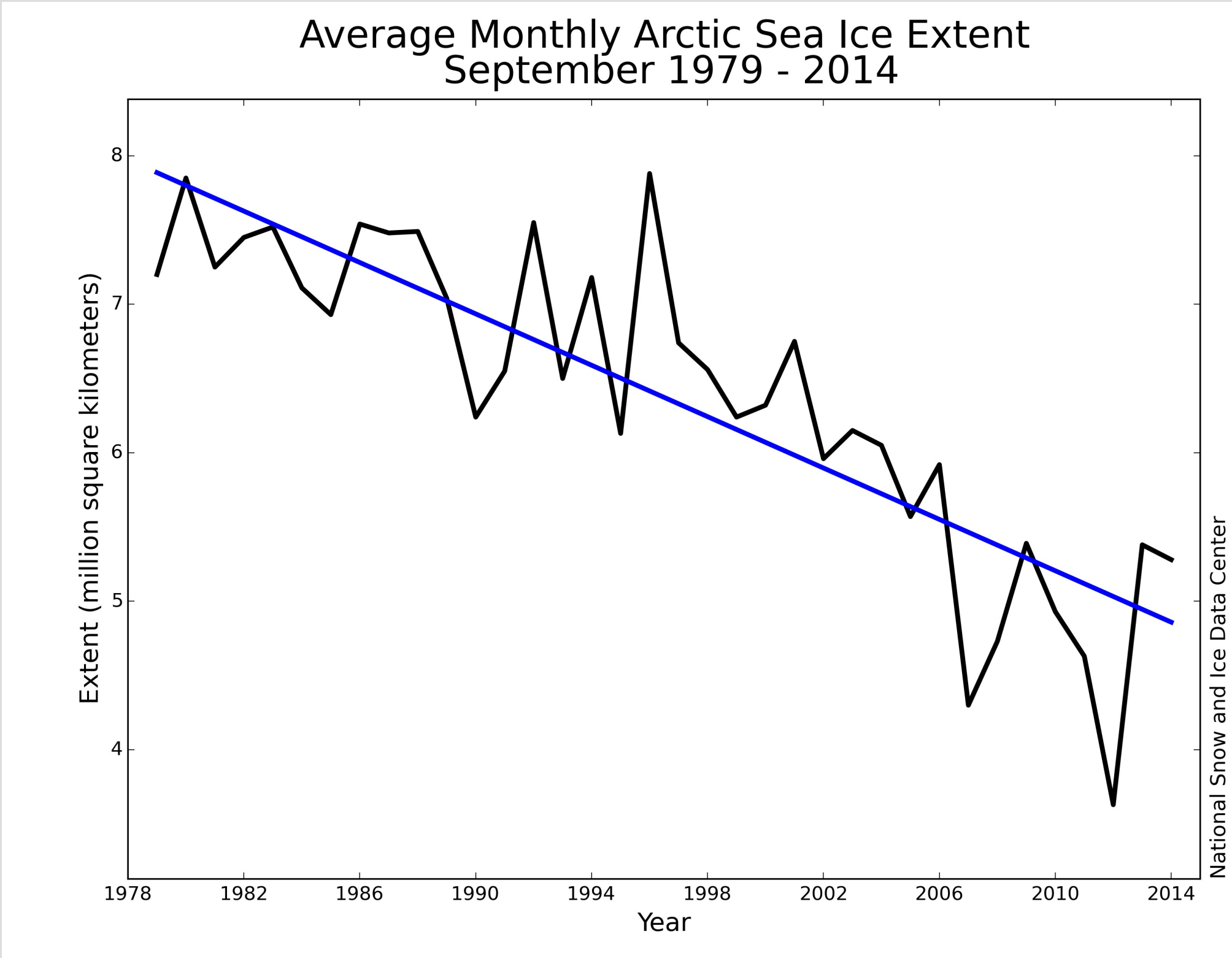
Arctic September Sea Ice Extent: Observations and Model Runs

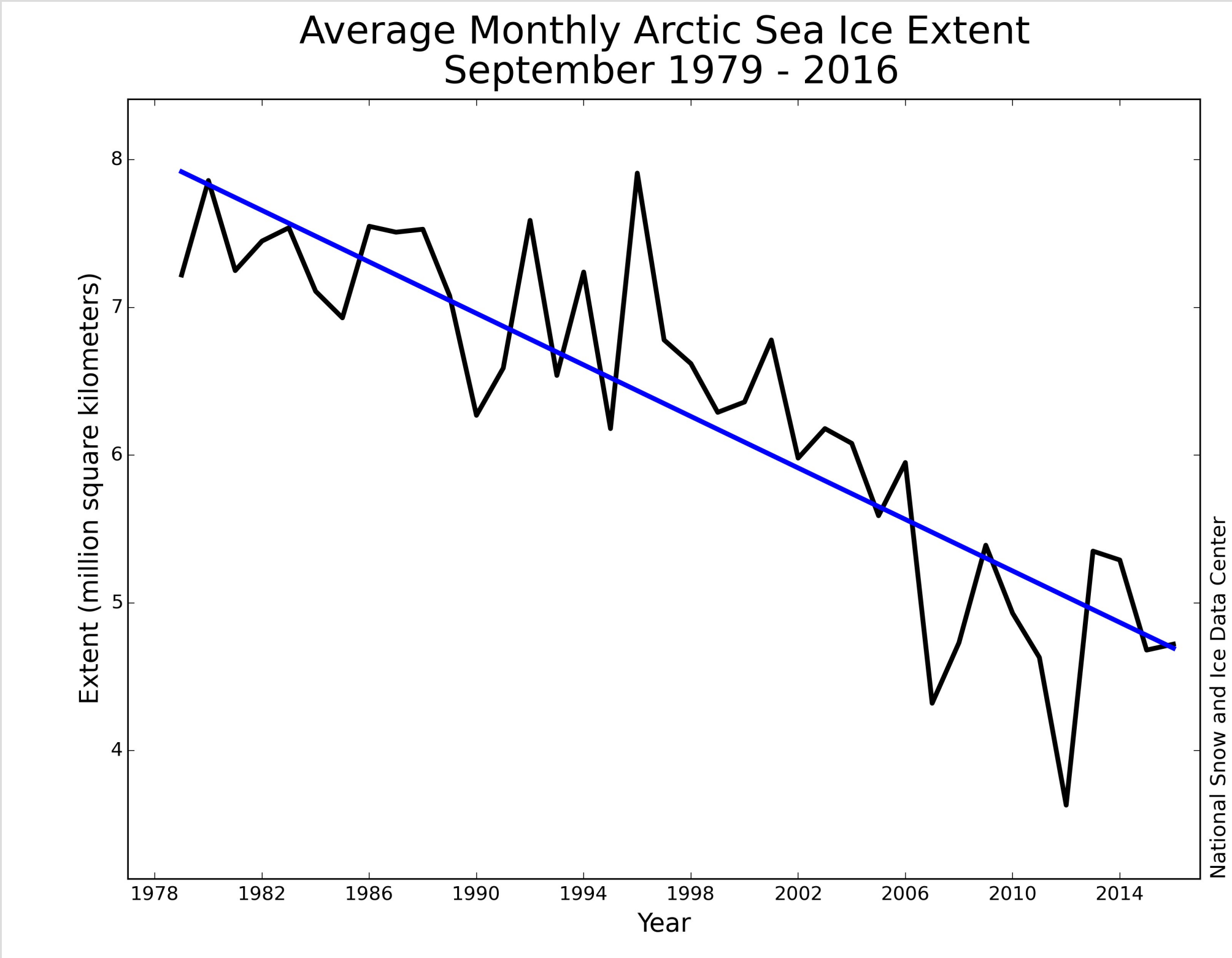


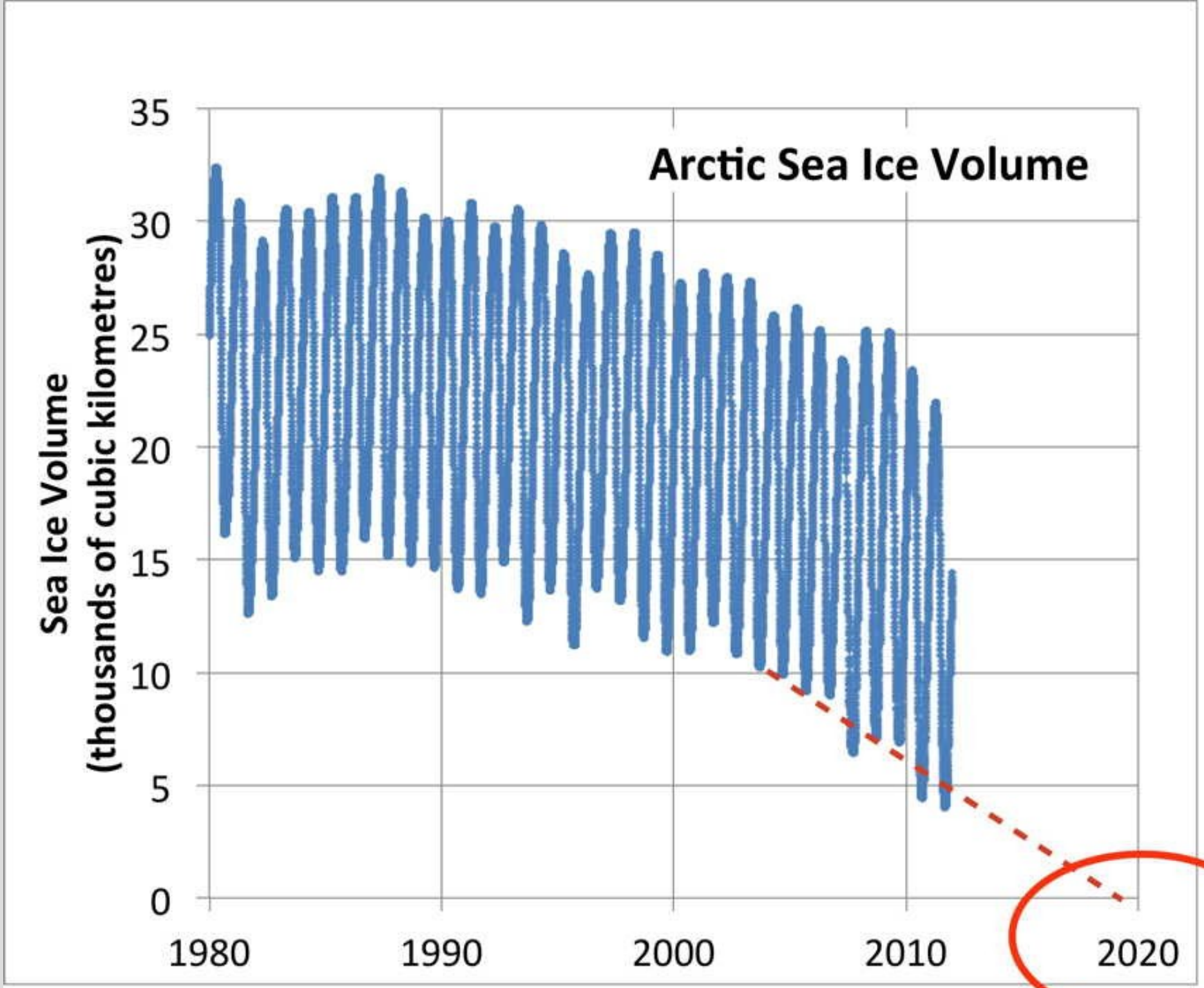
NSIDC data/UCAR image

Average Monthly Arctic Sea Ice Extent
October 1979 - 2013




Average Monthly Arctic Sea Ice Extent
September 1979 - 2014
Extent (million square kilometers)
8
7
6
5
4
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014
Year
National Snow and Ice Data Center


Average Monthly Arctic Sea Ice Extent
September 1979 - 2016
Extent (million square kilometers)
8
7
6
5
4
1978
1982
1986
1990
1994
1998
2002
2006
2010
2014
Year
National Snow and Ice Data Center

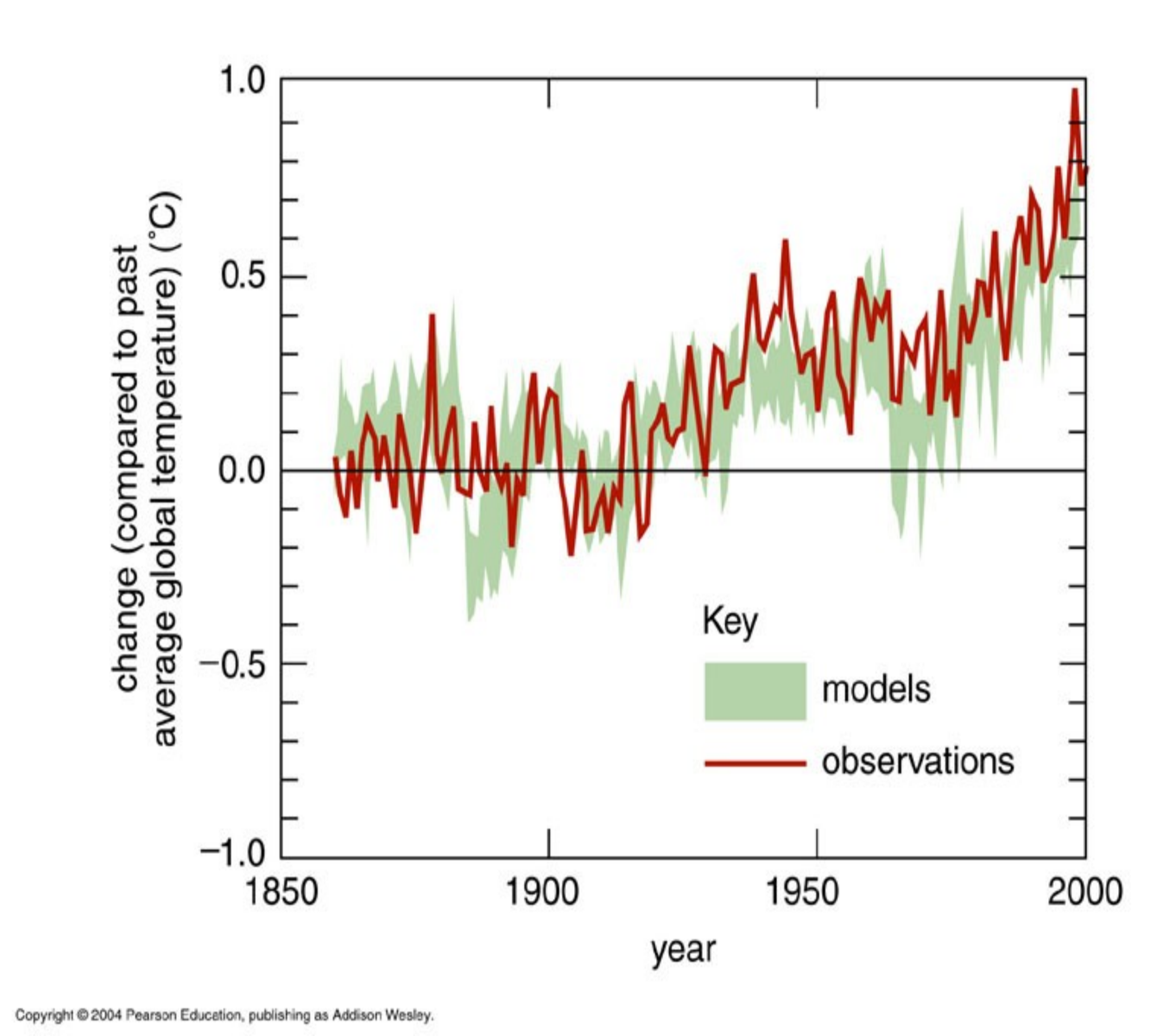

Arctic Sea Ice Volume
Sea Ice Volume
(thousands of cubic kilometres)
35
30
25
20
15
10
5
0
1980
1990
2000
2010
2020

Global climate changes

In the last 50 years, climate has been changing fast.

Global temperatures rising

Is this natural or man-made?



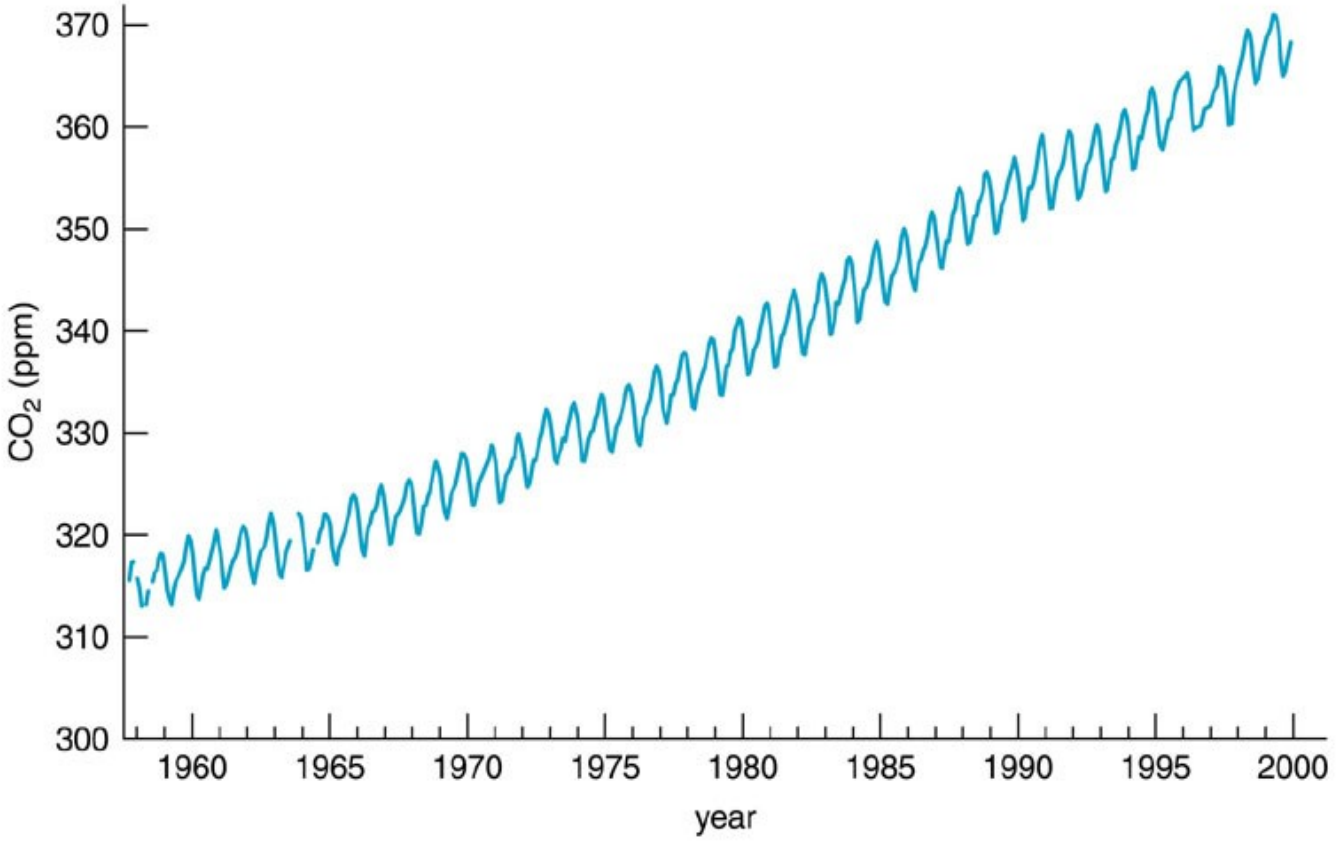
Global atmospheric changes

Global CO2 levels are on the rise

Rate of increase much faster than the rate that the oceans take up the carbon dioxide.

The polar caps and the glaciers ARE melting.

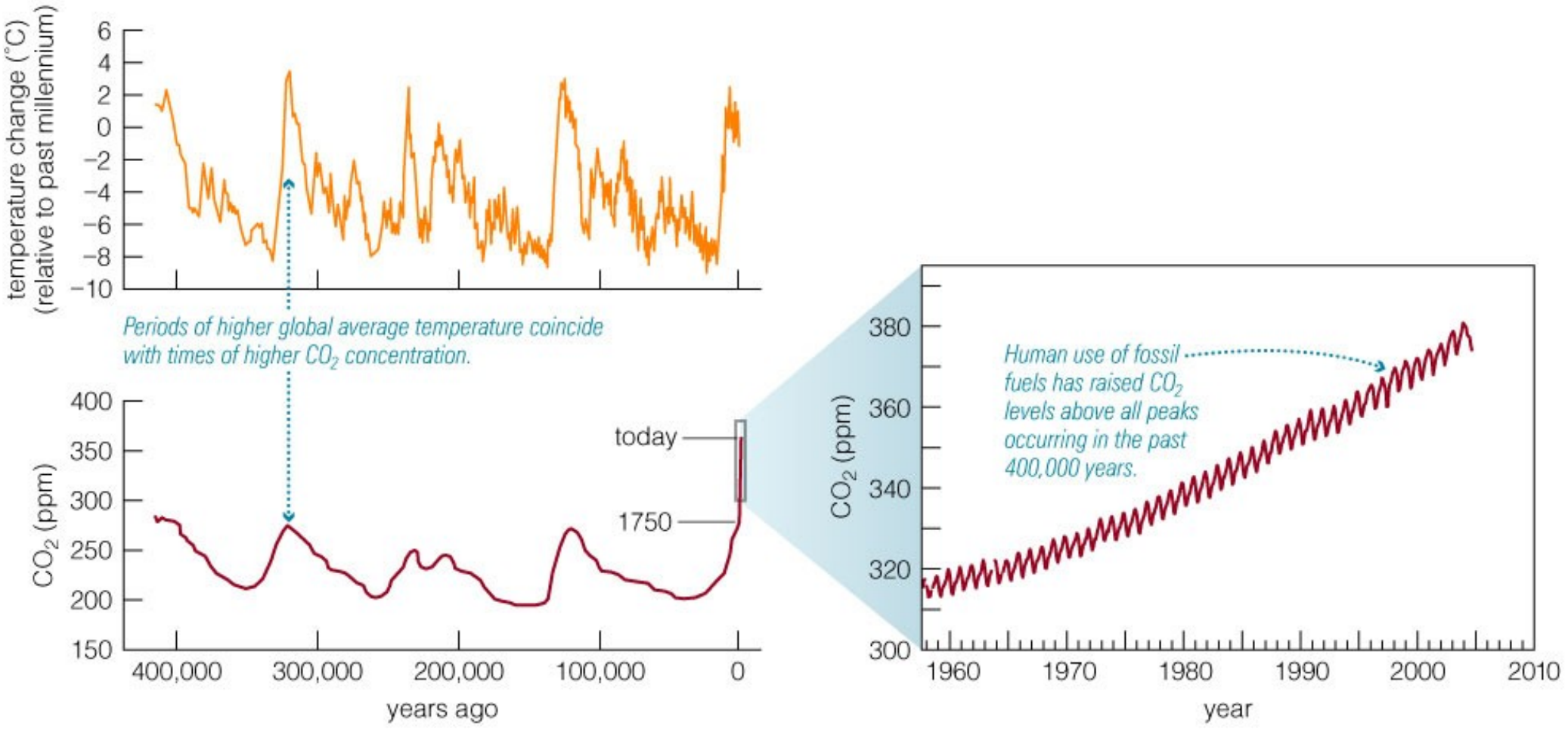
Why do we *care* if it's man-made?



Is this likely just a natural cycle?

No, at least not one seen in the last half-million yr

Ice-core samples record CO2 levels back that far



The hypothesis of natural cycles

Proposal that the current warming is part of the natural heating/cooling cycles and has nothing to do with humans

This is certainly a valid scientific hypothesis

As such, what should we do with it?

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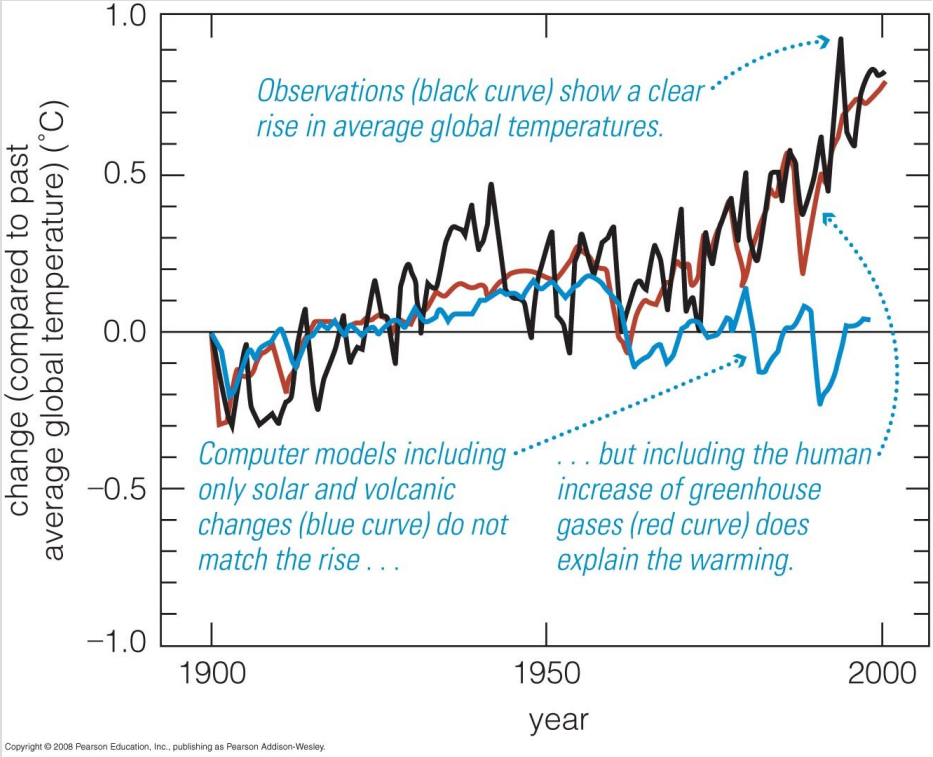
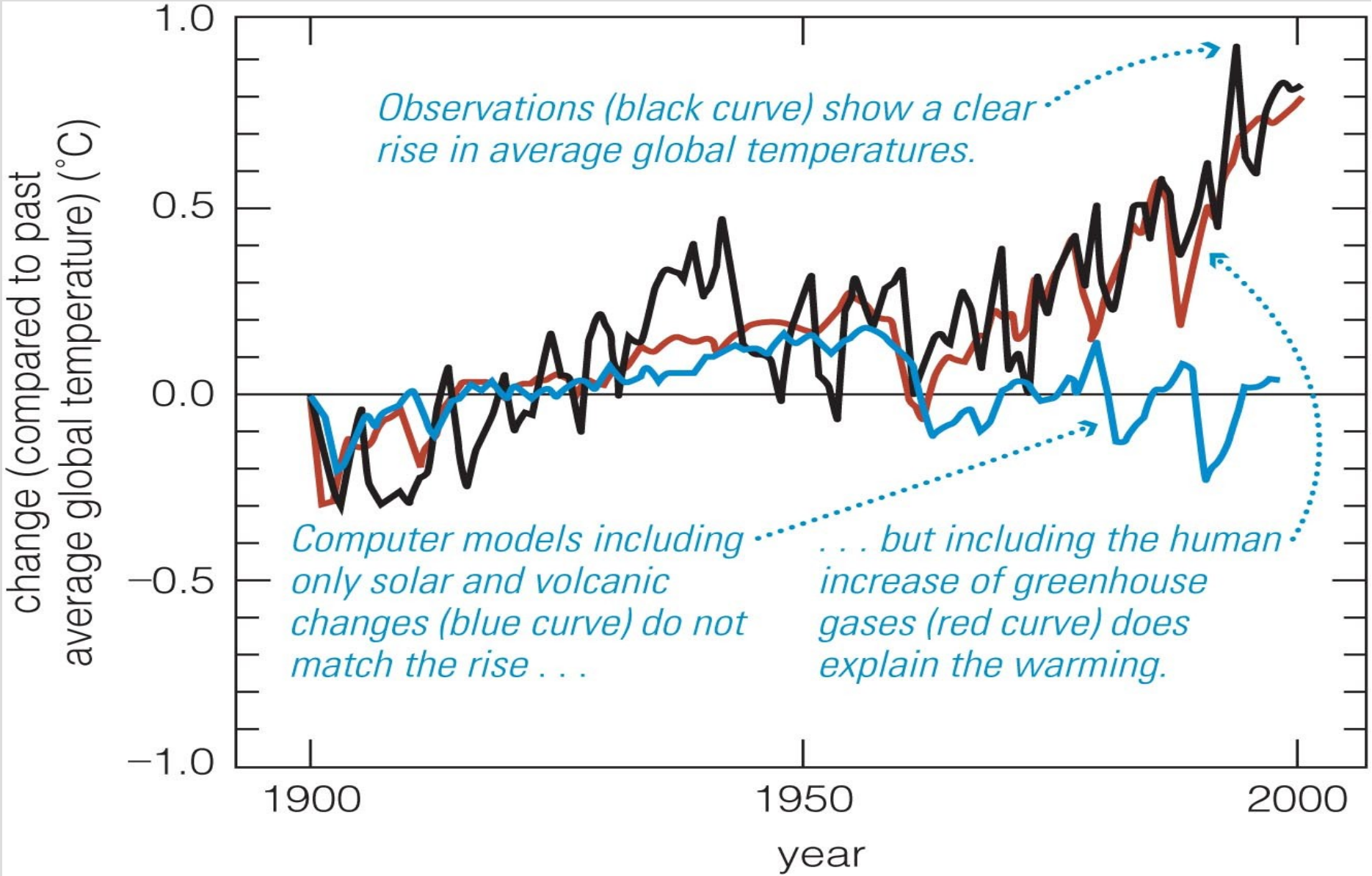
Test it....how???



The hypothesis of natural cycles

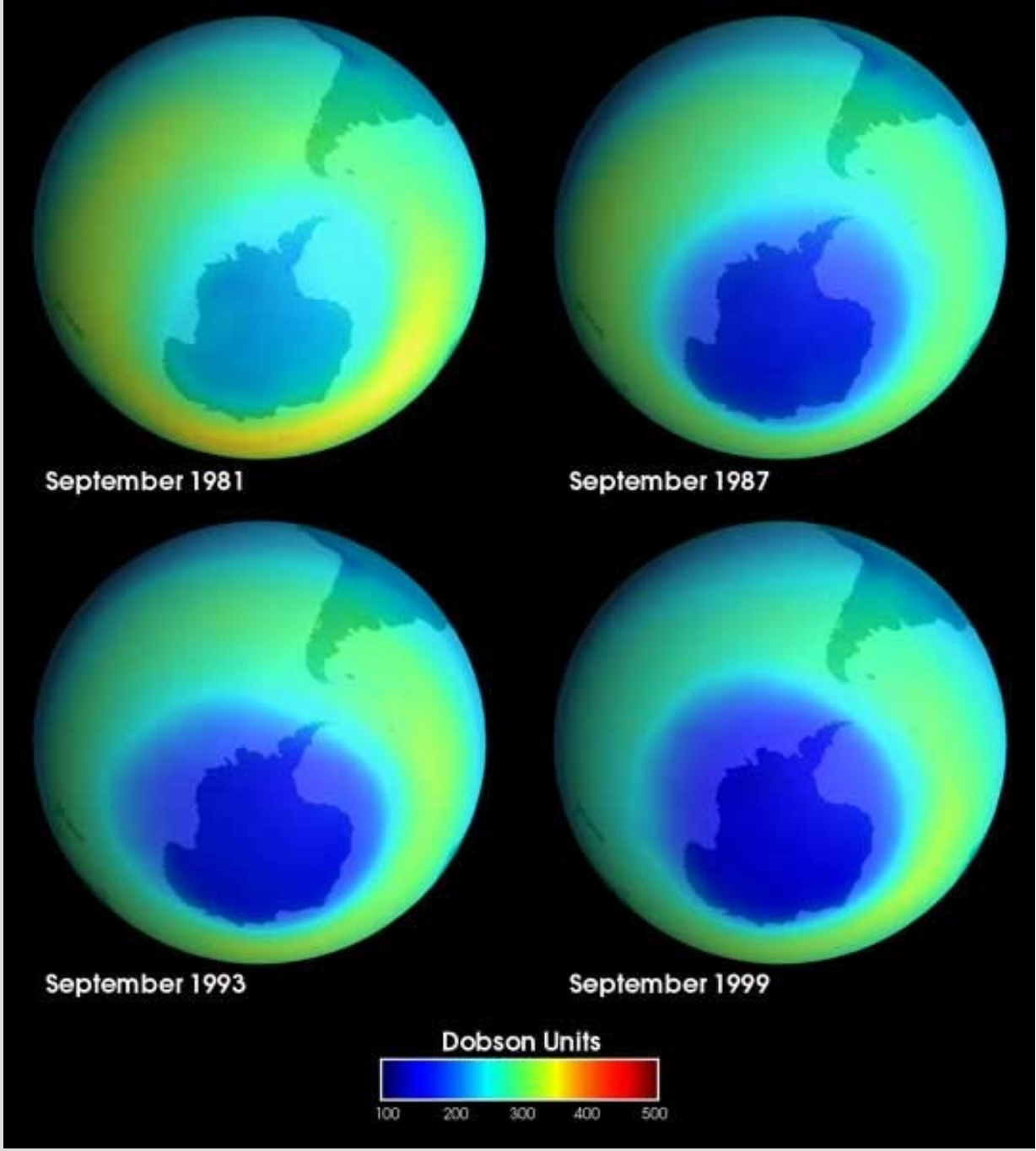
Test it by seeing how the climate would respond if the extra human CO_2 emissions were not there!



The story of the ozone hole

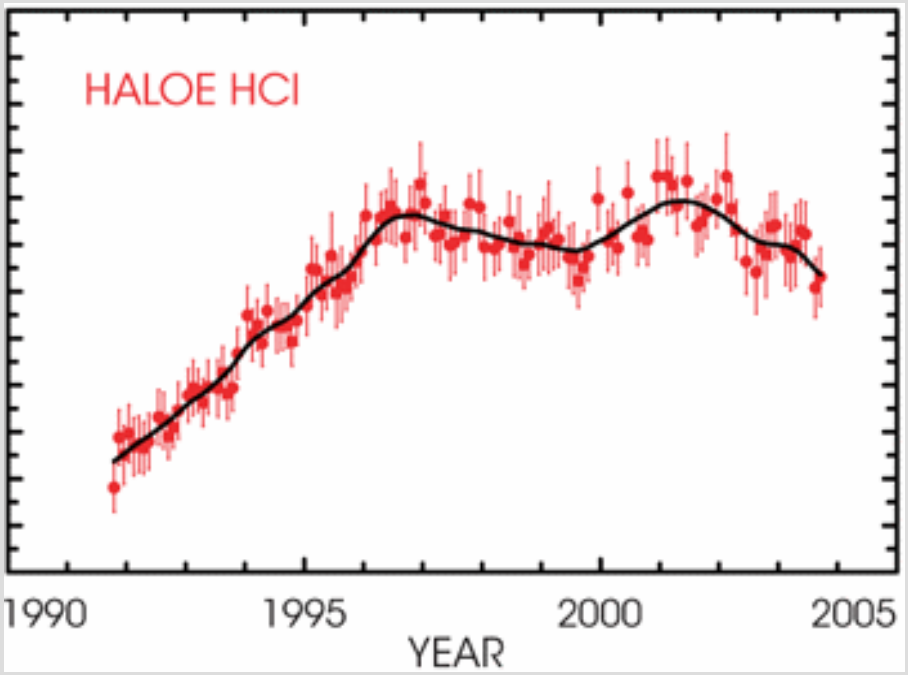
It was realized in the 1970s that an annual hole in the ozone was developing over Antarctica

Global CFCs (which destroy ozone) banned in early 1990s...hole recovering.



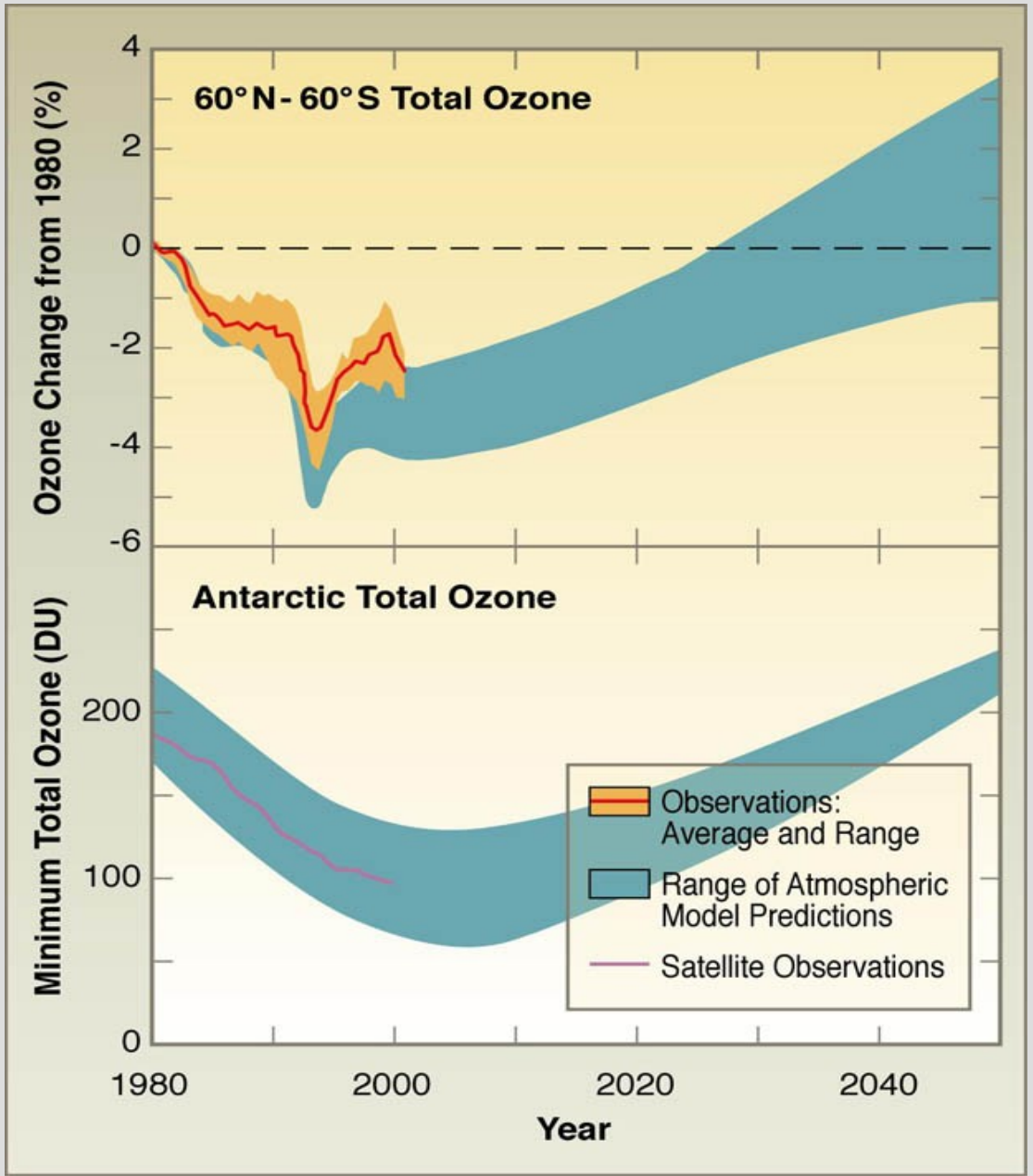
Ban of CFCs caused Hcl to stop increasing

Ozone hole should recover by end of 21st century

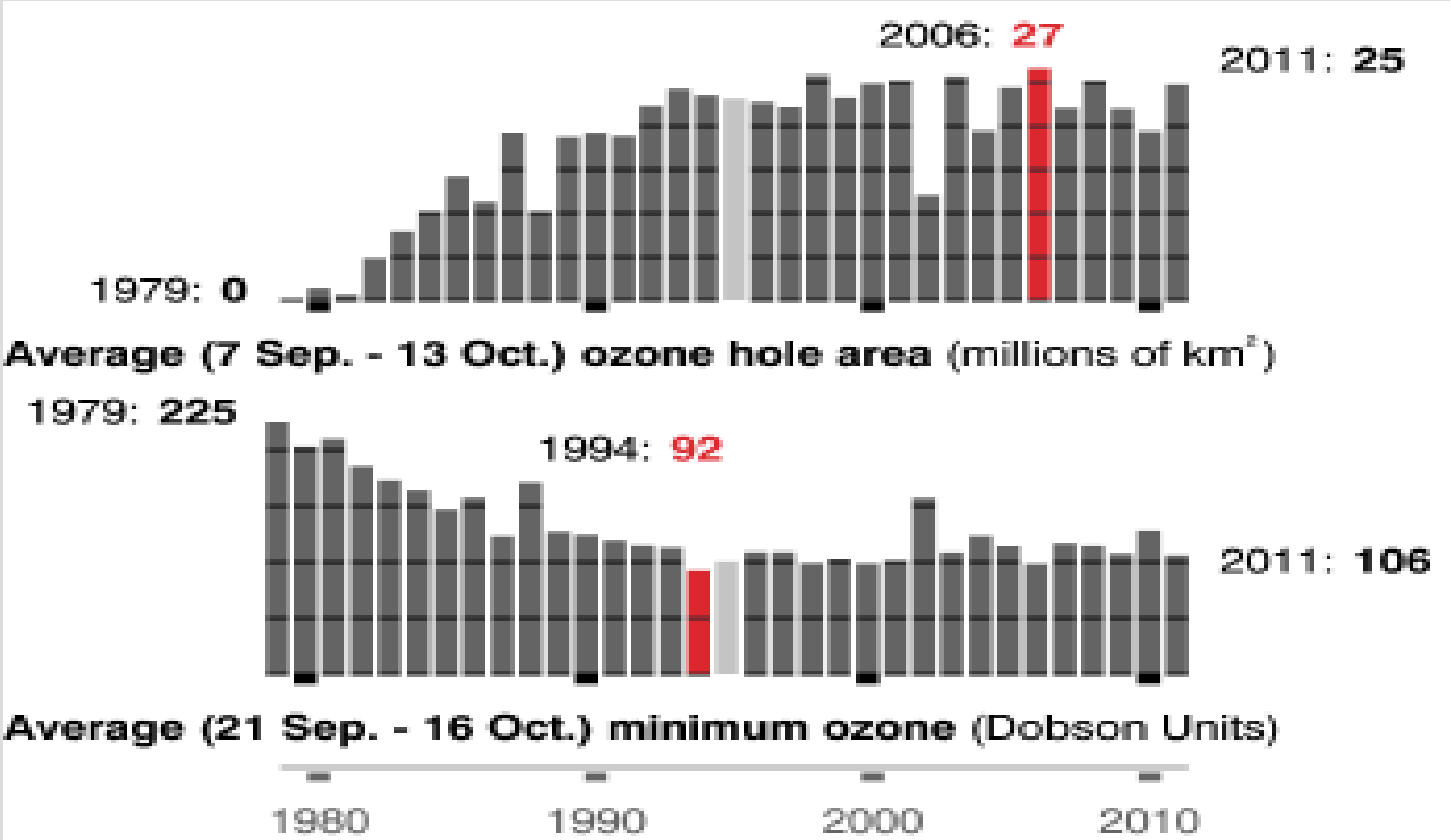


Hope for global climate change?

Intelligent choices DO make a difference!



More recent data...holding....

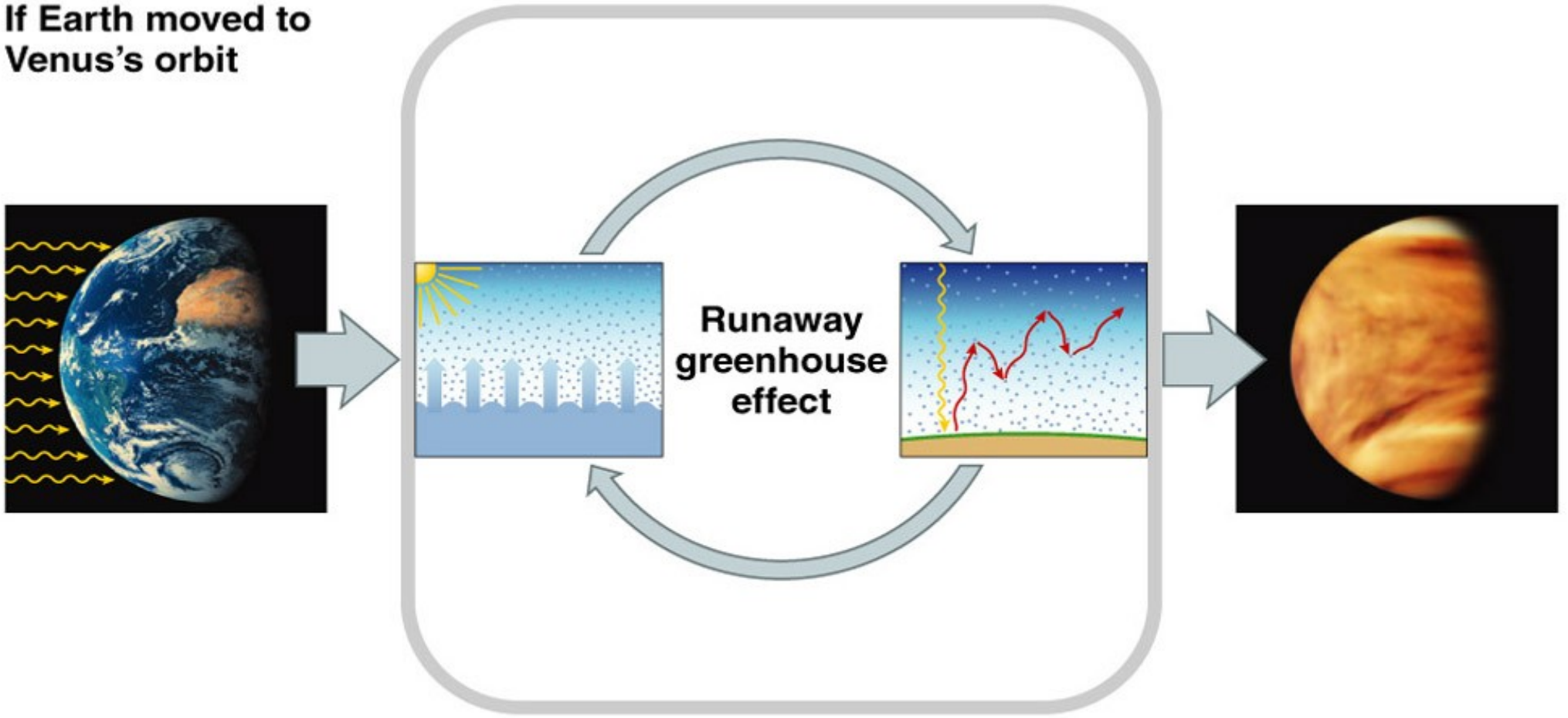


Note: No data were acquired during the 1995 season

Why didn't Venus regulate it's climate?

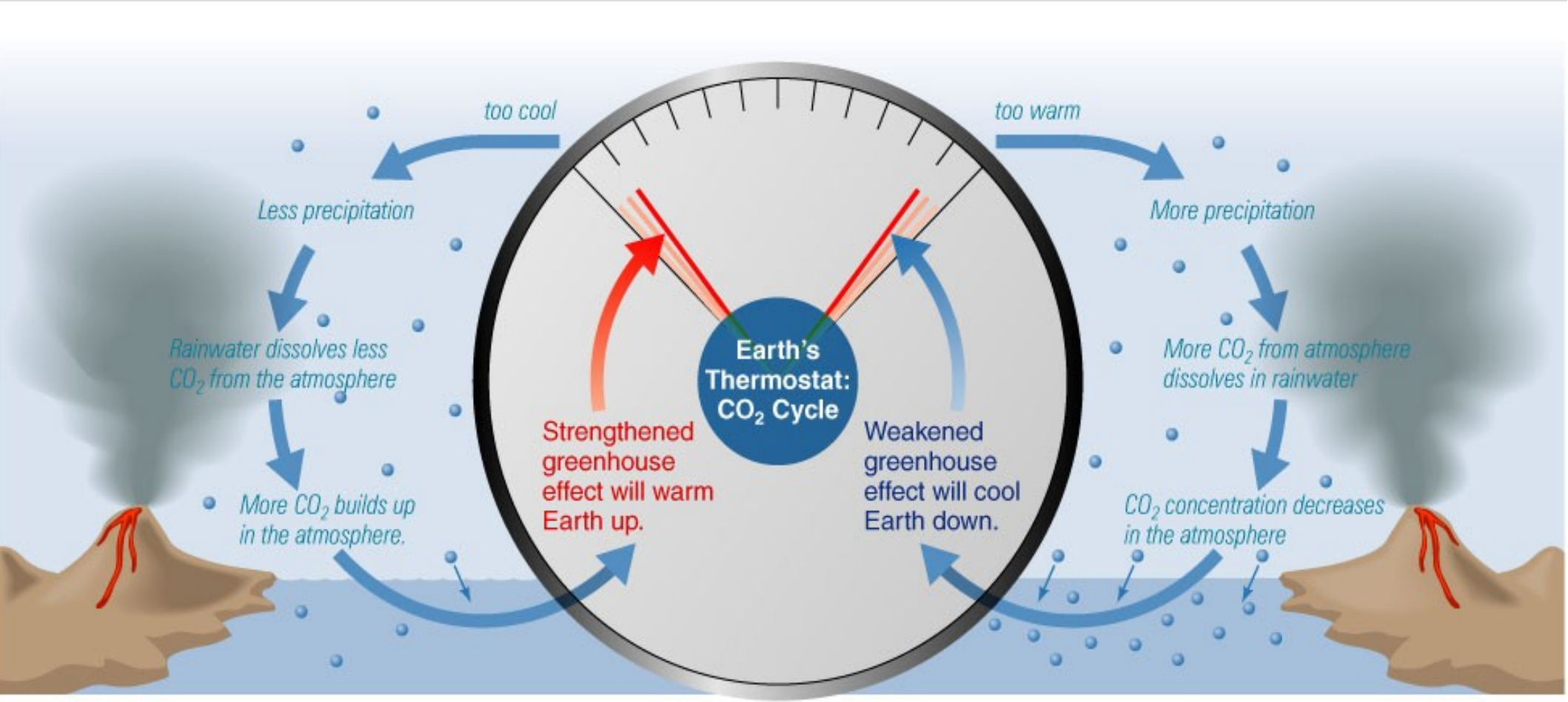
Earth has managed to avoid the runaway greenhouse effect. *Further from Sun.*

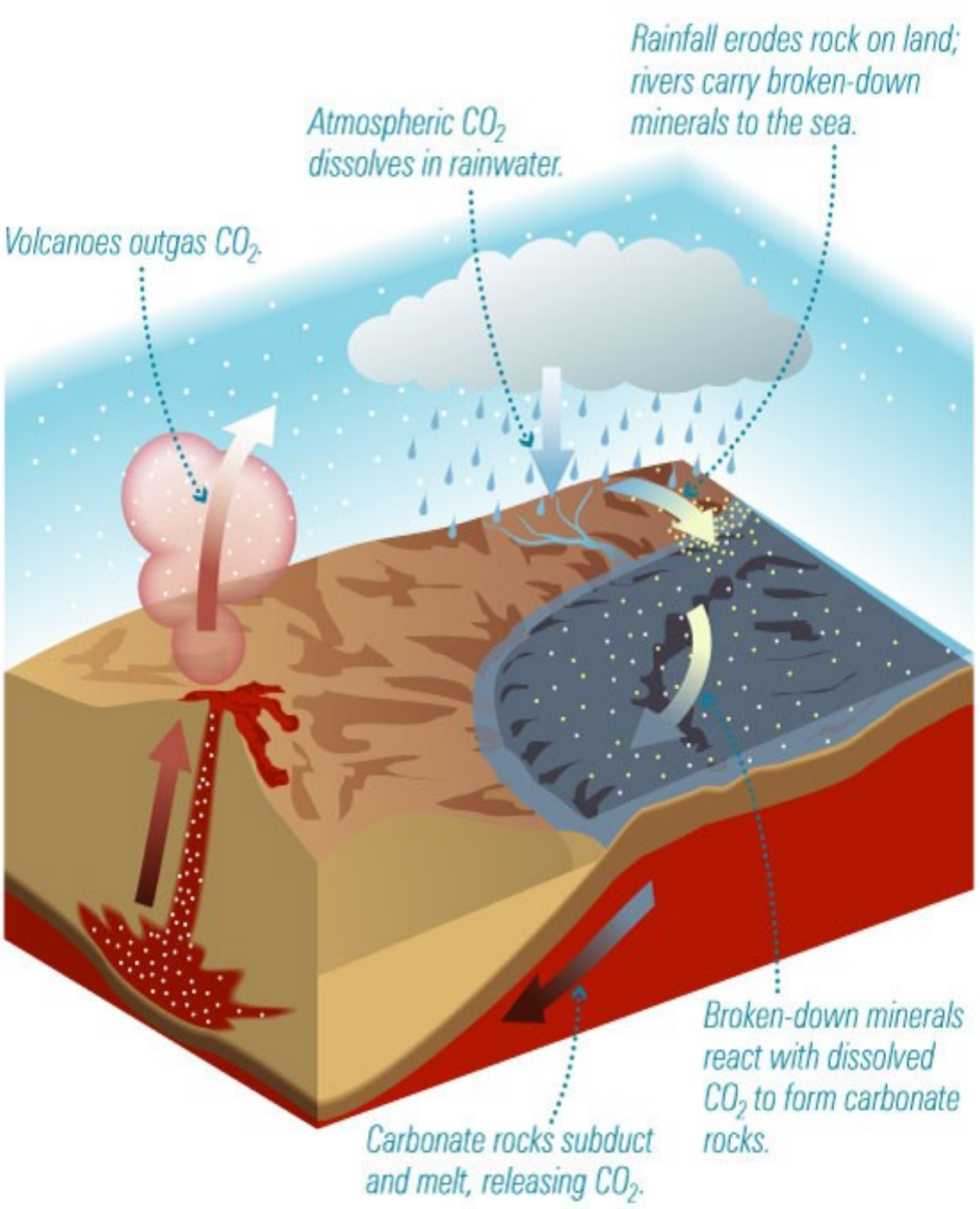
What would happen if you moved Earth to the same distance as Venus?



Why doesn't the runaway happen on Earth now?
Because of the **Carbon Dioxide Thermostat**

This **negative feedback cycle** doesn't exist on Venus





The CO2 Thermostat cycle

CO2 outgassed

Brought to ground in rain

Transported with silicate minerals to ocean

CO2 combines and forms carbonate rocks

Seafloor subducted