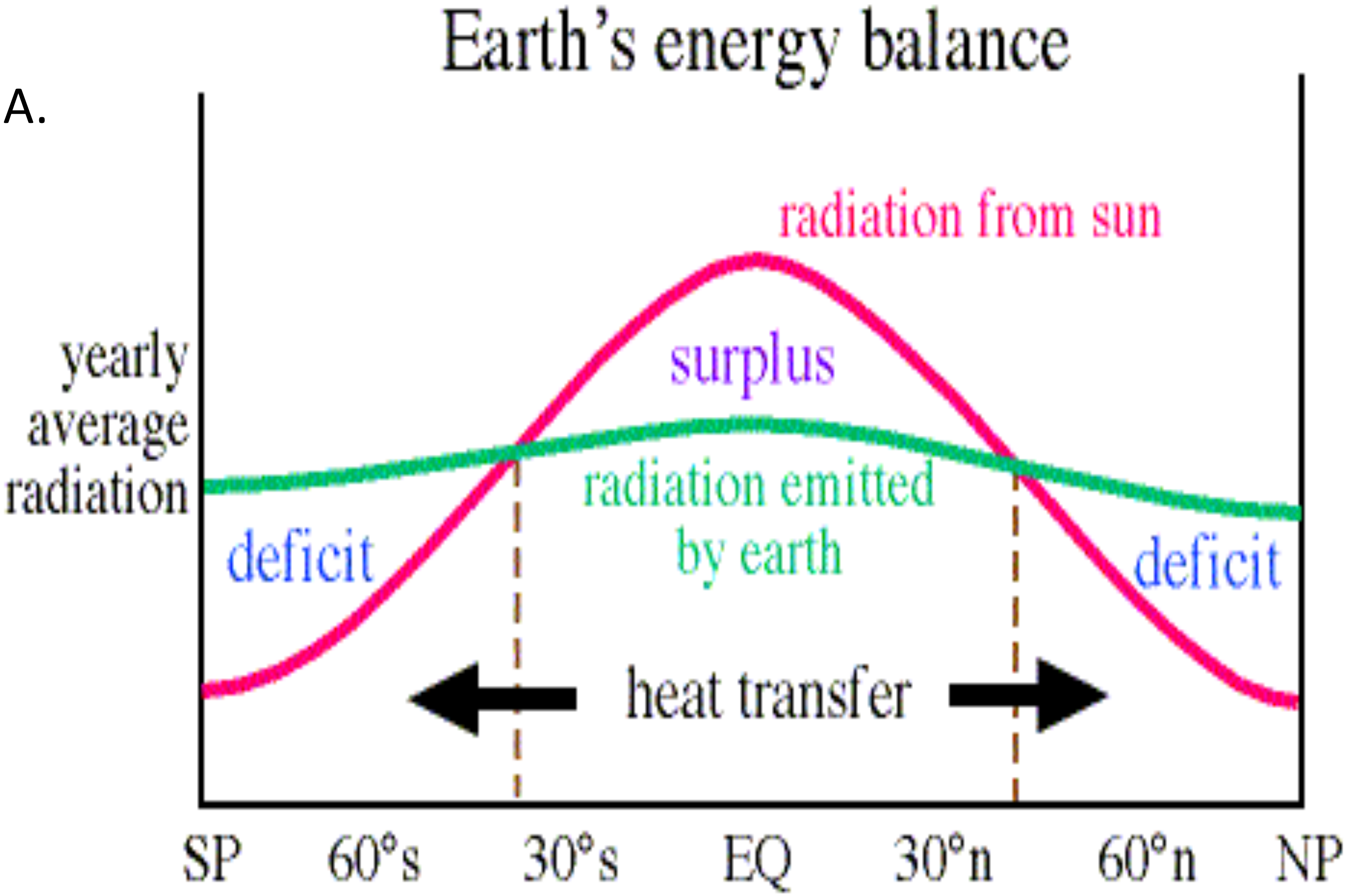
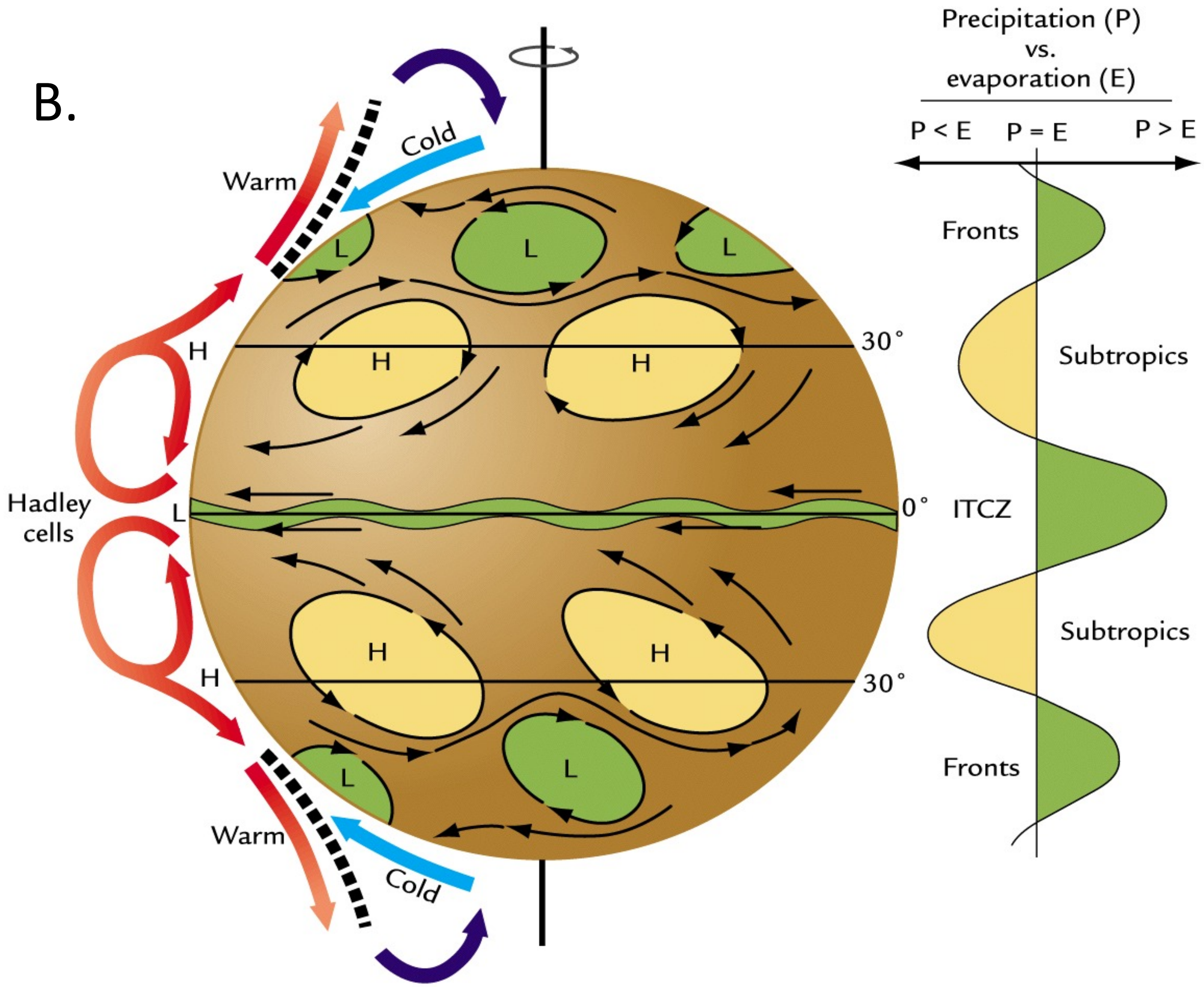
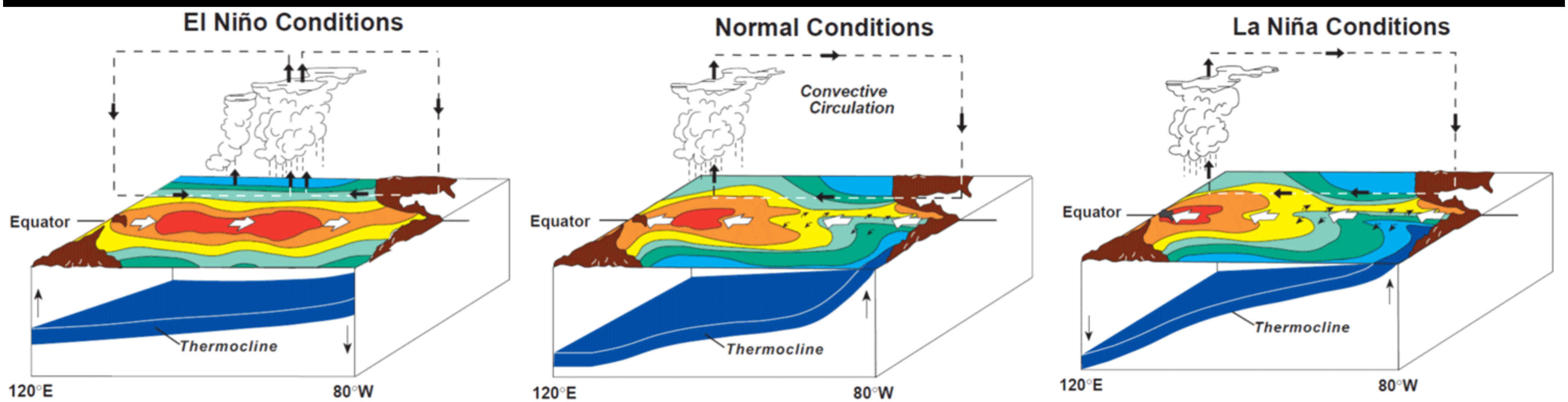
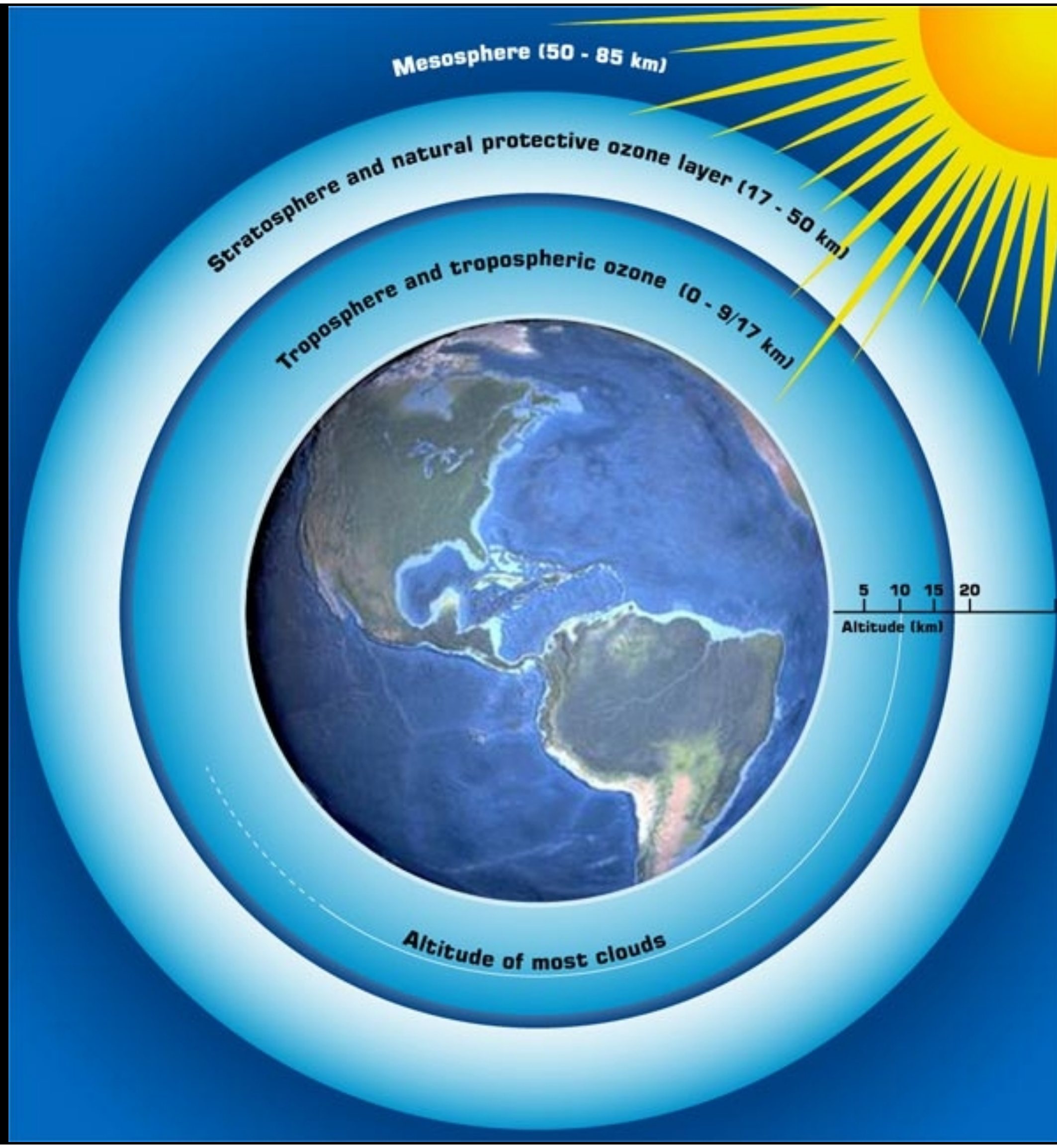
A.


Earth's energy balance
yearly average radiation
radiation from sun
surplus
radiation emitted by earth
deficit
deficit
heat transfer
SP
60°s
30°s
EQ
30°n
60°n
NP


B.
Precipitation (P)
vs.
evaporation (E)
P < E
P = E
P > E
Fronts
Subtropics
ITCZ
Subtropics
Fronts
Warm
Cold
Warm
Cold
H
L
H
Hadley
cells
H
H
L
L
L
H
H
L
L
30°
0°
30°

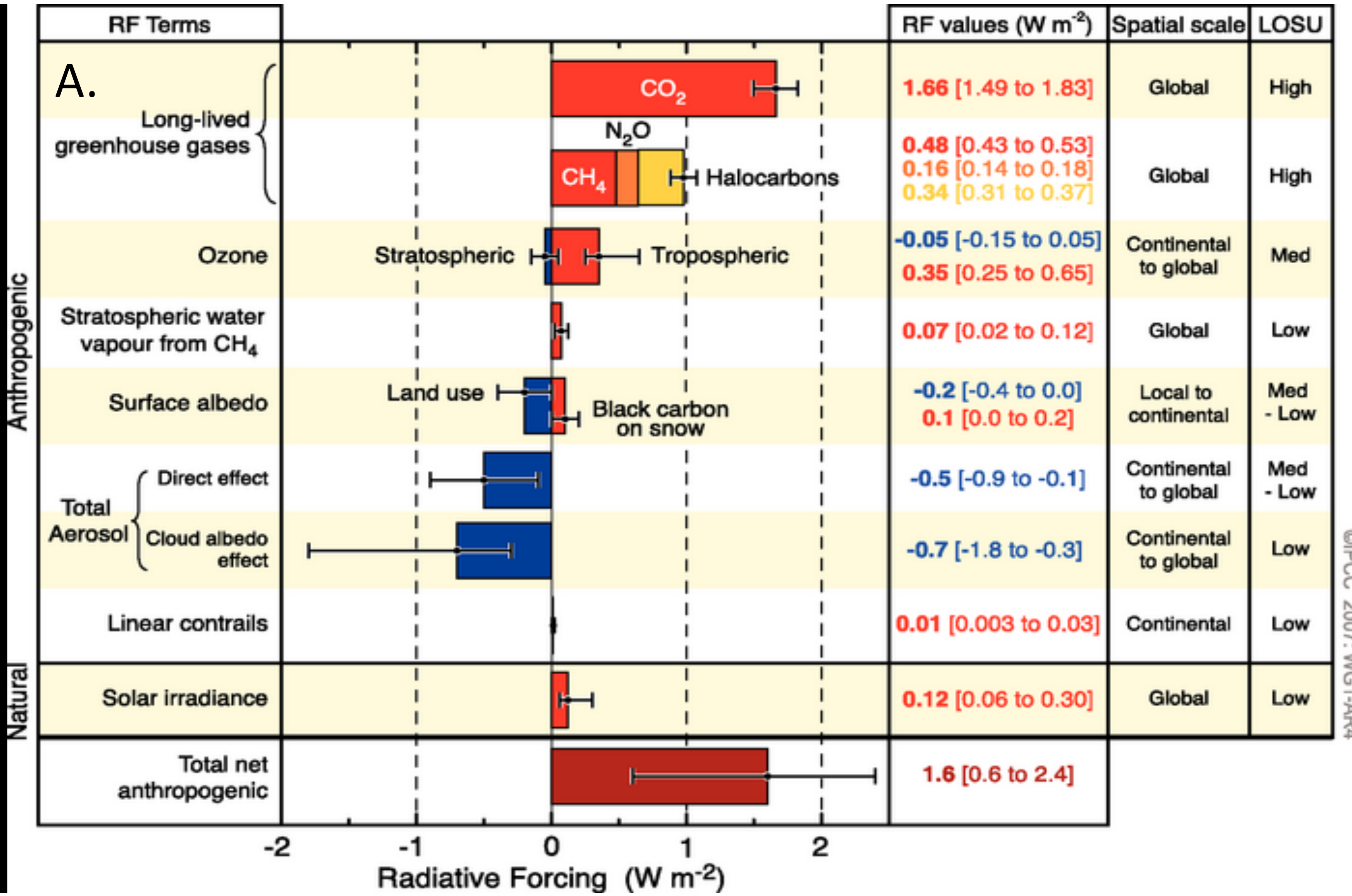

El Niño Conditions
Equator
Thermocline
120°E
80°W
Normal Conditions
Convective Circulation
Equator
Thermocline
120°E
80°W
La Niña Conditions
Equator
Thermocline
120°E
80°W

A.

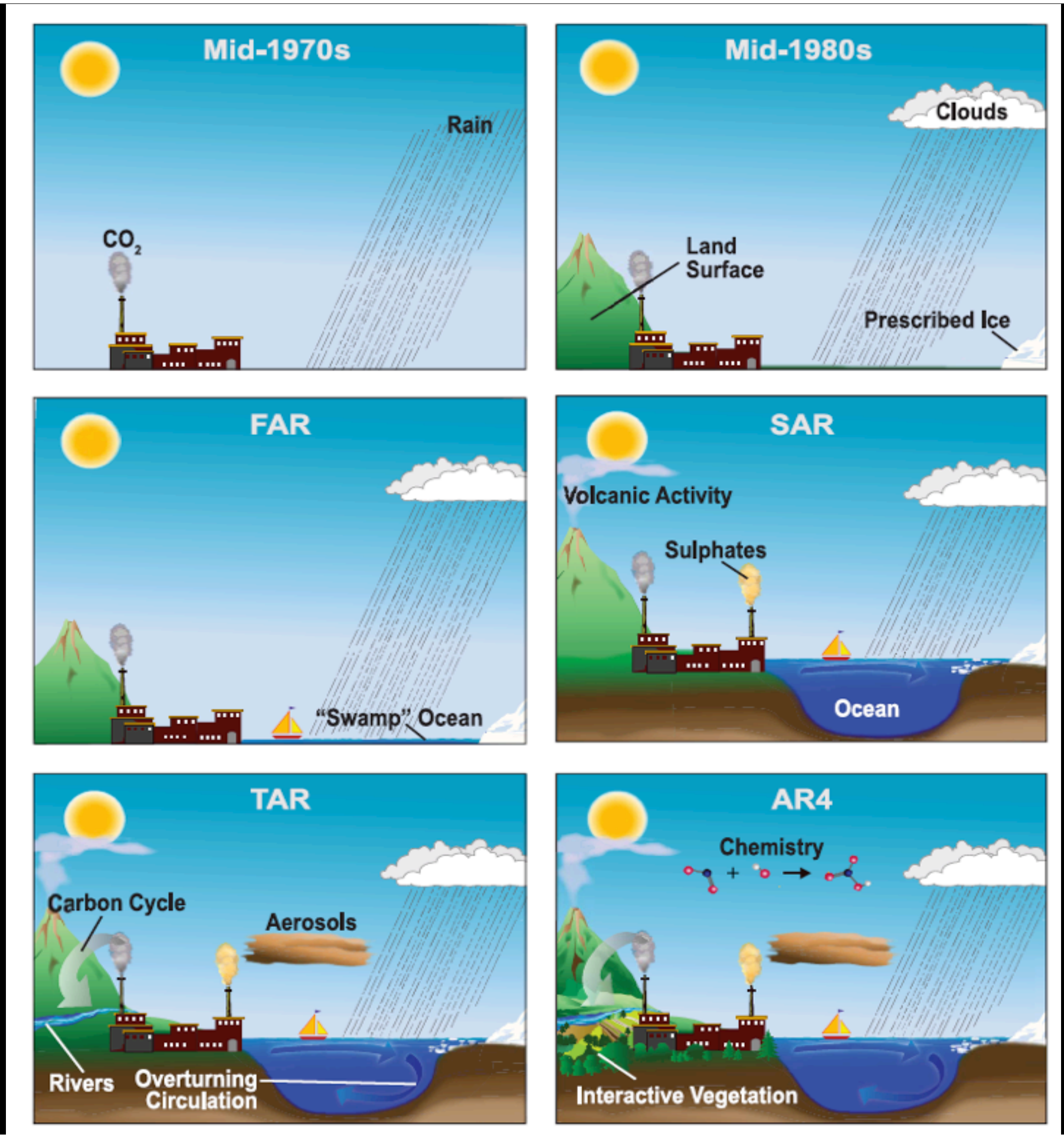

Mesosphere (50 - 85 km)
Stratosphere and natural protective ozone layer (17 - 50 km)
Troposphere and tropospheric ozone (0 - 9/17 km)
5 10 15 20
Altitude (km)
Altitude of most clouds

B.

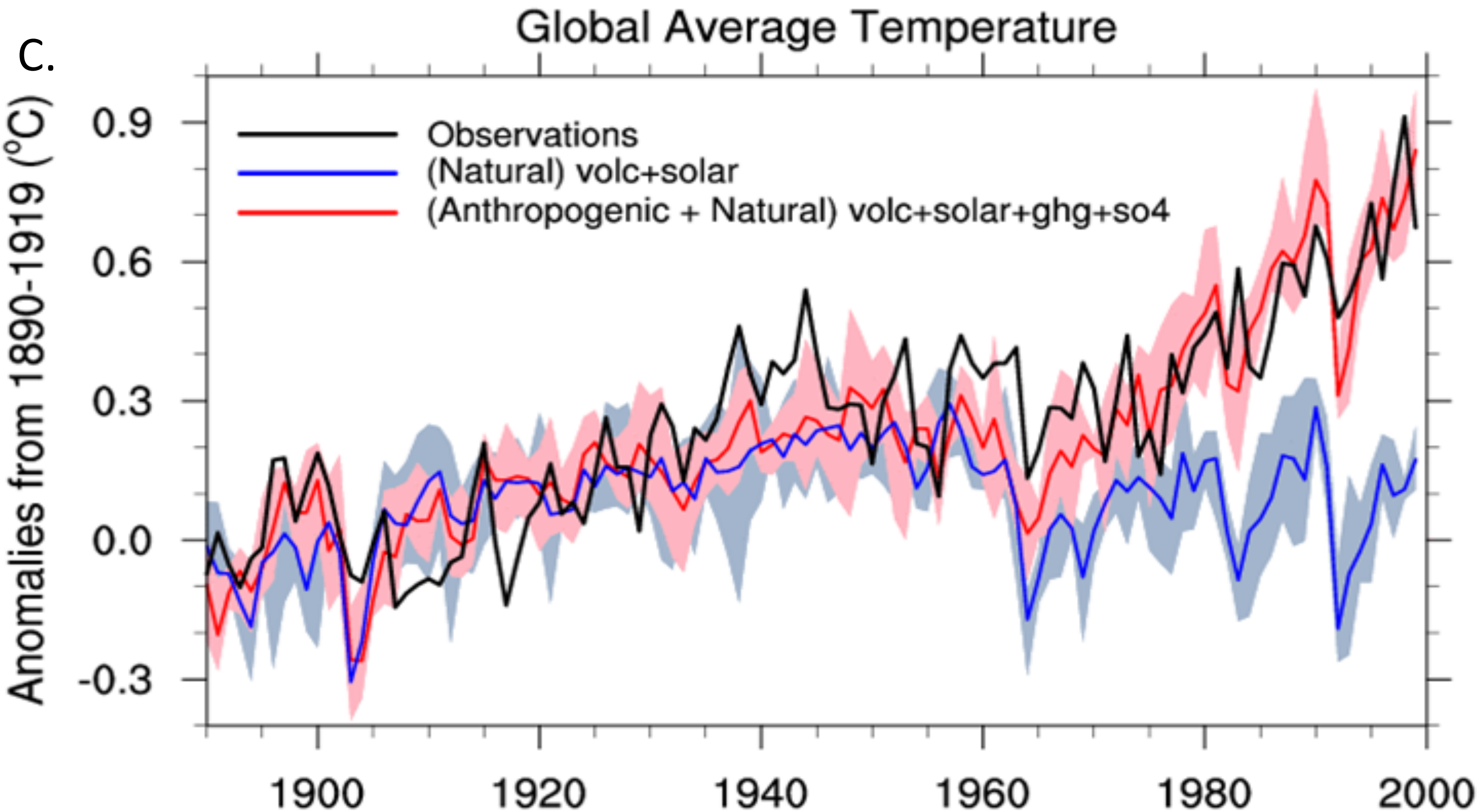
- Ozone (O3) high in the atmosphere absorbs ultraviolet radiation from the sun, thereby protecting living organisms below from this dangerous radiation. The term 'ozone hole' refers to recent depletion of this protective layer over Earth's polar regions. People, plants, and animals living under the ozone hole are harmed by the solar radiation now reaching the Earth's surface—where it causes health problems from eye damage to skin cancer.
- The ozone hole, however, is not the mechanism of global warming. Ultraviolet radiation represents less than one percent of the energy from the sun—not enough to be the cause of the excess heat from human activities. Global warming is caused primarily from putting too much carbon into the atmosphere when coal, gas, and oil are burned to generate electricity or to run our cars. These gases spread around the planet like a blanket, capturing the solar heat that would otherwise be radiated out into space. (For more detail on the basic mechanism of global warming, see carbon dioxide FAQ.)


A.
RF Terms
RF values (W m-2)
Spatial scale
LOSU
Anthropogenic
Long-lived greenhouse gases
CO2
1.66 [1.49 to 1.83]
Global
High
N2O
CH4
Halocarbons
0.48 [0.43 to 0.53]
0.16 [0.14 to 0.18]
0.34 [0.31 to 0.37]
Global
High
Ozone
Stratospheric
Tropospheric
-0.05 [-0.15 to 0.05]
0.35 [0.25 to 0.65]
Continental to global
Med
Stratospheric water vapour from CH4
0.07 [0.02 to 0.12]
Global
Low
Surface albedo
Land use
Black carbon on snow
-0.2 [-0.4 to 0.0]
0.1 [0.0 to 0.2]
Local to continental
Med - Low
Total Aerosol
Direct effect
-0.5 [-0.9 to -0.1]
Continental to global
Med - Low
Cloud albedo effect
-0.7 [-1.8 to -0.3]
Continental to global
Low
Linear contrails
0.01 [0.003 to 0.03]
Continental
Low
Natural
Solar irradiance
0.12 [0.06 to 0.30]
Global
Low
Total net anthropogenic
1.6 [0.6 to 2.4]
-2
-1
0
1
2
Radiative Forcing (W m-2)
©IPCC 2007: WG1-AR4

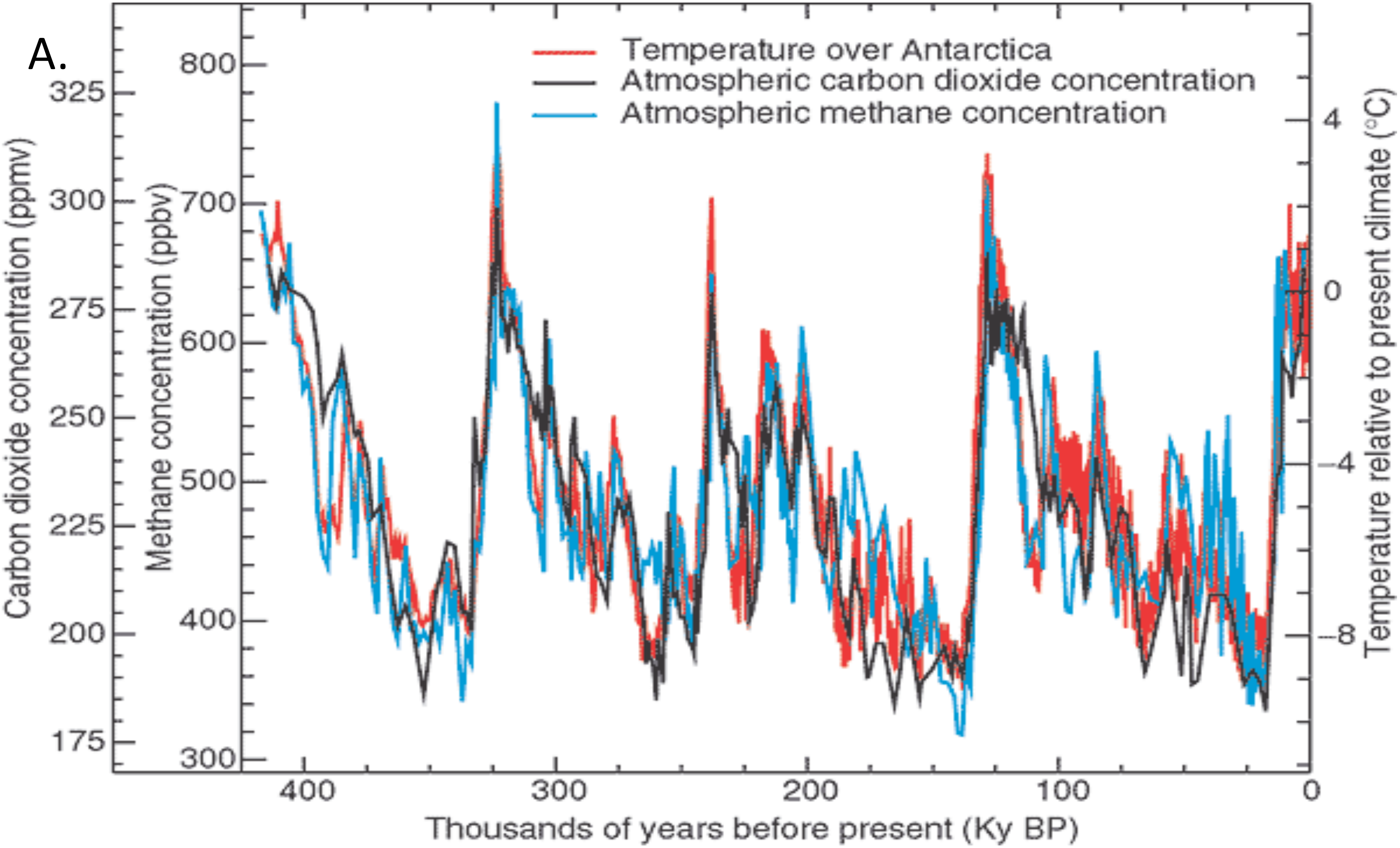
B.


Mid-1970s
Rain
CO2
Mid-1980s
Clouds
Land Surface
Prescribed Ice
FAR
"Swamp" Ocean
SAR
Volcanic Activity
Sulphates
Ocean
TAR
Carbon Cycle
Aerosols
Rivers
Overturning Circulation
AR4
Chemistry
Interactive Vegetation

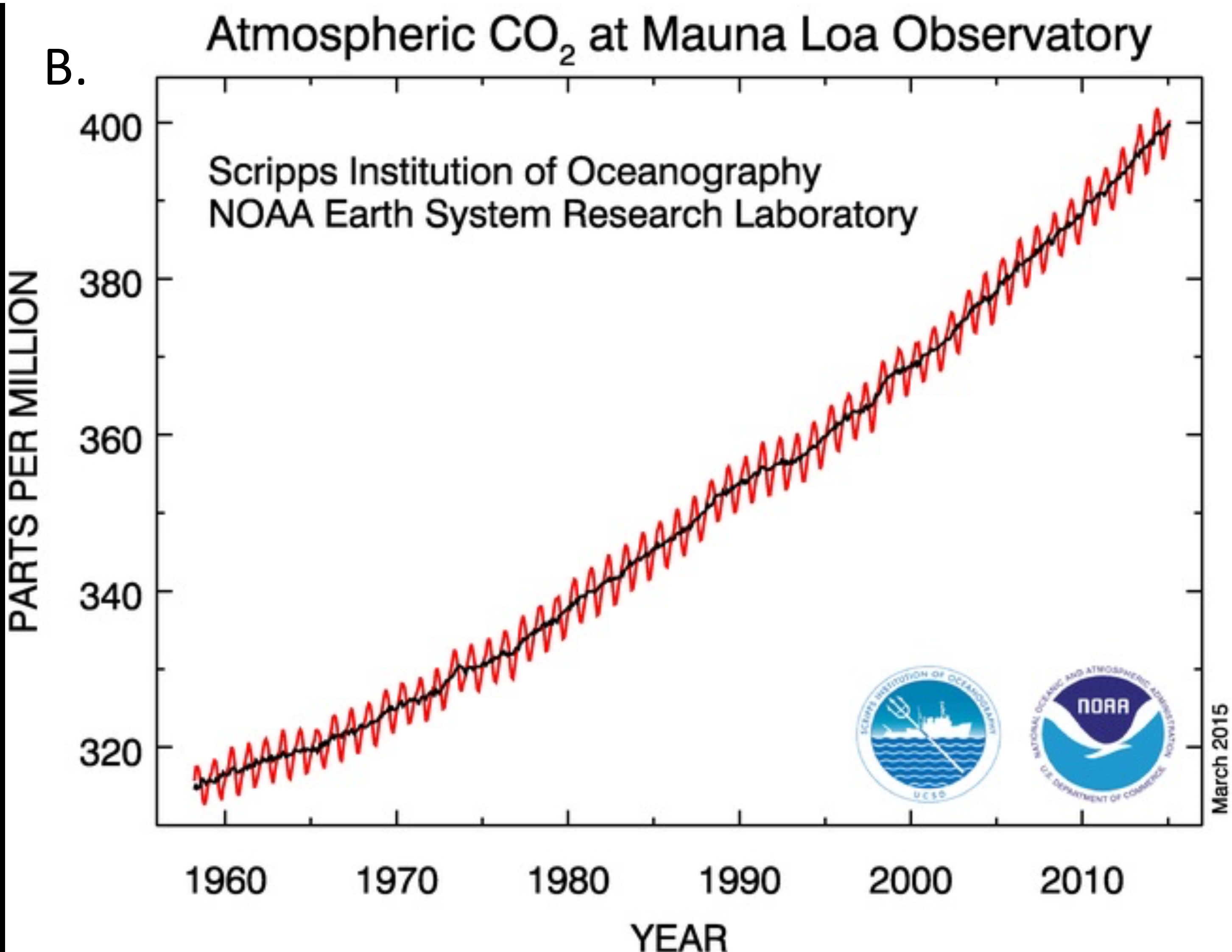
C.



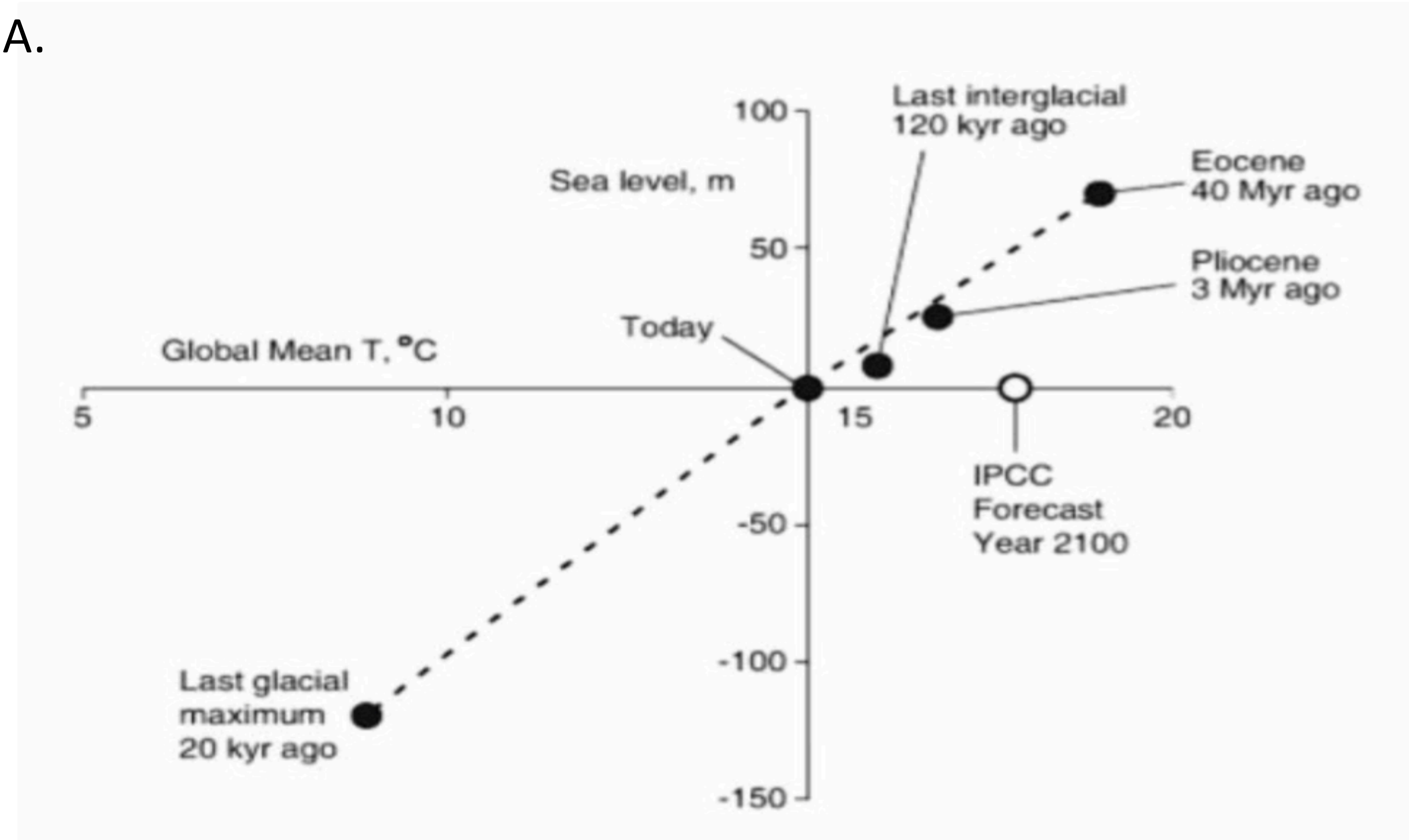
Global Average Temperature
Observations
(Natural) volc+solar
(Anthropogenic + Natural) volc+solar+ghg+so4
Anomalies from 1890-1919 (°C)
0.9
0.6
0.3
0.0
-0.3
1900
1920
1940
1960
1980
2000

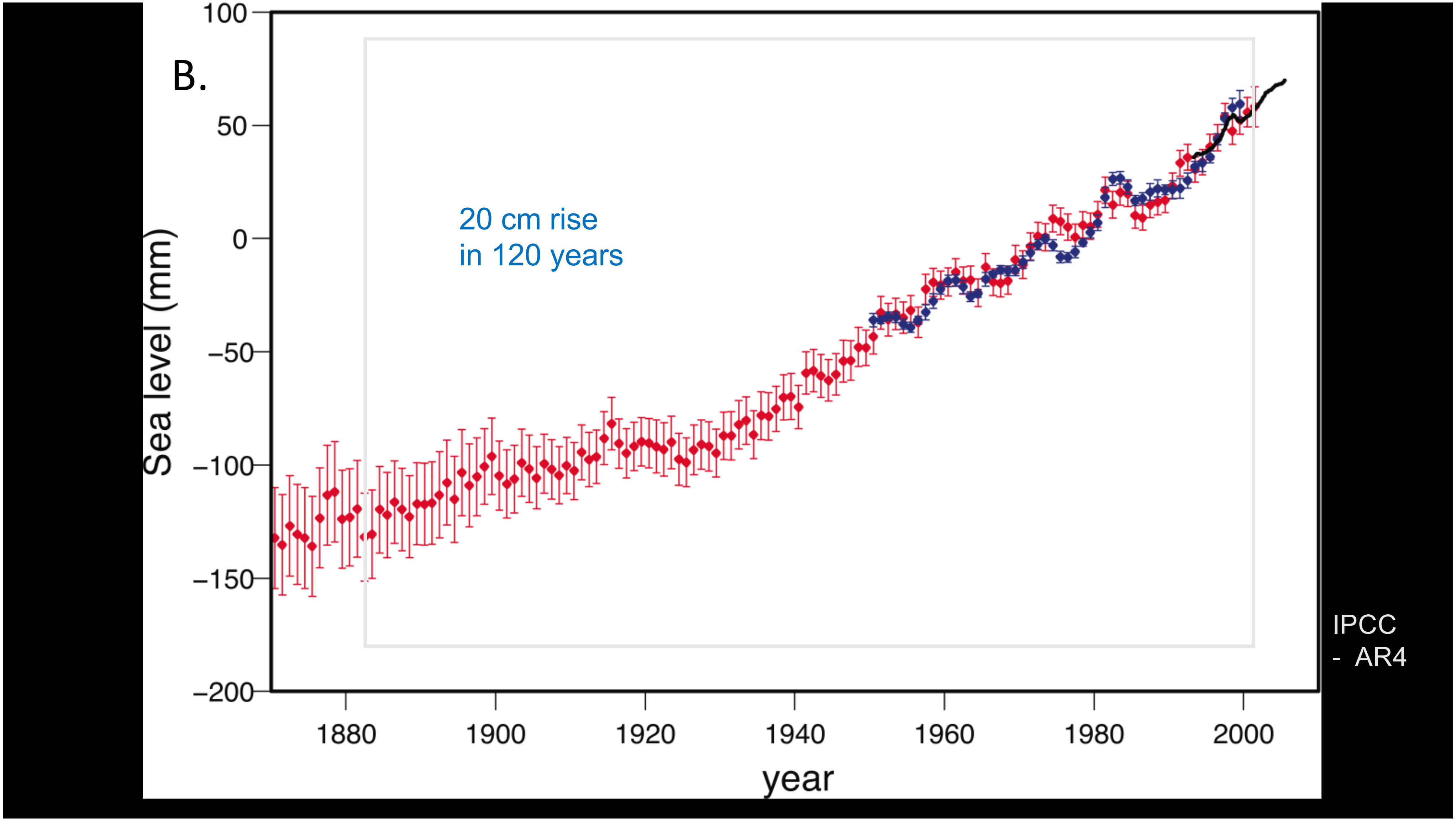

A.
Temperature over Antarctica
Atmospheric carbon dioxide concentration
Atmospheric methane concentration
Carbon dioxide concentration (ppmv)
325
300
275
250
225
200
175
Methane concentration (ppbv)
800
700
600
500
400
300
Temperature relative to present climate (°C)
4
0
−4
−8
400
300
200
100
0
Thousands of years before present (Ky BP)

B.


Atmospheric CO2 at Mauna Loa Observatory
Scripps Institution of Oceanography
NOAA Earth System Research Laboratory
PARTS PER MILLION
400
380
360
340
320
1960
1970
1980
1990
2000
2010
YEAR
March 2015

A.


Last interglacial
120 kyr ago
100
Sea level, m
Eocene
40 Myr ago
50
Pliocene
3 Myr ago
Today
Global Mean T, °C
5
10
15
20
IPCC
Forecast
Year 2100
-50
-100
Last glacial
maximum
20 kyr ago
-150

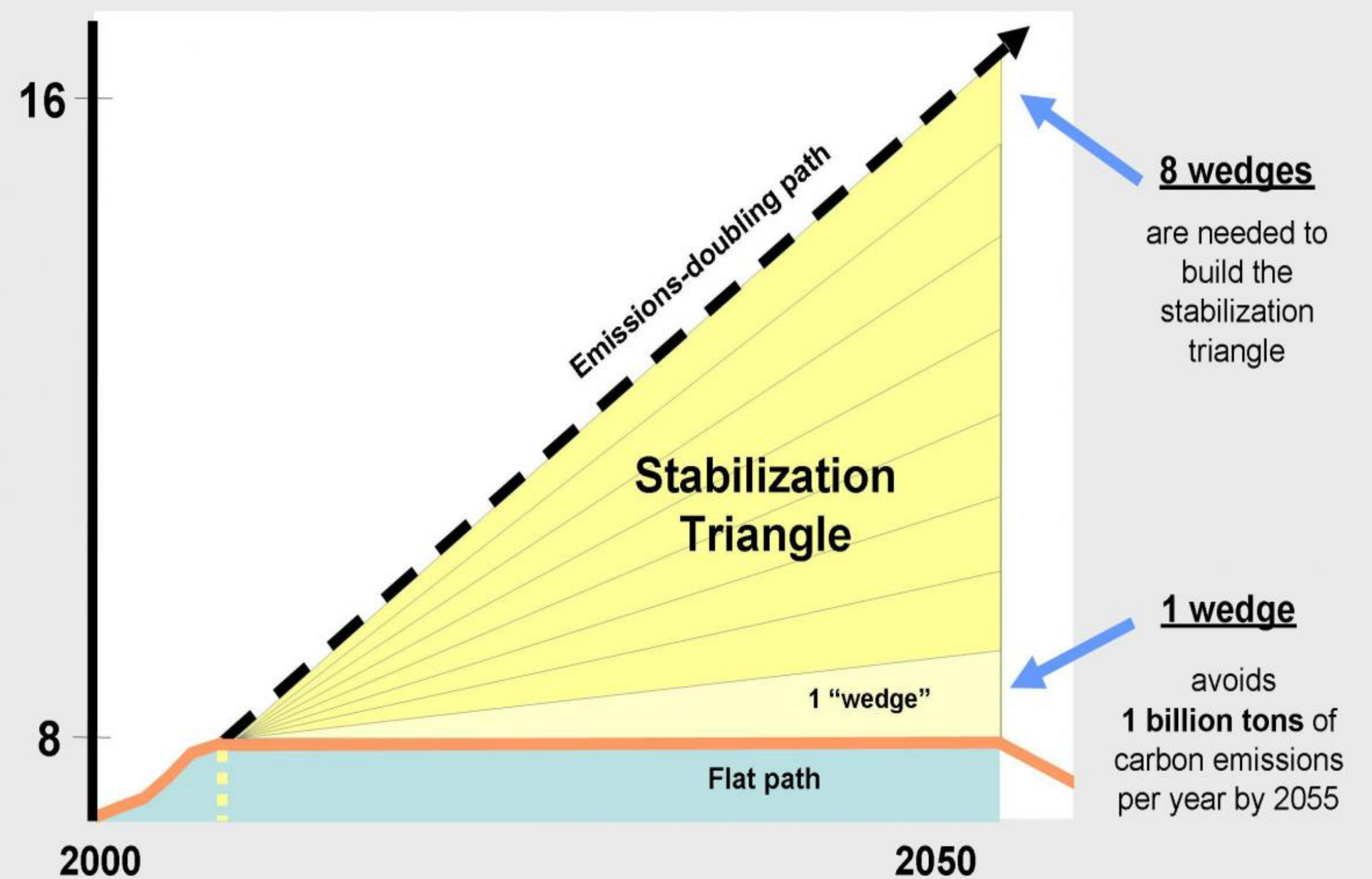

B.
20 cm rise
in 120 years
Sea level (mm)
100
50
0
−50
−100
−150
−200
1880
1900
1920
1940
1960
1980
2000
year
IPCC
- AR4

C.

Table 13.1 | Global mean sea level budget (mm yr^{-1}) over different time intervals from observations and from model-based contributions. Uncertainties are 5 to 95%. The Atmosphere–Ocean General Circulation Model (AOGCM) historical integrations end in 2005; projections for RCP4.5 are used for 2006–2010. The modelled thermal expansion and glacier contributions are computed from the CMIP5 results, using the model of Marzeion et al. (2012a) for glaciers. The land water contribution is due to anthropogenic intervention only, not including climate-related fluctuations.

Source	1901–1990	1971–2010	1993–2010
Observed contributions to global mean sea level (GMSL) rise			
Thermal expansion	–	0.8 [0.5 to 1.1]	1.1 [0.8 to 1.4]
Glaciers except in Greenland and Antarctica[a]	0.54 [0.47 to 0.61]	0.62 [0.25 to 0.99]	0.76 [0.39 to 1.13]
Glaciers in Greenland[a]	0.15 [0.10 to 0.19]	0.06 [0.03 to 0.09]	0.10 [0.07 to 0.13][b]
Greenland ice sheet	–	–	0.33 [0.25 to 0.41]
Antarctic ice sheet	–	–	0.27 [0.16 to 0.38]
Land water storage	–0.11 [–0.16 to –0.06]	0.12 [0.03 to 0.22]	0.38 [0.26 to 0.49]
Total of contributions	**–**	**–**	**2.8 [2.3 to 3.4]**
Observed GMSL rise	**1.5 [1.3 to 1.7]**	**2.0 [1.7 to 2.3]**	**3.2 [2.8 to 3.6]**

A.


16
8
2000
2050
Emissions-doubling path
Stabilization
Triangle
1 “wedge”
Flat path
8 wedges
are needed to
build the
stabilization
triangle
1 wedge
avoids
1 billion tons of
carbon emissions
per year by 2055

B.

Stabilization Wedges – 15 Ways to Cut Carbon

= Electricity Production, =Heating and Direct Fuel Use, =Transportation, = Biostorage

Strategy	Sector	Description	1 wedge could come from...	Cost	Challenges
1. Efficiency – Transport		Increase automobile fuel efficiency (2 billion cars projected in 2050)	... doubling the efficiency of all world's cars from 30 to 60 mpg	$	Car size & power
2. Conservation - Transport		Reduce miles traveled by passenger and/or freight vehicles	... cutting miles traveled by all passenger vehicles in half	$	Increased public transport, urban design
3. Efficiency - Buildings		Increase insulation, furnace and lighting efficiency	... using best available technology in all new and existing buildings	$	House size, consumer demand for appliances
4. Efficiency – Electricity		Increase efficiency of power generation	... raising plant efficiency from 40% to 60%	$	Increased plant costs
5. CCS Electricity		90% of CO_2 from fossil fuel power plants captured, then stored underground (800 large coal plants or 1600 natural gas plants)	... injecting a volume of CO_2 every year equal to the volume of oil extracted	$$	Possibility of CO_2 leakage
6. CCS Hydrogen		Hydrogen fuel from fossil sources with CCS displaces hydrocarbon fuels	... producing hydrogen at 10 times the current rate	$$$	New infrastructure needed, hydrogen safety issues
7. CCS Synfuels		Capture and store CO_2 emitted during synfuels production from coal	... using CCS at 180 large synfuels plants	$$	Emissions still only break even with gasoline
8. Fuel Switching – Electricity		Replacing coal-burning electric plants with natural gas plants (1400 1 GW coal plants)	... using an amount of natural gas equal to that used for all purposes today	$	Natural gas availability
9. Nuclear Electricity		Displace coal-burning electric plants with nuclear plants (Add double current capacity)	... ~3 times the effort France put into expanding nuclear power in the 1980's, sustained for 50 years	$$	Weapons proliferation, nuclear waste, local opposition
10. Wind Electricity		Wind displaces coal-based electricity (10 x current capacity)	... using area equal to ~3% of U.S. land area for wind farms	$$	Not In My Back Yard (NIMBY)
11. Solar Electricity		Solar PV displaces coal-based electricity (100 x current capacity)	.. using the equivalent of a 100 x 200 km PV array	$$$	PV cell materials
12. Wind Hydrogen		Produce hydrogen with wind electricity	... powering half the world's cars predicted for 2050 with hydrogen	$$$	NIMBY, Hydrogen infrastructure, safety
13. Biofuels		Biomass fuels from plantations replace petroleum fuels	... scaling up world ethanol production by a factor of 12	$$	Biodiversity, competing land use
14. Forest Storage		Carbon stored in new forests	... halting deforestation in 50 years	$	Biodiversity, competing land use
15. Soil Storage		Farming techniques increase carbon retention or storage in soils	... practicing carbon management on all the world's agricultural soils	$	Reversed if land is deep-plowed later

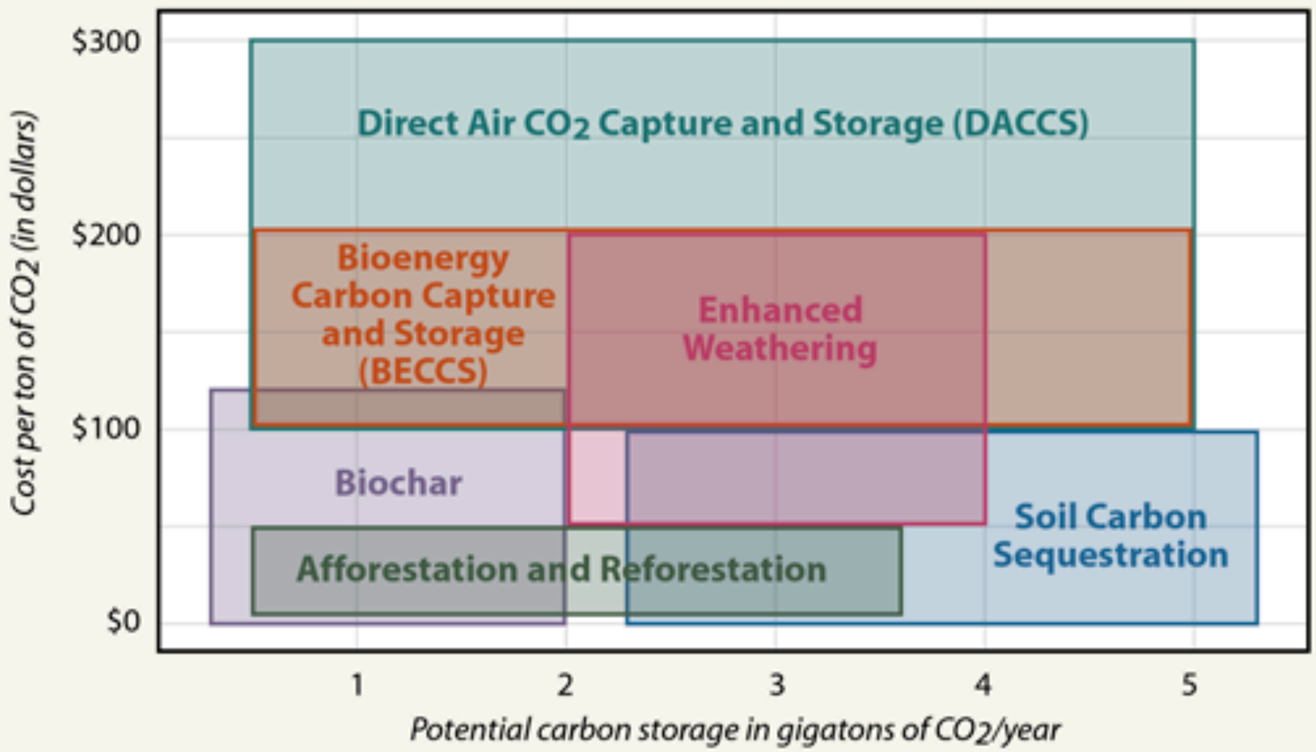
For more information, visit our website at http://cmi.princeton.edu/wedges.

Yellow = Efficiency and conservation strategies
Blue = Fossil fuel-based strategies
Red = Nuclear energy strategies
Green = Renewables and biostorage strategies

C.

How Do Carbon Storage Techniques Stack Up?

To meet the goals of the Paris climate agreement and keep global warming under 1.5 degrees Celsius, the world will have to increase the amount of carbon dioxide pulled from the atmosphere, the IPCC reports. It compared the costs and storage potential of six key methods of carbon dioxide removal. Soil carbon sequestration is one of the cheapest with the most potential.



SOURCE: IPCC

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