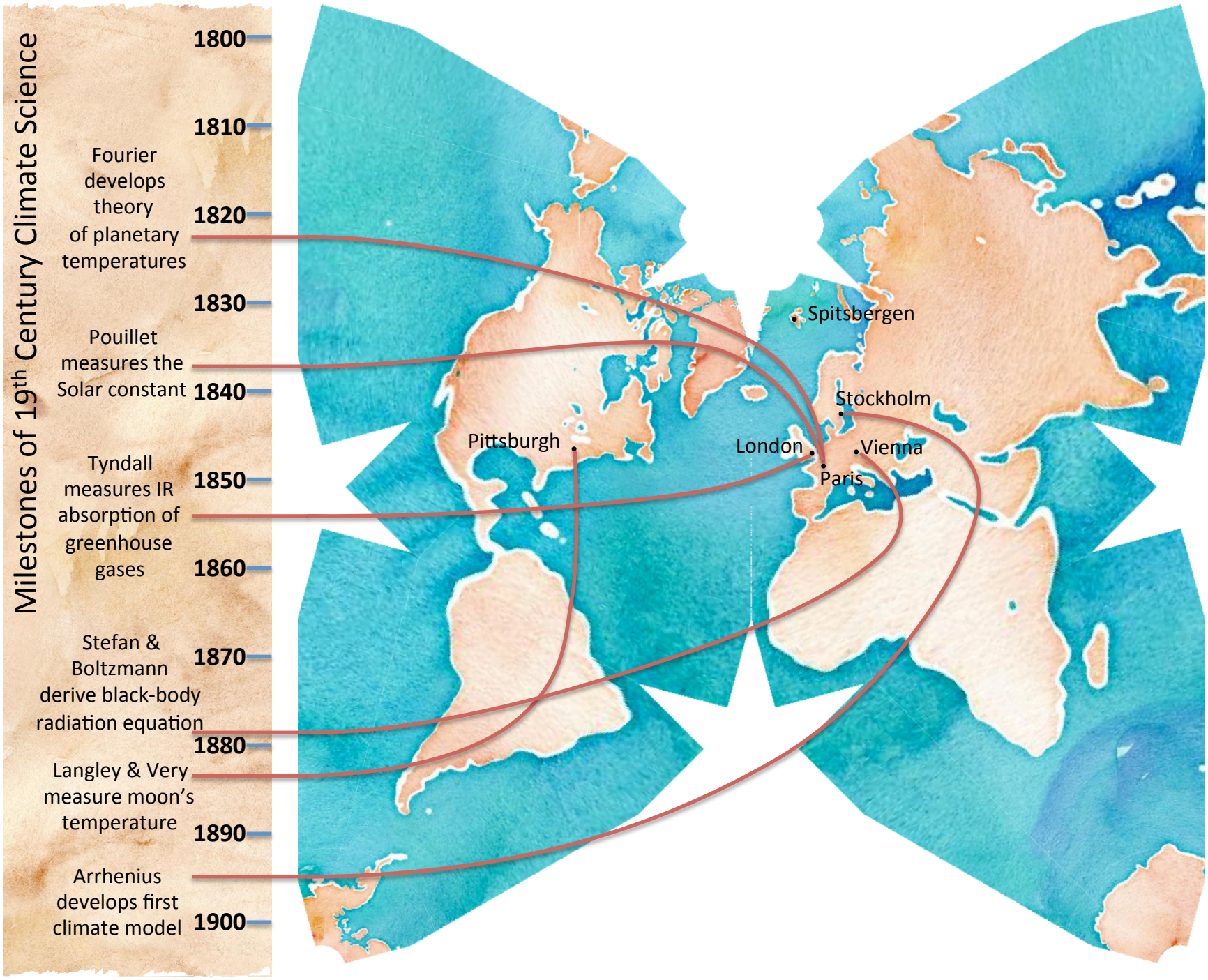
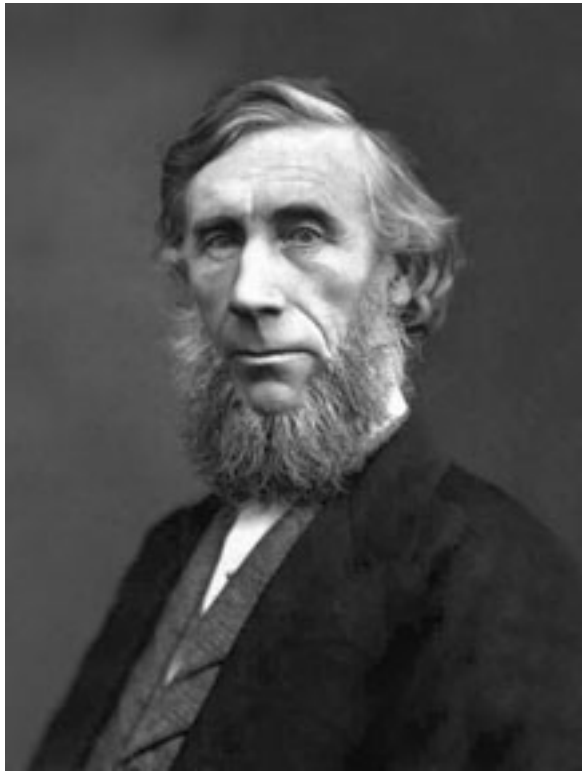
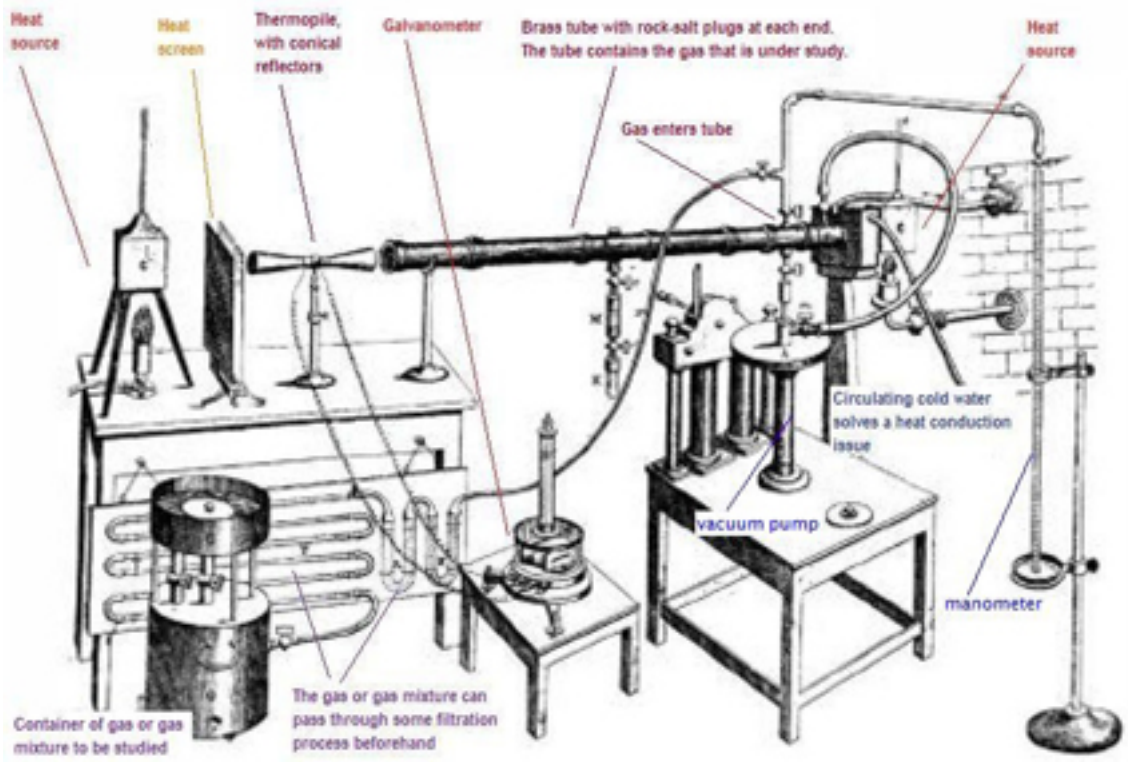

Milestones of 19th Century Climate Science
1800
1810
1820
1830
1840
1850
1860
1870
1880
1890
1900
Fourier develops theory of planetary temperatures
Pouillet measures the Solar constant
Tyndall measures IR absorption of greenhouse gases
Stefan & Boltzmann derive black-body radiation equation
Langley & Very measure moon's temperature
Arrhenius develops first climate model
Spitsbergen
Stockholm
Pittsburgh
London
Vienna
Paris

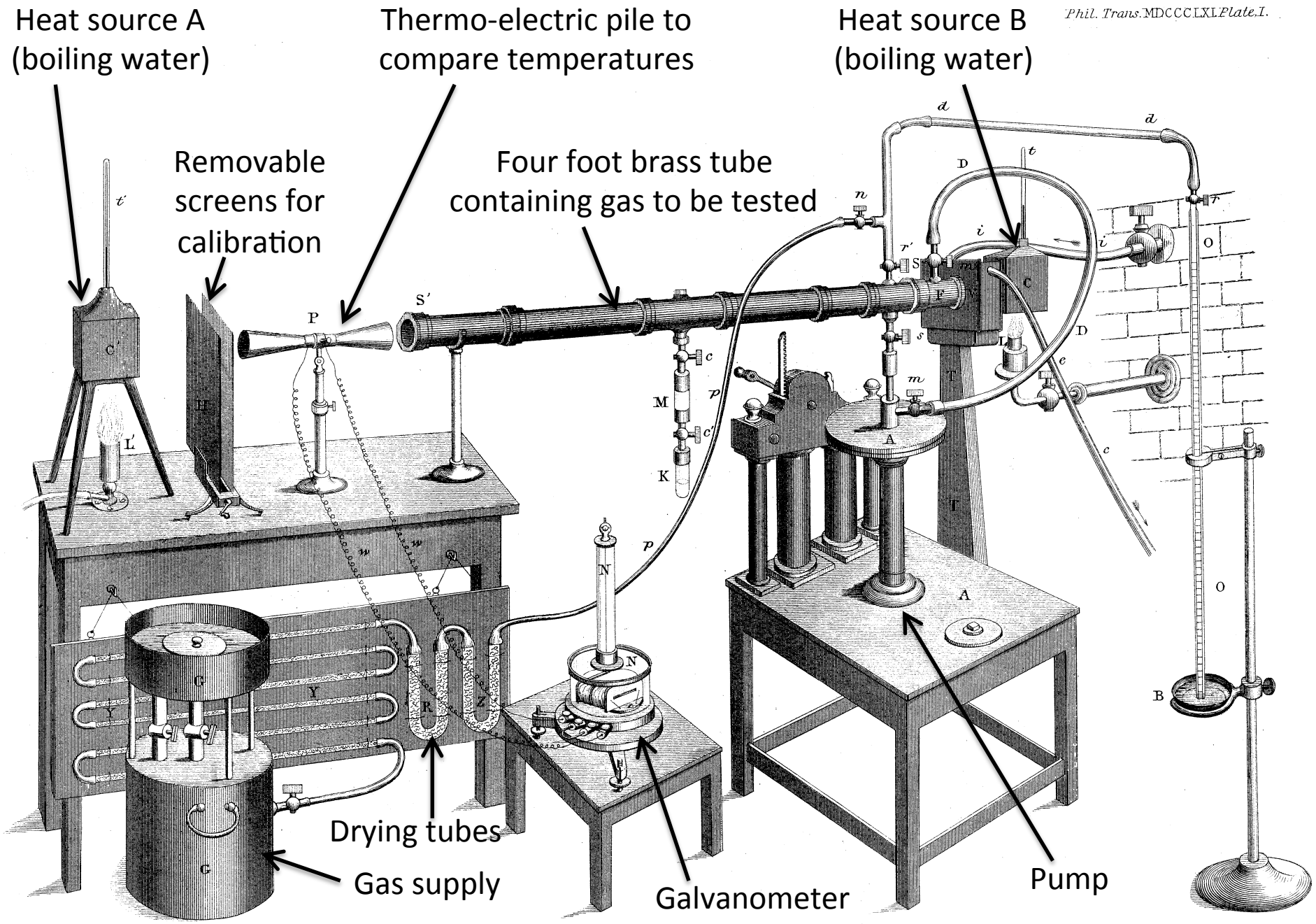
Discovery of the Greenhouse Effect

1850s: John Tyndall discovers through a series of experiments that certain gases absorb infrared radiation;

Demonstrated existence of the "greenhouse effect"

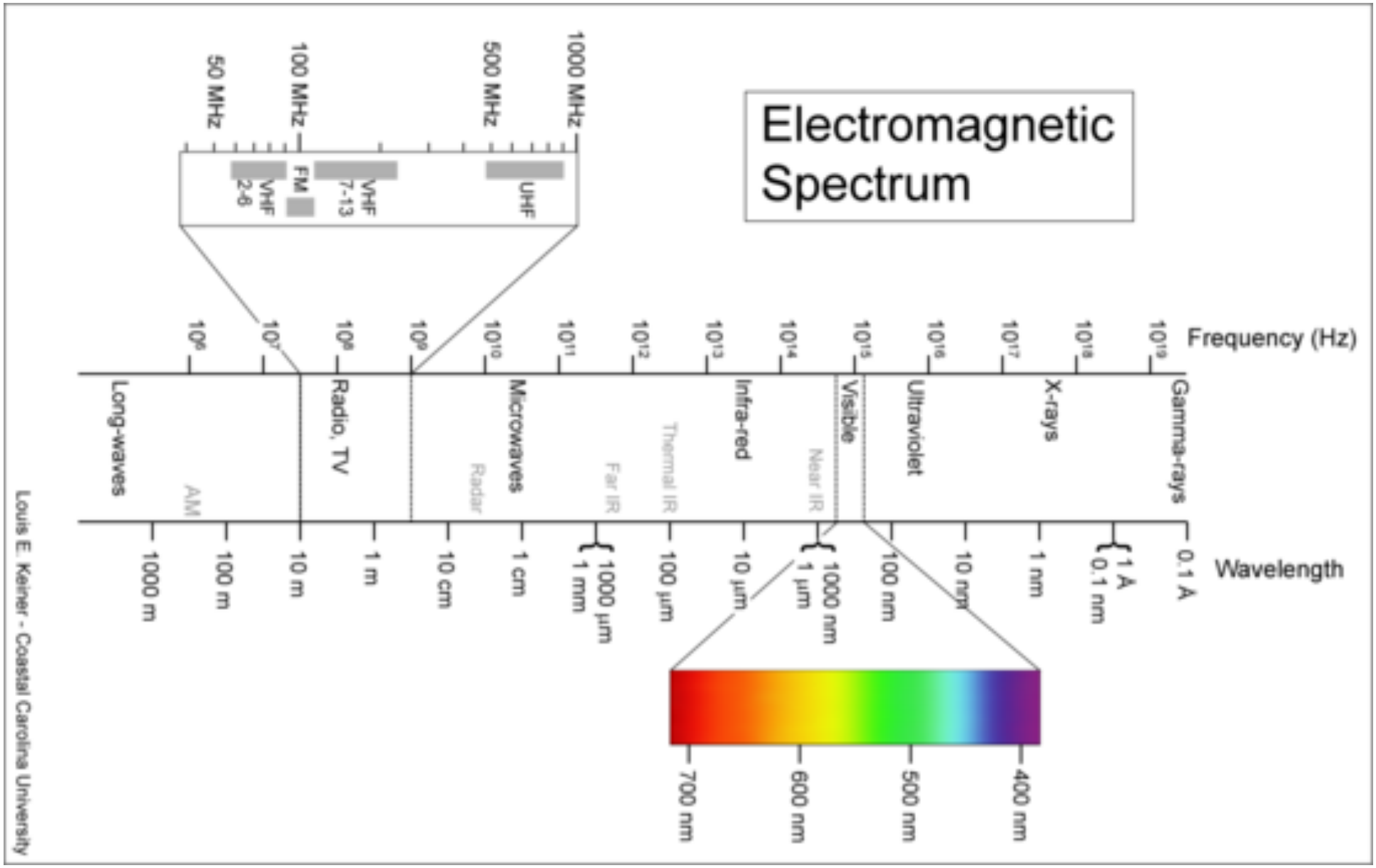




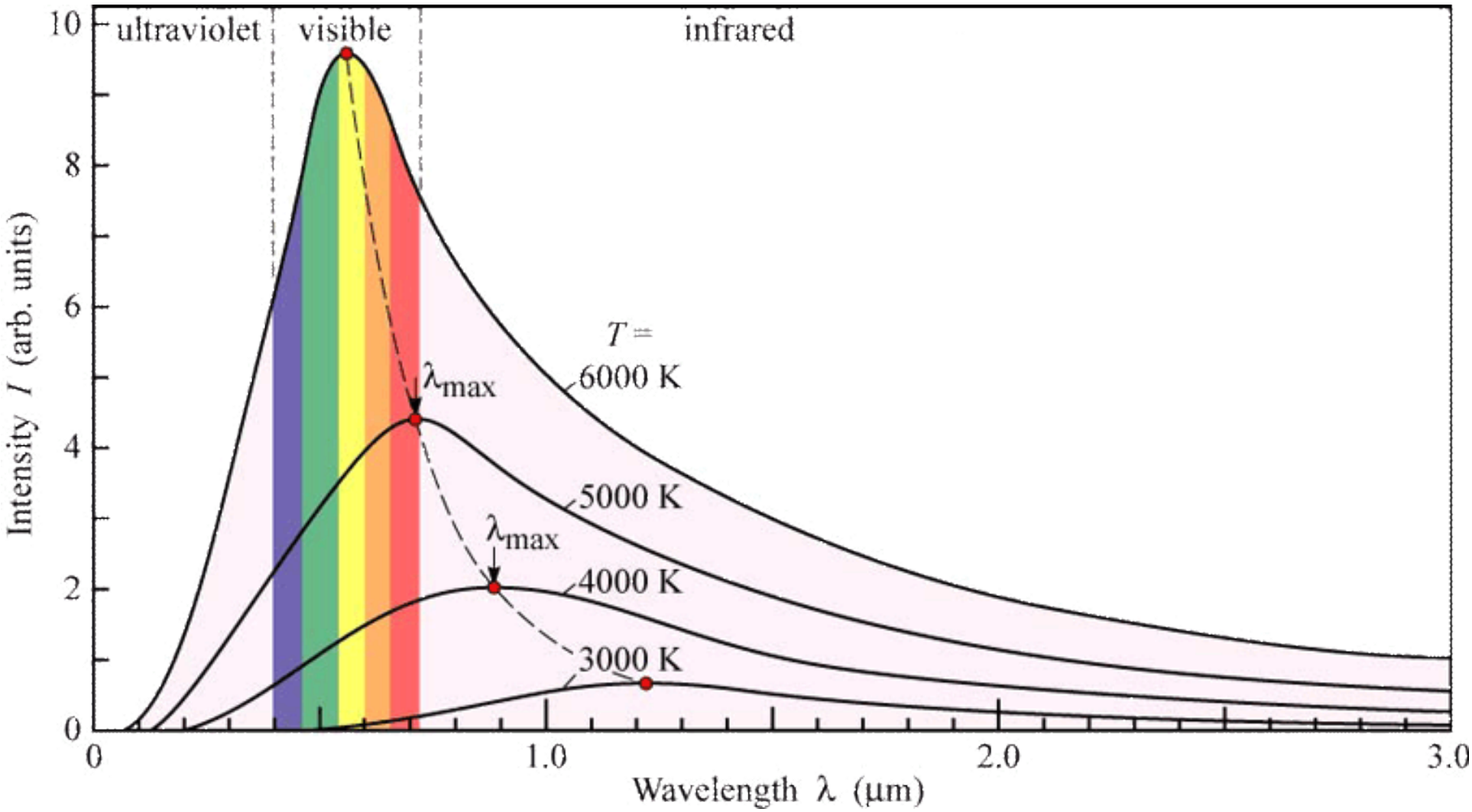

Heat source A
(boiling water)
Thermo-electric pile to
compare temperatures
Heat source B
(boiling water)
Phil. Trans. MDCCCLXI. Plate. I.
Removable
screens for
calibration
Four foot brass tube
containing gas to be tested
Drying tubes
Gas supply
Galvanometer
Pump

The First Computational Climate Model

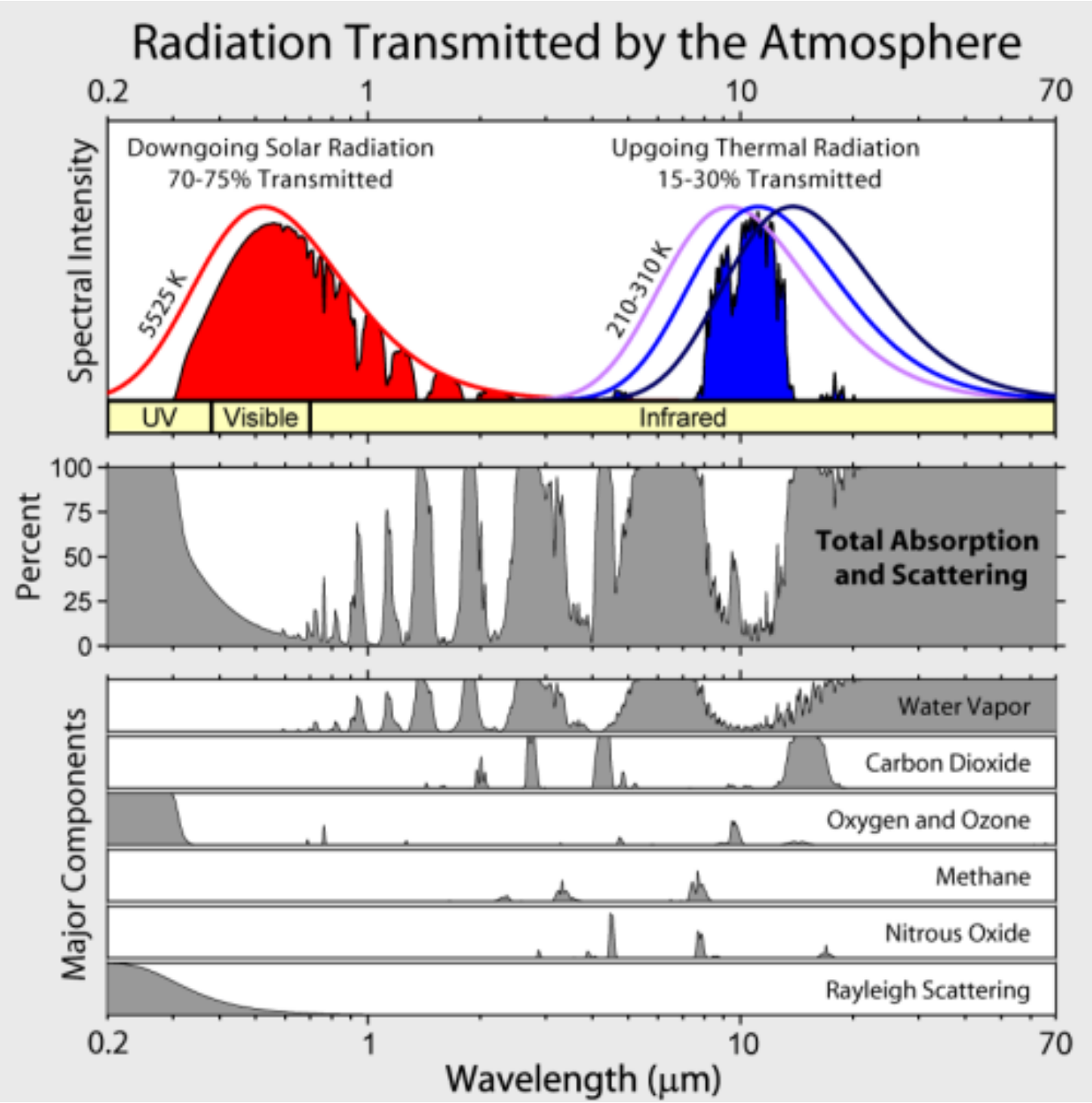
1895: Svante Arrhenius constructs an energy balance model to test his hypothesis that the ice ages were caused by a drop in CO2;
(Predicts global temperature rise of 5.7°C if we double CO2)



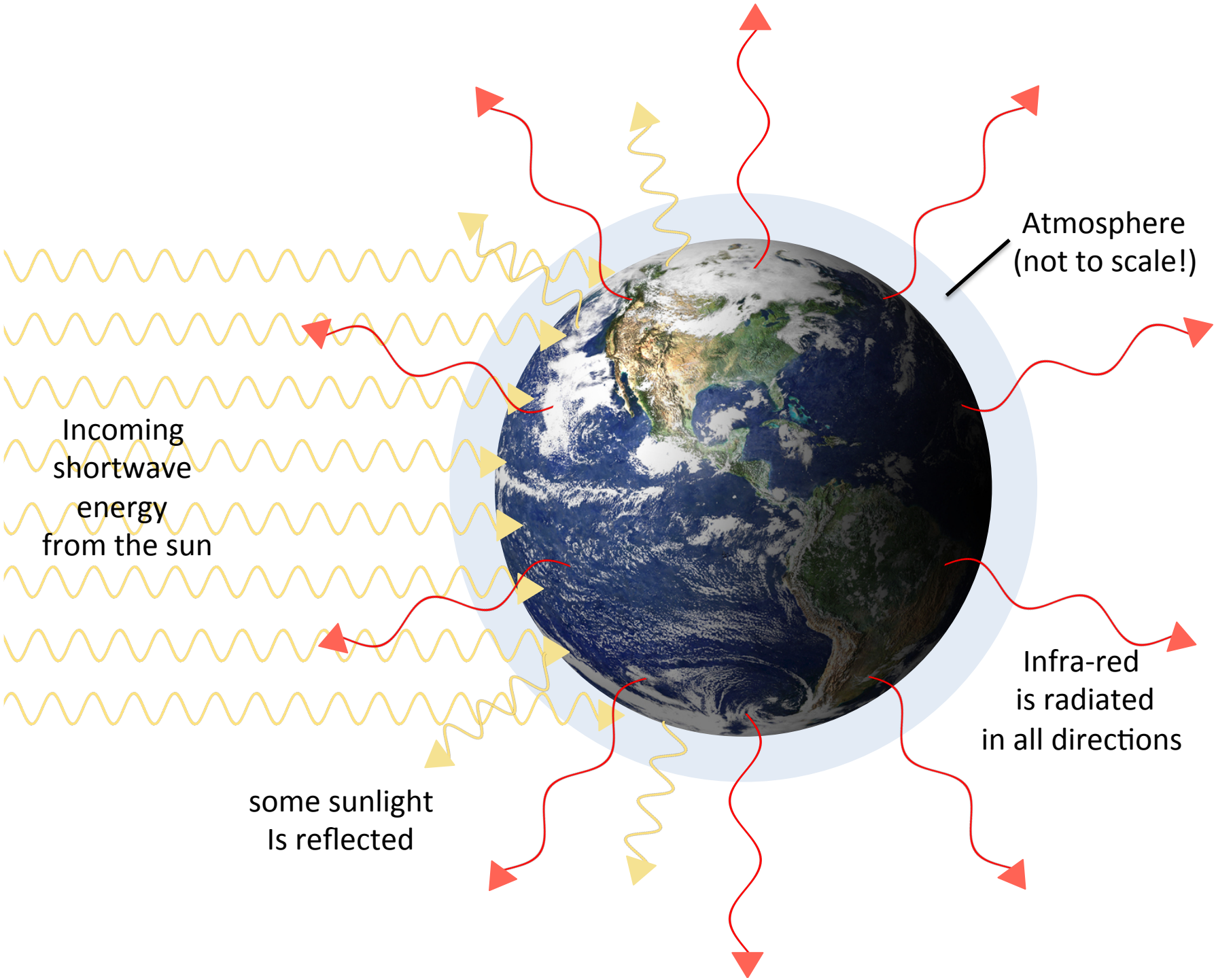
Source: https://chriscolose.wordpress.com/2010/02/18/greenhouse-effect-revisited/

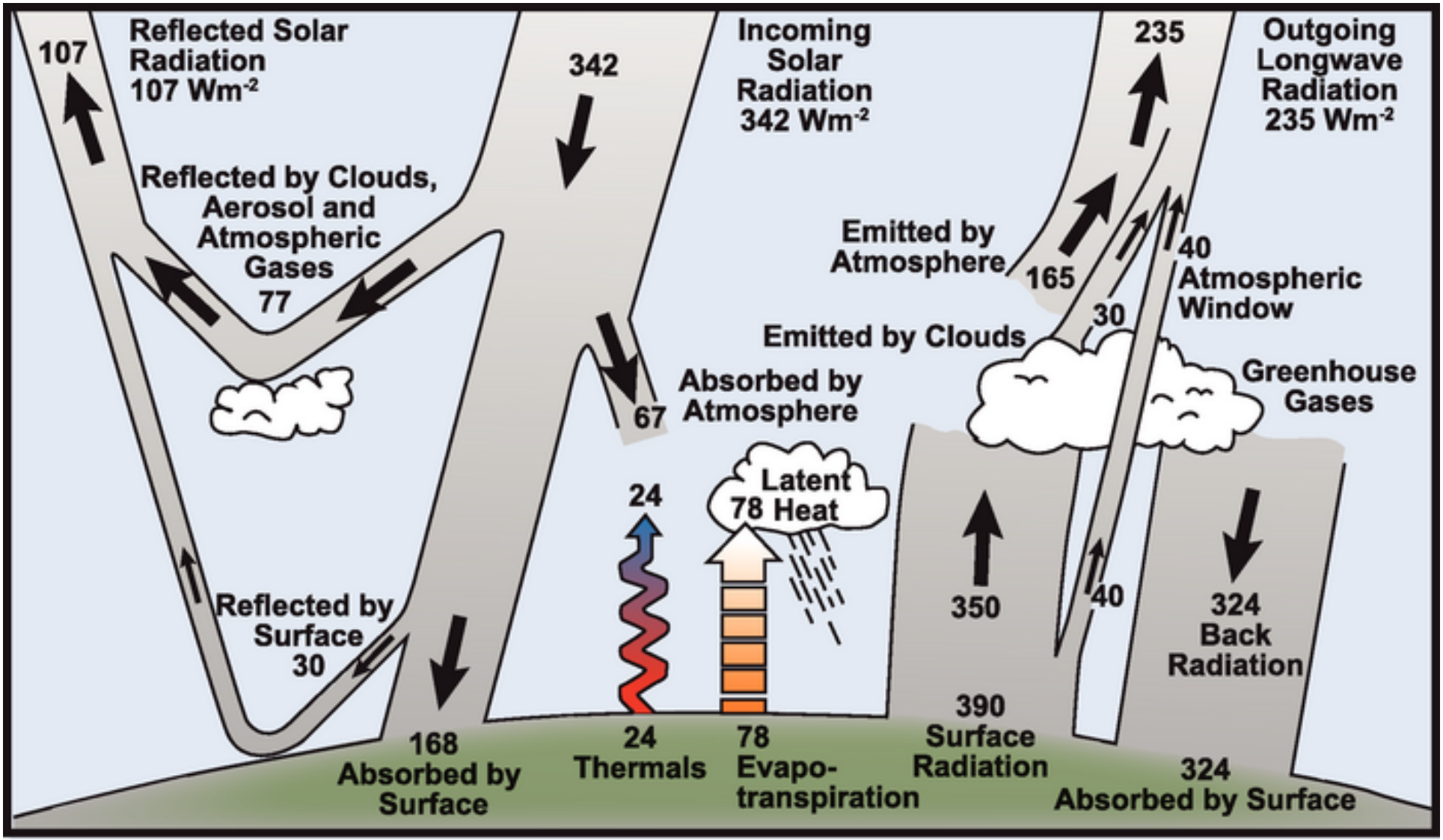


Source: https://chriscolose.wordpress.com/2010/02/18/greenhouse-effect-revisited/



Source: https://chriscolose.wordpress.com/2010/02/18/greenhouse-effect-revisited/

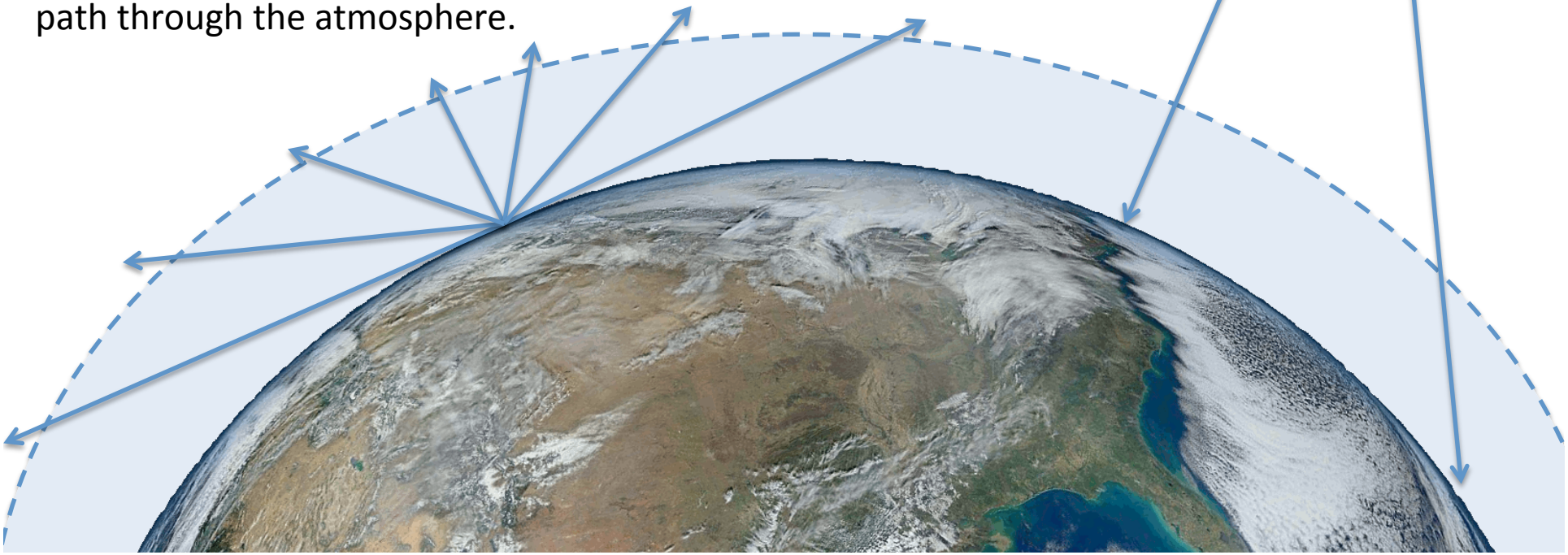

Atmosphere
(not to scale!)
Incoming
shortwave
energy
from the sun
some sunlight
Is reflected
Infra-red
is radiated
in all directions



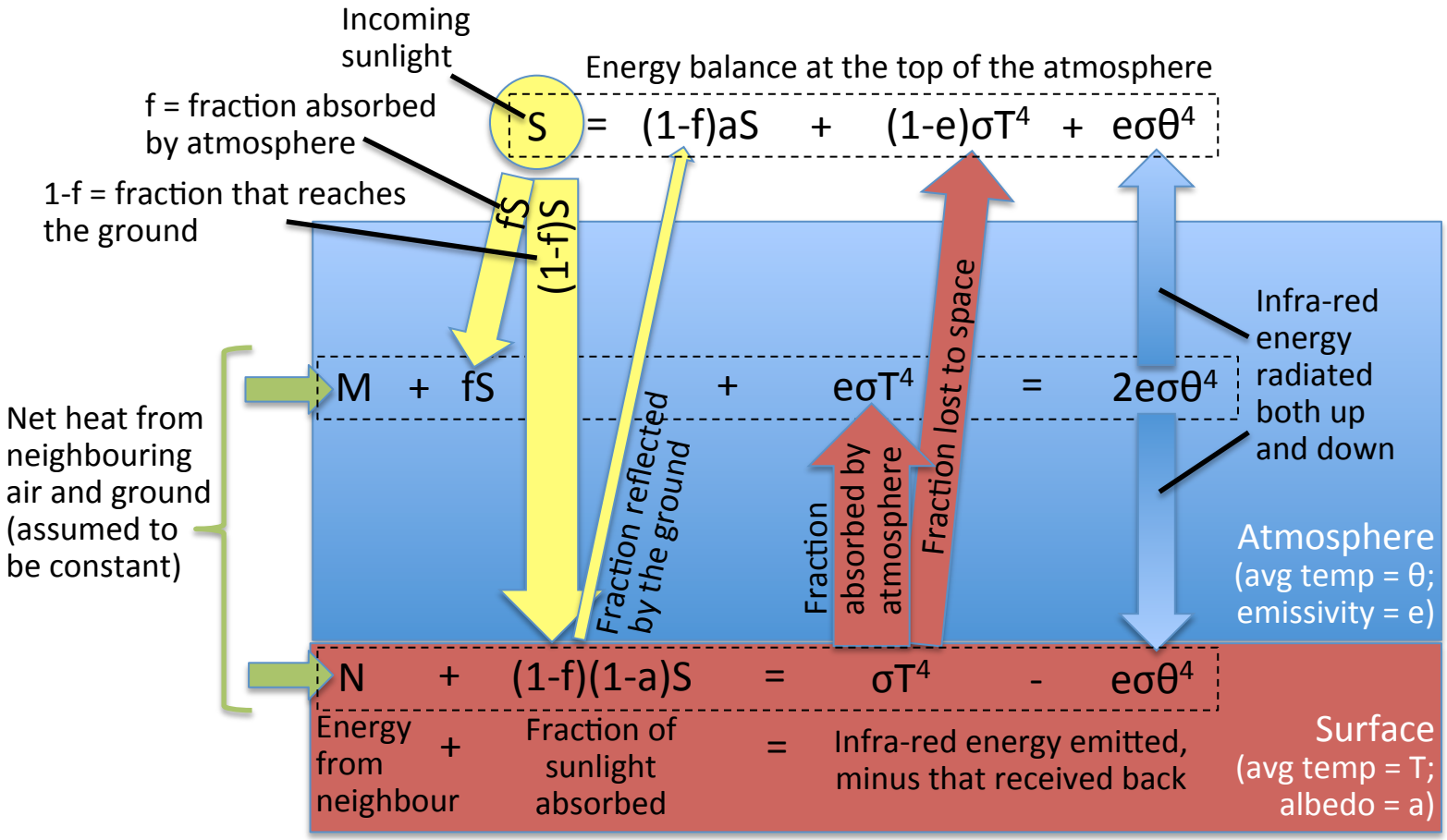
Source: IPCC AR4 WG1, p96

When the moon is directly overhead, its rays have a shorter path through the atmosphere than when it's closer to the horizon.

Infra-red rays from each point on the earth radiate in all directions. The shallower the angle, the longer their path through the atmosphere.



For each column of air, of cross section 1 square meter
S = Solar constant (in Watts per square meter)
M = Net energy flow from neighbouring air columns
N = Net energy flow from neighbouring ground
f = fraction of solar energy absorbed by atmosphere
σ = Stefan-Boltzmann constant
g = emissivity of the ground (in the visible spectrum, g=1-albedo)
e = emissivity of the atmosphere
T = temperature of the ground (dependent variable)
θ = temperature of the atmosphere



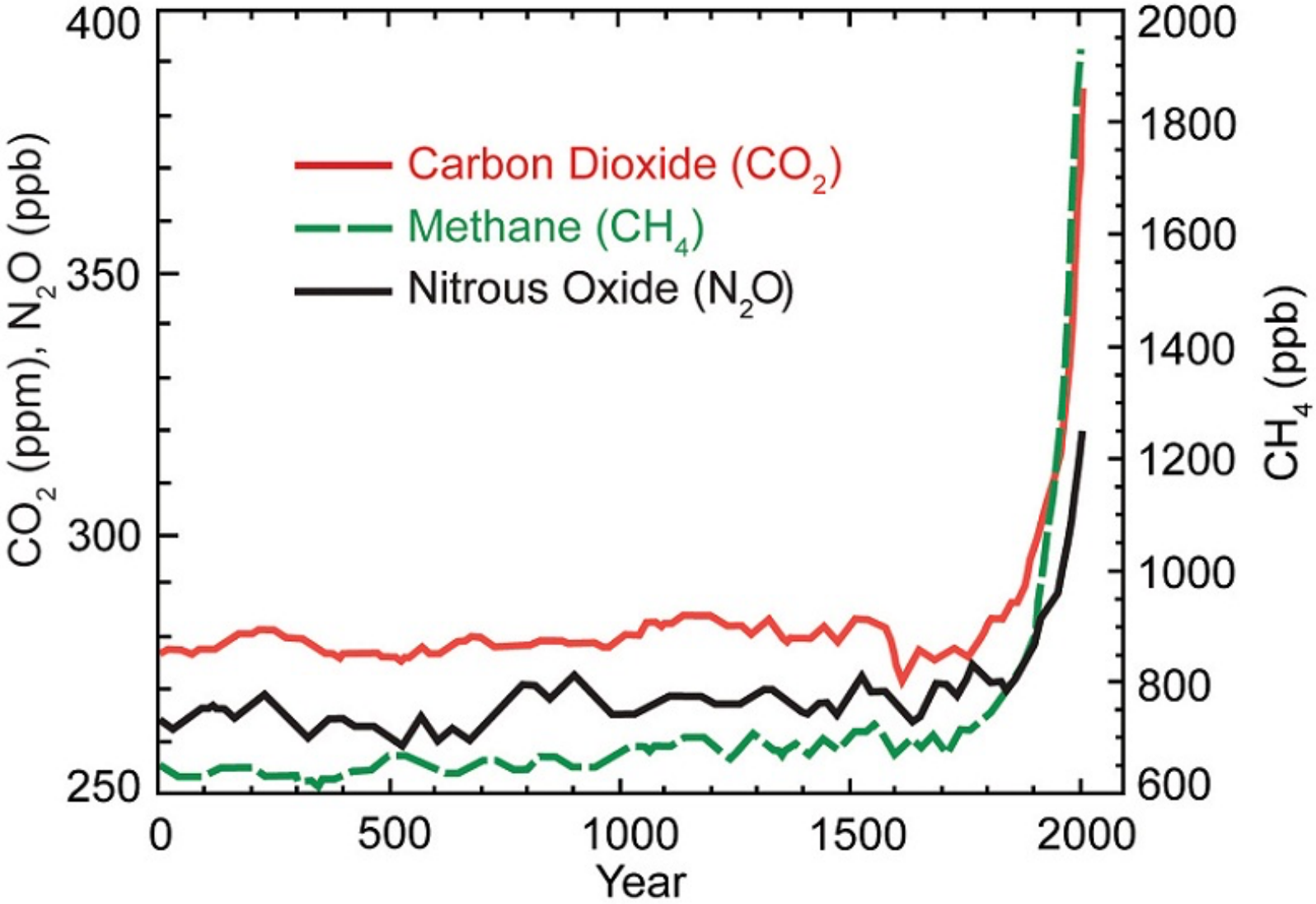
Arrhenius' model results

TABLE VII.—*Variation of Temperature caused by a given Variation of Carbonic Acid.*

Latitude.	Carbonic Acid=0·67.					Carbonic Acid=1·5.					Carbonic Acid=2·0.					Carbonic Acid=2·5.					Carbonic Acid=3·0.				
	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.	Dec.–Feb.	March–May.	June–Aug.	Sept.–Nov.	Mean of the year.
70	−2·9	−3·0	−3·4	−3·1	−3·1	3·3	3·4	3·8	3·6	3·52	6·0	6·1	6·0	6·1	6·05	7·9	8·0	7·9	8·0	7·95	9·1	9·3	9·4	9·4	9·3
60	−3·0	−3·2	−3·4	−3·3	−3·22	3·4	3·7	3·6	3·8	3·62	6·1	6·1	5·8	6·1	6·02	8·0	8·0	7·6	7·9	7·87	9·3	9·5	8·9	9·5	9·3
50	−3·2	−3·3	−3·3	−3·4	−3·3	3·7	3·8	3·4	3·7	3·65	6·1	6·1	5·5	6·0	5·92	8·0	7·9	7·0	7·9	7·7	9·5	9·4	8·6	9·2	9·17
40	−3·4	−3·4	−3·2	−3·3	−3·32	3·7	3·6	3·3	3·5	3·52	6·0	5·8	5·4	5·6	5·7	7·9	7·6	6·9	7·3	7·42	9·3	9·0	8·2	8·8	8·82
30	−3·3	−3·2	−3·1	−3·1	−3·17	3·5	3·3	3·2	3·5	3·47	5·6	5·4	5·0	5·2	5·3	7·2	7·0	6·6	6·7	6·87	8·7	8·3	7·5	7·9	8·1
20	−3·1	−3·1	−3·0	−3·1	−3·07	3·5	3·2	3·1	3·2	3·25	5·2	5·0	4·9	5·0	5·02	6·7	6·6	6·3	6·6	6·52	7·9	7·5	7·2	7·5	7·52
10	−3·1	−3·0	−3·0	−3·0	−3·02	3·2	3·2	3·1	3·1	3·15	5·0	5·0	4·9	4·9	4·95	6·6	6·4	6·3	6·4	6·42	7·4	7·3	7·2	7·3	7·3
0	−3·0	−3·0	−3·1	−3·0	−3·02	3·1	3·1	3·2	3·2	3·15	4·9	4·9	5·0	5·0	4·95	6·4	6·4	6·6	6·6	6·5	7·3	7·3	7·4	7·4	7·35
−10	−3·1	−3·1	−3·2	−3·1	−3·12	3·2	3·2	3·2	3·2	3·2	5·0	5·0	5·2	5·1	5·07	6·6	6·6	6·7	6·7	6·65	7·4	7·5	8·0	7·6	7·62
−20	−3·1	−3·2	−3·3	−3·2	−3·2	3·2	3·2	3·4	3·3	3·27	5·2	5·3	5·5	5·4	5·35	6·7	6·8	7·0	7·0	6·87	7·9	8·1	8·6	8·3	8·22
−30	−3·3	−3·3	−3·4	−3·4	−3·35	3·4	3·5	3·7	3·5	3·52	5·5	5·6	5·8	5·6	5·62	7·0	7·2	7·7	7·4	7·32	8·6	8·7	9·1	8·8	8·8
−40	−3·4	−3·4	−3·3	−3·4	−3·37	3·6	3·7	3·8	3·7	3·7	5·8	6·0	6·0	6·0	5·95	7·7	7·9	7·9	7·9	7·85	9·1	9·2	9·4	9·3	9·25
−50	−3·2	−3·3	—	—	—	3·8	3·7	—	—	—	6·0	6·1	—	—	—	7·9	8·0	—	—	—	9·4	9·5	—	—	—
−60																									

Source: Arrhenius, S. (1896). On the Influence of Carbonic Acid in the Air upon the Temperature of the Ground. Philosophical Magazine and Journal of Science, 41(251).

Exponential rise of GHGs



Source: http://www3.epa.gov/climatechange/science/causes.html

Multi-loop systems