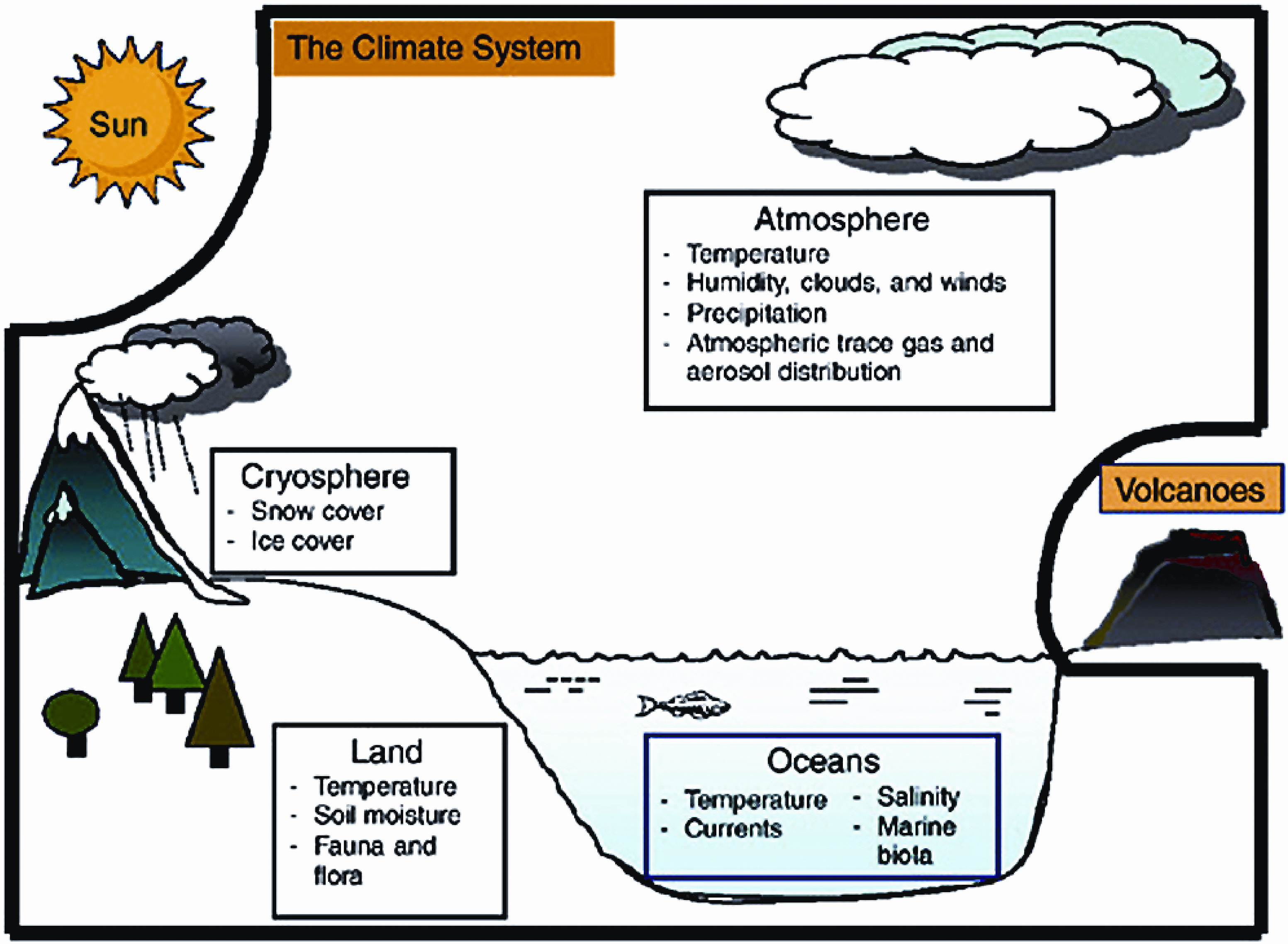
Overview of Global Climate Forcings and Feedbacks

Roger A. Pielke Sr.

March 16, 2007



The Climate System

Sun

Atmosphere
- Temperature
- Humidity, clouds, and winds
- Precipitation
- Atmospheric trace gas and aerosol distribution

Cryosphere
- Snow cover
- Ice cover

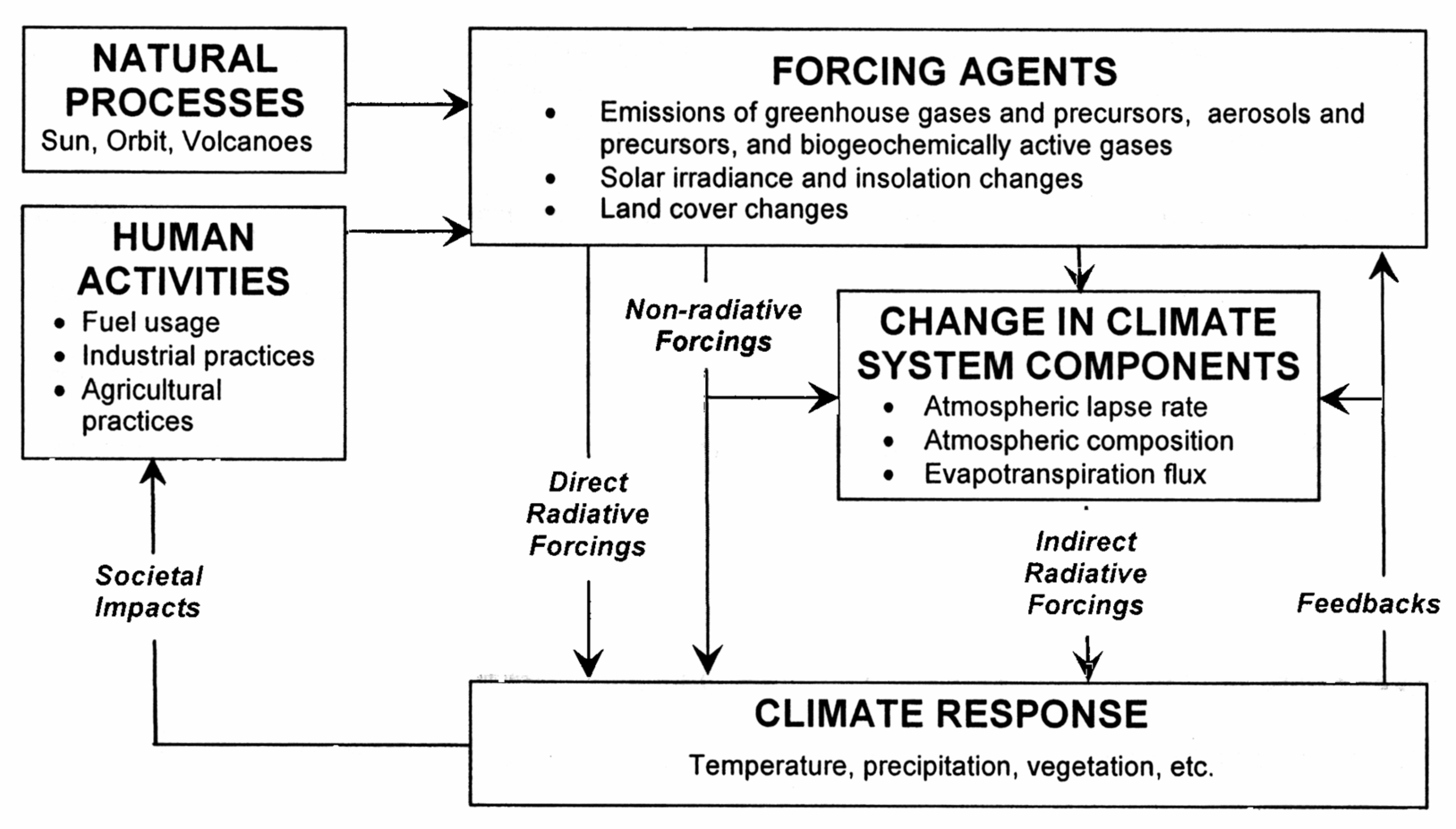
Volcanoes

Land
- Temperature
- Soil moisture
- Fauna and flora

Oceans
- Temperature
- Currents
- Salinity
- Marine biota

The climate system, consisting of the atmosphere, oceans, and land. Critical state variables for each sphere of the climate system are listed in the boxes. For the purposes of this report, the Sun, volcanic emissions, and human-caused emissions of greenhouse gases or changes to the land surface are considered external to the climate system. (From the National Research Council, 2005)

Conceptual framework for the climate forcings that impact the physical components of the climate system under present-day conditions. From NRC, 2005.



NATURAL PROCESSES

Sun, Orbit, Volcanoes

HUMAN ACTIVITIES

- Fuel usage
- Industrial practices
- Agricultural practices

FORCING AGENTS

- Emissions of greenhouse gases and precursors, aerosols and precursors, and biogeochemically active gases
- Solar irradiance and insolation changes
- Land cover changes

Non-radiative Forcings

Direct Radiative Forcings

CHANGE IN CLIMATE SYSTEM COMPONENTS

- Atmospheric lapse rate
- Atmospheric composition
- Evapotranspiration flux

Indirect Radiative Forcings

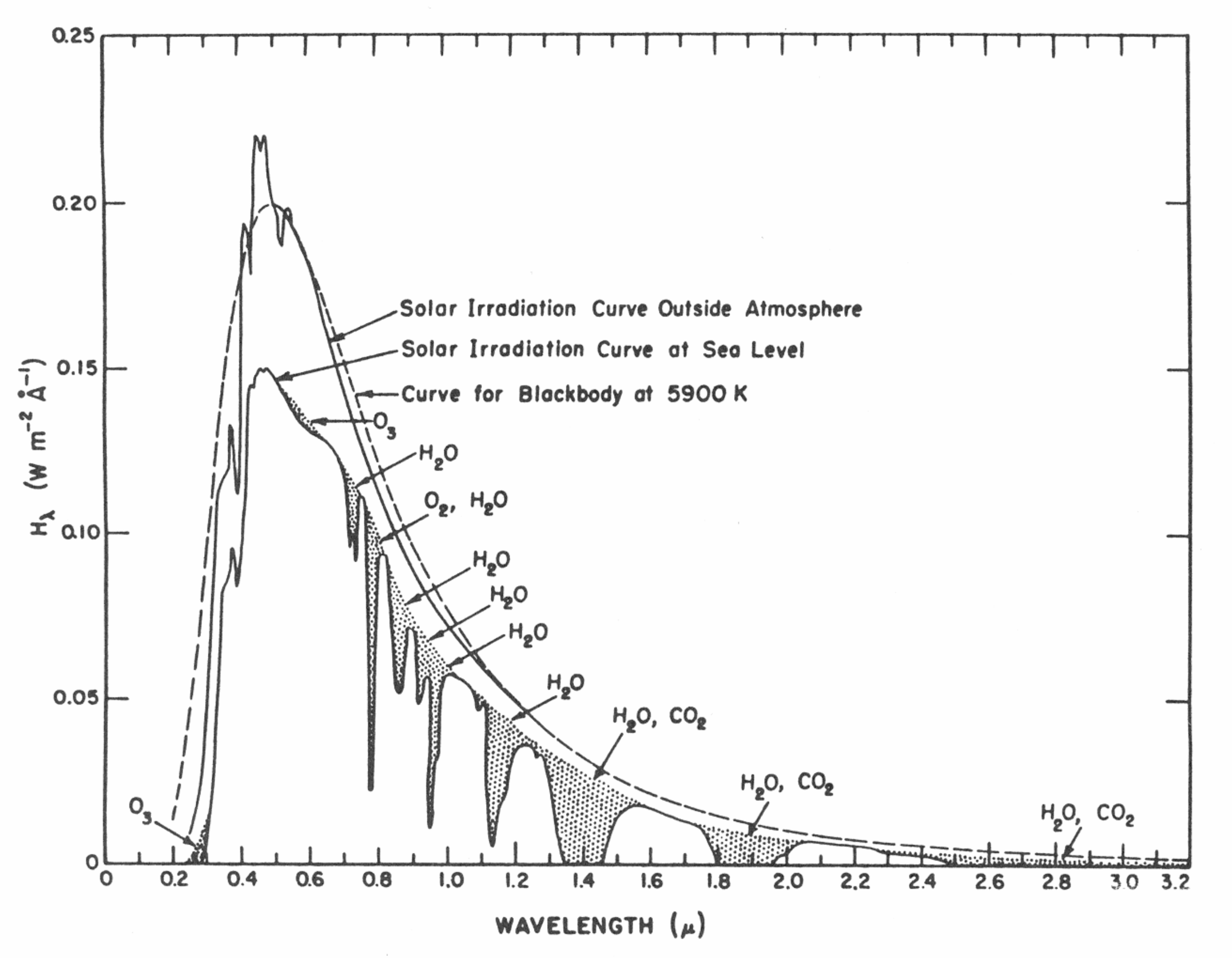
Feedbacks

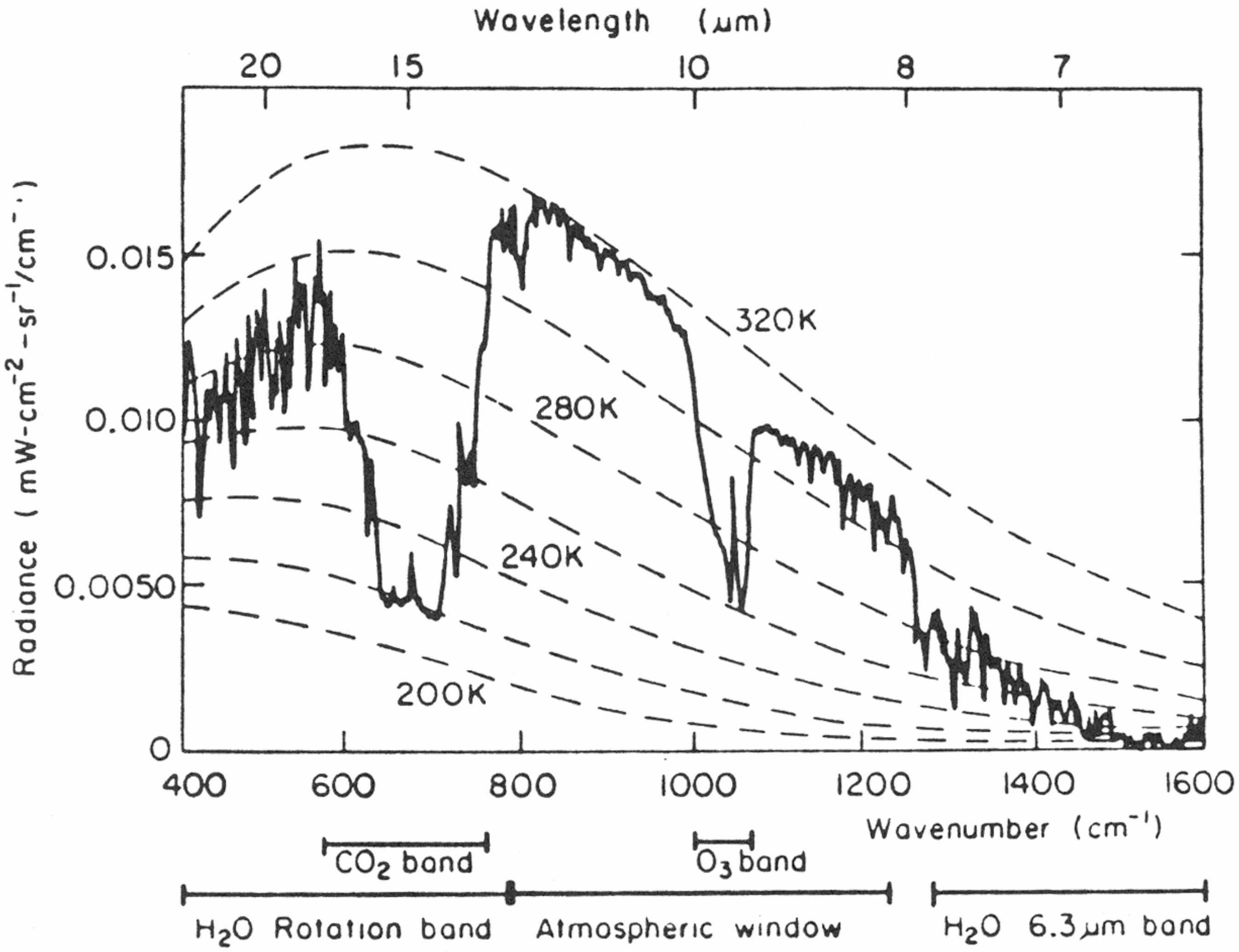
Societal Impacts

CLIMATE RESPONSE

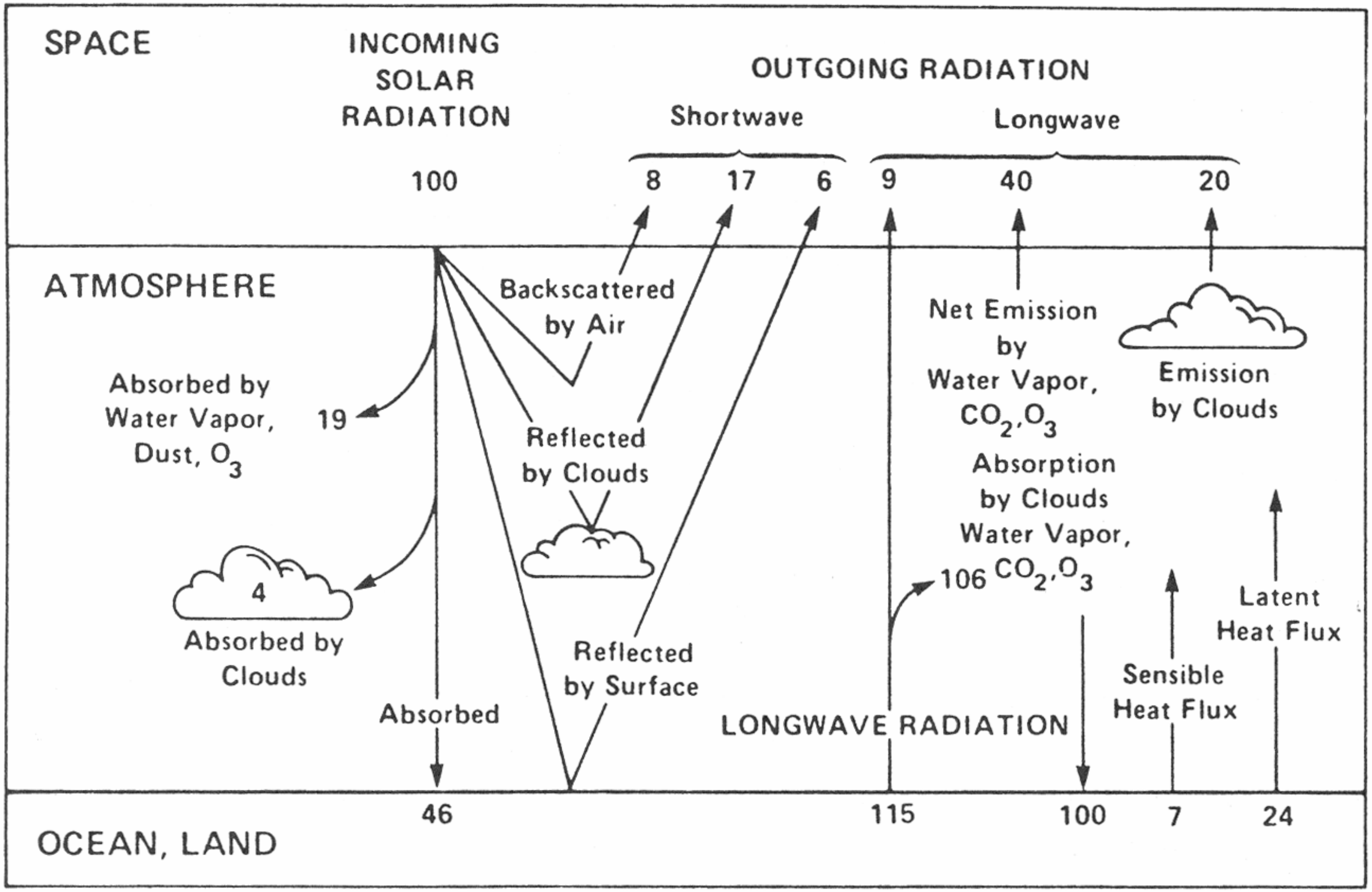
Temperature, precipitation, vegetation, etc.

Spectral distribution curves related to the sun; shaded areas indicate absorption at sea level, due to the atmospheric constituents shown. From Gast, P.R., A.S. Jursa, J. Castelli, S. Basu, and J. Aarons, 1965: Solar electromagnetic radiation. In Handbook of Geophysics and Space Environments, S.L. Valley, Ed., pp. 16-1--16-38. McGraw-Hill, New York.



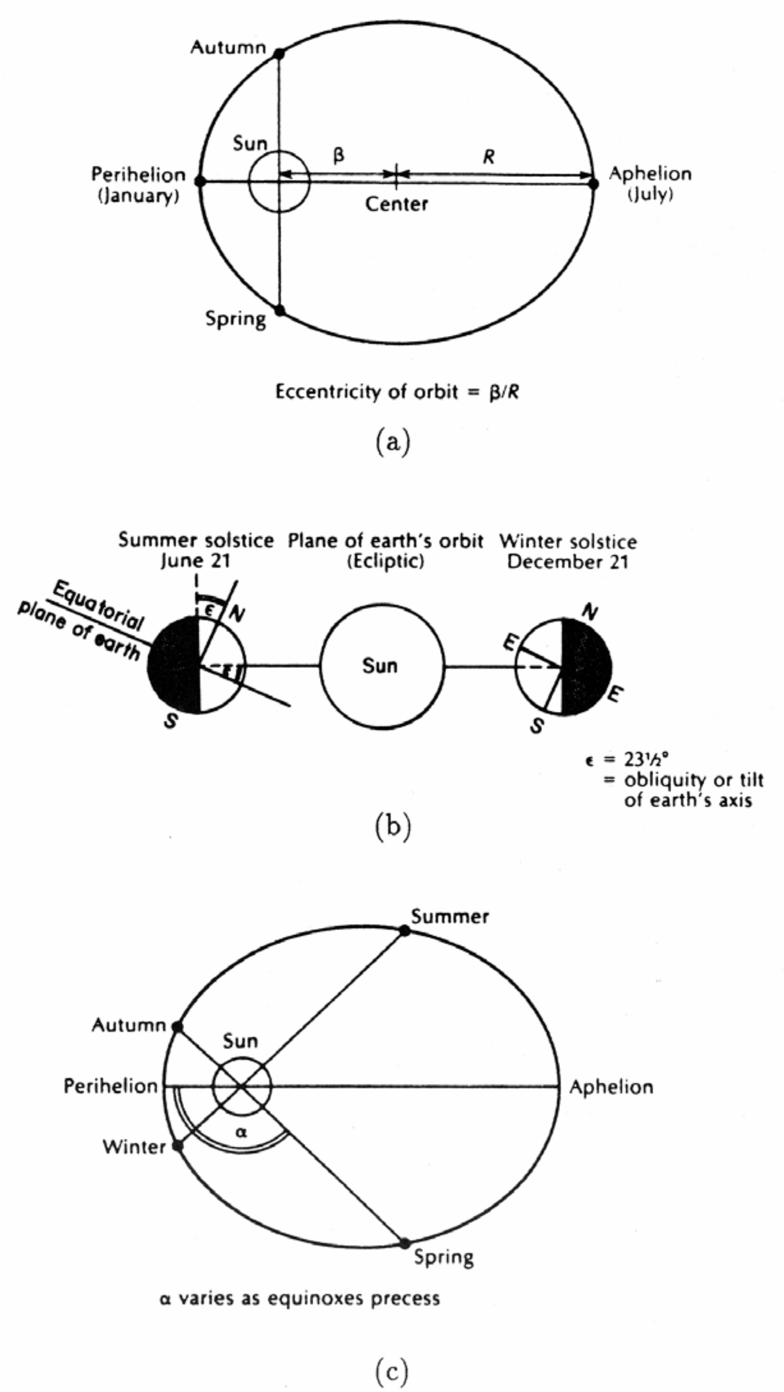


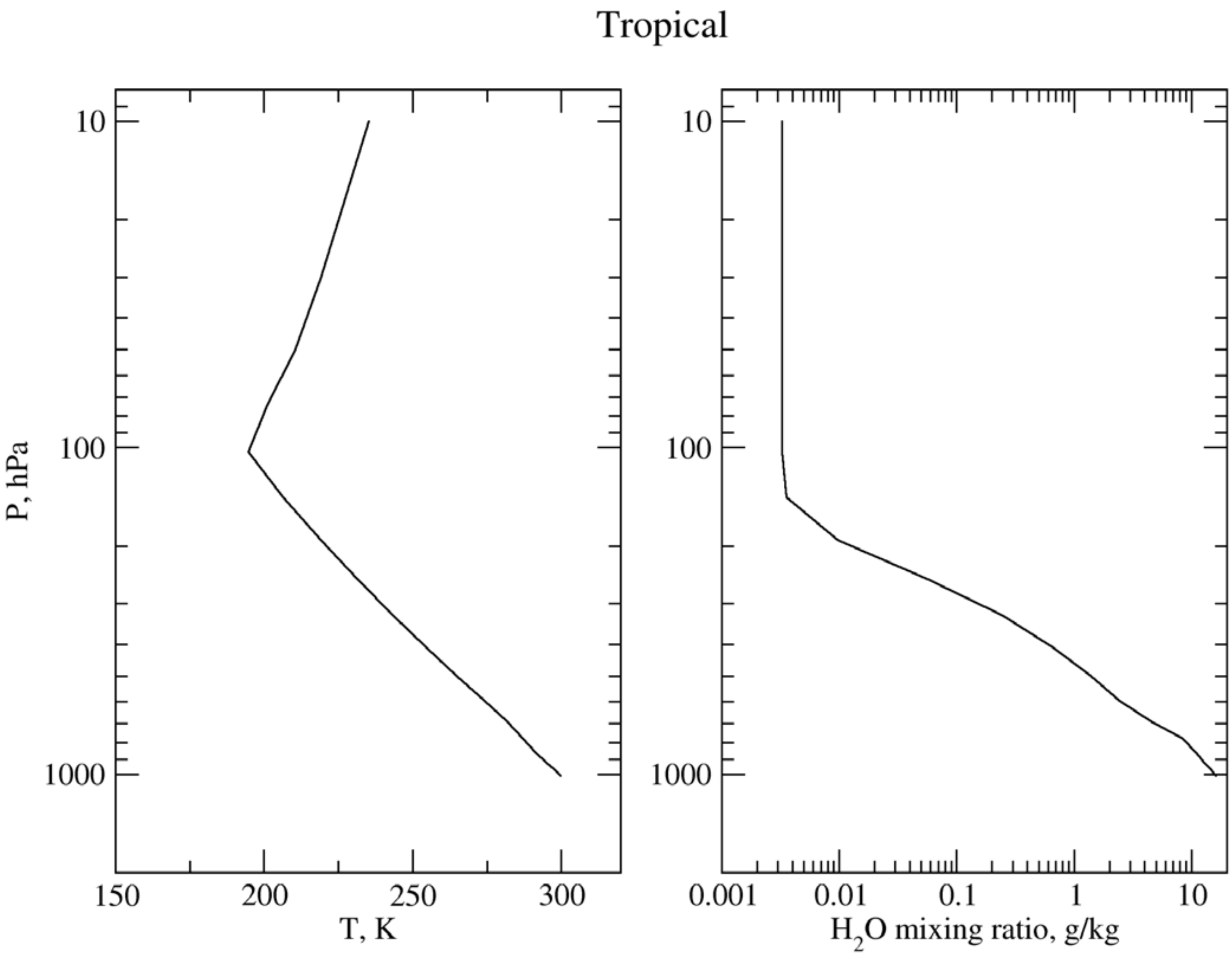
Atmospheric spectrum obtained with a scanning interferometer on board the Nimbus 4 satellite. The interferometer viewed the earth vertically as the satellite was passing over the North African desert. From Paltridge, G.W., and C.M.R. Platt, 1976: Radiative processes in meteorology and climatology. Developments in Atmospheric Science, 5. Elsevier Science Publishers, New York.



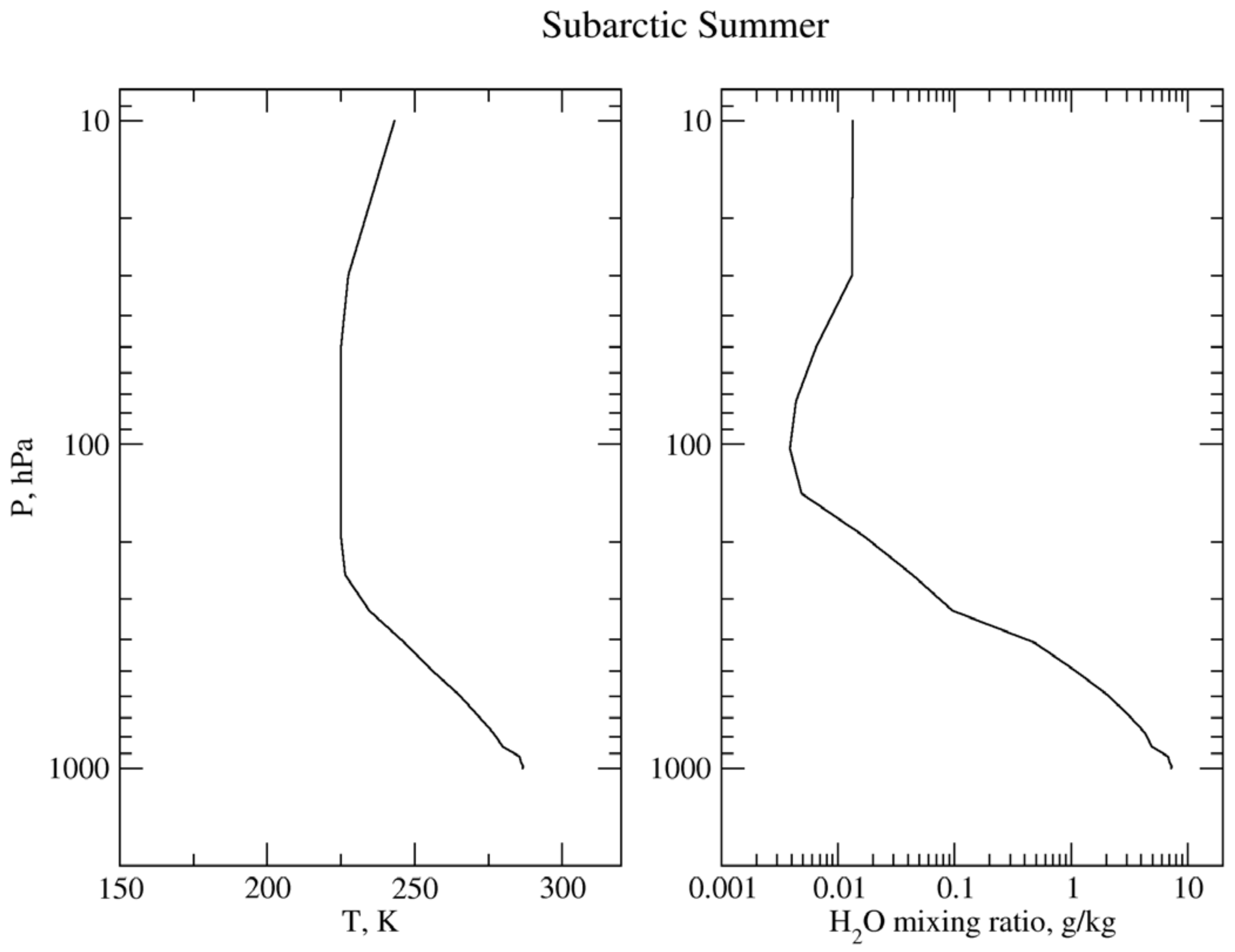
Schematic diagram of the global average components of the Earth's energy balance. Adapted from MacCracken, M.C., 1985: Carbon dioxide and climate change: Background and overview. In The Potential Climatic Effects of Increasing Carbon Dioxide. MacCracken, M.C., and F.M. Luther, Eds., U.S. Department of Energy, Washington, DC, and the University of California, Lawrence Livermore National Laboratory, (DOE/ER-0237), 381 pp.

Important components of earth sun geometry. Important orbital parameters: (a) eccentricity of orbit, (b) axial tilt, and (c) precession of the equinoxes. [From Griffiths, J.F., and D.M. Driscoll, 1982: Survey of climatology. Charles E. Merrill Publishing Co., Columbus, Ohio.]

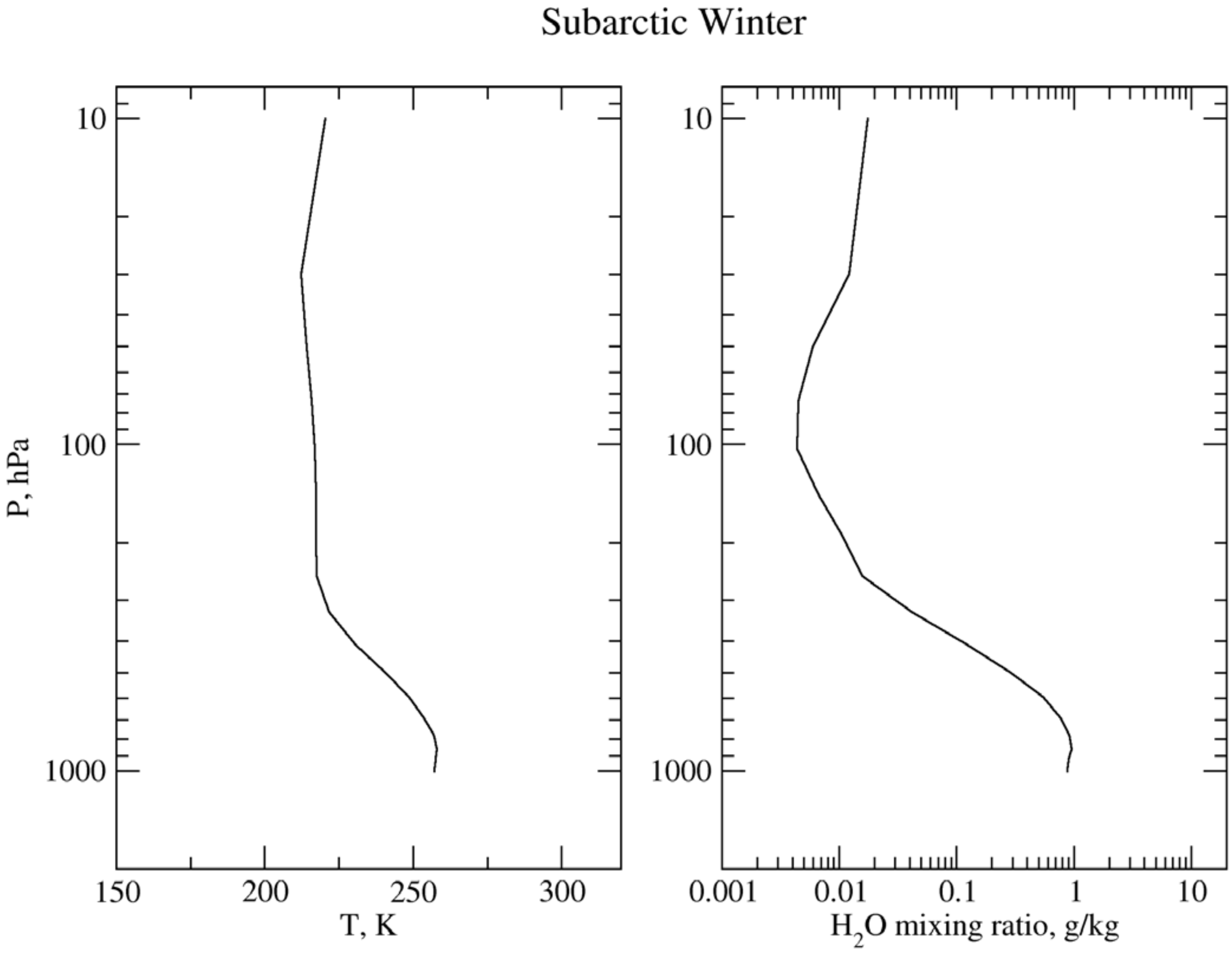




Profiles of temperature and water vapor mixing ratio for tropical atmosphere. Figure courtesy of Norm Wood, Colorado State University.

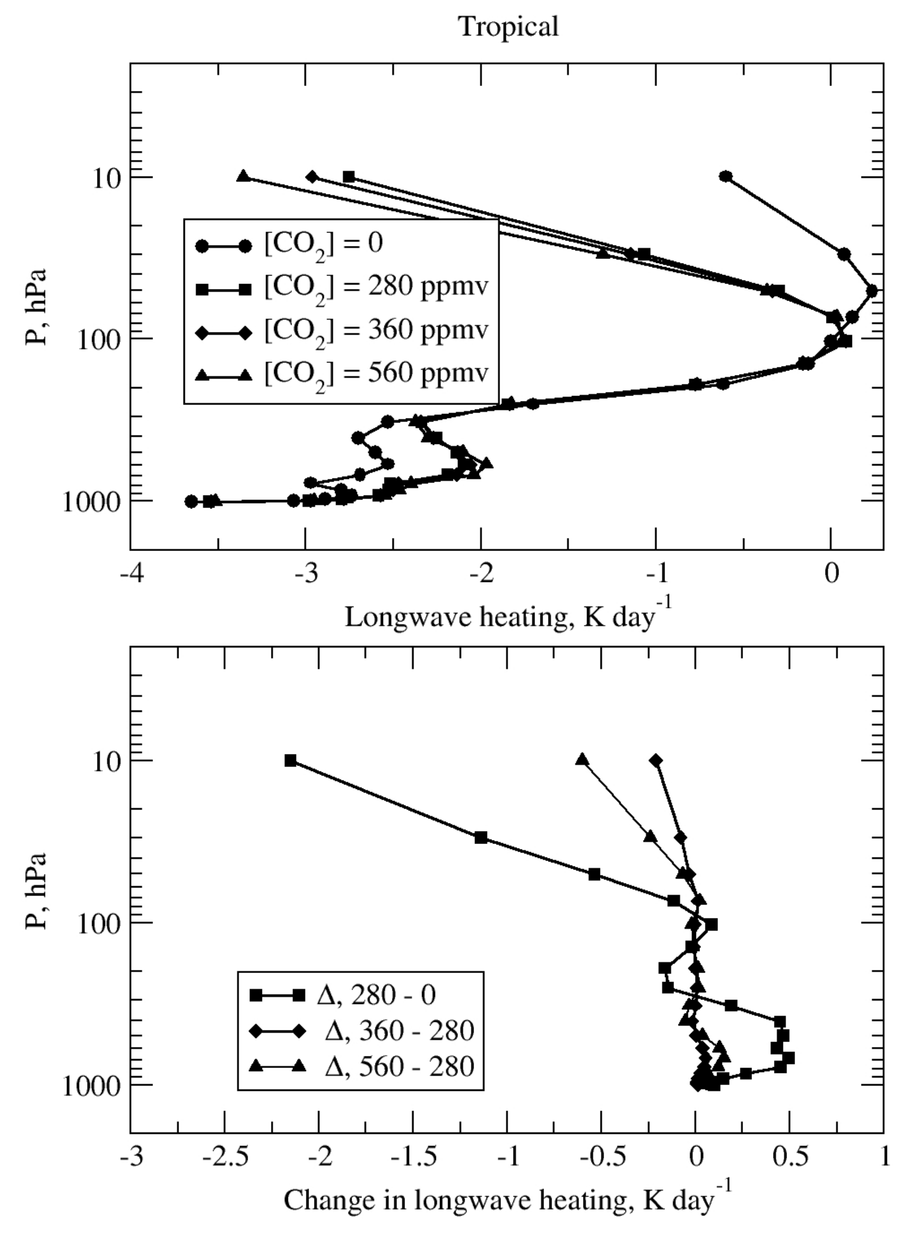


Profiles of temperature and water vapor mixing ratio for subarctic summer atmosphere. Figure courtesy of Norm Wood, Colorado State University.

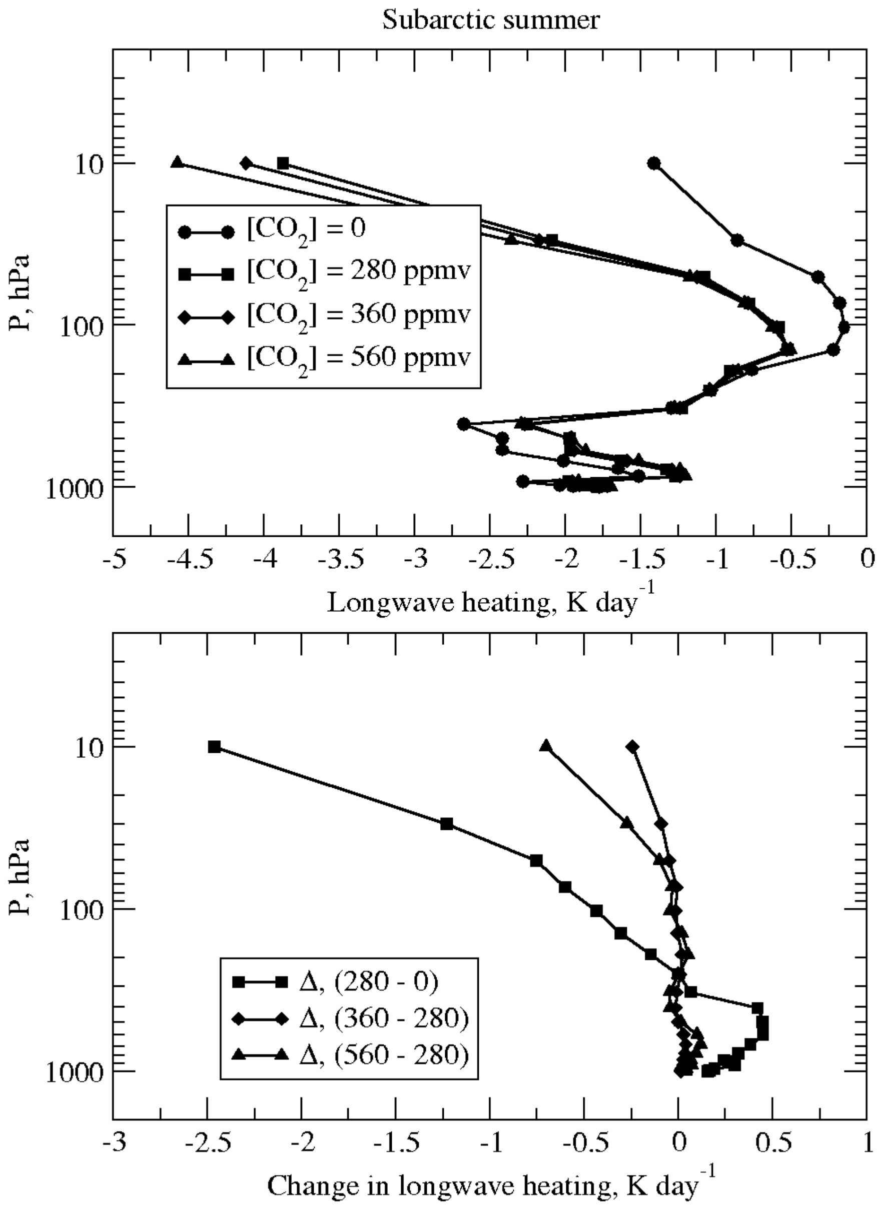


Profiles of temperature and water vapor mixing ratio for subarctic winter atmosphere. Figure courtesy of Norm Wood, Colorado State University.

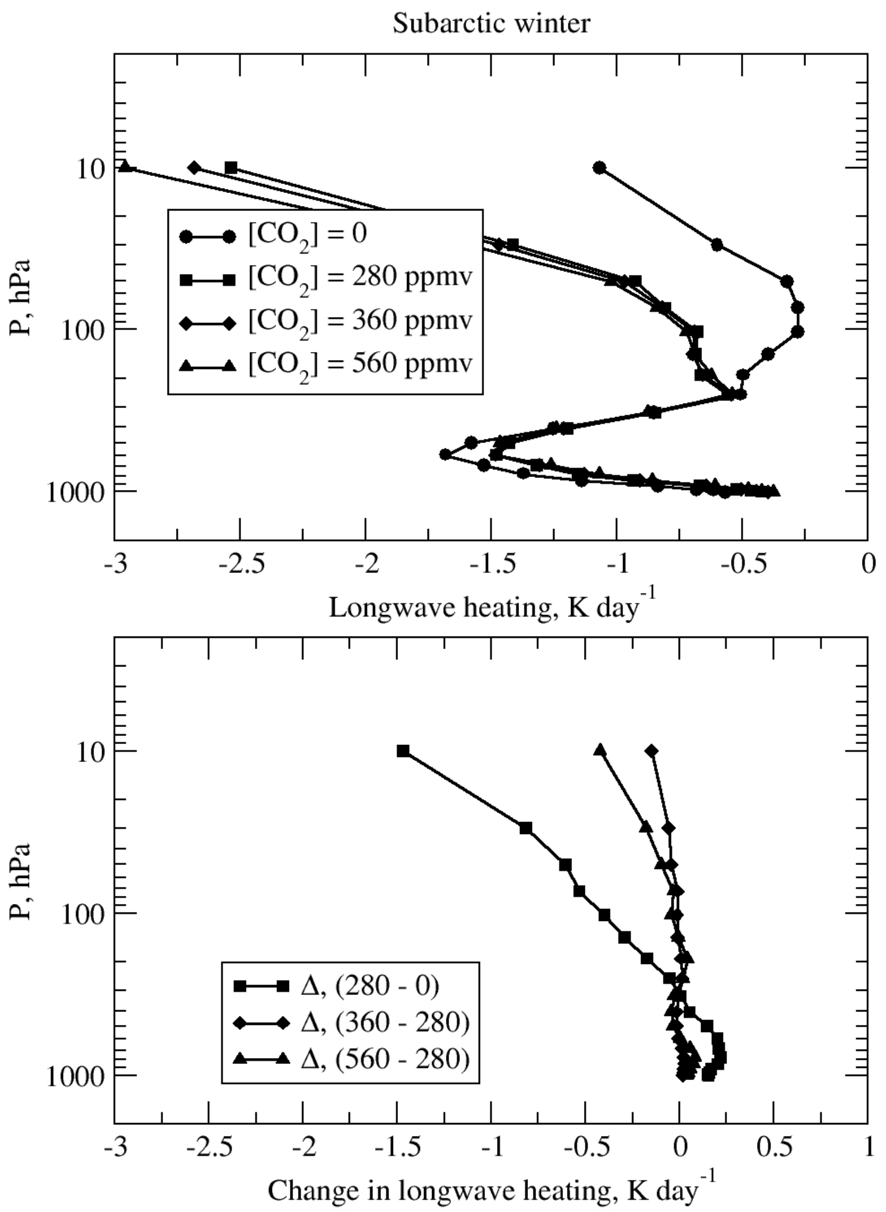
Longwave heating rates (upper) and change in longwave heating rates (lower) for tropical atmosphere with perturbed carbon dioxide. Figure courtesy of Norm Wood, Colorado State University.



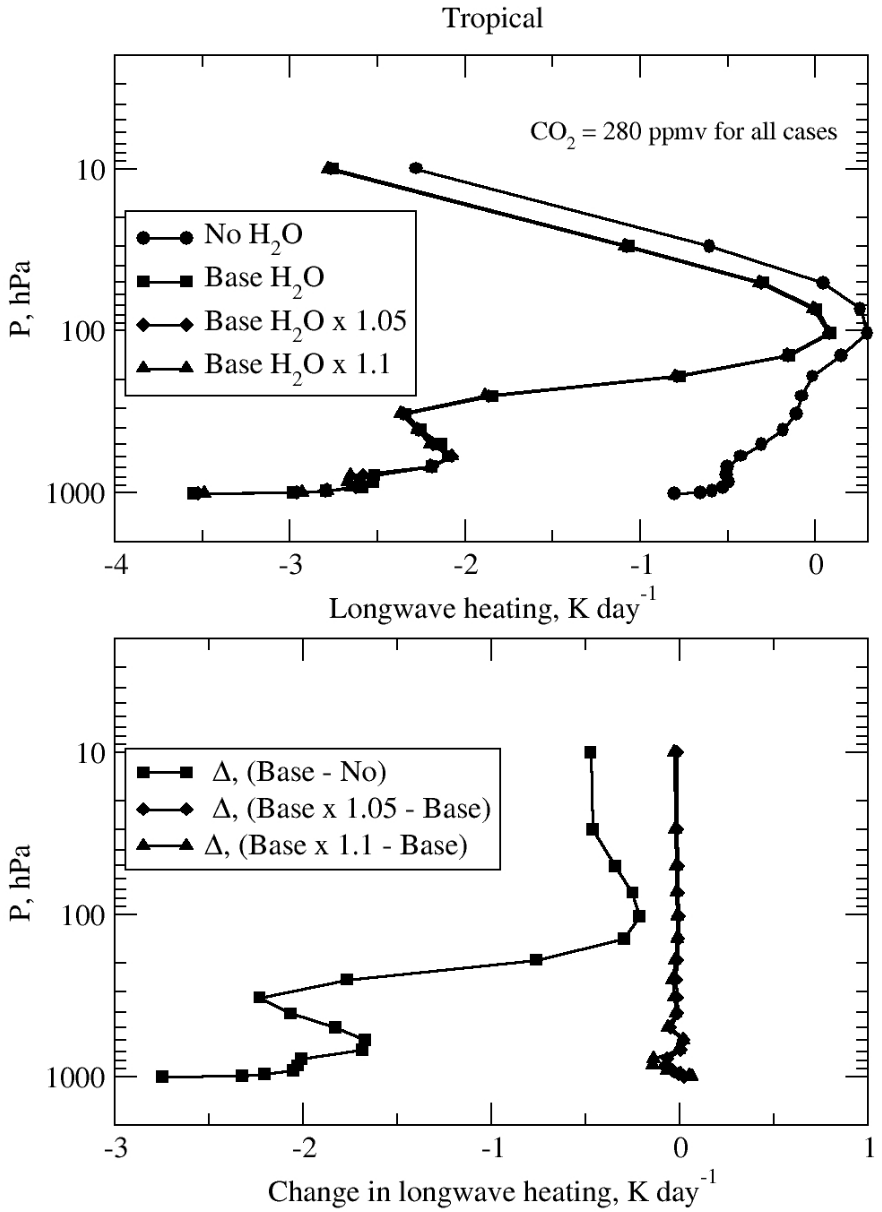
Longwave heating rates (upper) and change in longwave heating rates (lower) for subarctic summer atmosphere with perturbed carbon dioxide. Figure courtesy of Norm Wood, Colorado State University.



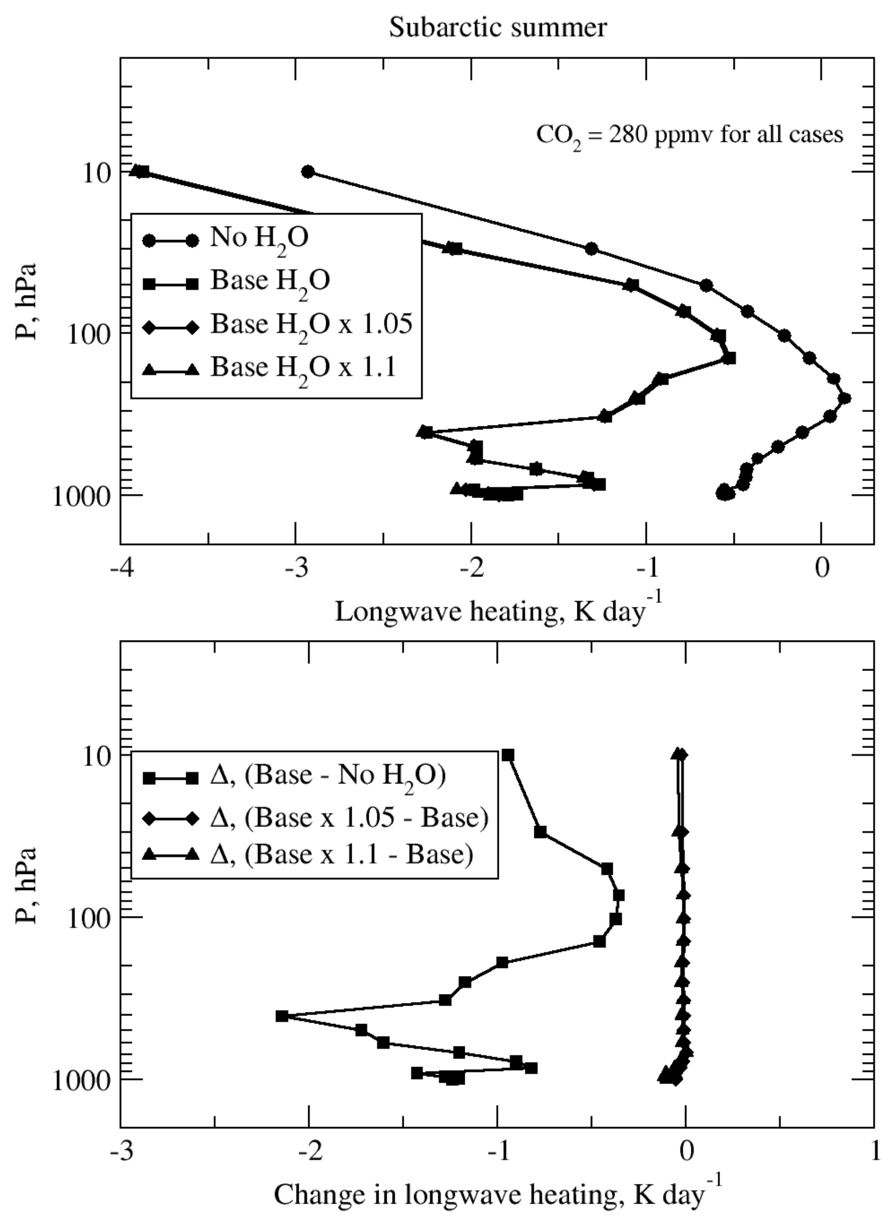
Longwave heating rates (upper) and change in longwave heating rates (lower) for subarctic winter atmosphere with perturbed carbon dioxide. Figure courtesy of Norm Wood, Colorado State University.



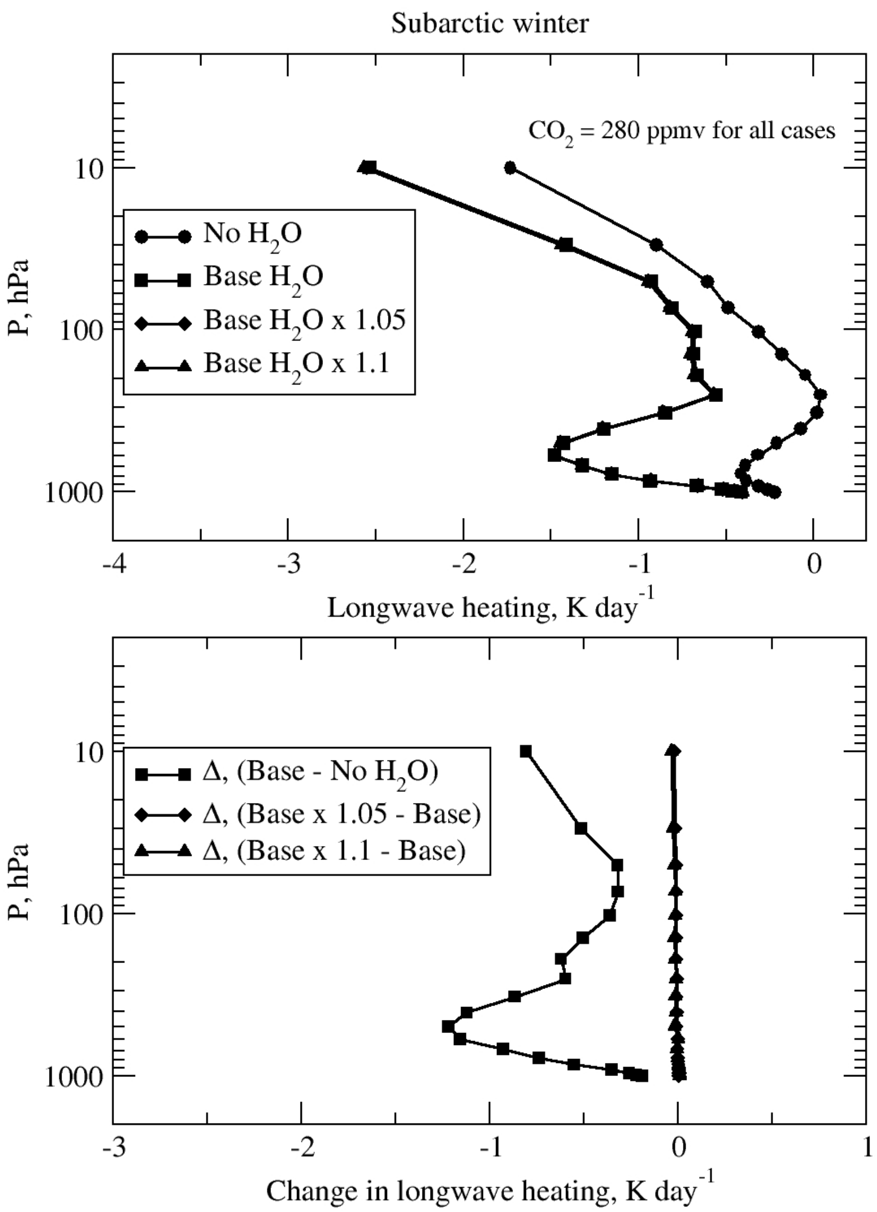
Longwave heating rates (upper) and change in longwave heating rates (lower) for tropical atmosphere with perturbed water vapor. Figure courtesy of Norm Wood, Colorado State University.

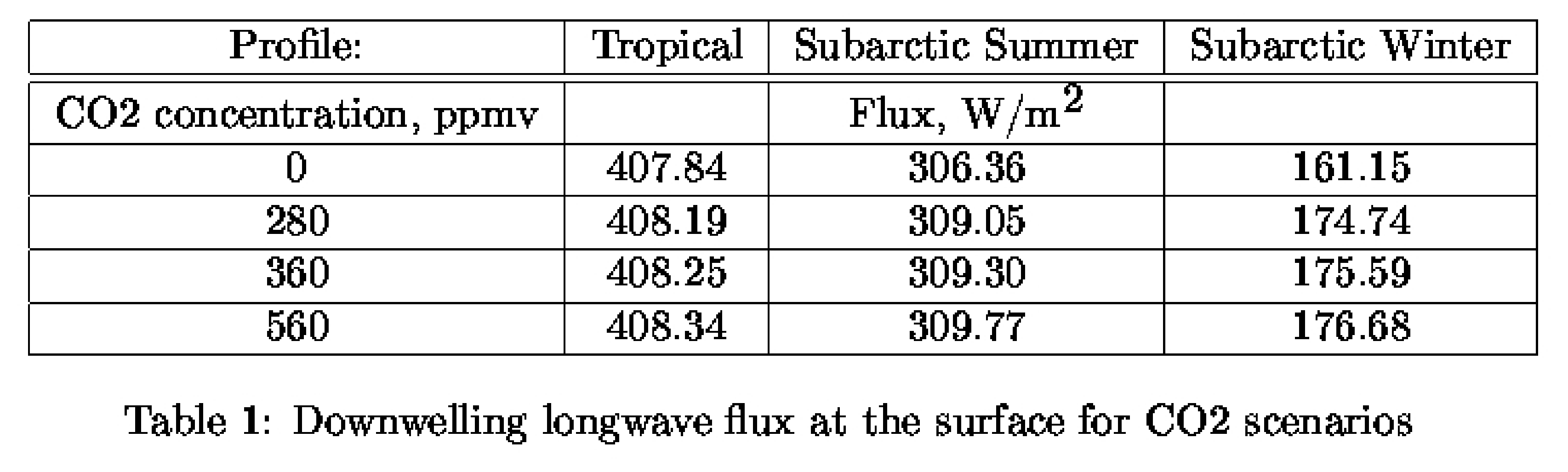


Longwave heating rates (upper) and change in longwave heating rates (lower) for subarctic summer atmosphere with perturbed water vapor. Figure courtesy of Norm Wood, Colorado State University.



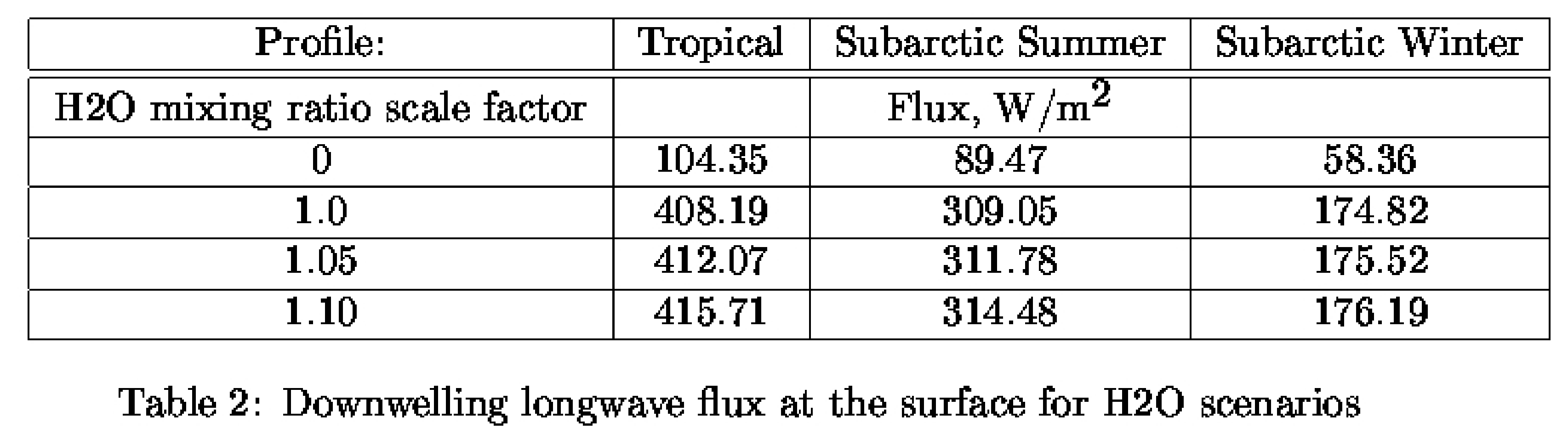
Longwave heating rates (upper) and change in longwave heating rates (lower) for subarctic winter atmosphere with perturbed water vapor. Figure courtesy of Norm Wood, Colorado State University.





Profile:	Tropical	Subarctic Summer	Subarctic Winter
CO2 concentration, ppmv		Flux, W/m^2	
0	407.84	306.36	161.15
280	408.19	309.05	174.74
360	408.25	309.30	175.59
560	408.34	309.77	176.68

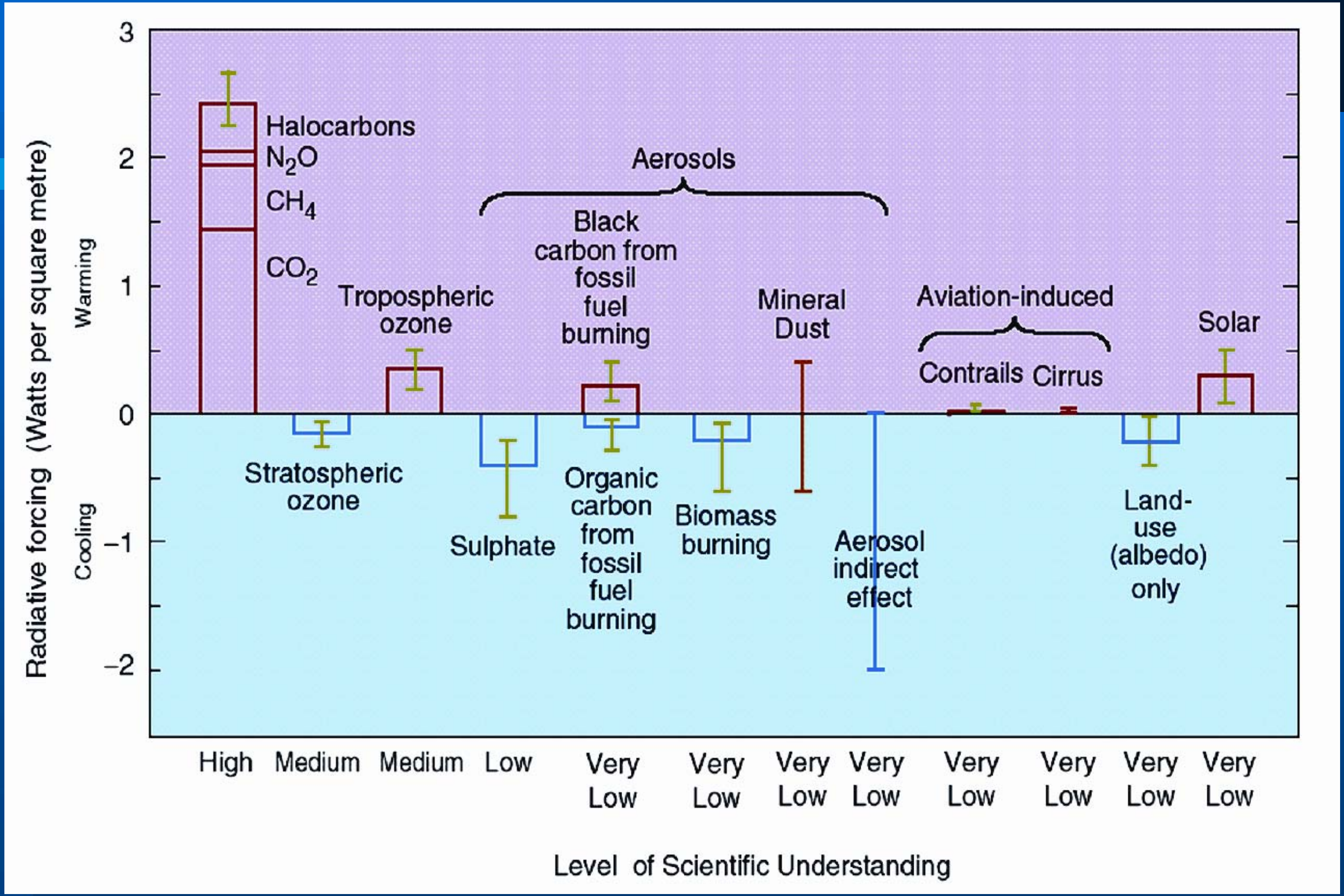
Table 1: Downwelling longwave flux at the surface for CO2 scenarios



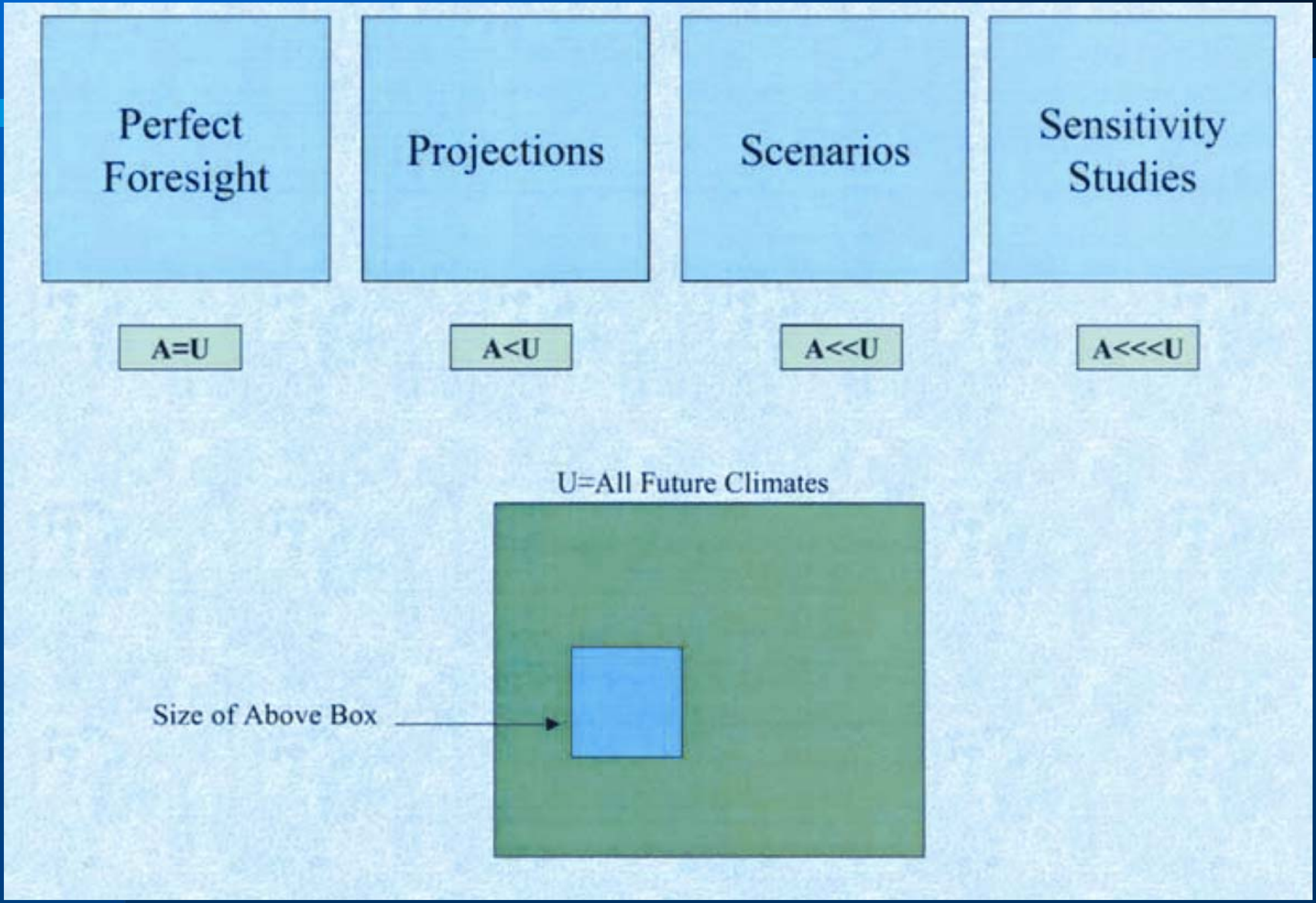
Profile:	Tropical	Subarctic Summer	Subarctic Winter
H2O mixing ratio scale factor		Flux, W/m^2	
0	104.35	89.47	58.36
1.0	408.19	309.05	174.82
1.05	412.07	311.78	175.52
1.10	415.71	314.48	176.19

Table 2: Downwelling longwave flux at the surface for H2O scenarios

Global, annual-mean radiative forcings (W m^2 due to a number of agents for the period from pre-industrial (1750) to present (late 1900s; about 2000). The height of the rectangular bar denotes a central or best estimate value, while the absence denotes no estimate is possible the vertical line about the rectangular bar with ``x'' delimiters indicates an estimate of the uncertainty range, for the most part guided by the spread in the published values of the forcing. A vertical line without a rectangular bar and with ``o'' delimiters denotes a forcing for which no central estimate can be given owing to large uncertainties. The well-mixed greenhouse gases are grouped together into a single rectangular bar with the individual mean contributions due to CO_2, CH_4, N_2O, and halocarbons shown. Fossil fuel burning is separated into the ``black carbon'' and ``organic carbon'' components with its separate best estimate and range. The sign of the effects due to mineral dust is itself an uncertainty. The indirect forcing due to troposphere aerosols is poorly understood. The same is true for the forcing due to aviation via its effects on contrails and cirrus clouds. Only the ``first'' type of indirect effect due to aerosols as applicable in the context of liquid clouds is considered here. The ``second'' type of effect is conceptually important, but there exists very little confidence in the simulated quantitative estimates. The forcing associated with stratospheric aerosols from volcanic eruptions is highly variable over the period and is not considered for this plot. All the forcings shown have distinct spatial and seasonal features such that the global, annual means appearing here do not yield a complete picture of the radiative perturbation. They are only intended to give, in a relative sense, a first-order perspective on a global, annual mean scale and cannot be readily employed to obtain the climate response to the total natural and/or anthropogenic forcings. As in the SAR, it is emphasized that the positive and negative global mean forcings cannot be added up and viewed a priori as providing offsets in terms of the complete global climate impact. [From Houghton et al., 2001]


3
2
1
0
−1
−2
Radiative forcing (Watts per square metre)
Warming
Cooling
Halocarbons
N₂O
CH₄
CO₂
Tropospheric ozone
Stratospheric ozone
Aerosols
Black carbon from fossil fuel burning
Organic carbon from fossil fuel burning
Sulphate
Biomass burning
Mineral Dust
Aerosol indirect effect
Aviation-induced
Contrails
Cirrus
Land-use (albedo) only
Solar
High
Medium
Medium
Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Very Low
Level of Scientific Understanding

Schematic of different classes of prediction. The size of the box labeled `U' represents the range of future climate, while the box labeled `A' indicates the relative subset of possible future climate estimated using the different classes of prediction [from Pielke, 2002]



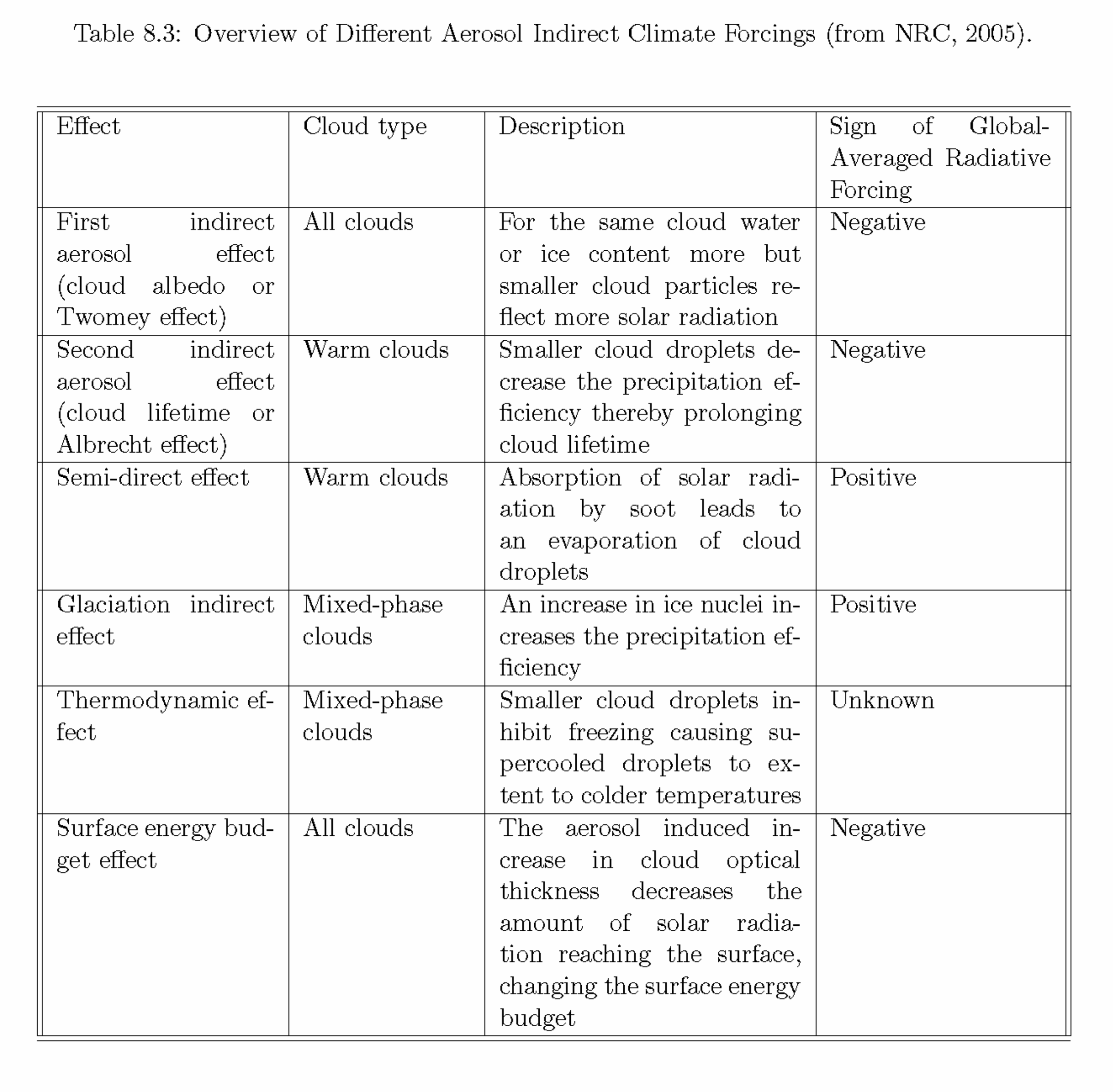


Table 8.3: Overview of Different Aerosol Indirect Climate Forcings (from NRC, 2005).

Effect	Cloud type	Description	Sign of Global-Averaged Radiative Forcing
First indirect aerosol effect (cloud albedo or Twomey effect)	All clouds	For the same cloud water or ice content more but smaller cloud particles reflect more solar radiation	Negative
Second indirect aerosol effect (cloud lifetime or Albrecht effect)	Warm clouds	Smaller cloud droplets decrease the precipitation efficiency thereby prolonging cloud lifetime	Negative
Semi-direct effect	Warm clouds	Absorption of solar radiation by soot leads to an evaporation of cloud droplets	Positive
Glaciation indirect effect	Mixed-phase clouds	An increase in ice nuclei increases the precipitation efficiency	Positive
Thermodynamic effect	Mixed-phase clouds	Smaller cloud droplets inhibit freezing causing supercooled droplets to extent to colder temperatures	Unknown
Surface energy budget effect	All clouds	The aerosol induced increase in cloud optical thickness decreases the amount of solar radiation reaching the surface, changing the surface energy budget	Negative

Prepared by Dallas Jean Staley

For copies email: dallas@cires.colorado.edu