CLIMATE CHANGE 1995

The Science of Climate Change

WMO

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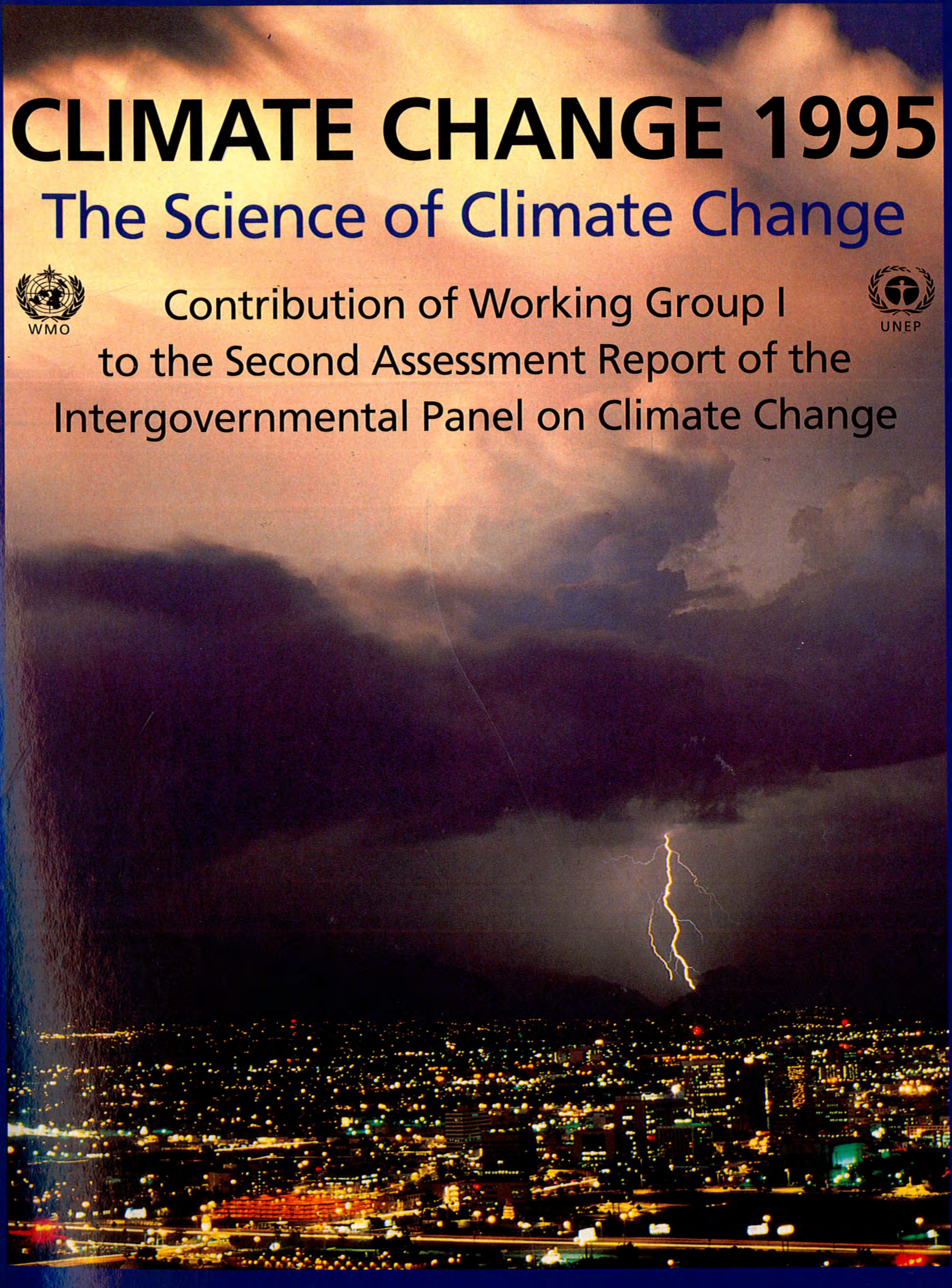
to the Second Assessment Report of the
Intergovernmental Panel on Climate Change



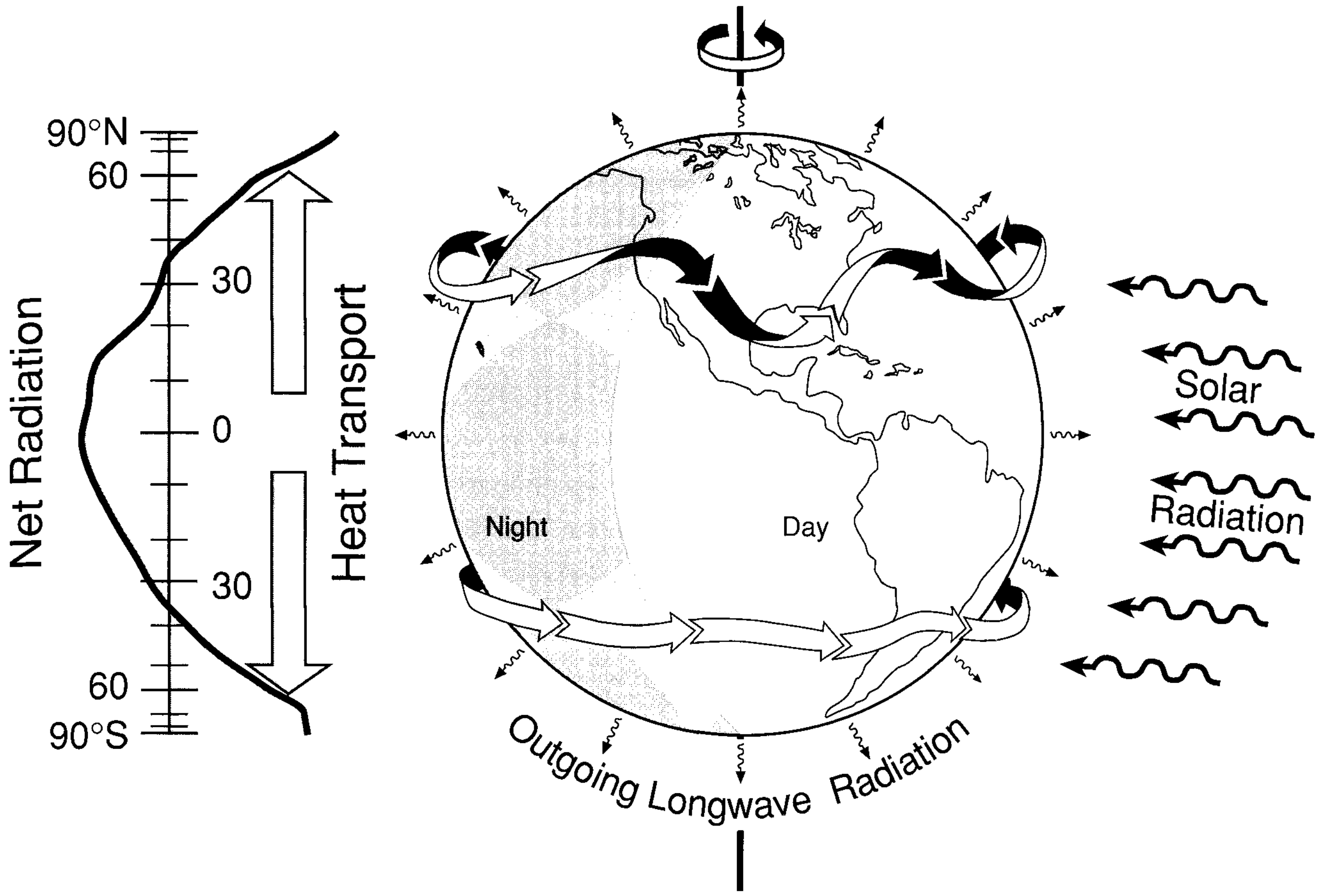


Figure 1.2: The incoming solar radiation (right) illuminates only part of the Earth while the outgoing long-wave radiation is distributed more evenly. On an annual mean basis, the result is an excess of absorbed solar radiation over the outgoing long-wave radiation in the tropics, while there is a deficit at middle to high latitudes (far left), so that there is a requirement for a poleward heat transport in each hemisphere (arrows) by the atmosphere and the oceans. This radiation distribution results in warm conditions in the tropics but cold at high latitudes, and the temperature contrast results in a broad band of westerlies in the extra-tropics of each hemisphere in which there is an embedded jet stream (shown by the "ribbon" arrows) at about 10 km above the Earth's surface. The flow of the jetstream over the different underlying surface (ocean, land, mountains) produces waves in the atmosphere and adds geographic spatial structure to climate. The excess of net radiation at the equator is 68 Wm^{-2} and the deficit peaks at -100 Wm^{-2} at the South Pole and -125 Wm^{-2} at the North Pole; from Trenberth and Solomon (1994).

time half the Earth is in night (Figure 1.2) and the average amount of energy incident on a level surface outside the atmosphere is one quarter of this or 342 Wm^{-2}. About 31% of this energy is scattered or reflected back to space by molecules, microscopic airborne particles (known as aerosols) and clouds in the atmosphere, or by the Earth's surface, which leaves about 235 Wm^{-2} on average to warm the Earth's surface and atmosphere (Figure 1.3).

To balance the incoming energy, the Earth itself must radiate on average the same amount of energy back to space (Figure 1.3). It does this by emitting thermal "long-wave" radiation in the infrared part of the spectrum. The amount of thermal radiation emitted by a warm surface depends on its temperature and on how absorbing it is. For a completely absorbing surface to emit 235 Wm^{-2} of thermal radiation, it would have a temperature of about -19°C. This is much colder than the conditions that actually exist near the Earth's surface where the annual average global mean temperature is about 15°C. However, because the temperature in the troposphere – the lowest 10-15 km of the atmosphere – falls off quite rapidly with height, a temperature of -19°C is reached typically at an altitude of 5 km above the surface in mid-latitudes.

1.2.2 The Greenhouse Effect

Some of the infrared radiation leaving the atmosphere originates near the Earth's surface and is transmitted relatively unimpeded through the atmosphere; this is the

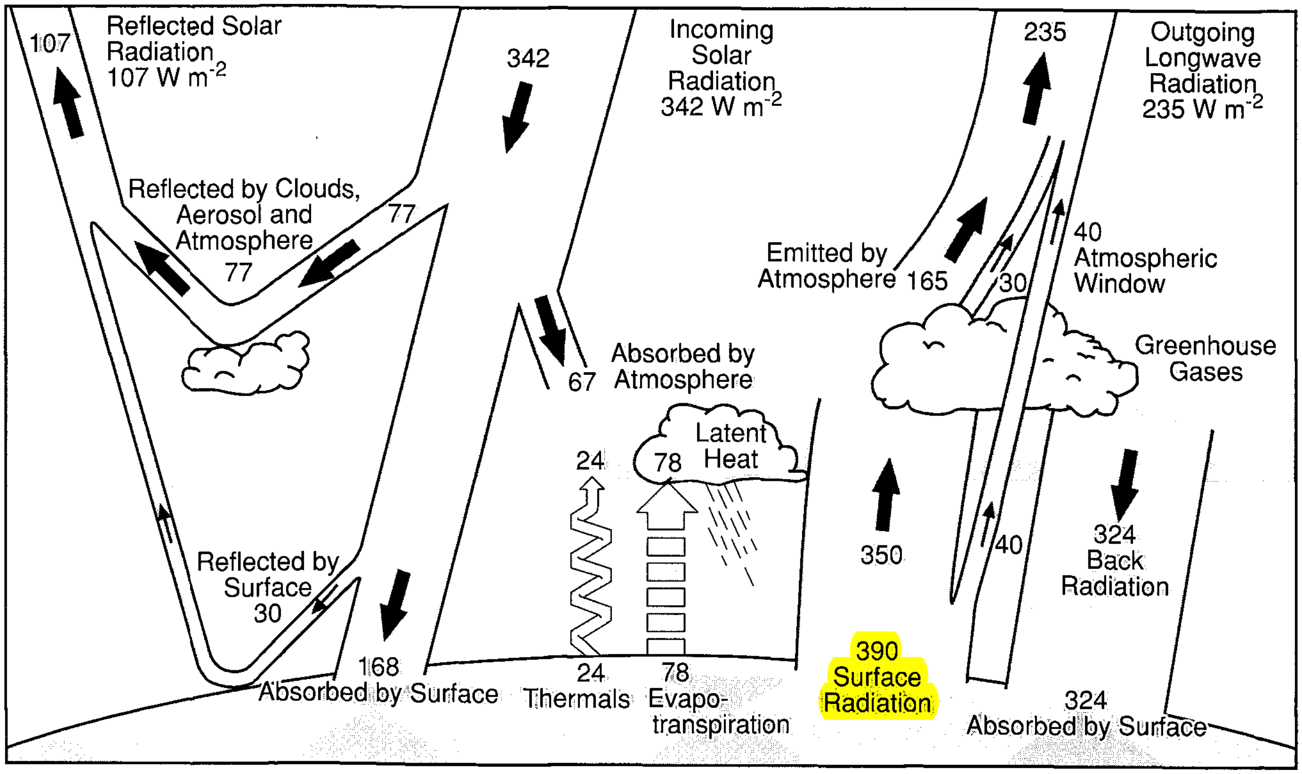


Figure 1.3: The Earth's radiation and energy balance. The net incoming solar radiation of 342 Wm^{-2} is partially reflected by clouds and the atmosphere, or at the surface, but 49% is absorbed by the surface. Some of that heat is returned to the atmosphere as sensible heating and most as evapotranspiration that is realised as latent heat in precipitation. The rest is radiated as thermal infrared radiation and most of that is absorbed by the atmosphere which in turn emits radiation both up and down, producing a greenhouse effect, as the radiation lost to space comes from cloud tops and parts of the atmosphere much colder than the surface. The partitioning of the annual global mean energy budget and the accuracy of the values are given in Kiehl and Trenberth (1996).

radiation from areas where there is no cloud and which is present in the part of the spectrum known as the atmospheric "window" (Figure 1.3). The bulk of the radiation, however, is intercepted and absorbed by the atmosphere which in turn emits radiation both up and down. The emissions to space occur either from the tops of clouds at different atmospheric levels (which are almost always colder than the surface), or by gases present in the atmosphere which absorb and emit infrared radiation. Most of the atmosphere consists of nitrogen and oxygen (99% of dry air) which are transparent to infrared radiation. It is the water vapour, which varies in amount from 0 to about 2%, carbon dioxide and some other minor gases present in the atmosphere in much smaller quantities which absorb some of the thermal radiation leaving the surface and emit radiation from much higher and colder levels out to space. These radiatively active gases (see Chapter 2 for details) are known as greenhouse gases because they act as a partial blanket for the thermal radiation from the surface and enable it to be substantially warmer than it would otherwise be, analogous to the effects of a greenhouse. This blanketing is known as the natural greenhouse effect.

Clouds also absorb and emit thermal radiation and have a blanketing effect similar to that of the greenhouse gases. But clouds are also bright reflectors of solar radiation and thus also act to cool the surface. While on average there is strong cancellation between the two opposing effects of short-wave and long-wave cloud radiative forcing (Chapter 4) the net global effect of clouds in our current climate, as determined by space-based measurements, is a small cooling of the surface.

1.2.3 Mars and Venus

Similar greenhouse effects also occur on our nearest planetary neighbours, Mars and Venus. Mars is smaller than the Earth and possesses, by Earth's standards, a very thin atmosphere (the pressure at the Martian surface is less than 1% of that on Earth) consisting almost entirely of carbon dioxide which contributes a small but significant greenhouse effect. The planet Venus, by contrast, has a