faces is therefore very close to their actual physical temperature.

> **Problem 6.8:** A satellite viewing a surface location under cloud-free conditions measures a 12 micron radiance of 6.2 W $m^{-2}\mu m^{-1}sr^{-1}$. (a) Compute the brightness temperature T_B. (b) Compute the actual temperature, assuming that the atmosphere is completely transparent, and that the surface in question is known to have an emissivity of 0.9 at this wavelength. (c) Is the ratio of the brightness temperature to the actual temperature equal to the emissivity?

At microwave wavelengths, on the other hand, the emissivity of some surfaces (especially water and glacial ice) is substantially less than unity, in which case the brightness temperature may be substantially less than the physical temperature. Nevertheless, the Rayleigh-Jeans approximation which is valid for microwave wave-

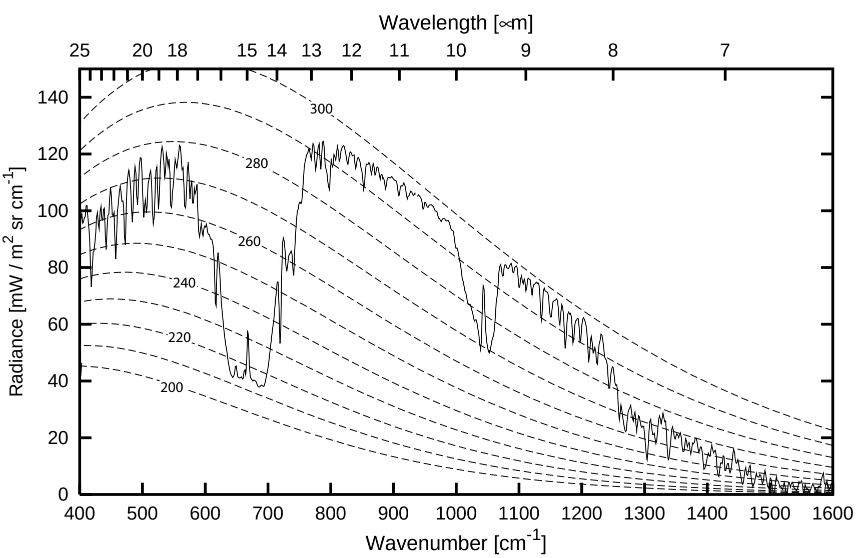

Fig. 6.6: Example of an actual infrared emission spectrum observed by the Nimbus 4 satellite over a point in the tropical Pacific Ocean. Dashed curves represent blackbody radiances at the indicated temperatures in Kelvin. *(IRIS data courtesy of the Goddard EOS Distributed Active Archive Center (DAAC) and instrument team leader Dr. Rudolf A. Hanel.)*

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lengths (see Section 6.1.4) implies a direct proportionality between intensity I_λ and brightness temperature T_B. Therefore T_B remains a very convenient substitute for I_λ in radiative transfer calculations used in microwave remote sensing.

Problem 6.9: Repeat the previous problem, only for a wavelength of 1 cm and an intensity of 2.103×10^{-10} W m$^{-2}\mu$m^{-1}sr^{-1}. How does your answer to part (c) change?

In some wavelength bands, the cloud-free atmosphere is far from transparent. In this case, the brightness temperature observed from space can no longer be interpreted in terms of the apparent physical temperature of a surface but rather as a weighted average of all of the atmospheric temperatures encountered along the line-of-sight. The more opaque the atmosphere, the greater the altitude of the maximum atmospheric contribution to the observed T_B. This principle is at the foundation of satellite techniques for estimating atmospheric temperature profiles from space. We will discuss this problem in greater detail in a later chapter.

Problem 6.10: The irregular solid curve in Fig. 6.6 depicts an actual satellite-derived spectrum of radiant intensity when the satellite passed over a particular ocean location on a cloudless day. The smooth curves represent Planck's function curves for various temperatures. (a) Estimate the brightness temperature at 11 μm. (b) Estimate the brightness temperature at 15 μm. (c) For which of these two wavelengths would you guess that you are looking primarily at emission from the surface? (d) For the wavelength that is *not* seeing the surface, make a rough estimate of the approximate altitude in the atmosphere that corresponds to the observed brightness temperature, assuming a standard lapse rate of 6.5 K/km.

6.3 When Does Thermal Emission Matter?

We have seen that all surfaces reflect and absorb radiation. We have also seen that all matter in local thermal equilibrium emits

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thermal radiation according to its emissivity and Planck's function. Common experience, however, tells us that thermal emission by the earth or atmosphere isn't always worth worrying about. For example, it is clear that all natural light visible to the naked eye normally originates from extraterrestrial sources (lightning, volcanoes, and fireflies excepted!); otherwise it would not be dark at night after the sun goes down.

An important question, therefore, is when one can and can't ignore thermal emission from the earth and atmosphere. The simplistic answer is that, for wavelengths shorter than a certain value, the contribution of incident and reflected solar radiation to the total radiation field far exceeds the contribution due to direct thermal emission. For slightly longer wavelengths, one might need to consider both solar radiation and thermal emission from the earth-atmosphere system itself. For even longer wavelengths, one may often (though not always) ignore the solar component relative to the thermally emitted component.

How short must the wavelength be in order for thermal emission to be unimportant? A common (but somewhat misleading) way to answer that question is to compare the distributions of radiation emitted by a blackbody for two temperatures: that of the sun (approximately 6000 K) and a much cooler temperature characteristic of the earth and atmosphere (200–300 K). If the Planck function is normalized so as to have the same area under the curve (Fig. 6.2b), we see that there is surprisingly little overlap between the two areas of significant emission. In fact, a threshold of $\lambda \approx 4\ \mu$m does a very nice job of separating solar emission from terrestrial emission, with more than 99% of solar emission taking place at wavelengths shorter than 4 μm and more than 99% of terrestrial emission taking place at longer wavelengths (Fig. 6.4). According to this analysis, therefore, one might neglect the sun as a source of atmospheric radiation much longer than 4 μm wavelength, and one may neglect terrestrial emission at wavelengths much shorter than this value.

In reality, the above argument glosses over some important facts. To begin with, while Fig. 6.2b does a nice job of showing the *relative* spectral distribution of emission for terrestrial and solar sources, recall that we normalized the curves so that the areas would be equal! If we had not done this, we would have seen that, for any given