band, the spectrometer records emission from the coldest air right at the surface. At the edges of the band, where the air is less opaque, it sees emission from the warmer layer of air at the top of the inversion. This example hints at the possibility of using remote measurements of atmospheric emission to infer atmospheric temperature structure. We will return to that topic shortly.

Let's now take a look at how the atmospheric emission spectrum changes depending on whether you are looking down from above or looking up from the surface. Fig. 8.2 gives us a rare opportunity to compare the two perspectives for the same atmospheric conditions: an aircraft flying at 20 km altitude measured the upwelling emission spectrum at exactly the same time and location as a surface instrument looking up measured the downwelling spectrum. The measurements in this case were taken over the arctic ice pack and are therefore comparable in some respects to the arctic spectrum already discussed. The following exercise asks you to provide the physical interpretation:

Problem 8.8: Based on the measured spectra depicted in Fig. 8.2, answer the following questions: (a) What is the approximate temperature of the surface of the ice sheet, and how do you know? (b) What is the approximate temperature of the near-surface *air*, and how do you know? (c) What is the approximate temperature of the air at the aircraft's flight altitude of 20 km, and how do you know? (d) Identify the feature seen between 9 and 10 μm in both spectra. (e) In Fig. 8.1, we saw evidence of a strong inversion in the near-surface atmospheric temperature profile. Can similar evidence be seen in Fig. 8.2? Explain.

We'll conclude our discussion of atmospheric emission spectra by looking at examples of satellite observations made under diverse conditions around the globe (Fig. 8.3). Once again, I'll leave most of the physical interpretation as an exercise. Only one new point requires a brief explanation, because it didn't arise in our previous discussion of surface- and aircraft-measured spectra. That concerns the prominent narrow spike observed at the center of the 15 μm CO_2 band in all four panels. This spike occurs where absorption is by far

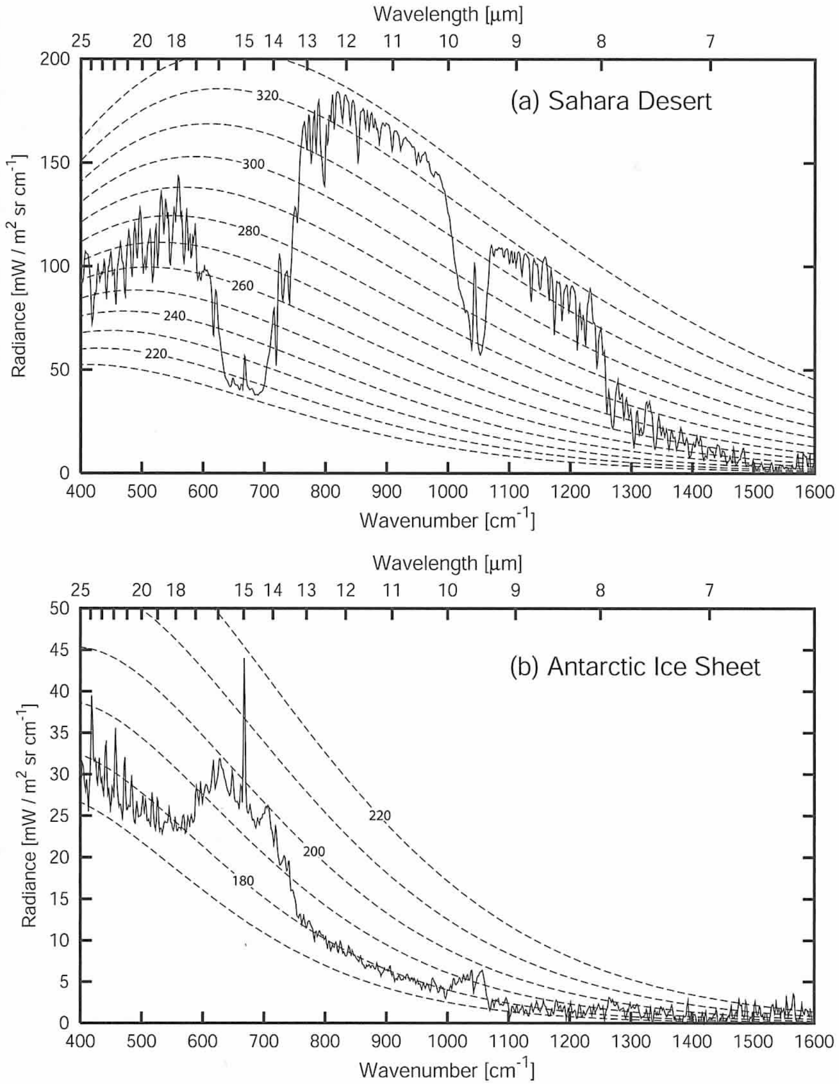

Fig. 8.3: Examples of moderate resolution IR spectra observed by a satellite spectrometer. Except for the curve labeled "thunderstorm anvil" in panel (c), all spectra were obtained under cloud-free conditions. *(Nimbus-4 IRIS data courtesy of the Goddard EOS Distributed Active Archive Center (DAAC) and instrument team leader Dr. Rudolf A. Hanel.)*

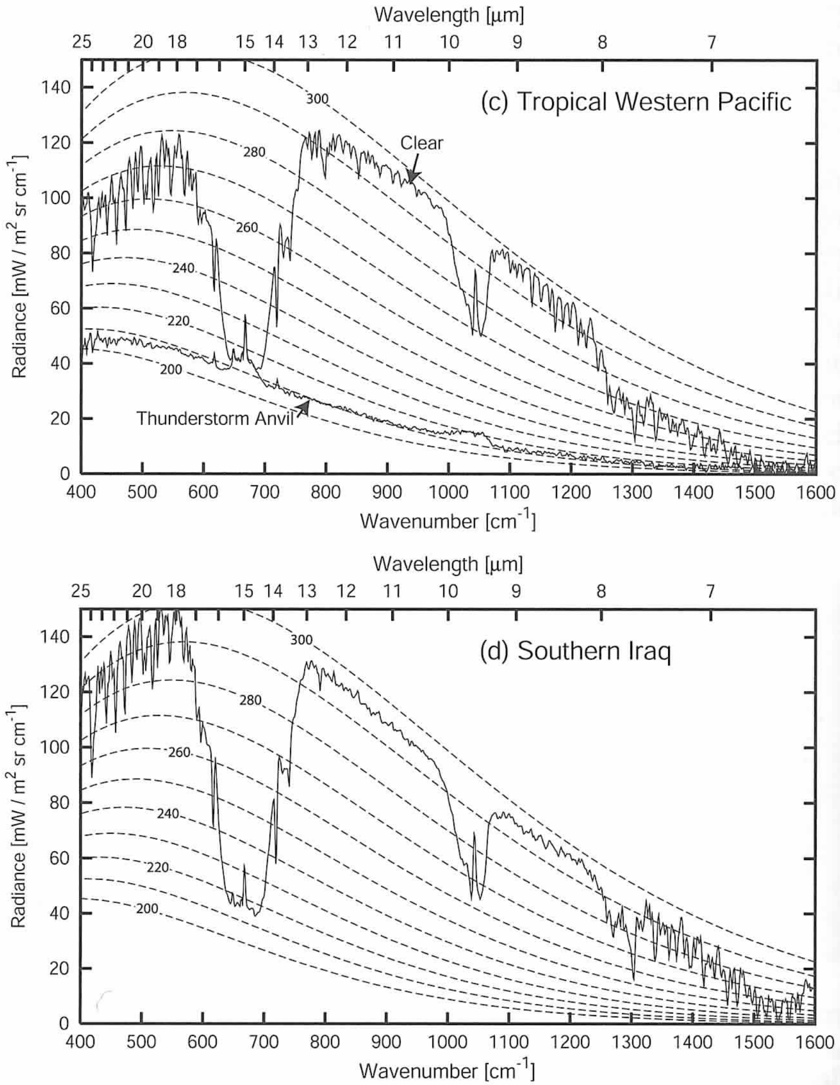

Fig. 8.3: (cont.)

the most intense of any point in the thermal IR band. From the vantage point of a satellite sensor viewing downward, emission at this wavelength therefore originates almost entirely in the stratosphere, whereas most of the remaining emission spectrum is associated primarily with the surface and troposphere.[4]

To summarize, as you move from the edge of the CO_2 band toward the center, the general tendency for satellite-observed spectra is *usually*: (i) decreasing brightness temperature as the emission weighting function $W^{\uparrow}$ peaks at higher (and colder) levels in the troposphere, followed by (ii) a sharp reversal of this trend at the strongly absorbing center of the band, where the weighting function peaks at an altitude solidly within the relatively warm stratosphere.

Problem 8.9: Contrast the above explanation for the narrow warm spike at the center of the 15 μm CO_2 band with the explanation for the similar-appearing warm spike at the center of the 9.6 μm ozone band, as seen in several panels of Fig. 8.3.

Problem 8.10: Referring to Fig. 8.3, answer each of following questions.

(a) For each of the four scenes, provide an estimate of the surface temperature.

(b) For which scene does the surface appear to be significantly colder than any other level in the atmosphere?

(c) Compare the apparent humidity of the atmosphere over Southern Iraq with that over the Sahara Desert, and explain your reasoning.

[4]The *troposphere* is the layer of the atmosphere closest to the surface and is usually characterized by decreasing temperature with height. The troposphere is typically anywhere from a few km to 15 km deep, depending on latitude and season. The *stratosphere* is the deep layer above the troposphere in which temperature generally increases with height. The boundary between the troposphere and the stratosphere, called the *tropopause*, is often (though not always) the coldest point in the atmospheric temperature profile below 40 km. The layer of highest ozone concentration is found in the stratosphere between 15 and 30 km. If these facts are new to you, then I recommend that you spend an evening with Chapter 1 of WH77 and/or Section 3.1 of L02.