باسمه تعالی

Climate Change and Climate Modeling

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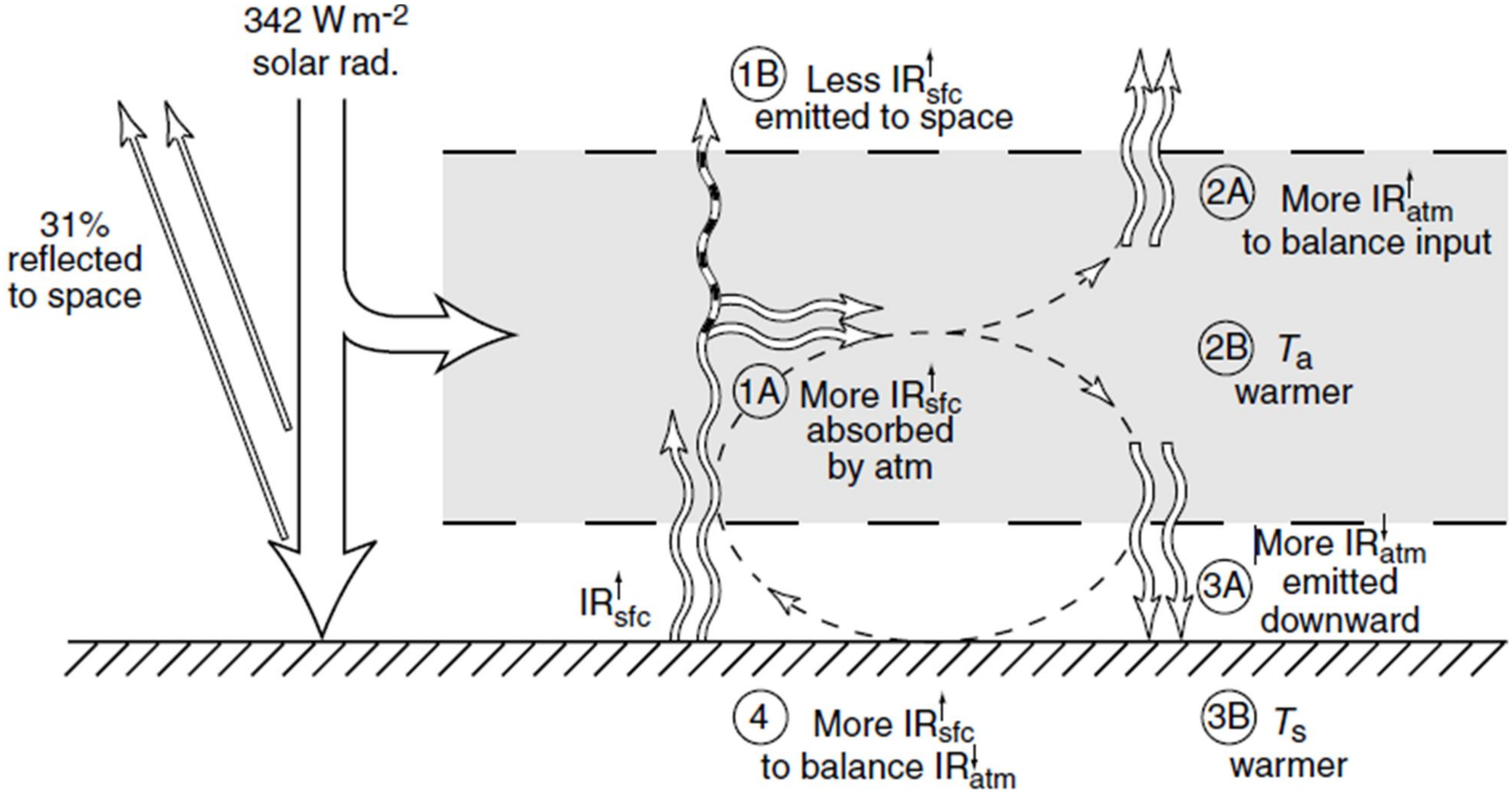
- Human activities are increasing the concentration of greenhouse gases – gases that significantly absorb infrared radiation – in the atmosphere. Let us first examine how this can cause warming without considering that clouds and other aspects of the climate system might also change.
- We will call this the "basic greenhouse effect" for ease of discussion later (terminology varies within the field). Figure 6.3 indicates schematically how these changes occur. The steps indicated in the figure are based on the one-layer atmospheric model, but hold qualitatively for more complex models. This is the same pathway as the greenhouse effect in climatology, simply increasing the effect.
- The atmospheric temperature in the one-layer model must be interpreted as a tropospheric temperature, since that is where the bulk of IR emissions originate. The stratospheric temperature actually cools when CO2 is increased.



Schematic of how increased absorption of infrared radiation by greenhouse gases leads to surface warming. Stages are shown in conceptual sequence from the point of view of energy balance requirements. (1) More upgoing IR from the surface is absorbed by the atmosphere and so does not escape directly to space. (2A) Since the input of solar energy is the same as always, while direct IR loss from the surface is decreased, more IR must be emitted from the atmosphere to achieve balance. This occurs by (2B) an increase in tropospheric temperature. A consequence of this is (3A) that more IR is emitted downward. To balance this increased input, there must be (4) increased IR upward from the surface, which occurs after (3B) surface temperature has increased sufficiently.

Climate feedback parameter

We wish to generalize the climate feedback parameter, so we can use the equation

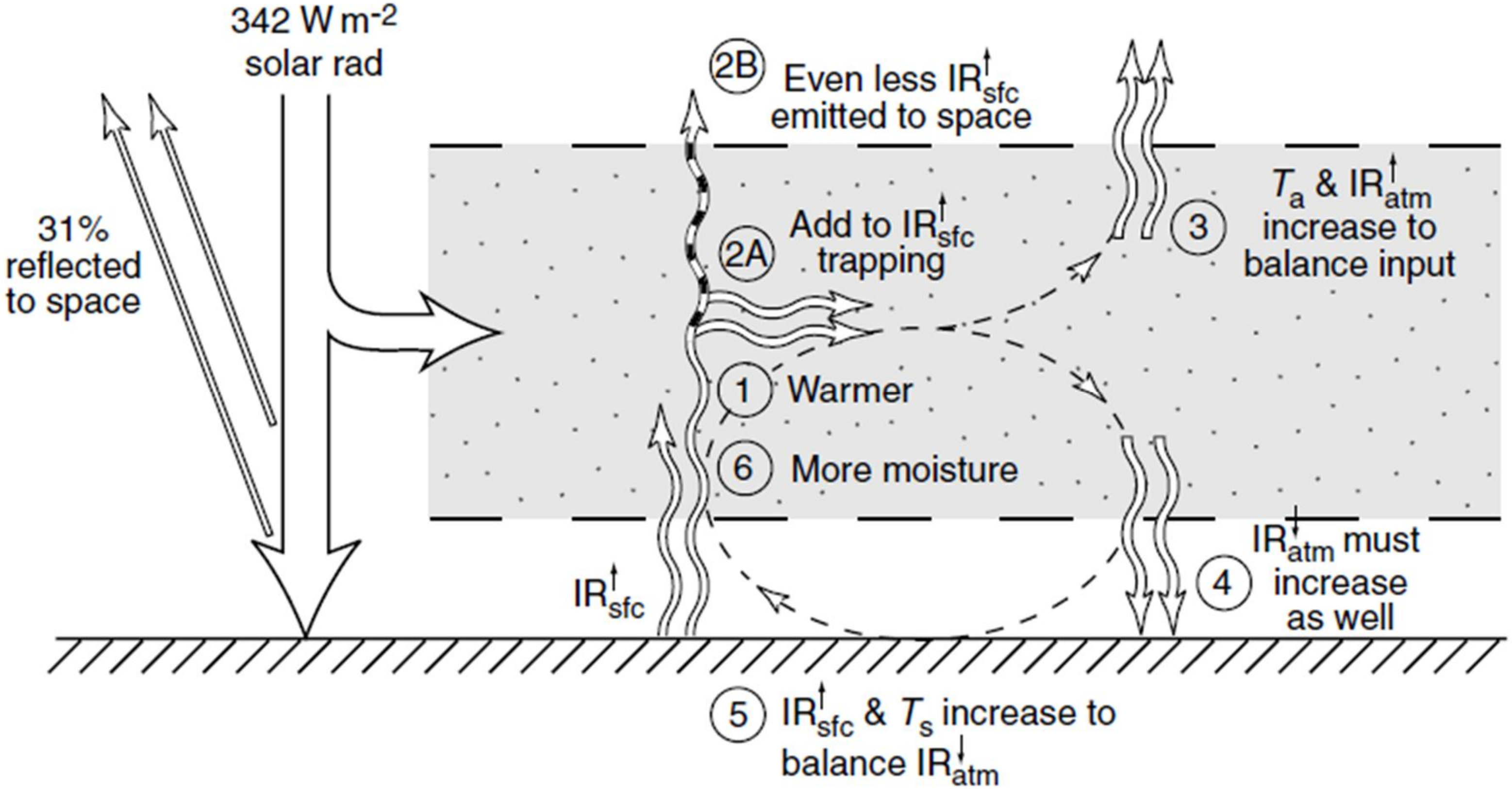
$$\alpha \Delta T_s = G \quad (6.11)$$

to analyze the results of full climate models, where ΔT_s is the surface temperature change. If we can calculate a greenhouse forcing, G, then the ratio of the forcing to the temperature response can be defined as the climate feedback parameter α.

In order to measure the effects of different feedbacks, one holds different parts of the climate system constant. For instance, to measure the negative feedback associated with increased IR loss to space as temperature increases, hold water vapor, ice, snow and clouds fixed at their climatological values, but allow temperature to vary. This defines the temperature contribution αT to the climate feedback parameter. Contributions to α are approximately additive if the changes are small enough:

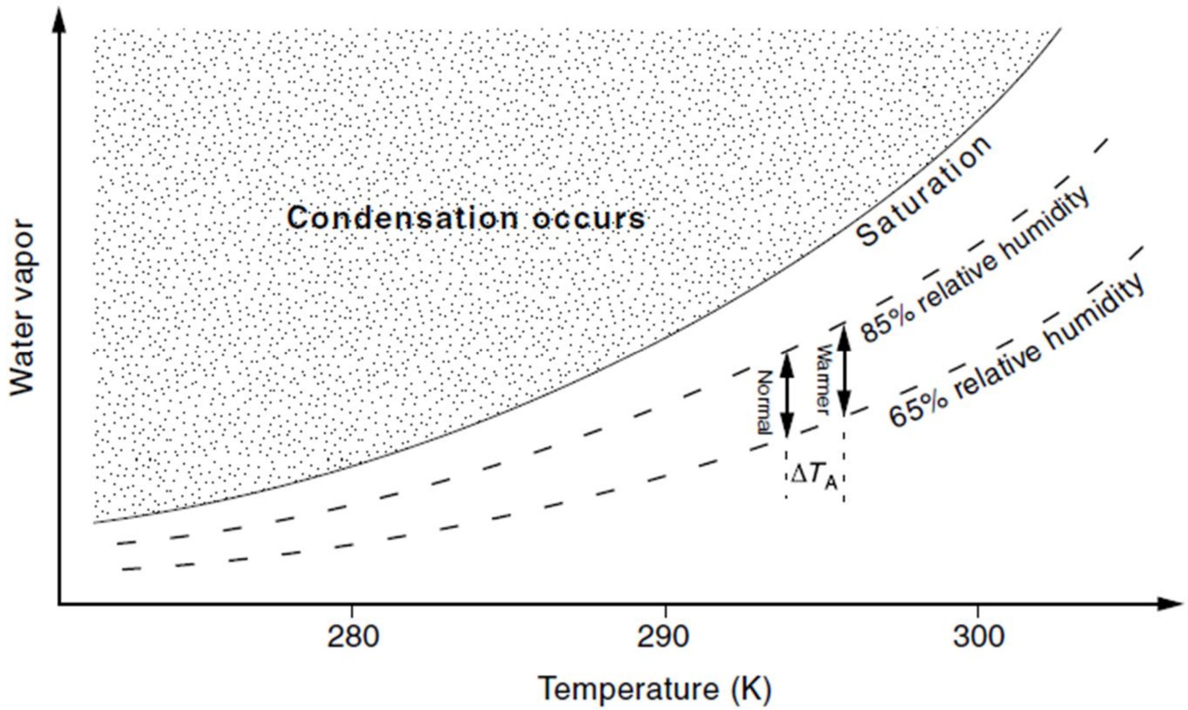
$$\alpha = \alpha_T + \alpha_{H_2O} + \alpha_{ice} + \alpha_{cloud}$$

The water vapor feedback



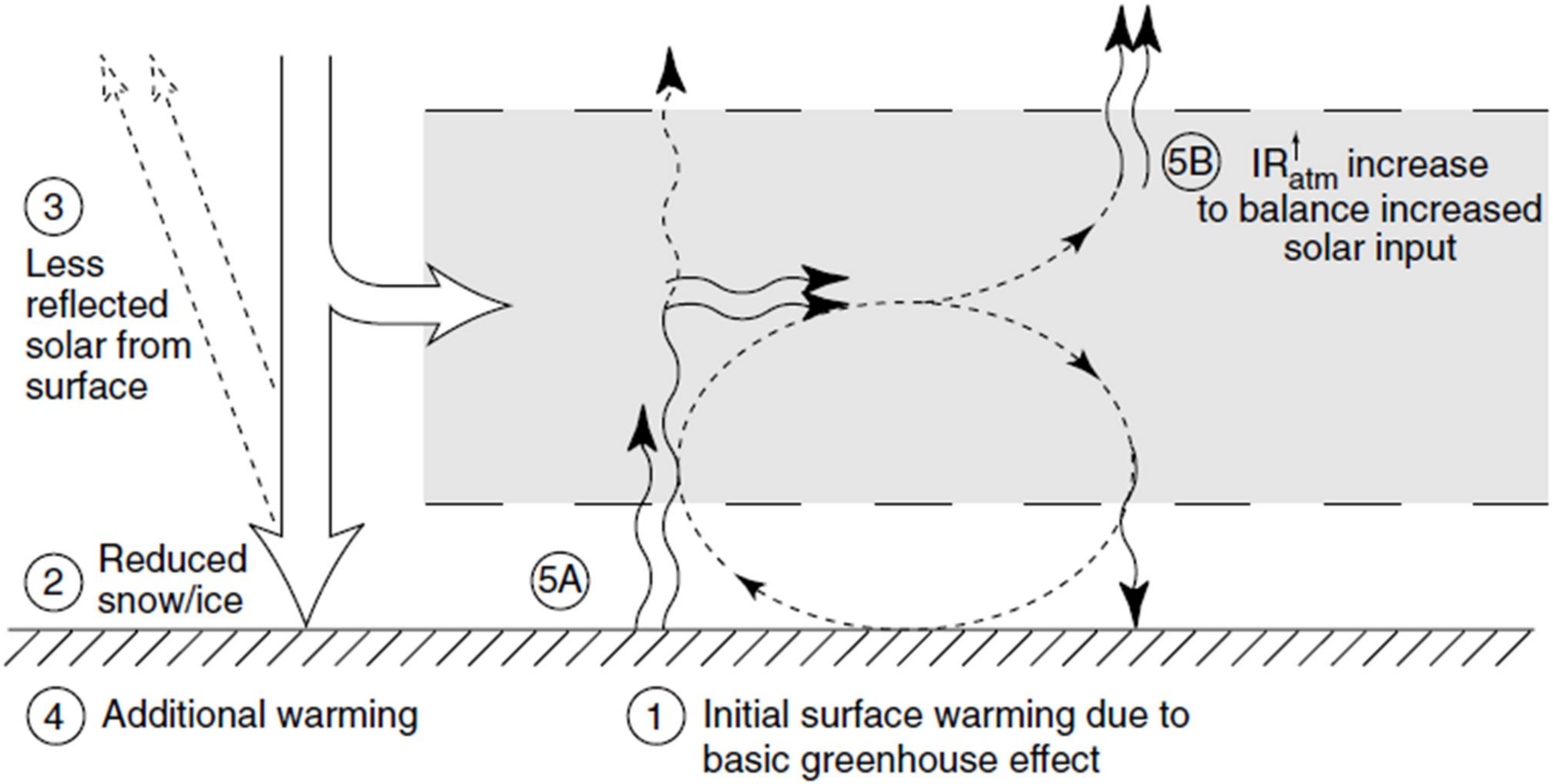
Schematic of water vapor feedback in the greenhouse effect. (1) The initial warming by the basic greenhouse effect allows the atmosphere to hold more water vapor. (2) This increases IR trapping and reduces the IR lost directly to space from the surface, just as in the basic greenhouse effect. (3) The atmospheric temperature must warm until increased upward IR from the atmosphere compensates for the reduction in IR escaping from the surface to space. (4) Since atmospheric temperature has increased, downward IR increases also, resulting in (5) increased surface temperature until increased upward IR from the surface can balance the extra input from the atmosphere. (6) The warming due to the water vapor feedback itself increases water vapor

The water vapor feedback



Water vapor (as measured by vapor pressure) versus temperature, schematizing how water vapor might increase in global warming. The solid curve is the saturation value of vapor pressure as a function of temperature. Condensation would occur in an air parcel with initial vapor and temperature values to the upper left of this curve. An air parcel might have any combination of temperature and vapor corresponding to a point below this curve; the fraction of the saturation value at a given temperature is the relative humidity. Dashed curves show vapor pressure values as a function of temperature for 85% and 65% relative humidity. Atmospheric values of water vapor quite commonly fall between these lines. For a particular latitude and height, the arrow marked "Normal" indicates a typical range of water vapor pressures in the normal climate. After global warming, if the *relative* humidity remains in the same range, the arrow marked "Warmer" shows the range of vapor pressure in the warm climate.

Snow/ice feedback

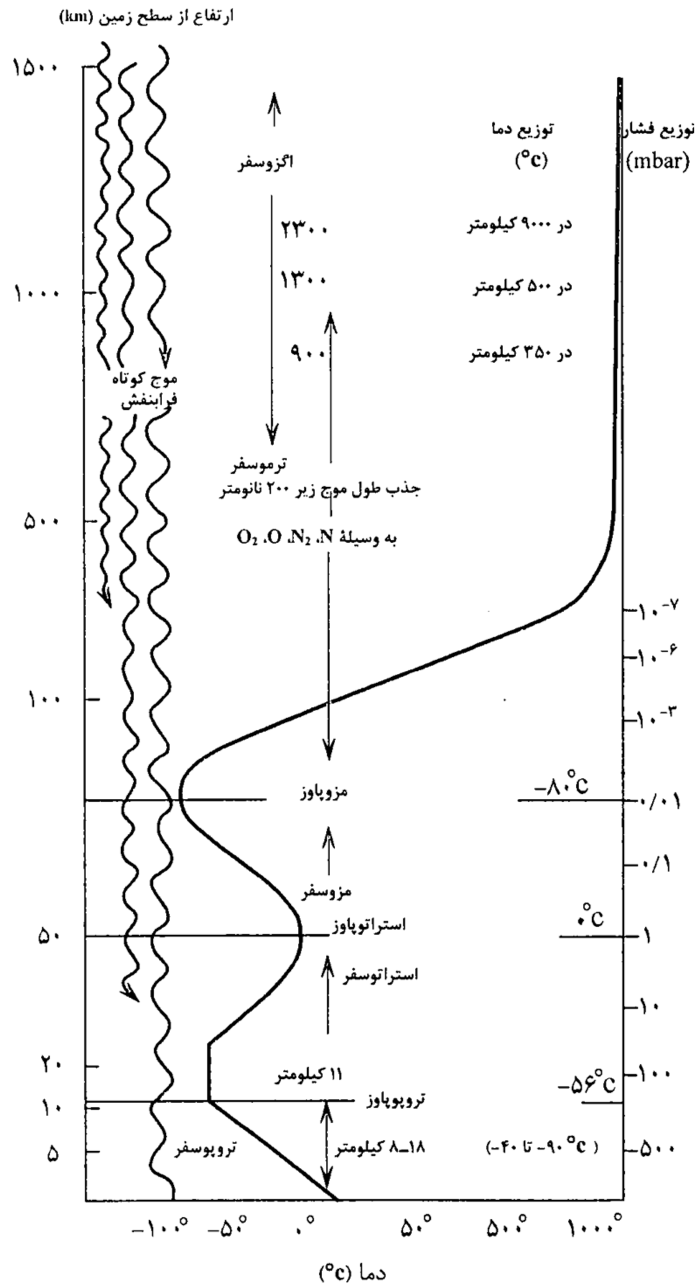


Schematic of the snow/ice feedback in the global energy balance. Beginning with the initial warming at the surface caused by the basic greenhouse effect, the reduction (2) of snow and ice leads to (3) less reflected solar, i.e. greater net solar input into the climate system. This leads to (4) additional warming of the surface until (5) increased upward heat flux from the surface and warming of the atmosphere give enough increase in upward IR to space to balance the additional solar input.

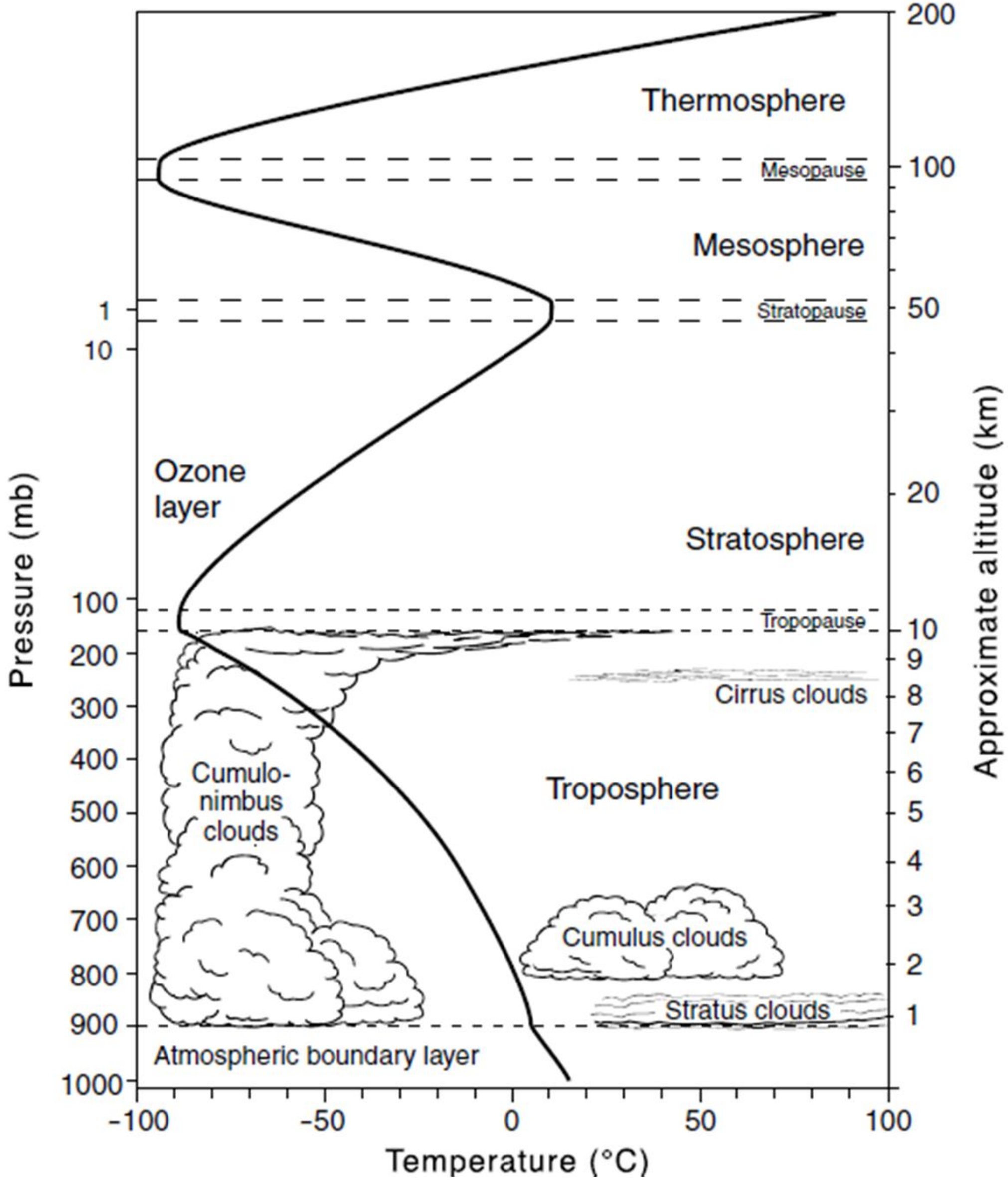
Cloud feedbacks

Cloud feedbacks are challenging to represent in climate models for three reasons:

- (i) Clouds are small-scale motions compared with the grid size of climate models. Their average effects at the grid size must be parameterized on large-scale motions.
- (ii) Clouds have opposing effects in infrared and solar contributions to the energy budget.
- (iii) Several types of cloud properties can affect radiative processes: these include cloud fraction, cloud top height, cloud depth, and cloud water and ice content. Different cloud types will thus have different feedbacks. Cloud amount is usually measured as *cloud fraction*, i.e. for a given area, such as a 200 km square grid box, the fraction that is covered by cloud of a given type.
- Among several cloud feedbacks currently being studied, the schematics in Figure 6.8 and Figure 6.9 illustrate two of the better understood ones.

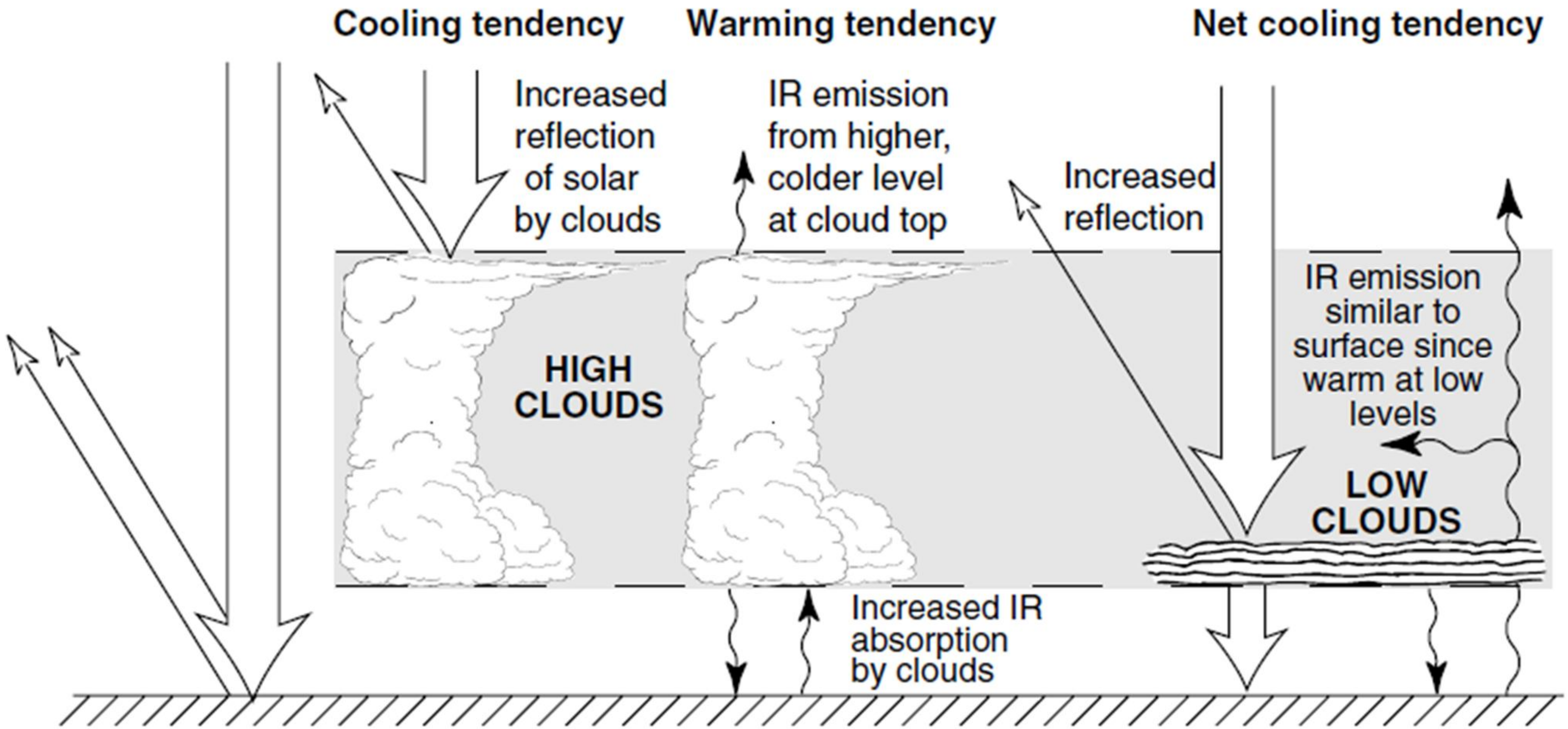


شکل ۲ـ۱ ساختار اتمسفر زمین و توزیع دما و فشار در آن



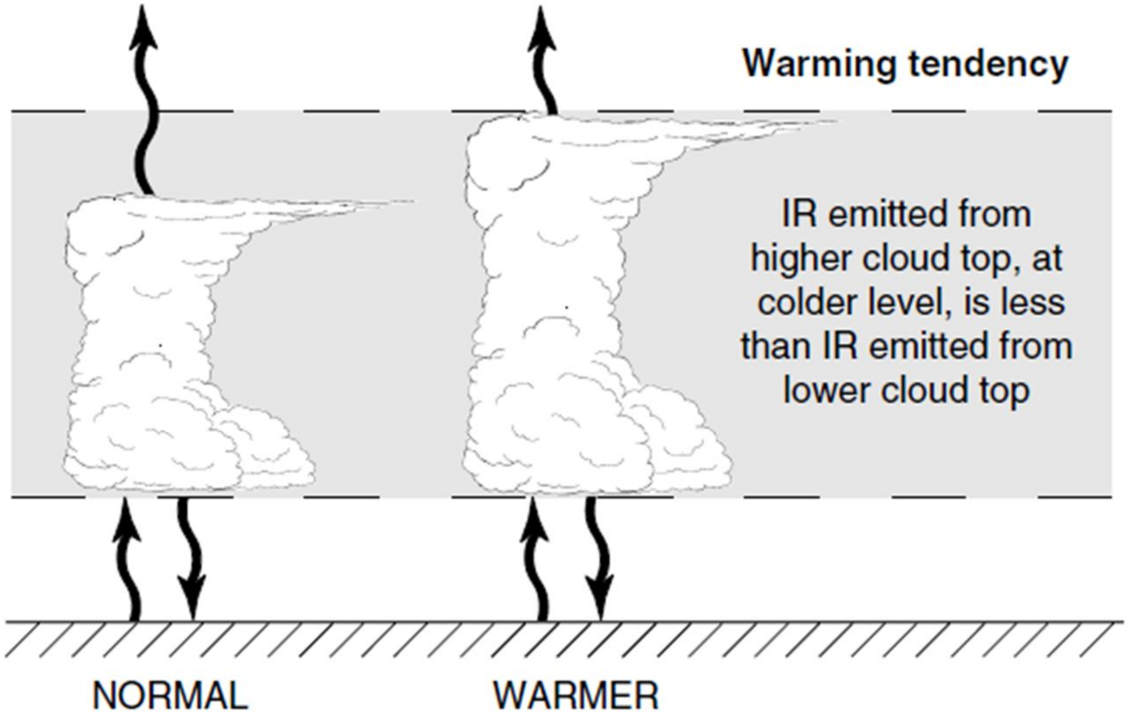
Temperature as a function of height or pressure. Nomenclature for atmospheric vertical regions and common cloud types is also given. Temperature data are from the Standard Atmosphere except in the troposphere where it has been modified to a profile typical of deep convective regions. The vertical scale is linear in pressure from the surface to 100 mb, but stretched in the upper half.

Cloud feedbacks



Schematic of effects of cloud amount in the global energy balance. The feedback depends on whether the cloud fraction increases for a given cloud type. This figure shows cases of increased deep cloud fraction and low cloud fraction. Solar effects are shown on the left cloud, and infrared effects on the right hand cloud. If cloud fraction increases in a warmer climate, solar effects give a negative feedback, while IR effects give a positive feedback. For deep clouds these effects are similar in magnitude. For low clouds, the IR effects are smaller because the cloud top temperature is closer to surface temperature, so IR emitted from the cloud top is not changed as strongly.

Cloud feedbacks



Schematic of cloud top feedback. Cloud top tends to reach higher (and thus colder) levels because low-level moisture and temperature are increased. IR emissions from colder cloud top are thus decreased (a positive feedback).