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Continuing our discussion of clouds and feedbacks, we have to address the amount of water vapor that an air parcel can hold, because that vapor is both the source of the water that forms droplets and ice crystals, and it is itself a gas that can absorb infrared energy. The figure at upper left shows this visually.

Starting at right, we have about 1 kilogram of air at zero degrees C. This amount of air can hold about 3.5 grams of water vapor. The beaker in question holds a total of 7 grams of water, so 3.5 grams of this water must be condensed, and it falls the bottom of the beaker. Moving to the center, the kilogram of air is warmed to 10 degrees C. In this case, the air can hold all 7 grams of water. There's no condensed-phase water at the bottom, but the air itself is saturated. It holds as much water vapor as it possibly can.

Moving to the leftmost panel, the same 1 kilogram of air is raised to 20 degrees C. In this case the air could actually hold more water vapor than is present. So the relative humidity is lower. It's not saturated. The RH is instead 50 percent.

Using this illustration, we can see that air with increased temperature holds more water vapor, which in turn leads to more infrared absorption. This is what we termed a positive feedback. Furthermore, warmer air, holding more water vapor, is also holding more of the building blocks for cloud formation. This means potentially more and/or thicker clouds.

Dessler and coworkers estimated the effect of this as up to 2 watts per meter squared [per degree C of warming]. This is an upper limit since it did not account for the formation of clouds, only the increase in the radiative effect of an increase in water vapor in the air.

Other feedbacks of note include an increased surface albedo in winter and spring, a net cooling effect, an increased evaporation in the summer and in the tropics, a net warming effect. Put together, Chow and coworkers suggest that the net effect of both might be a cooling of 0.01 degrees C. Other workers suggest that this might be a cooling of as much as 0.25 degrees C.

There are other so-called biogeochemical feedbacks. These act on the climate system through an increase in CO_2, changing plant physiology. For example, an increase in carbon dioxide could act to fertilize plants by stimulating photosynthesis. Kramer and coworkers suggest that this took place during the 20th century and that as a result there was more vegetative cover to the planet.

The Intergovernmental Panel on Climate Change notes that the radiative forcing due to these processes has not been fully evaluated, and there is very low scientific understanding of these effects. There are two related points we will discuss.

First, in addition to the carbon dioxide fertilization effect, there can be negative effects on plants due to temperature rising above their optimum for growth. Many crops are planted in specific temperature zones to optimize productivity. Increase in temperature can reduce yields by moving crops out of their optimum temperature regime. In estimates compiled by the USDA, we note a combination of the CO2 fertilization effect, and non-optimal temperature can lead to lower yields. In the case of corn in the Midwestern United States, the negative temperature effect can be as much as minus 4 percent in yield, even though this is offset to some extent by the CO2 fertilization effect, which would be an increase of 1%, for a net change of minus 3%.

Second, an increased temperature can lead to a higher rate of wildfires due to drying of soils and plants. In complementary works, Logan and coworkers, and Solomon and coworkers showed increases from 50 to 175 percent in the burn area in the Western United States by 2050. This continues on a trend that is already visible today.

We summarize our recent discussion of forcing and feedbacks with this figure, originally from work by Hanson and coworkers. The upper figure represents pure climate forcings, such as the greenhouse gases and aerosols. The lower figure includes feedbacks, such as on water vapor and some cloud processes. We can see the inclusion of feedbacks, which are generally less well understood than forcings, can significantly change some of the anthropogenic effects.

One particularly striking example is for soot, which we noted in the aerosol lecture is a positive forcer due to absorption of solar radiation. When feedbacks are considered, the effect of biomass burning, which produces soot, but also effects clouds and surface albedo, leads to a negative total radiative effect.