RealClimate
Climate science from climate scientists

Technical note (Dec 17): A significant number of comments have been inadvertently sent to spam in recent weeks. Some have been rescued (and so numbering in some threads may have changed). We have now changed the system so that you are notified of any potential problems, but please email us at contrib -at- realclimate.org if there are any continuing issues.

7 December 2004

Why does the stratosphere cool when the troposphere warms?

Filed under: **Attic** — gavin @ 11:21 AM - ()

This post is obsolete and wrong in many respects. Please see this more recent post for links to the answer.

14/Jan/05: This post was updated in the light of my further education in radiation physics.
25/Feb/05: Groan…and again.

Recent discussions of climate change (**MSU Temperature Record**, **ACIA**) have highlighted the fact that the stratosphere is cooling while the lower atmosphere (troposphere) and surface appear to be warming. The stratosphere lies roughly 12 to 50 km above the surface and is marked by a temperature profile that increases with height. This is due to the absorbtion by ozone of the sun's UV radiation and is in sharp contrast to the lower atmosphere. There it generally gets colder as you go higher due to the expansion of gases as the pressure decreases. Technically, the stratosphere has a negative 'lapse rate' (temperature increases with height), while the lower atmosphere's lapse rate is positive.

(New. A brief discussion of the greenhouse effect is useful here. You can read the technical reasons below, but the key point for this discussion is that increasing greenhouse gases increases the temperature gradient from the surface.

[**Technical digression:** Imagine an atmosphere with multiple isothermal layers that only interact radiatively. At equilibrium each layer can only emit what it absorbs. If the amount of greenhouse gas (GHG) is low enough, each layer will basically only see the emission from the ground and so by Stefan-Boltzmann you get for the air temperature (Ta) and the ground temperature (Tg) that $2\ Ta^4 = Tg^4$, i.e. Ta=0.84 Tg for all layers (i.e. an isothermal atmosphere). On the other hand, if the amount of GHGs was very high then each layer would only see the adjacent layers and you can show that the temperature in the top layer would approximate ~~0.84^n Tg~~ $(n+1)^{-1/4}$ Tg, (see **note**) where n is the number of layers - much colder than the low GHG case. Hence the increased GHG steepens the surface-to-top temperature gradient.]

In the case of the Earth, the solar input (and therefore long wave output) are roughly constant. This implies that there is a level in the atmosphere (called the effective radiating level) that must be at the effective radiating temperature (around 252K). This is around the mid-troposphere ~ 6km. Since increasing GHGs implies an increasing temperature gradient, the temperatures must therefore 'pivot' around this (fixed) level. i.e. everything below that level will warm, and everything above that level will cool.

Even though the stratosphere has an opposite lapse rate to the troposphere because of the ozone absorption, the effect of increasing GHGs is the same, i.e. since it is above the effective radiating level, it will cool. The cooling will be greatest as you go higher. In the troposphere, there are important other effects that change the temperature, cheifly moist convection, and that smears out the temperature changes you expect from a pure radiative atmosphere. So while the troposphere does warm as a function of increasing GHGs, the maximum change is not at the surface, but actually in the mid-troposhere. **End new)**

To be sure, this is a very rough picture and where other feedbacks are important (due to clouds, convection, dynamics etc.) the picture locally can be significantly different from this one-dimensional cartoon. Nonetheless, at the global mean level, this is the dominant effect.

Another important climate forcing, volcanic aerosols, can also give a similar opposing trend between the stratosphere and troposphere. In this case, large amounts of sulphate aerosols (small particles) are injected into the stratosphere by large explosive eruptions (the most recent one being Mt. Pinatubo in 1991). These aerosols are reflective and increase the albedo of the planet. This reduces the amount of solar radiation reaching the surface and therefore cause a cooling in the troposphere. However, they also absorb some radiation, and so in the lower stratosphere, they actually cause a warming.

So do all climate changes cause opposing trends in stratospheric and tropospheric temperatures? No, it depends on the physics of each case. A good counter-example is that of solar forcing. An increase in the sun's irradiance such as occurs over the 11-year sunspot cycle (or potentially longer time scales) warms the stratosphere (due to increased absorbtion by ozone) but it also warms the troposphere.

25/Feb/2005 Note: thanks to JBS for the correction to the n-shell calculation (see comment 11)

NB. The following text was originally in the post (paragraph 2), and has subsequently turned out to be wrong. It is left here so that the comments on it can remain comprehensible.

~~The effect on local temperatures of increasing greenhouse gases depends on this lapse rate. Greenhouse gases (like~~ ~~CO_2, CH_4~~ ~~or water) absorb and re-radiate infra-red (IR) radiation that is emitted from the planet's surface at rates that depend on the temperature (the Stefan-Boltzmann law). If the temperature below is warmer than the local temperature, IR radiation that is re-radiated is less than is absorbed, the net effect of the greenhouse gases is to warm that layer. Conversely, if the temperatures below are cooler, the local emissions will be larger than the IR radiation absorbed, and thus the net impact of the GHG will be to cool. In steady state, these effects are balanced principally by convection in the troposphere, and by ozone UV absorbtion in the stratosphere. As GHG levels change though, especially in the case of the well mixed gases like~~ ~~CO_2~~~~, the tendencies described above will be enhanced, and thus in the troposphere, where GHGs warm, they will warm further, and conversely, in the stratosphere, where they cool, they will cool further. Thus the impact of GHGs locally is dependent on the local lapse rate.~~

*Powered by **WordPress***