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Applications of Atomic Molecular Physics to Global Change

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Abstract:

Over the last several decades there has been increasing concern about the global environment and the effect of human perturbations on it. This whole area has become known as global change, involving a wide range of scientific disciplines.

Given the increase in concentrations of greenhouse gases that has occurred and is predicted to continue, the change in radioactive heating of the troposphere can be calculated.

Models generally predict an increase in tropospheric temperatures. Doubling of CO_2 and CH_4 concentrations in the mesosphere (50km-80km above sea level) and at the lower boundary of the thermosphere, which extends from approximately 90km upward.

Using sophisticated atmospheric general circulation models, they predict that the stratosphere (extending from -15 to 50KM) mesosphere, and thermosphere will show significant cooling.

Key words: Global change–energy fluxes-troposphric warming-upper atmosphere cooling-atomic and molecular physics.

Tropospheric Warming / Upper Atmosphere Cooling

Incoming and Outgoing Energy Fluxes

The overall temperature of a plant is determined by a balance between incoming and outgoing energy fluxes. In a steady state, the planet must radiate as much energy as it absorbs from the sun. the earth, radiating as a blackbody at an effective temperature, T_E, obeys the Stefan-Boltzmann law in which the energy emitted is expressed as $\sigma T_E^4 4\pi T_E^2$ where u is the Stefan-

Boltzmann constant, and RE the radius of the earth. An equation expressing the equality of energy absorbed and energy emitted can be written as

$$F_s \pi R_E^2 (1 - A) = \sigma T_E^4 4\pi T_E^2$$

Where A is the albedo of the earth (the fraction of solar radiation reflected from, rather than absorbed by, the Earth). F' is the solar flux at the edge of the earth's atmosphere. and $4\pi T_E^2$ is the Earth's area normal to the solar flux. Solving this

equation for T_E, one obtains T_E approximately 255 K (-.18°C)

The sun, which has a surface temperature of approximately 6000 K, emits most of its radiation in the 0.2-4.0 pm region of the spectrum (2 000-40 000 A). The upper atmosphere of the Earth (thermosphere, ionosphere, mesosphere, and stratosphere) absorbs all the solar radiation short ward of 320 nm. The atmosphere of the earth absorbs only weakly in the visible region of the spectrum where the solar flux peaks.

The Earth, with an effective radiating temperature of 255 K. emits mainly long-wavelength radiation in the 4-100 pm region. Molecules naturally present in the atmosphere in trace amounts, such as carbon dioxide, water and methane, absorb strongly in this wavelength region Radiation coming from the Earth is thus absorbed. reradiated back to the surface, and thermalized through collisions with the ambient gas. This trapping of the radiation produces an additional warming of 33 K.

Thus the mean surface temperature of the Earth is 288 K, not 255 I(as found for *TE* above. This effect of the Earth's atmosphere is known as the *greenhouse* effect. The greenhouse effect is what makes Earth habitable for life as we know it. Gases, both natural and man-made, which absorb strongly in the 4-100 pm region, are known collectively as greenhouse gases.

Tropospheric "Global" Warming

From air bubbles trapped at different depths in polar ice, it is possible to determine carbon dioxide and methane concentrations several thousand years ago. Over the last two hundred years, CO_2 levels have increased by 20%, from 280 to 330 ppm. Over the next century the total amount of CO_2 in the atmosphere since 1900 is expected to double to as much as 600 ppm. This increase is due primarily to the burning of fossil fuels.

Although methane is present at levels several orders of magnitude less than $C0_2$, it is increasing much more rapidly. Methane concentrations have more than doubled over the last two hundred years due to industrial processes, fuels, and agriculture.

The man-made chiorofluorocarbons (CFCs), which have been widely used as refrigerants and in industry, have been increasing in the atmosphere at a rate of over 5% per year since the 1970s. Only recently has there been an indication that this trend is slowing down Ozone, which is a primary component of chemical smog, is a pollutant when it occurs in the troposphere and arm effective greenhouse gas. It has been increasing worldwide also.

This buildup of CO_2, CH_4, CFCs and tropospheric O_3 causes a problem. In much of the spectral region from 5-100 pm, there is 100% absorption of radiation by the atmosphere- due mainly w naturally occurring water vapor. There is, however, a region of rather weak absorption, from '.'7-15 pm. known as the " atmospheric window". Increased concentrations of the greenhouse gases strengthen the absorption in this region, tending to "close" this window, thus increasing the infrared opacity of the atmosphere. The increased opacity causes an immediate decrease *in* the thermal radiation from the planet-atmosphere system, forcing the temperature to rise until the energy balance is restored.

There are some indications that this heating may already be occurring. Over the last century the mean global temperature has increased by approximately 0.5°C. It is difficult, however, to prove that the buildup of greenhouse gases is the cause of this temperature rise. Other possible causes include slight changes in solar activity and irradiance, and changes in ocean currents, which may have a profound effect on global temperature and climate. These are areas of active research.

Given the increase in concentrators of greenhouse gases that has occurred and is predicted to continue, the change irradiative heating of the troposphere can be calculated. Models generally predict an increase in troposphere temperatures ranging from 1.5 to 4.5°C, upon doubling the CO_2 concentrations over the next century. The 3°C range in predicted temperature increase is due to the ways that different models incorporate climate feedbacks. Climate feedbacks include water vapor, snow and sea ice, and clouds. Rising temperatures increase the concentration of water vapor, which is itself a greenhouse gas, producing further warming. Rising temperatures reduce the extent of reflective snow and ice, thus reducing the Earth's albedo. This leads to increased absorption of solar radiation, further increasing temperatures. Clouds both contribute to the albedo, thereby reducing the solar flux reaching the Earth, and absorb infrared radiation causing temperatures to rise. The modeling of clouds and their radiation properties is very difficult, and is one of the largest sources of uncertainty in the climate models. Understanding the role that the ocean, with its giant heat capacity, plays in global warming, and identifying and quantifying the various interactions occurring at the ocean-atmosphere interface, are vital areas of research which will affect the size of the predicted temperature increase. At present, there are few obvious opportunities for traditional atomic and molecular physics to play a significant part in global-warming research.

Upper Atmosphere cooling the buildup of CO_2 has an even greater effect on the temperature in the upper atmosphere than on that in the troposphere CO_2 is a coolant in the stratosphere, mesosphere, and thermosphere, but as a greenhouse gas is involved in heating the troposphere. The explanation for this revolves around the collision physics issue of quenching versus radiating.

In the troposphere, CO_2 absorbs infrared radiation coming from the Earth, exciting the *υ2* vibrational bending mode at 15 µm. The excited molecule can either reradiate or collisionally de-excite. In the lower atmosphere where densities are large, the lifetime against collisions is very short and the excited molecule is rapidly quenched. This transfer of energy from radiation through collisions into the kinetic energies of the colliding partners results in a net heating.

In the stratosphere and above, atomic oxygen collisions with CO_2 excite this same bending mode. But at these higher altitudes, densities are lower and quenching is greatly reduced. The excited molecule radiates and the radiation escapes to space. A net cooling results because the opacity is low at these altitudes.

Doubling of CO_2 and CH_4 concentrations (as predicted for the next century) in the mesosphere and at the lower boundary of the thermosphere. Using sophisticated atmospheric general circulation models, they predict that the stratosphere, mesosphere, and thermosphere will show significant cooling - the largest cooling of 40-50°C occurring in the thermosphere.

The overall consequences of such a large temperature decrease in the upper atmosphere have not been fully explored - particularly, the question as to how the dynamics of the atmosphere will be affected. Since many chemical reactions depend on temperature, there may be considerable readjustments in the vertical distribution of minor species in the atmosphere. Cooler temperatures cause the atmosphere to contract, reducing densities and, consequently, satellite drag. Cooler temperatures may also increase the occurrence of polar stratospheric clouds, thereby affecting ozone depletion - Most significantly, troposphere warming and upper atmosphere cooling both result from a buildup of CO2. The size of the predicted cooling is greater by an order of magnitude than the amount of the predicted heating. Thus it may be possible to monitor the global warming trend by observing the predicted cooling in the upper atmosphere.

There is evidence in the mesosphere that this cooling has already begun. Temperatures appear to have decreased by 3—4°C over the last decade it has also found that the frequency of occurrence of noctilucent clouds, the highest-lying clouds in the atmosphere, has more than doubled over the last twenty-five years. It was calculated that this change could result from a decrease of 6.4°C in the mean temperature at the menopause during this time period. However increased concentrations of water produced by oxidation of increased amounts of methane may be responsible for the more frequent appearance of the clouds.

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