CO_2 GREENHOUSE EFFECTS ON VENUS, EARTH, AND MARS. D. Crisp, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA, 91011, David.Crisp@jpl.nasa.gov.

Introduction: Carbon dioxide (CO_2) is an efficient, long-lived greenhouse gas that has played a key role in the evolution of the climates of Venus, Earth, and Mars. On Venus, where it constitutes over 96% of the massive, 90-bar atmosphere, CO_2 is the dominant greenhouse gas. However, even there, other greenhouse agents including trace amounts of H_2O, SO_2, and the planet enshrouding H_2SO_4 clouds are needed to maintaining the 730 K surface temperatures. On Earth, CO_2 is a trace gas whose concentration and climate impact has varied over time. It currently makes up ~0.04% of the atmosphere but is still the second most important greenhouse gas, after water vapor. On Mars, CO_2 constitutes over 95% of the ~6 hPa atmosphere and is currently the only significant greenhouse gas. If Mars was substantially warmer and wetter earlier in its history, other greenhouse agents must have contributed to the surface thermal balance.

The role of CO_2 in the Venus greenhouse mechanism has been studied extensively since the beginning of the space age. Initially, the focus of these studies was to demonstrate that CO_2, water vapor, and other known greenhouse agents could maintain the high surface temperatures in the presence of the H_2SO_4 clouds, which reflect almost 80% of the incident sunlight back to space before it can be absorbed the planet. More recent greenhouse experiments have provided a more detailed assessment of the details of the vertical absorption profile of CO_2 and their contributions to the the atmospheric thermal structure. Other investigations have focused on the role of these processes in the early evolution of the Venus environment, including the runaway greenhouse and subsequent loss of water from the surface and atmosphere. These investigations led to numerous insights into the evolution of terrestrial planetary atmospheres beyond the inner boundary of the solar system's habitable zone.

Studies of the role of CO_2 in the Venus greenhouse continue to place stringent demands on our understating of gas absorption at high pressures and temperatures and other radiative processes essential for simulating planetary atmospheres. Much of what we know about the absorption by CO_2 isotopes, hot bands, and other effects including non-local thermodynamic equilibrium (NLTE), quantum-mechanical line mixing and pressure-induced absorption was derived from pioneering laboratory measurements designed to support Venus greenhouse studies. These processes still are poorly understood at the temperatures and pressures found in the lowest scale height of the Venus atmosphere.

While the CO_2 concentration in the Earth's atmosphere has varied substantially over time, recent increases associated with fossil fuel emissions and other human activities have generated the greatest attention. For at least 600,000 years prior to the start of the industrial age, the CO_2 concentration rarely exceeded 300 parts per million (ppm) relative to dry air. Since the 1750's, fossil fuel emissions and cement production have added ~1,300 billion tons of CO_2 into the atmosphere. Almost half of this emission has occurred since the mid 1970's. The atmospheric concentrations of CO_2 are now increasing by about 0.5% per year, in response to these emissions, but this is not the whole story. Given the known emission rates, the CO_2 should be increasing at twice this rate. Apparently, almost half to the CO_2 emitted into the atmosphere by these human activities is being reabsorbed by the ocean and the land biomass. Measurements of the concentration of dissolved carbon in the ocean water indicate that about half of the "missing CO_2" is being absorbed by the ocean. The rest is being absorbed somewhere on land, but nature and geographic distribution of these "CO_2 sinks" is currently unknown. Because of this, there is no way to predict how these sinks may respond to a changing climate.

These changes in the Earth's atmospheric CO_2 concentration have generated substantial concern about greenhouse gas induced climate change. Climate models developed as early as the 1960's showed that doubling the CO_2 concentration would increase the global average surface temperature by ~3 ºC. These predictions have been verified repeatedly by increasingly more sophisticated climate models. They are now appearing as robust features in global measurements of surface and atmospheric temperature.

While the Martian atmosphere contains about 70 times as CO_2 as the Earth's, this gas produces only a weak greenhouse effect. In the global average, CO_2 adds less than 18 W/m^2 to the surface radiation budget. Most studies of the Martian atmospheric greenhouse have focused on whether, or to what extent, CO_2 and other greenhouse agents (gases, aerosols) warmed the Martian surface in the past. Was the ancient Martian climate warm and wet or cold and dry? If it was much warmer, how much CO_2 was there in the atmosphere at that time? What other greenhouse agents were available in conjunction with CO_2, how long did they last, and how effective were they at trapping thermal radiation and warming the surface? New measurements and more innovative modeling studies are needed to convincingly answer these questions.

Here, we will attempt to review the recent progress in each of these areas and define the next logical steps in the investigation of CO_2 greenhouse effects on Venus, Earth and Mars.

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