Atmospheres of Terrestrial Planets in the Solar System

1. Introduction

All planets in the Solar System have an atmosphere of some kind. Whether thick ones like Venus or life-supporting like Earth's, atmospheres are part of the complex processes that make each planet unique. As Earth shows, there's a strong link between life and the atmosphere, a lesson researchers use when looking for life elsewhere in the galaxy.

The study of planetary atmospheres of the solar system encompasses thermodynamics, radiation, dynamics and chemistry. The atmospheres of different planets exhibit diversity of basic physical properties (including the vertical structure) and atmospheric composition. The observed composition of a planetary atmosphere is the product of planetary formation and evolution, including the chemical and physical processes shaping atmospheric abundances into the present day. The composition of each atmosphere affects the climate through energy transfer and the greenhouse effect.

The present understanding of planetary atmospheres is the result of over a century of observations, including ground-based, space-based, and in situ measurements of the major and minor species, meteorological and physical quantities. These observations have been accompanied by the development of theoretical models to identify the key processes shaping the climate of a planet, as observed today. Models of the Earth's atmosphere (example Climate Models) have reached a level of complexity, where we can well predict our weather and climate. Such models have been developed for atmospheres of Mars and Venus also.

Being closest planets to Earth, Venus and Mars have received considerable attention from the beginning of space age. Consequently, there have been several planetary missions to explore the atmosphere and ionosphere of these planets.

In this lecture, we will discuss all above aspects, that we have understood about atmospheres of terrestrial planets of the Solar System.

2. Atmospheric Composition

The most abundant gas in the Earth's atmosphere is observed as nitrogen N_2 (78%) and oxygen O_2 (21%). CO_2 is the dominant gas in the Martian (95%) and the Venusian (96%) atmospheres. Minor constituents such as water vapor, argon, Krypton, ozone and aerosols are also observed on these planets. Inspite of their small proportion by volume, scientists are concerned about these minor constituents and aerosols because of their distinctive but very important roles in the physico-chemical and radiative effects in the atmosphere.

The presence of oxygen in Earth's atmosphere is a consequence of the presence of living organisms on the planet. Water is present in the atmospheres of all three terrestrial planets in different forms. On Venus, a trace amount of the compound occurs in the atmosphere in combination with oxides of sulfur in the form of sulfuric acid. On

Earth, most water has condensed to the liquid form and can be found in the massive oceans that cover the planet’s surface. On Mars, the relatively small amounts of water available on the planet have been frozen out of the atmosphere and have condensed in polar ice caps.

3. Thermal Structure of Atmospheres

The primary source of heating a planetary atmosphere is the solar energy. The surface then heats the atmosphere which comes in contact with it. The planet-atmosphere system radiates back into space in the infrared and there is a radiative balance between the incoming and outgoing radiation. The greenhouse effect of the atmosphere elevates the temperature of the planet.

Radiative transfer of energy is calculated by radiative transfer models using the basic principles of thermodynamics. This includes detailed calculations of absorption and emission by atmospheric gases. The processes of absorption, scattering and emission give rise to the vertical temperature structure of an atmosphere.

4. Physical Structure of Atmospheres

Apart from the temperature structure, an atmosphere is characterised by its pressure variation. The Martian surface pressure is 7.0-9.0 mb, which is 0.7% of the Earth’s surface pressure (1013.25 mb). The surface atmospheric pressure on Venus is about 92 bar, about 90 times that of Earth.

The decrease of pressure with altitude, is exponential, in the terrestrial atmospheres, assuming pressure gradient forces are balanced by gravity.

Apart from neutral constituents, atmospheres also contain ions and electrons. The solar radiation interacts with the atmospheric constituents of a planet, resulting in dissociation and ionisation of atmospheric constituents. This results in the ionosphere of planets, which is strongly influenced by the solar wind in the upper heights.

Gradients in temperature and pressure lead to atmospheric motion. These exist at various length and time scales, from local turbulence to large scale planetary circulations.

5. Models to Study Climate of Planets

Over the last few decades, models have been applied to study weather and climate, and the basic science behind various processes that occur in atmospheres. Meteorological models and General Circulation Models have been used to simulate weather and climate. Photochemical models have been used to study atmospheric chemistry (for example air-pollution in Earth's atmosphere). Now many of these models have been merged together to tackle the complex problems of a planet's climate. Modelling of the atmosphere involves representation of the coupled chemical radiative and dynamical processes. Thes coupled differential equations are solve numerically, on high performance computers.

An example is the study of dust storms on Mars, which are the biggest weather events on the planet. PRL scientists have worked on this for the past few years. These storms, which are related to the wind patterns and global atmospheric dynamics, can have significant impact of the climate of Mars. It's also important to study them, for possible future human missions to the red planet.

<u>**Reference material for study**</u>:

1. An Introduction to Atmospheric Physics by David G. Andrews, 237 pages
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   Published: 2000
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2. An Introduction to Planetary Atmospheres, by A. Sanchez-Lavega, 629 pages
   Publisher: Taylor & Francis
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   DOI: https://doi.org/10.1080/00107514.2011.580060

3. Modelling of Planetary Atmospheres,
   edited by S.A. Haider, Varun Sheel and Shyam Lal, 374 Pages
   Publisher: Macmillan Publishers India Ltd.,
   Published: 2010