Assessment of atmospheric carbon dioxide and aerosols from ground spectroradiometry and hyperspectral image analysis

Thesis submitted for the partial fulfillment of the requirements for the degree

Doctor of Philosophy in **Science**

By

Santanu Roy

Under the Supervision of

Prof. Barun Raychaudhuri

Department of Physics

Faculty of Natural and Mathematical Sciences

Presidency University,

Kolkata, India

2022

Recommendation

Atmospheric carbon dioxide (CO_2) is the greenhouse gas most vulnerable to human activities and has serious effects on climate change. Developing precise monitoring systems for CO_2 has been an important issue during the last two decades. The present work has applied the physical principles of assessing gaseous concentration from the spectral absorption of radiation to the estimate of CO_2 and has proposed several new methodologies and results in that connection. It has applied the techniques of hyperspectral remote sensing, popularly known as 'imaging spectroscopy' in three different ways: ground-based high resolution spectroscopy, airborne hyperspectral images and satellite-borne hyperspectral database. Analyses are made for both global and local levels, particularly in the Indian context. Both the atmospheric column average and the surface level CO_2 concentrations are estimated. The spatial as well as the temporal variations of the column concentration are explored. This work may be recommended as a study on the recent CO_2 scenario of India and world that has both application of physics and interdisciplinary relevance.

Summary and Conclusion

This work has addressed several facets of the present CO_2 scenario and its correlations with human activities. The spatial distribution of CO_2 abundance is estimated by propounding a new methodology for averaging the CO_2 absorption depths, referred to as *a*-DOAS in this connection. The candidate believes that this is the first report on the spatial distributions of CO_2 column averages at different places of the tropical atmosphere of India, retrieved from AVIRIS-NG image analysis.

A novel technique is put forward for the radiation absorption correction for atmospheric water vapour by comparison with the spectral radiance of Mars' atmosphere. A balanced condition of anthropogenic emission and vegetative sequestration was revealed for the places of varied CO_2 source and sink potentials. A steady linear increase in the CO_2 concentration was found in the Indian atmospherefor the past two decades. This work has also developed a technique for the spatial mapping of atmospheric water vapour concentration by comparing two consecutive CO_2 absorption bands. The detection of point sources of CO_2 from high spatial resolution airborne hyperspectral image is validated by comparing the CO_2 extent at Jharia coalfield and that at other urban regions.

The seasonal variation of atmospheric CO_2 is studied in both time and frequency domains. The reason for the annual variability of CO_2 in India is explained as a combined influence of vegetation vigour and atmospheric pressure and temperature. The interpretation is made more generalized by developing a climate model based on the vertical redistribution of CO_2 molecules.

The study incorporates the analysis of the data procured by Orbiting Carbon Observatory-3 (OCO-3), the recent-most global CO_2 sensor. During the work, an unexpected situation of global lockdown took place related to the novel coronavirus (COVID-19) pandemic. The consequent restricted fossil fuel burning situation might have some effect on the atmospheric CO_2. Considering this point, a comparative analysis with the predecessor Orbiting Carbon Observatory-2 (OCO-2) was carried out and a temporary reduction in the CO_2 column average was noted, especially in the urban regions. A wavelet coherence technique was adopted to quantifying that reduction.

Along with CO_2, this work has taken into account urban aerosols as closely related to man-made activities and has estimated the aerosol optical depth from hyperspectral images. In brief, the main highlights of the work are spectral calibration of CO_2 absorption profile, spatial distribution of the concentration of CO_2 column average, detection of point source, the correction of CO_2 absorption profile due to the influence of water vapour in the tropical atmosphere of India, new techniques for estimating CO_2, aerosol and water vapour concentrations, seasonal changes of CO_2 and aerosol and the present trends of CO_2 in Indian and Global context.

Future Scopes

This work has noted that the regions of wide variations of CO_2 and its sequestering agents, when accommodated to coarser spatial resolutions, such as that of global CO_2 sensors like OCO-2 and OCO-3, the diversities in emission and sequestration are averaged out and an overall uniformity of CO_2 column average is obtained. A reasonably steady increase in the atmospheric CO_2 is obtained in the Indian environment, which may be credited to the wide-ranging vegetated regions dispersed throughout the country. In contrast, higher values of CO_2 at deep sea regions hint at the insufficiency of the slow sea sequestration to meet the global increase. These findings may be explored in future as an interdisciplinary issue.

The global CO_2 sensors like OCO-2 and OCO-3, because of coarser spatial resolution may be unable to detect local point sources of CO_2, hence the local atmospheric changes. This opens the scope for adopting a similar methodology, like the present one, of procuring hyperspectral images more frequently with more adjustable platforms, such as drones. The database thus built-up can be networked to develop an Internet of things for smart monitoring of local variations of atmospheric CO_2 due to human activities.

The present work has established that the vertical redistribution of air-mixed CO_2 molecules can cause an apparent change in the atmospheric radiation absorption path and an apparent change in the gas concentration. A similar treatment, considering the changed conditions of temperature and pressure is expected to be a useful climate model for interpreting the CO_2 concentration.

The present work has established from different angles of studies that the atmospheric CO_2 assessment in India has some specific features. It is a big and densely populated country with high fossil fuel burning and diversified environments. The tropical atmosphere contains widely varying water vapour concentration that can partly mask the radiation absorption profile of CO_2. Considering these features, the present methodologies involving the combination of field work of surface level CO_2 measurement and spectroradiometric assessment of the CO_2 column average, spectral standardization, analyzing the hyperspectral images, comparing with open source satellite data and recording the seasonal, spatial long term temporal variations may be adopted in future also.