Effects of Lower Atmospheric and Solar Forcings on Daytime Upper Atmospheric Dynamics

A thesis submitted in partial fulfilment of

the requirements for the degree of

Doctor of Philosophy

by

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Under the guidance of

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DISCIPLINE OF PHYSICS

INDIAN INSTITUTE OF TECHNOLOGY GANDHINAGAR

2014 - 2015

to

my family

Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above can cause disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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Thesis Approval

The thesis entitled

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is approved for the degree of

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Abstract

The upper atmosphere of the Earth is influenced by incoming solar radiation (UV, EUV, and X-rays) and by secondary effects like waves from the lower atmosphere. The EUV radiation is absorbed above about 100 km altitude of the Earth's surface by atomic and molecular constituents resulting in their excitation to higher energy states. These excited species while returning to their respective ground states give rise to radiations, which are called dayglow (or daytime airglow). Chemically excited atmospheric species can also contribute to dayglow emissions. The intensity of these dayglow emissions depends on the number densities of the reactants and on the temperature. The distribution in densities of the reactants can be affected by the waves, thereby leading to the variations in the intensities of the dayglow emissions. Thus, the dayglow measurements provide an effective means to investigate the upper atmospheric dynamics, which are influenced by both solar flux variations and lower atmospheric processes.

Solar activity changes due to its internal dynamics giving rise to variations of different periods ranging from hours to years. The lower atmospheric waves are excited by topography, convection, etc., and in the presence of stable atmosphere they can propagate to the upper atmospheric altitudes. In this study we characterize various types of coupling processes in the atmosphere and their variations with waves and solar activity. The main data set that has been used in this work has been retrieved using Multiwavelength Imaging Spectrograph using Echelle-grating (MISE). MISE is a unique instrument capable of obtaining daytime sky spectra at high-spectral resolutions over a large field-of-view. From such spectra of MISE oxygen dayglow emission intensities at 557.7 nm, 630.0 nm, and 777.4 nm wavelengths have been obtained. In addition to oxygen dayglow emission intensities, data sets of ionospheric total electron content (TEC), zonal mean winds and temperatures from the stratosphere to the lower thermosphere, and the equatorial electrojet (EEJ) strengths have been used.

In this thesis, it has been shown that the lower atmospheric influence on the upper atmosphere through waves is affected by solar activity. This is because the latter is responsible for the alteration of the atmospheric background condi-

tions on which wave propagation and dissipation depend. From an investigation of the oscillations of planetary wave regime in dayglow and other atmospheric parameters at three different levels of solar activity, it has been shown that the vertical coupling of atmospheres through these waves is solar activity dependent. It is proposed that: (i) the effect on upper atmospheric dynamics due to lower atmosphere exists at least until the average sunspot number (SSN) is ≤ 35, (ii) there is a transition from the lower atmospheric forcing to mixed behavior between average SSNs of 35 to 52, and (iii) another transition from mixed effects to those of purely solar origin occurs between SSN values of 52 to 123. Further, in this thesis it has also been shown that even during high solar activity period if a sudden stratospheric warming (SSW) event occurs then the vertical coupling is enhanced, as the SSW related processes provide additional energy to enable this coupling.

A statistical study of gravity waves present in the thermospheric altitudes is made using the three dayglow emissions and the EEJ strength data obtained during the years 2011 to 2013. The gravity waves are found to be present in higher numbers in the thermosphere during higher solar activity of 2013 compared to 2011, which is attributed to a reduction in dissipation in the lower thermosphere during higher solar activity epoch.

Investigations using long-term data sets of EEJ and TEC revealed that the vertical coupling during SSW events depends on the strength of the SSW. Also, the interaction between quasi-16-day planetary waves and semi-diurnal tides has been found to be very strong for the strong major SSW events. In an another result, using both ground- and satellite-based optical remote sensing measurements, a new circulation cell in the mesosphere-thermosphere system has been shown to exist during SSW events, which has been alluded to in previous modeling studies.

Keywords: Atmospheric coupling, Dayglow, Ionosphere, Upper atmosphere, Sudden stratospheric warming, Sun-Earth interaction, Gravity waves, Planetary waves.

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