

Investigations of Daytime Thermospheric Wave Dynamics Over Low-Latitudes Using Ground-Based Optical Techniques

A thesis submitted in partial fulfilment of

the requirements for the degree of

Doctor of Philosophy

by

Deepak Kumar Karan

(Roll No. 11330025)

Under the guidance of

Prof. Duggirala Pallamraju

Space and Atmospheric Sciences Division

Physical Research Laboratory, Ahmedabad, India.



DISCIPLINE OF PHYSICS

INDIAN INSTITUTE OF TECHNOLOGY, GANDHINAGAR

2017

to

My Parents

Its all about your love and blessings

and

My Teachers

I am blessed to have teachers like you

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.

(Signature)

(Name: Deepak Kumar Karan)

(Roll No: 11330025)

Date: October 16, 2017

Thesis Approval

The thesis entitled

Investigations of Daytime Thermospheric Wave Dynamics Over Low-Latitudes Using Ground-Based Optical Techniques

by

Deepak Kumar Karan

(Roll No. 11330025)

is approved for the degree of

Doctor of Philosophy

Examiner

Examiner

Examiner

Examiner

Supervisor

Date: _____

Place: _____

Acknowledgments

The guidance, support, advice, motivation, and encouragement from my supervisor, colleagues, teachers, friends, family members and my well wishers had made this thesis work possible. Its indeed a great pleasure for me to acknowledge them all.

At first, with due respect, I would like to express my sincere thanks and gratitude to my thesis supervisor Prof. Duggirala Pallamraju for introducing me to this subject. I am delighted to have a supervisor like him, who could recognize my potentials very well from the beginning and had given me the freedom of investigating the research problems and for scientific discussions with no time bound. His enormous patience of listening and discussing the scientific problems; and during experimental observations and analysis, always inspired and motivated me towards the research work. His vast knowledge and depth understanding on various aspects of the subject helped me to bring clarity in my understanding the field. During confusion and upset hours of my research work, a short discussion with him would bring my focus back to the research. I am thankful for his countless support and invaluable guidance throughout the duration of this thesis work. Thank you sir. I would like to extend my thanks to Bhuvaneswari ma'am, Ananth, and Samba for their affection. Thank you so much ma'am for those tasty dishes, specially Dahivada.

I am thankful to my Doctoral Studies Committee (DSC) members Dr. D. Chakrabarty and Dr. Varun Sheel for evaluating my progress reports and suggesting improvements through out all the semesters. I thank them for critically going through the thesis and making valuable suggestions. The scientific input during discussions with Dr. D. Chakrabarty has increased my understanding the field better. I also thank the academic committee members of PRL for their inputs during review seminars.

I am obliged to Department of Space, Govt. of India for the research grant offered to me during my tenure at PRL. I extend my thanks to Dr. Anil Bhardwaj, Director, PRL, Ahmedabad and Prof. Sudhir K. Jain, Director, IIT, Gandhinagar for providing me with timely administrative help and necessary facilities to carry out my research work. I am also thankful to Prof. P. Janardhan, Dean, PRL and Dr. Bhushit Vaishnav, Head Academic Services for their support with academic matters. My sincere thanks to Prof. Nithin V George, Associate Dean, Prof. Vinod Chandra, Co-ordinator, Discipline of Physics, and the officials at the Academic section of IIT Gandhinagar for their help and cooperation with regard to the submission and evaluation process of my thesis.

I am highly obliged to Prof. R. Sridharan and Prof. R. Sekar for their encouragements, discussions and critical questions during the seminars, which were very helpful during my research. I always felt motivated after the inspiring discussions with Prof. R. Sridharan. I express my sincere thanks to Prof. S. Ramachandran, Chairman, Space and Atmospheric Sciences division, PRL. I also extend my thanks to Dr. L. K. Sahoo, Dr. S. K. Sharma, Dr. A. Guharay, Dr. H. Gadhvi, Mr. S. Venkataramani, Mr. T. A. Rajesh, Mr. A. A. Manke, Mr. M. B. Bhavsar, Mr. T. K. S. Kumar, Malai, Aditya, Anil, Vishnu, Hetal, Sourita, and Mahipath for providing nice atmosphere in the office.

The primary data set for this thesis work is obtained using MISE which is installed at Jawaharlal Nehru Technological University, Hyderabad (JNTUH) under the PRL-JNTUH collaboration. In this regard, I am thankful to the Vice Chancellor, JNTUH, Prof. A. Reddy, Director, University Foreign Relation, and Dr. T. Vijayalakshmi, Head, Center for Environment, IST, JNTUH for enabling smooth operation of this project. I would like to thank Samba bhai, Moid and Abhilash for the logistic support during my field trips to JNTUH.

I sincerely acknowledge the Director, Indian Institute of Geomagnetism, Mumbai, for making the magnetic data available. The geomagnetic indices are made available by ISGI collaborating institutes from data collected at magnetic observatories. I thank all those involved with ISGI (isgi.unistra.fr) and INTERMAGNET network. The GUVI data has been obtained from guvitimed.jhuapl.edu. I thank the GUVI team.

I thank all the staff members of PRL computer center for providing excellent computational facilities. I also appreciate the co-operation by the library staff members.

I am thankful to colleagues of my group F. I. Laskar, Kedar A. Phadke, R. P. Singh, Sneha Yadav, Subir Mandal, and Pradip S., who are always helpful and cooperative. I thank Fazlul bhaiya and R. P. sir for giving me their invaluable time for scientific discussions. I thank Subir and Pradip for making friendly environment in the lab. In particular, I am happy to have a lab mate and colleague like Subir, to have involved scientific discussions besides endless plans for good and tasty food. I am extremely happy to have a colleague, collaborator cum friend like Kedar. I fondly recollect his companionship during the scientific discussions, field trips to Hyderabad, over breakfast-lunch-snacks-dinner, on playground etc. I thank Sneha Nair and Kedar, for their mind relaxing gossips and encouragements, which used to motivate me to work hard. Thank you Sneha, for bringing those tasty food for the two other musketeers and you are a true inspiration.

I thank all my sweet batch mates (Dipti, Bivin, Lalit, Venky, Sukanya, Ritwik,

Chandana, Apurv, Pankaj, Rahul, Newton, Ashim, and Jinia), caring seniors (Susanta Bhai, Nigam Bhai, Priyanka, Arko, Tanmoy, Shweta, Monojit, Dilip, Naveen, Gaurav(T), Bhavya, Gaurav(J), Girish Kumar, Arun, Devrup, Damu, Ikshu, Anirban, Shraddha, Manu, Avdesh), loving juniors (Rukmani, Navpreet, Rupa, Kuldeep, Chandan, Prahlad, Satish, Kumar, Bhavesh, Pradeep, Niharika, Anil, Archita, Aarthy, Richa, Ranadeep, Kaustav, Nidhi, Shefu, Varun, Rahul, Shivangi, Arvind, Naman, Deepika, Sushree, Nisha, Sandeep, Soamdutta, Avik, Ayan, Harish, Abdur, Surendra, Priyank, Deepali, Sana, Ashwin), and many more for making my stay in hostel homely. The friendly and funny activities in the hostel used to refresh my thoughts and continue the research work with more zeal. I remember those memorable days of late night talks near the thinking tree in front of our hostel, going for bird watching in early morning of winter with seniors, playing various games, unique way of celebrating the festivals with you all. Thank you Subir, Aarthy, and Archita for planning those delicious cooking parties in hostel. I must thank Kuldeep, Prahlad, Archita, Subir, and Dipti for their valuable scientific and non-scientific inputs during my rehearsal presentations in hostel. Specially, I would like to thank Deepika and Sushree for making a true homely environment. Thank you Richa for the motivational and supportive discussions. I am extremely happy and thankful to you all for your help and support. Thank you all for being so supportive and kind to me. I would like to thank my friend Diptiranjan Rout who is there with me from the very beginning of the journey.

I would like to take this opportunity to thank my dear friends Pankaj, Pradip, Gautam, Mitun, Ajay, Tiku, Subhanand, Uppu, and Manish Bhai for their encouragement. Specially, I thank Kadambinee for her continuous support, inspiration, and motivation throughout the journey. I fondly recollect the time I spent with Mr. Dharmananda Sahoo and his family. Thank you Nani and Moni for fueling the aspiration inside me. My heart felt thank to late Ajaa who took care of food during my college days. His love and affection is unforgettable. I extend my thanks to Mr. Haladhar Panda and his family to be always my well wisher.

My sincere thanks to my teachers, Mr. Shudarsana Mohapatra, Jalinani, Gitani, Sabitrinani, Mr. Brajabandhu Karan, Debananda Sir, Bai Sir, Shiba Sir, Bada Didi, Mr. Rameshchandra Dalua, Mr. Padmanava Satpathy, Mrs. Suchismita Mohanty, Mr. Pranab Das, Mr. Anirudha Senapati, Mrs. Rita Paikray, and Prof. Gananath Dash who have enlightened me with their vast knowledge at each step of my academic life.

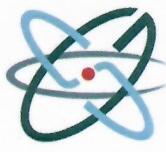
Last, but not the least, I express my indebtedness, love, and gratitude to the four pillars upon which the base of this journey stands. My deepest gratitude and respect to Mr. Pradeep Kumar Sahoo and Mr. Rajesh Moharana sir for whatever

you both have done for me. This long journey would not have possible without you. I fall short of words to express my thanks and appreciation to you and your family members. Thank you, for always being there with me.

Finally, my sincere respect and biggest thank to my parents whose moral support and encouragement has always been a great source of inspiration to me. Thank you Bapa and Bou. This is the result of your blessing. I express my heartfelt thanks to all my family members (Late grand parents, Badabapa, Late Badabou, Sujibhai, Bhauja, Dudu, Samibhai, Babinani, Mitanani, Gitanani, Manashbhai, Puchun, Kajal, Tumpul, Gugu, Ritanani, Babulibhai, Prachi, Pilu, Late Badadata, Badakhudi, Lipu, Anitanani, Bedudata, Sanadata, Sanakhudi, Papu, Puja, and Bapu) for your love and support.

Deepak Kumar Karan

GUJARAT SCIENCE ACADEMY



॥ વિજાનસત્કારભિર્બદ્ધિ ॥

CHAROTAR UNIVERSITY OF SCIENCE AND TECHNOLOGY, CHANGA INSPIRED

BEST PH. D. THESIS AWARD – PHYSICAL SCIENCES

For The Year 2017

Awarded To

Dr. Deepak Kumar Karan
of IIT, Gandhinagar

IN RECOGNITION OF THE CONTENT AND THE PRESENTATION OF HIS THESIS

Prof. A. K. Singhvi
PRESIDENT

Prof. P. N. Gajjar
SECRETARY

Abstract

The equatorial- low-latitude ionosphere-thermosphere system (ITS) hosts several inter-coupled process during the daytime. Various dynamical effects due to winds and waves affect the ITS. Further, solar forcing and geomagnetic storm effects also modulate the low-latitude ITS coupling. The varying nature of these dynamics in response to different geophysical conditions bring in complexities in these coupled processes, which result small and large scale variations in the behavior of the ITS, both in temporal and spatial domain. Even though, investigations of the wave characteristics in spatial domain of the ITS have been carried out over several decades for nighttime conditions, such investigations during the daytime are in a state of infancy. Therefore, systematic investigations of the wave characteristics for daytime conditions are essential in order to gain a comprehensive understanding of the ionospheric and thermospheric system.

The optical dayglow emission intensity variations can be used as tracers of the neutral dynamical variations that exist at the altitudes of their origin. In the present thesis work, by using a high spectral resolution large field-of-view spectrograph, MISE, we have obtained the neutral oxygen dayglow emission intensities at three wavelengths (OI 557.7, 630.0, and 777.4 nm) from Hyderabad, a low-latitude location in India. These emissions are considered to originate from altitudes around 130, 230 and 300 km. The dayglow emissions are used as the primary data set for the investigations carried out in this thesis work.

The dayglow emission intensity patterns showed both symmetric and asymmetric diurnal behavior with respect to local noon. Considering purely photochemical nature of the production mechanisms of the dayglow, the asymmetric diurnal behavior is not expected and hence, it is clear that transport processes play a role. The extent of asymmetric behavior in the dayglow emission intensity is characterized in terms of Asymmetry in Time (AT), which is the product of difference in time of occurrence of peak intensity and local noon and the ratio of intensities at the peak and local noon. The days with $AT \leq 0.4$ h and $AT > 0.4$ h are considered to be the days with symmetric and asymmetric diurnal behavior in the emission intensities, respectively. Comparing the roles of neutral

winds and the EEJ strengths on the days with $AT > 0.4$ h, it is conclusively shown that the dayglow emission intensities over the off-equatorial thermosphere are predominantly affected by the equatorial electrodynamics. It is also noted that this asymmetric diurnal behavior in the neutral emission intensities has a solar cycle dependence with more number of days during high solar activity period showing larger AT values as compared to those during the low solar activity epoch.

Periodogram analyses of the dayglow emission intensity have been carried out at all the three emission wavelengths in three distinctly different directions (west, zenith and east) which are separated by 3^0 - 8^0 depending on the altitude of dayglow emissions. Presence/absence of the time periods with similar values in these three directions indicates the non-existence/existence of longitudinal differences in the gravity wave (GW) features suggesting to a common/different source driving the waves at these locations. The non-existence of the similar time periods on the days with asymmetric diurnal behavior was attributed to the stronger equatorial electrodynamics. Moreover, GW features in terms of the zonal scale sizes and propagation directions also show different behavior on the days with and without the existence of longitudinal differences in the equatorial processes. Thus, our results show, for the first time, that there exist longitudinal variations in the equatorial electrodynamics in as small separations as 3^0 - 8^0 .

Variations in the dayglow emission intensities have been investigated for three geomagnetic disturbances that occurred in different seasons. It is found that the dayglow variations showed similarity with the variation of O/N_2 during geomagnetic disturbances that occurred in solstices. However, during the equinox, the dayglow showed similar variations with that of the EEJ strengths. Taken together, this shows the dominance of the equatorial electric field over the storm influenced neutral wave dynamics on low-latitude ITS during equinox times, and the effect of neutral wave dynamics from high-latitude during solstices. Moreover, contrasting distributions of the GW zonal scale sizes are observed on geomagnetically quiet and disturbed days in different seasons. This shows that changes are brought-in in the zonal GW scale sizes during geomagnetic disturbances irrespec-

tive of the season of the storm occurrence.

Near-simultaneous measurements of the spatial varying dayglow along both the zonal and meridional directions are obtained. From the wave number spectral analysis of these data, the zonal and meridional component of the horizontal waves are obtained. These values are used to calculate the horizontal scale sizes and their propagation angles. Such measurements on the horizontal scale sizes (in two dimensions) are first results of their kind. Moreover, these measured values have been used in conjunction with the GW dispersion relation to calculate the plausible wave features in the vertical direction. Thus, the first three dimensional GW characteristics in the daytime upper atmosphere has been derived. This technique opens up new possibilities in the investigations of the daytime wave dynamics.

Keywords: Dayglow, Ionosphere, Thermosphere, Upper atmosphere, Equatorial electrodynamics, Ionospheric-Thermospheric coupling, Gravity waves, Geomagnetic storm, Latitudinal coupling, Three dimensional gravity waves.

Contents

Acknowledgements	i
Abstract	vii
Contents	xi
List of Figures	xv
List of Tables	xxi
1 Introduction	1
1.1 Background	1
1.2 Structure of Earth's Atmosphere	2
1.3 Ionospheric and Thermospheric Dynamics	9
1.3.1 Thermospheric Neutral Winds	9
1.3.2 Waves	11
1.3.3 Solar Forcing	24
1.4 Daytime Equatorial-Low Latitude Upper Atmospheric Phenomena	27
1.5 Disturbed Time Low Latitude Upper Atmospheric Behavior . . .	34
1.5.1 Electrodynamical Perspective	36
1.5.2 Neutral Dynamics Perspective	39
1.6 Methods To Investigate The Upper Atmospheric Dynamics	42
1.6.1 Optical Method of Measurement	42
1.6.2 Radio Measurements	45
1.6.3 Magnetic Measurements	46
1.7 Objective of The Thesis	46

1.8	Overview of The Thesis	47
1.9	Summary	48
2	Experimental Technique and Data Analysis	49
2.1	Introduction	49
2.2	Optical Dayglow Emissions	50
2.2.1	OI 557.7 nm (Oxygen Green Line)	51
2.2.2	OI 630.0 nm (Oxygen Red Line)	55
2.2.3	OI 777.4 nm	57
2.3	Observational Technique	57
2.3.1	Optical Design of MISE	58
2.3.2	Sample Spectral Image Obtained From MISE	63
2.3.3	Extraction of Dayglow Emission Intensities	64
2.3.4	Commissioning of MISE	69
2.4	Other Data Sets Used	70
2.4.1	EEJ data	70
2.4.2	Ionospheric data	71
2.4.3	D_{st} index	72
2.4.4	Thermospheric O/N_2 data	73
2.5	Data Analysis	74
2.5.1	Fourier Series	75
2.5.2	Fourier Transform (FT)	76
2.5.3	Lomb Scargle Fourier Transfrom (LSFT)	79
2.5.4	Wavelet Analysis	83
2.5.5	Spectral Analysis of Dayglow Data	90
2.6	Conclusion	94
3	Influence of Equatorial Electrodynamics on Daytime Low-Latitude Thermospheric Optical Emissions	95
3.1	Introduction	95
3.2	Data Set	97
3.3	Results and Discussion	99

3.4 Conclusion	119
4 Longitudinal Variations in Daytime Thermospheric Wave Dynamics Over Low-Latitudes	121
4.1 Introduction	121
4.2 Data Used	127
4.3 Results	128
4.4 Discussion	146
4.5 Conclusion	149
5 Response of Low-Latitude Thermospheric Wave Dynamics Due to Geomagnetic Storms	151
5.1 Introduction	151
5.2 Experimental Technique and Data Set	154
5.3 Results	155
5.3.1 Geomagnetic storm effect on the OI dayglow emission intensities over Hyderabad	157
5.3.2 Geomagnetic storm effect on the GW scale sizes over the low-latitudes	162
5.4 Discussion	167
5.5 Conclusion	172
6 Daytime Three Dimensional Wave Characteristics Over Low-Latitudes	175
6.1 Introduction	175
6.2 Measurement Technique And Data Analysis	178
6.3 Results	179
6.4 Discussion	187
6.5 Conclusion	193
7 Summary and Future Scope	195
7.1 Summary of The Thesis Work	195
7.2 Future Scope of The Thesis Work	200

Bibliography	205
List of Publications	235
Publications Attached with Thesis	239

List of Figures

1.1	Classification of the Earth's atmosphere showing variations of neutral temperature, number densities of different atomic and molecular species along with electron density	3
1.2	Typical electron density profiles during the day and nighttime in solar maximum and minimum periods	7
1.3	Latitudinal variations of the geomagnetically quiet time model zonal and meridional winds as a function of the solar local time at 250 km altitude derived using HWM14	10
1.4	Schematic of the three types of atmospheric fundamental waves .	12
1.5	Air parcel displaced vertically upward with a displacement of δz from its equilibrium position	14
1.6	Air parcel displaced along an inclined plane with a displacement of δs from its equilibrium position	17
1.7	An illustration of wavefronts, wave vectors, phase velocity and phase propagation angle of a wave	18
1.8	Schematic of a vertical propagating GW depicting direction of phase propagation and energy flow	19
1.9	Schematic of mountain wave (lee wave), an internal GW that blow over a mountain range	20
1.10	Schematic of the diurnal temperature profile of the Earth's atmosphere	22
1.11	Schematic of the lunar gravitational tides	22
1.12	Solar cycle variation of sunspot number, F10.7 cm index, Mg II index and He 1083 index	25

1.13 Altitudinal variations of thermospheric and ionospheric parameters during high and low solar activity periods	25
1.14 Solar cycle variations of Total Electron Content (TEC), F-region critical frequency (f_0F_2) and sunspot number	26
1.15 Latitudinal distribution of the horizontal magnetic field strength .	28
1.16 Altitudinal distribution of the current density over geomagnetic equator	29
1.17 Schematic of the EIA	30
1.18 Latitudinal variations of the model values of IEC, N_{max} and N_e at different altitudes over Jicamarca and Trivandrum	31
1.19 Latitudinal distribution of N ₂ density at different longitudes depicting the EA	32
1.20 Schematic of reconnection between interplanetary magnetic field lines and Earth's magnetic field lines both in day and nightside .	35
1.21 Schematic of the combined field-aligned currents and ionospheric current system	37
1.22 Schematic presentation of the energy and mass transport during geomagnetic storm period	39
1.23 Schematic presentation of composition and the wind effects during geomagnetic storm	40
2.1 Oxygen atom energy level diagram	50
2.2 Green line volume emission rate profiles along with contributions of various production processes on two sample days	53
2.3 Sample green line volume emission rate profiles on four days . . .	54
2.4 Vertical profile of 630.0 nm dayglow emission	56
2.5 Sample 630.0 nm dayglow volume emission rate profiles on two days	56
2.6 Schematic of MISE	58
2.7 Chromatic aberration of light and its correction by apochromat .	60
2.8 Geometry of the echelle grating depicting the groove spacing, grating normal, facet normal, angle of incidence and diffraction, blaze angle and lateral angle	61

2.9	Sample image obtained from MISE	63
2.10	Schematic of viewing geometry of MISE	64
2.11	Method of extraction of dayglow emission intensities at 630.0 nm wavelength	65
2.12	Method of extracting dayglow emission intensities at 557.7 nm wavelength	67
2.13	Method of extracting dayglow emission intensities at 777.4 nm wavelength	68
2.14	Installation of hood and MISE supported to the roof during it's operation	69
2.15	Variation of D_{st} index during various types of storms	73
2.16	Spectral analysis of evenly, unevenly and re-binned spaced thermospheric neutral temperature data obtained from the NRLMSISE-00 model carried out by various methods	77
2.17	Fourier transform of signals with uniform and discrete distribution of periodicities in time	84
2.18	Box presentation of uncertainty in time-frequency resolution in STFT	85
2.19	Box presentation of the uncertainty in time-frequency resolution in FT, STFT and WT	87
2.20	Wavelet transform of the signals with uniform and discrete distribution of periodicities as shown in Figures 2.17a,c	89
2.21	Wavelet transform of both evenly and unevenly spaced thermospheric neutral temperature data as shown in Figure 2.16	89
2.22	Sample periodogram and wave number spectral analysis of the 630.0 nm dayglow emission intensities	91
2.23	Wavelet transform of the 630.0 nm dayglow emission intensities as shown in Figure 2.22a	92
3.1	Location of stations are shown from where data have been obtained	98
3.2	Samples of the diurnal behavior of OI 630.0 nm dayglow emission intensities	99

3.3	Diurnal behavior of the dayglow emission intensities at 777.4, 630.0, and 557.7 nm wavelength on some days	101
3.4	Diurnal variations of OI 777.4, 630.0, and 557.7 nm dayglow emissions, neutral winds and EEJ strength on two selected days	105
3.5	Variations of model neutral winds, asymmetry in time (AT), and EEJ strength on several days	107
3.6	Variations of $h_m F_2$ and IEC on the days with symmetric and asymmetric diurnal behavior	109
3.7	Diurnal variations of the dayglow as reproduced from Figure No 2 of <i>Pallamraju and Chakrabarti [2006]</i>	111
3.8	Diurnal variations of the dayglow as reproduced from Figure No 1 of <i>Laskar et al. [2015]</i>	112
3.9	Sample figures obtained from the literature to calculate the AT values	114
3.10	Sample figures obtained from the literature to calculate AT values	115
3.11	Solar cycle variation of the AT values and sunspot number	116
4.1	Magnetic field intensity (F) map obtained from world magnetic model	122
4.2	Magnetic main field inclination (I) map obtained from world magnetic model	123
4.3	Global wave number 4 longitudinal structure	124
4.4	Schematic of the viewing direction of MISE showing the regions of interest in West, Zenith, and East directions	127
4.5	Periodogram analyses in all the three dayglow emission intensities carried out over west, zenith, and East directions	130
4.6	Wavelet analyses of the dayglow emission intensities at all the three wavelengths obtained along the west, zenith, and east directions on 30 December 2013.	132
4.7	Wavelet analyses of the dayglow emission intensities at all the three wavelengths obtained along the east, zenith, and west directions on 6 February 2014	133

4.8	Zenith diurnal behaviors of the dayglow emission intensities at all the three wavelengths on the four days considered for the periodogram analyses in Figure ?? is shown.	134
4.9	Sample of the wave number spectral analyses of the dayglow emission intensity at 7.8 LT on 10 May 2015 are shown	139
4.10	Diurnal distribution of the significant zonal scale sizes on the days with symmetric/asymmetric diurnal behavior in the dayglow emission intensities	140
4.11	Contours of the normalized relative dayglow emission intensity variations on four sample days	145
5.1	Variations of the D_{st} and Ap indices during four geomagnetic events	156
5.2	Variations of the daily mean of the D_{st} index, monthly normalized daily mean dayglow emission intensity in the three wavelengths, normalized daily mean dayglow emission intensity during the four events in the three wavelengths, daily averaged O/N_2 and peak EEJ and IEC are shown for different events	158
5.3	Local time distribution of the zonal scale sizes on 18 February 2014 and 19 February 2014	163
5.4	Local time distribution of the zonal scale sizes on 6 and 7 March 2016	165
5.5	Local time distribution of the zonal scale sizes on 10 and 12 May 2015	166
6.1	Wavenumber spectral analysis showing λ_x , λ_y , τ , λ_H , and θ_H . . .	179
6.2	Keograms of normalized relative dayglow emission intensity variations at 777.4 nm wavelengths on 19 May 2015	182
6.3	Keograms of normalized relative dayglow emission intensity variations at 630.0 nm wavelengths on 19 May 2015	183
6.4	Keograms of normalized relative dayglow emission intensity variations at 557.7 nm wavelengths on 19 May 2015	184

6.5 Keograms of normalized relative dayglow emission intensity variations at 557.7, 630.0 and 777.4 nm wavelengths on 19 May 2015	185
6.6 Characteristics of the 3-Dimensional wave on 19 May 2015 is shown	186
6.7 Neutral temperature, scale height and BV time period on 19 May 2015	188
7.1 Schematic presentation of the result discussed in Chapter-3 of the thesis	197
7.2 Schematic presentation of the result discussed in Chapters-3 and 4 of the thesis	198
7.3 Schematic presentation of the result discussed in Chapters-3, 4, and 5 of the thesis	199
7.4 Schematic presentation of the result discussed in Chapters-3, 4, 5, and 6 of the thesis	200

List of Tables

1.1	Categorization of atmospheric waves according to time periods and scale sizes	13
2.1	Characteristics of MISE. Specifications of each optical components are given. After <i>Pallamraju et al.</i> [2013].	59
4.1	Summary of the GW characteristics (similarity in time periods and zonal scale sizes) on the days with a similar type of diurnal behavior (either symmetric or asymmetric) in all the three dayglow emission intensities.	137
6.1	Summary of the 3-D Daytime Thermospheric GW Characteristics Obtained for 19 May 2015.	190

Bibliography

- Abdu, M. A., J. A. Bittencourt, and I. S. Batista (1981), Magnetic declination control of the equatorial F region dynamo electric field development and spread F, *J. Geophys. Res.*, 86(A13), 11,443–11,446, doi:10.1029/JA086iA13p11443.
- Abdu, M. A., J. H. A. Sobral, E. R. de Paula, and I. S. Batista (1991), Magnetospheric disturbance effects on the equatorial ionization anomaly (EIA) : An overview, *J. Atmos. Terr. Phys.*, 53(8), 757 – 771, doi:[https://doi.org/10.1016/0021-9169\(91\)90126-R](https://doi.org/10.1016/0021-9169(91)90126-R).
- Abdu, M. A., M. Takashi, I. S. Batista, S. Saito, and M. Nakamura (2007), Ionospheric responses to the october 2003 superstorm: Longitude/local time effects over equatorial low and middle latitudes, *J. Geophys. Res.*, 112(A10), doi:10.1029/2006JA012228.
- Anandaraao, B. G. (1976), Effects of gravity wave winds and wind shears on equatorial electrojet, *Geophys. Res. Lett.*, 3(9), 545–548, doi:10.1029/GL003i009p00545.
- Anandaraao, B. G., and R. Raghavarao (1987), Structural changes in the currents and fields of the equatorial electrojet due to zonal and meridional winds, *J. Geophys. Res.*, 92(A3), 2514–2526, doi:10.1029/ja092ia03p02514.
- Anderson, D. N. (1973), A theoretical study of the ionospheric F region equatorial anomaly—I. Theory, *Planet. Space Sci.*, 21(3), 409–419, doi:10.1016/0032-0633(73)90040-8.
- Andrews, D. G. (2010), *An Introduction to Atmospheric Physics*, Cambridge University Press.
- Appleton, E. V. (1946), Two anomalies in the ionosphere, *Nature*, 157(3995), 691–691, doi:10.1038/157691a0.
- Appleton, E. V., and L. J. Ingram (1935), Magnetic storms and upper atmospheric ionization, *Nature*, 136, 548–549.

- Bagiya, M. S., K. N. Iyer, H. P. Joshi, S. V. Thampi, T. Tsugawa, S. Ravindran, R. Sridharan, and B. M. Pathan (2011), Low-latitude ionospheric-thermospheric response to storm time electrodynamical coupling between high and low latitudes, *J. Geophys. Res.*, 116(A1), doi:10.1029/2010JA015845.
- Balan, N., G. J. Bailey, R. J. Moffett, Y. Z. Su, and J. E. Titheridge (1995), Modelling studies of the conjugate-hemisphere differences in ionospheric ionization at equatorial anomaly latitudes, *J. Atmos. Terr. Phys.*, 57(3), 279 – 292, doi:[https://doi.org/10.1016/0021-9169\(94\)E0019-J](https://doi.org/10.1016/0021-9169(94)E0019-J).
- Balan, N., G. J. Bailey, M. A. Abdu, K. I. Oyama, P. G. Richards, J. MacDougall, and I. S. Batista (1997), Equatorial plasma fountain and its effects over three locations: Evidence for an additional layer, the F3 layer, *J. Geophys. Res.*, 102(A2), 2047–2056, doi:10.1029/95JA02639.
- Barmore, F. E. (1977), High resolution observations of the 6300 Å oxygen line in the day airglow, *Planet. Space Sci.*, 25(2), 185–191, doi:10.1016/0032-0633(77)90023-X.
- Barth, C. A. (1964), Three-body reactions, *Ann. de Geophys.*, 20, 182.
- Barth, C. A., and A. F. Hildebrandt (1961), The 5577 Å airglow emission mechanism, *J. Geophys. Res.*, 66(3), 985–986, doi:10.1029/JZ066i003p00985.
- Basu, S., S. Basu, K. M. Groves, H. C. Yeh, S. Y. Su, F. J. Rich, P. J. Sultan, and M. J. Keskinen (2001a), Response of the equatorial ionosphere in the south atlantic region to the great magnetic storm of July 15, 2000, *Geophys. Res. Lett.*, 28(18), 3577–3580, doi:10.1029/2001GL013259.
- Basu, S., et al. (2001b), Ionospheric effects of major magnetic storms during the international space weather period of September and October 1999: Gps observations, VHF/UHF scintillations, and in situ density structures at middle and equatorial latitudes, *J. Geophys. Res.*, 106(A12), 30,389–30,413, doi:10.1029/2001JA001116.
- Beer, T. (1974), *Atmospheric Waves*, Wiley.

- Bens, A. R., L. L. Cogger, and G. G. Shepherd (1965), Upper atmospheric temperatures from Doppler line widths-III: Observation of the OI dayglow emission at 6300 Å, *Planet. Space Sci.*, 13(6), 551–563, doi:10.1016/0032-0633(65)90168-6.
- Biondi, M. A., and D. P. Sipler (1985), Horizontal and vertical winds and temperatures in the equatorial thermosphere: Measurements from Natal, Brazil during August-September, *Planet. Space Sci.*, 33, 817–823.
- Blanc, M., and A. D. Richmond (1980), The ionospheric disturbance dynamo, *J. Geophys. Res.*, 85(A4), 1669–1686, doi:10.1029/JA085iA04p01669.
- Burnside, R. G., and C. A. Tepley (1989), Optical observations of thermospheric neutral winds at Arecibo between 1980 and 1987, *J. Geophys. Res.*, 94(A3), 2711–2716, doi:10.1029/JA094iA03p02711.
- Chakrabarti, S., D. Pallamraju, and J. Baumgardner (2001), HiTIES: A High Throughput Imaging Echelle Spectrograph for ground-based visible airglow and auroral studies, *J. Geophys. Res.*, 106(A12), 30,337–30,348.
- Chakrabarty, D., R. Sekar, H. Chandra, R. Narayanan, B. M. Pathan, and K. S. V. Subbarao (2002), Characterizations of the diurnal shapes of OI 630.0 nm dayglow intensity variations: inferences, *Ann. Geophys.*, 20(11), 1851–1855, doi:10.5194/angeo-20-1851-2002.
- Chakrabarty, D., R. Sekar, R. Narayanan, C. V. Devasia, and B. M. Pathan (2005), Evidence for the interplanetary electric field effect on the OI 630.0 nm airglow over low latitude, *J. Geophys. Res.*, 110(A11), doi:10.1029/2005JA011221.
- Chakrabarty, D., R. Sekar, J. H. Sastri, B. M. Pathan, G. D. Reeves, K. Yumoto, and T. Kikuchi (2010), Evidence for OI 630.0 nm dayglow variations over low latitudes during onset of a substorm, *J. Geophys. Res.*, 115(A10), doi:10.1029/2010JA015643.
- Chakrabarty, D., D. Rout, R. Sekar, R. Narayanan, G. D. Reeves, T. K. Pant, B. Veenadhari, and K. Shiokawa (2015), Three different types of elec-

- tric field disturbances affecting equatorial ionosphere during a long-duration prompt penetration event, *J. Geophys. Res.*, *120*(6), 4993–5008, doi:10.1002/2014JA020759.
- Chamberlain, J. W. (1961), *Physics of the Aurora and Airglow*, 704 pp., Academic Press.
- Chapman, S. (1931), Bakerian lecture. Some phenomena of the upper atmosphere, *Proc. R. Soc. London. Ser. A*, *132*(820), 353–374, doi:10.1098/rspa.1931.0105.
- Chimonas, G., and C. O. Hines (1971), Atmospheric gravity waves induced by a solar eclipse, 2, *J. Geophys. Res.*, *76*(28), 7003–7005, doi:10.1029/JA076i028p07003.
- Christensen, A. B., et al. (2003), Initial observations with the Global Ultraviolet Imager (GUVI) in the NASA TIMED satellite mission, *J. Geophys. Res.*, *108*(A12), doi:10.1029/2003JA009918.
- Cocks, T. D., D. F. Creighton, and F. Jacka (1980), Application of a dual fabry-perot spectrometer for daytime airglow studies, *J. Atmos. Terr. Phys.*, *42*(5), 499 – 511, doi:10.1016/0021-9169(80)90010-0.
- Culot, F., C. Lathuillère, J. Lilensten, and O. Witasse (2004), The OI 630.0 and 557.7nm dayglow measured by WINDII and modeled by TRANSCAR, *Ann. Geophys.*, *22*(6), 1947–1960, doi:10.5194/angeo-22-1947-2004.
- Culot, F., C. Lathuillre, and J. Lilensten (2005), Influence of geomagnetic activity on the o i 630.0 and 557.7 nm dayglow, *J. Geophys. Res.*, *110*(A1), doi:10.1029/2004JA010667, a01304.
- Dabas, R. S., D. R. Lakshmi, and B. M. Reddy (1989), Effect of geomagnetic disturbances on the VHF nighttime scintillation activity at equatorial and low latitudes, *Radio Science*, *24*(4), 563–573, doi:10.1029/RS024i004p00563.
- Das, U., D. Pallamraju, and S. Chakrabarti (2010), Effect of an X-Class solar flare on the OI 630 nm dayglow emissions, *J. Geophys. Res.*, *115*(A8), doi:10.1029/2010JA015370.

- Daubechies, I. (1988), Orthonormal bases of compactly supported wavelets, *Commun. Pure Appl. Math.*, *41*(7), 909–996, doi:10.1002/cpa.3160410705.
- Deeming, T. J. (1975), Fourier analysis with unequally-spaced data, *Astrophys. Space Sci.*, *36*(137D), 137–158, doi:10.1007/BF00681947.
- Dougherty, J. P., and D. T. Farley (1963), A theory of incoherent scattering of radio waves by a plasma: 3. Scattering in a partly ionized gas, *J. Geophys. Res.*, *68*(19), 5473–5486, doi:10.1029/JZ068i019p05473.
- Drob, D. P., et al. (2008), An empirical model of the Earth's horizontal wind fields: HWM07, *J. Geophys. Res.*, *113*(A12), doi:10.1029/2008JA013668.
- Drob, D. P., et al. (2015), An update to the Horizontal Wind Model (HWM): The quiet time thermosphere, *Earth and Space Science*, *2*(7), 301–319, doi:10.1002/2014EA000089.
- Emmert, J. T., D. P. Drob, G. G. Shepherd, G. Hernandez, M. J. Jarvis, J. W. Meriwether, R. J. Niciejewski, D. P. Sipler, and C. A. Tepley (2008), DWM07 global empirical model of upper thermospheric storm-induced disturbance winds, *J. Geophys. Res.*, *113*(A11), doi:10.1029/2008JA013541.
- England, S. L., S. Maus, T. J. Immel, and S. B. Mende (2006), Longitudinal variation of the E-region electric fields caused by atmospheric tides, *Geophys. Res. Lett.*, *33*(21), doi:10.1029/2006GL027465.
- Farley, D. T. (1969), Faraday rotation measurements using incoherent scatter, *Radio Science*, *4*(2), 143–152, doi:10.1029/RS004i002p00143.
- Fejer, B. G., and L. Scherliess (1995), Time dependent response of equatorial ionospheric electric fields to magnetospheric disturbances, *Geophys. Res. Lett.*, *22*(7), 851–854, doi:10.1029/95GL00390.
- Fejer, B. G., and L. Scherliess (1997), Empirical models of storm time equatorial zonal electric fields, *J. Geophys. Res.*, *102*(A11), 24,047–24,056, doi:10.1029/97JA02164.

Fejer, B. G., C. A. Gonzales, D. T. Farley, M. C. Kelley, and R. F. Woodman (1979), Equatorial electric fields during magnetically disturbed conditions 1. The effect of the interplanetary magnetic field, *J. Geophys. Res.*, 84(A10), 5797–5802, doi:10.1029/JA084iA10p05797.

Floyd, L., J. Newmark, J. Cook, L. Herring, and D. McMullin (2005), Solar EUV and UV spectral irradiances and solar indices, *J. Atmos. Sol. Terr. Phys.*, 67(1-2), 3–15, doi:10.1016/j.jastp.2004.07.013.

Forbes, J. M. (1981), The equatorial electrojet, *Rev. Geophys.*, 19(3), 469–504, doi:10.1029/RG019i003p00469.

Forbes, J. M., R. G. Roble, and F. A. Marcos (1987), Thermospheric dynamics during the March 22, 1979, magnetic storm: 2. Comparisons of model predictions with observations, *J. Geophys. Res.*, 92(A6), 6069–6081, doi:10.1029/JA092iA06p06069.

Forbes, J. M., S. L. Bruinsma, Y. Miyoshi, and H. Fujiwara (2008), A solar terminator wave in thermosphere neutral densities measured by the CHAMP satellite, *Geophys. Res. Lett.*, 35(14), doi:10.1029/2008GL034075.

Frederick, J. E., D. W. Rusch, G. A. Victor, W. E. Sharp, P. B. Hays, and H. C. Brinton (1976), The O I (λ 5577 Å) airglow: Observations and excitation mechanisms, *J. Geophys. Res.*, 81(22), 3923–3930, doi:10.1029/JA081i022p03923.

Fritts, D. C., and M. J. Alexander (2003), Gravity wave dynamics and effects in the middle atmosphere, *Rev. Geophys.*, 41(1), doi:10.1029/2001RG000106.

Fujiwara, H., S. Maeda, H. Fukunishi, T. J. Fuller-Rowell, and D. S. Evans (1996), Global variations of thermospheric winds and temperatures caused by substorm energy injection, *J. Geophys. Res.*, 101(A1), 225–239, doi:10.1029/95JA01157.

Fuller-Rowell, T. J., M. V. Codrescu, R. J. Moffett, and S. Quegan (1994), Response of the thermosphere and ionosphere to geomagnetic storms, *J. Geophys. Res.*, 99(A3), 3893–3914, doi:10.1029/93JA02015.

- Geisler, J. (1967), A numerical study of the wind system in the middle thermosphere, *J. Atmos. Terr. Phys.*, 29(12), 1469 – 1482, doi:[http://dx.doi.org/10.1016/0021-9169\(67\)90100-6](http://dx.doi.org/10.1016/0021-9169(67)90100-6).
- Gerrard, A. J., and J. W. Meriwether (2011), Initial daytime and nighttime SOFDI observations of thermospheric winds from Fabry-Perot Doppler shift measurements of the 630-nm OI line-shape profile, *Ann. Geophys.*, 29(9), 1529–1536, doi:[10.5194/angeo-29-1529-2011](https://doi.org/10.5194/angeo-29-1529-2011).
- Gilman, D. L., F. J. Fuglister, and J. M. Mitchell (1963), On the Power Spectrum of “Red Noise”, *J. Atmos. Sci.*, 20(2), 182–184, doi:[10.1175/1520-0469\(1963\)020<0182:OTPSON>2.0.CO;2](https://doi.org/10.1175/1520-0469(1963)020<0182:OTPSON>2.0.CO;2).
- Gonzales, C. A., M. C. Kelley, B. G. Fejer, J. F. Vickrey, and R. F. Woodman (1979), Equatorial electric fields during magnetically disturbed conditions 2. Implications of simultaneous auroral and equatorial measurements, *J. Geophys. Res.*, 84(A10), 5803–5812, doi:[10.1029/JA084iA10p05803](https://doi.org/10.1029/JA084iA10p05803).
- Gouin, P., and P. N. Mayaud (1967), A propos de l'existence possible d'un contre-electrojet aux latitudes magnétiques équatoriales, *Ann. Geophys.*, 23, 41–47.
- Goupillaud, P., A. Grossmann, and J. Morlet (1984), Cycle-octave and related transforms in seismic signal analysis, *Geoexploration*, 23(1), 85–102, doi:[10.1016/0016-7142\(84\)90025-5](https://doi.org/10.1016/0016-7142(84)90025-5).
- Grainger, J. F., and J. Ring (1962), Anomalous Fraunhofer line profiles, *Nature*, 193, 762, doi:[10.1038/193762a0](https://doi.org/10.1038/193762a0).
- Greenhow, J. S. (1954), A radio echo method for the investigation of atmospheric winds at altitudes of 80-100 km, using radio echoes from meteor trails, *Philosophical Magazine*, 7(45), 471–490.
- Grossmann, A., and J. Morlet (1984), Decomposition of Hardy functions into square integrable wavelets of constant shape, *SIAM J. Math. Anal.*, 15(4), 723–736, doi:[10.1137/0515056](https://doi.org/10.1137/0515056).

- Gurubaran, S. (2002), The equatorial counter electrojet: Part of a worldwide current system?, *Geophys. Res. Lett.*, 29(9), 511–514, doi:10.1029/2001GL014519.
- Hagan, M. E., R. G. Roble, and J. Hackney (2001), Migrating thermospheric tides, *J. Geophys. Res.*, 106(A7), 12,739–12,752, doi:10.1029/2000JA000344.
- Hajkowicz, L. (1991), Global onset and propagation of large-scale travelling ionospheric disturbances as a result of the great storm of 13 march 1989, *Planet. Space Sci.*, 39(4), 583 – 593, doi:[http://dx.doi.org/10.1016/0032-0633\(91\)90053-D](http://dx.doi.org/10.1016/0032-0633(91)90053-D).
- Hargreaves, J. K. (1992), *The Solar-Terrestrial Environment*, Cambridge University Press.
- Harris, F. J. (1978), On the use of windows for harmonic analysis with the discrete fourier transform, *Proceedings of the IEEE*, 66, 51–83.
- Hays, P. B., G. Carignan, B. C. Kennedy, G. G. Shepherd, and J. C. G. Walker (1973), The visible-airglow experiment on Atmosphere Explorer, *Radio Science*, 8(4), 369–377, doi:10.1029/RS008i004p00369.
- Hays, P. B., D. W. Rusch, R. G. Roble, and J. C. G. Walker (1978), The O-I (6300 Å) airglow, *Rev. Geophys.*, 16(2), 225–232, doi:10.1029/RG016i002p00225.
- Hays, P. B., V. J. Abreu, M. E. Dobbs, D. A. Gell, H. J. Grassl, and W. R. Skinner (1993), The high-resolution doppler imager on the Upper Atmosphere Research Satellite, *J. Geophys. Res.*, 98(D6), 10,713–10,723, doi:10.1029/93JD00409.
- Hedin, A. E., and H. G. Mayr (1973), Magnetic control of the near equatorial neutral thermosphere, *J. Geophys. Res.*, 78(10), 1688–1691, doi:10.1029/JA078i010p01688.
- Hedin, A. E., P. Bauer, H. G. Mayr, G. R. Carignan, L. H. Brace, H. C. Brinton, A. D. Parks, and D. T. Pelz (1977), Observations of neutral composition and related ionospheric variations during a magnetic storm in February 1974, *J. Geophys. Res.*, 82(22), 3183–3189, doi:10.1029/JA082i022p03183.

- Hedin, A. E., N. W. Spencer, and T. L. Killeen (1988), Empirical global model of upper thermosphere winds based on Atmosphere and Dynamics Explorer satellite data, *J. Geophys. Res.*, *93*(A9), 9959–9978, doi:10.1029/JA093iA09p09959.
- Hedin, A. E., et al. (1996), Empirical wind model for the upper, middle and lower atmosphere, *J. Atmos. Terr. Phys.*, *58*(13), 1421 – 1447, doi:[http://dx.doi.org/10.1016/0021-9169\(95\)00122-0](http://dx.doi.org/10.1016/0021-9169(95)00122-0).
- Heelis, R. A., P. C. Kendall, R. J. Moffett, D. W. Windle, and H. Rishbeth (1974), Electrical coupling of the E- and F-regions and its effect on F-region drifts and winds, *Planet. Space Sci.*, *22*(5), 743–756, doi:10.1016/0032-0633(74)90144-5.
- Hernandez, G., and R. G. Roble (1976), Direct measurements of nighttime thermospheric winds and temperatures, 2. Geomagnetic storms, *J. Geophys. Res.*, *81*(28), 5173–5181, doi:10.1029/JA081i028p05173.
- Herrero, F., H. Mayr, and N. Spencer (1988), Low latitude thermospheric meridional winds between 250 and 450 km altitude: AE-E satellite data, *J. Atmos. Terr. Phys.*, *50*(10), 1001 – 1006, doi:[http://dx.doi.org/10.1016/0021-9169\(88\)90087-6](http://dx.doi.org/10.1016/0021-9169(88)90087-6).
- Hickey, D. A., C. R. Martinis, F. S. Rodrigues, R. H. Varney, M. A. Milla, M. J. Nicolls, A. Strmme, and J. F. Arratia (2015), Concurrent observations at the magnetic equator of small-scale irregularities and large-scale depletions associated with equatorial spread F, *J. Geophys. Res.*, *120*(12), 10,883–10,896, doi:10.1002/2015JA021991.
- Hines, C. O. (1960), Internal atmospheric gravity waves at ionospheric heights, *Can. J. Phys.*, *38*(11), 1441–1481, doi:10.1139/p60-150.
- Hines, C. O. (1974), *The upper atmosphere in motion: A selection of papers with annotation*, Geophys. Monogr.
- Hinteregger, H. E. (1976), EUV Fluxes in the solar spectrum below 2000 Å, *J. Atmos. Terr. Phys.*, *38*(8), 791 – 806, doi:[http://dx.doi.org/10.1016/0021-9169\(76\)90020-9](http://dx.doi.org/10.1016/0021-9169(76)90020-9).

- Hocke, K., and N. Kämpfer (2009), Gap filling and noise reduction of unevenly sampled data by means of the Lomb-Scargle periodogram, *Atmos. Chem. Phys.*, *9*(12), 4197–4206, doi:10.5194/acp-9-4197-2009.
- Hocke, K. K. S. (1996), A review of atmospheric gravity waves and travelling ionospheric disturbances: 1982–1995, *Ann. Geophys.*, *14*(9), 917–940, doi:10.1007/s00585-996-0917-6.
- Horne, J. H., and S. L. Baliunas (1986), A prescription for period analysis of unevenly sampled time series, *Astrophys. J.*, *302*, 757–763, doi:10.1086/164037.
- Hsu, V. W., J. P. Thayer, J. Lei, and W. Wang (2014), Formation of the equatorial thermosphere anomaly trough: Local time and solar cycle variations, *J. Geophys. Res.*, *119*(12), 10,456–10,473, doi:10.1002/2014JA020416, 2014JA020416.
- Huba, J. D., D. P. Drob, T.-W. Wu, and J. J. Makela (2015), Modeling the ionospheric impact of tsunami-driven gravity waves with SAMI3: Conjugate effects, *Geophys. Res. Lett.*, *42*(14), 5719–5726, doi:10.1002/2015GL064871.
- Hunsucker, R. D. (1982), Atmospheric gravity waves generated in the high-latitude ionosphere: A review, *Rev. Geophys.*, *20*(2), 293–315, doi:10.1029/RG020i002p00293.
- Immel, T. J., G. Crowley, J. D. Craven, and R. G. Roble (2001), Dayside enhancements of thermospheric O/N₂ following magnetic storm onset, *J. Geophys. Res.*, *106*(A8), 15,471–15,488, doi:10.1029/2000JA000096.
- Immel, T. J., S. B. Mende, H. U. Frey, N. stgaard, and G. R. Gladstone (2003), Effect of the 14 July 2000 solar flare on Earth’s FUV emissions, *J. Geophys. Res.*, *108*(A4), doi:10.1029/2001JA009060.
- Immel, T. J., E. Sagawa, S. L. England, S. B. Henderson, M. E. Hagan, S. B. Mende, H. U. Frey, C. M. Swenson, and L. J. Paxton (2006), Control of equatorial ionospheric morphology by atmospheric tides, *Geophys. Res. Lett.*, *33*(15), doi:10.1029/2006GL026161.

- Jarrett, A. H., and M. J. Hoey (1963), A ground-level photographic observation of the day airglow emission of atomic oxygen at 6300 Å, *Planet. Space Sci.*, *11*(10), 1251–1252, doi:10.1016/0032-0633(63)90256-3.
- Jones, A. V., and A. W. Harrison (1955), Rotational temperatures of the auroral N₂⁺ bands, *J. Atmos. Terr. Physics*, *6*(1), 336 – 343, doi:[https://doi.org/10.1016/0021-9169\(55\)90051-9](https://doi.org/10.1016/0021-9169(55)90051-9).
- Karan, D. K., and D. Pallamraju (2017), Small-scale longitudinal variations in the daytime equatorial thermospheric wave dynamics as inferred from oxygen dayglow emissions, *J. Geophys. Res.*, pp. 6528–6542, doi:10.1002/2017JA023891.
- Karan, D. K., D. Pallamraju, K. A. Phadke, T. Vijayalakshmi, T. K. Pant, and S. Mukherjee (2016), Electrodynamic influence on the diurnal behaviour of neutral daytime airglow emissions, *Ann. Geophys.*, *34*(11), 1019–1030, doi:10.5194/angeo-34-1019-2016.
- Kelley, M. C. (2009), *The Earth's Ionosphere: Plasma Physics and Electrodynamics*, vol. 96, Academic press.
- Kelley, M. C., and J. J. Makela (2002), By-dependent prompt penetrating electric fields at the magnetic equator, *Geophys. Res. Lett.*, *29*(7), 571–573, doi:10.1029/2001GL014468.
- Kikuchi, T., K. K. Hashimoto, and K. Nozaki (2008), Penetration of magnetospheric electric fields to the equator during a geomagnetic storm, *J. Geophys. Res.*, *113*(A6), doi:10.1029/2007JA012628.
- Killeen, T. L., Q. Wu, S. C. Solomon, D. A. Ortland, W. R. Skinner, R. J. Niciejewski, and D. A. Gell (2006), TIMED Doppler Interferometer: Overview and recent results, *J. Geophys. Res.*, *111*(A10), doi:10.1029/2005JA011484.
- Kivelson, M. G., and C. T. Russell (1995), *Introduction to Space Physics*, Cambridge University Press.

Kohl, H., and J. W. King (1967), Atmospheric winds between 100 and 700 km and their effects on the ionosphere, *J. Atmos. Terr. Phys.*, *29*(9), 1045–1062, doi:10.1016/0021-9169(67)90139-0.

Kovács, G. (1981), Frequency shift in fourier analysis, *Astrophys. Space Sci.*, *78*(1), 175–188, doi:10.1007/BF00654032.

Kulkarni, P. V. (1976), Rocket study of 5577Å OI emission at night over the magnetic equator, *J. Geophys. Res.*, *81*(22), 3740–3744, doi:10.1029/JA081i022p03740.

Lakshmi Narayanan, V., S. Gurubaran, and K. Emperumal (2010), Airglow imaging observations of small-scale structures driven by convective instability in the upper mesosphere over Tirunelveli (8.7° N), *J. Geophys. Res.*, *115*(D19), doi:10.1029/2009JD012937.

Laskar, F. I. (2015), Effect of lower atmospheric and solar forcings on daytime upper atmospheric dynamics, Ph.D. thesis, Indian Institute of Technology, Gandhinagar.

Laskar, F. I., and D. Pallamraju (2014), Does sudden stratospheric warming induce meridional circulation in the mesosphere thermosphere system?, *J. Geophys. Res.*, *119*(12), 10,133–10,143, doi:10.1002/2014JA020086.

Laskar, F. I., D. Pallamraju, T. V. Lakshmi, M. A. Reddy, B. M. Pathan, and S. Chakrabarti (2013), Investigations on vertical coupling of atmospheric regions using combined multiwavelength optical dayglow, magnetic, and radio measurements, *J. Geophys. Res.*, *118*(7), 4618–4627, doi:10.1002/jgra.50426.

Laskar, F. I., D. Pallamraju, and B. Veenadhari (2014), Vertical coupling of atmospheres: dependence on strength of sudden stratospheric warming and solar activity, *Earth, Planets and Space*, *66*(1), 94, doi:10.1186/1880-5981-66-94.

Laskar, F. I., D. Pallamraju, B. Veenadhari, T. V. Lakshmi, M. A. Reddy, and S. Chakrabarti (2015), Gravity waves in the thermosphere: Solar activity de-

- pendence, *Adv. Space Res.*, 55(6), 1651 – 1659, doi:<https://doi.org/10.1016/j.asr.2014.12.040>.
- Lau, K. M., and H. Y. Weng (1995), Climate signal detection using wavelet transform: How to make a time series sing, *Amer. Meteor. Soc.*, 76, 2391–2402.
- Le, G., J. A. Slavin, and R. J. Strangeway (2010), Space technology 5 observations of the imbalance of regions 1 and 2 field-aligned currents and its implication to the cross-polar cap pedersen currents, *J. Geophys. Res.*, 115(A7), doi:10.1029/2009JA014979.
- Lean, J. (1997), The Sun's variable radiation and its relevance for Earth, *Annu. Rev. Astron. Astrophys.*, 35(1), 33–67, doi:10.1146/annurev.astro.35.1.33.
- Lei, J., J. P. Thayer, W. Wang, A. D. Richmond, R. Roble, X. Luan, X. Dou, X. Xue, and T. Li (2012), Simulations of the equatorial thermosphere anomaly: Field-aligned ion drag effect, *J. Geophys. Res.*, 117(A1), n/a–n/a, doi:10.1029/2011JA017114, a01304.
- Lindzen, R. S. (1990), *Dynamics in atmospheric physics*, Cambridge University Press.
- Liu, H., H. Lhr, S. Watanabe, W. Khler, and C. Manoj (2007), Contrasting behavior of the thermosphere and ionosphere in response to the 28 october 2003 solar flare, *J. Geophys. Res.*, 112(A7), doi:10.1029/2007JA012313.
- Lomb, N. R. (1976), Least-squares frequency analysis of unequally spaced data, *Astrophys. Space Sci.*, 39(2), 447–462, doi:10.1007/BF00648343.
- Maharaj-Sharma, R., and G. G. Shepherd (2004), Solar variability of the day-time atomic oxygen O(1S) emission in the middle and lower thermosphere, *J. Geophys. Res.*, 109(A3), doi:10.1029/2003JA010183.
- Makela, J. J., and Y. Otsuka (2011), Overview of nighttime ionospheric instabilities at low- and mid-latitudes: Coupling aspects resulting in structuring at the mesoscale, *Space. Sci. Rev.*, 168(1-4), 419–440, doi:10.1007/s11214-011-9816-6.

Makela, J. J., et al. (2011a), Imaging and modeling the ionospheric airglow response over hawaii to the tsunami generated by the tohoku earthquake of 11 march 2011, *Geophys. Res. Lett.*, 38(24), doi:10.1029/2011GL047860.

Makela, J. J., J. W. Meriwether, Y. Huang, and P. J. Sherwood (2011b), Simulation and analysis of a multi-order imaging Fabry–Perot interferometer for the study of thermospheric winds and temperatures, *Appl. Opt.*, 50(22), 4403–4416, doi:10.1364/ao.50.004403.

Makela, J. J., D. J. Fisher, J. W. Meriwether, R. A. Buriti, and A. F. Medeiros (2013), Near-continual ground-based nighttime observations of thermospheric neutral winds and temperatures over equatorial Brazil from 2009 to 2012, *J. Atmos. Sol. Terr. Phys.*, 103, 94 – 102, doi:<https://doi.org/10.1016/j.jastp.2012.11.019>.

Mallat, S. G. (1989), A theory for multiresolution signal decomposition: the wavelet representation, *IEEE Trans. Pattern Anal. Mach. Intell.*, 11(7), 674–693, doi:10.1109/34.192463.

Marshall, R. A., S. Smith, J. Baumgardner, and S. Chakrabarti (2011), Continuous ground-based multiwavelength airglow measurements, *J. Geophys. Res.*, 116(A11), doi:10.1029/2011JA016901.

Martinis, C., J. Baumgardner, M. Mendillo, J. Wroten, A. Coster, and L. Paxton (2015), The night when the auroral and equatorial ionospheres converged, *J. Geophys. Res.*, 120(9), 8085–8095, doi:10.1002/2015JA021555.

Maruyama, N., A. D. Richmond, T. J. Fuller-Rowell, M. V. Codrescu, S. Sazykin, F. R. Toffoletto, R. W. Spiro, and G. H. Millward (2005), Interaction between direct penetration and disturbance dynamo electric fields in the storm-time equatorial ionosphere, *Geophys. Res. Lett.*, 32(17), doi:10.1029/2005GL023763.

Maruyama, T., G. Ma, and M. Nakamura (2004), Signature of TEC storm on 6 November 2001 derived from dense GPS receiver network and ionosonde chain over Japan, *J. Geophys. Res.*, 109(A10), doi:10.1029/2004JA010451.

- Mayr, H. G., and H. Volland (1973), Magnetic storm characteristics of the thermosphere, *J. Geophys. Res.*, *78*(13), 2251–2264, doi:10.1029/JA078i013p02251.
- Mayr, H. G., I. Harris, and N. W. Spencer (1978), Some properties of upper atmosphere dynamics, *Rev. Geophys.*, *16*(4), 539–565, doi:10.1029/RG016i004p00539.
- Mendillo, M., and J. Baumgardner (1982), Airglow characteristics of equatorial plasma depletions, *J. Geophys. Res.*, *87*(A9), 7641, doi:10.1029/JA087iA09p07641.
- Mendillo, M., J. Baumgardner, D. Nottingham, J. Aarons, B. Reinisch, J. Scali, and M. Kelley (1997), Investigations of thermospheric-ionospheric dynamics with 6300Å images from the arecibo observatory, *J. Geophys. Res.*, *102*(A4), 7331–7343, doi:10.1029/96JA02786.
- Meriwether, J. (2006), Studies of thermospheric dynamics with a Fabry–Perot interferometer network: A review, *68*(13), 1576–1589, doi:10.1016/j.jastp.2005.11.014.
- Meriwether, J. W., P. Shih, T. L. Killeen, V. B. Wickwar, and R. G. Roble (1984), Nighttime thermospheric winds over Sondre Stromfjord, Greenland, *Geophys. Res. Lett.*, *11*(9), 931–934, doi:10.1029/GL011i009p00931.
- Meriwether, J. W., J. W. Moody, M. A. Biondi, and R. G. Roble (1986), Optical interferometric measurements of nighttime equatorial thermospheric winds at Arequipa, Peru, *J. Geophys. Res.*, *91*(A5), 5557–5566, doi:10.1029/JA091iA05p05557.
- Meriwether, J. W., J. J. Makela, Y. Huang, D. J. Fisher, R. A. Buriti, A. F. Medeiros, and H. Takahashi (2011), Climatology of the nighttime equatorial thermospheric winds and temperatures over Brazil near solar minimum, *J. Geophys. Res.*, *116*(A4), doi:10.1029/2011JA016477.
- Moffett, R. J. (1979), The Equatorial Anomaly in the electron distribution of the terrestrial F-region, *Fundam. Cosm. Phys.*, *4*, 313–391.

Morlet, J., G. Arens, E. Fourgeau, and D. Glard (1982), Wave propagation and sampling theoryPart I: Complex signal and scattering in multilayered media, *Geophysics*, 47(2), 203–221, doi:10.1190/1.1441328.

Nakamura, T., T. Tsuda, H. Miyagawa, Y. Matsushita, H. Fukunishi, Y. Takahashi, and Y. Yamada (1998), Propagation directions of gravity wave patterns observed in OH CCD images during the SEEK Campaign, *Geophys. Res. Lett.*, 25(11), 1793–1796, doi:10.1029/98GL01064.

Narayanan, R., J. N. Desai, N. K. Modi, R. Raghavarao, and R. Sridharan (1989), Dayglow photometry: a new approach, *Appl. Opt.*, 28, 2138–2142, doi:10.1364/AO.28.002138.

Nishida, A. (1968a), Geomagnetic DP 2 fluctuations and associated magnetospheric phenomena, *J. Geophys. Res.*, 73(5), 1795–1803, doi:10.1029/JA073i005p01795.

Nishida, A. (1968b), Coherence of geomagnetic DP 2 fluctuations with interplanetary magnetic variations, *J. Geophys. Res.*, 73(17), 5549–5559, doi:10.1029/JA073i017p05549.

Noxon, J. F. (1968), Day airglow, *Sp. Sci. Rev.*, 8(1), 92–134, doi:10.1007/BF00362572.

Noxon, J. F., and R. M. Goody (1962), Observation of day airglow emission, *J. Atmos. Sci.*, 19(4), 342–343, doi:10.1175/1520-0469(1962)019<0342:OODAE>2.0.CO;2.

Onwumechilli, A. (1967), Geomagnetic variations in the equatorial zone, in *Phys. of Geomagnetic Phenomena*, p. 426.

Owens, R. J., Mathew J.and Forsyth (2013), The heliospheric magnetic field, *Living Reviews in Solar Physics*, 10(1), 5, doi:10.12942/lrsp-2013-5.

Pallam Raju, D., R. Sridharan, R. Narayanan, N. K. Modi, R. Raghavarao, and B. H. Subbaraya (1995), Ground-based optical observations of daytime

- auroral emissions from Antarctica, *J. Atmos. Terr. Phys.*, 57(13), 1591–1597, doi:10.1016/0021-9169(95)00089-K.
- Pallam Raju, D., R. Sridharan, S. Gurubaran, and R. Raghavarao (1996), First results from ground-based daytime optical investigation of the development of the equatorial ionization anomaly, *Ann. Geophys.*, 14(2), 238–245, doi:10.1007/s00585-996-0238-9.
- Pallamraju, D. (1996), Studies of daytime upper atmospheric phenomena using ground-based optical techniques, Ph.D. thesis, Devi Ahilya Vishwa Vidyalaya of Indore.
- Pallamraju, D., and S. Chakrabarti (2005), First ground-based measurements of OI 6300 nm daytime aurora over Boston in response to the 30 October 2003 geomagnetic storm, *Geophys. Res. Lett.*, 32(3), doi:10.1029/2004GL021417.
- Pallamraju, D., and S. Chakrabarti (2006), Contributions of imaging Echelle spectrographs to daytime optical aeronomy, *J. Atmos. Sol. Terr. Phys.*, 68(13), 1459 – 1471, doi:10.1016/j.jastp.2005.05.013.
- Pallamraju, D., and R. Sridharan (1998a), High resolution 2-D maps of OI 630.0 nm thermospheric dayglow from equatorial latitudes, *Ann. Geophys.*, 16(8), 997–1006, doi:10.1007/s00585-998-0997-6.
- Pallamraju, D., and R. Sridharan (1998b), Ground-based optical measurements of daytime auroral emissions: A new means of investigating space-weather related processes, *Proceedings of the Indian Academy of Sciences - Earth and Planetary Sciences*, 107(3), 203–211, doi:10.1007/BF02840480.
- Pallamraju, D., J. Baumgardner, and S. Chakrabarti (2000), A multiwavelength investigation of the ring effect in the day sky spectrum, *Geophys. Res. Lett.*, 27(13), 1875–1878, doi:10.1029/1999gl010961.
- Pallamraju, D., J. Baumgardner, S. Chakrabarti, and T. R. Pedersen (2001), Simultaneous ground based observations of an auroral arc in day-

- time/twilighttime OI 630.0 nm emission and by incoherent scatter radar, *J. Geophys. Res.*, *106*(A4), 5543–5549, doi:10.1029/2000JA000244.
- Pallamraju, D., J. Baumgardner, and S. Chakrabarti (2002), HIRISE: A ground-based high-resolution imaging spectrograph using echelle grating for measuring daytime airglow/auroral emissions, *J. Atmos. Sol. Terr. Phys.*, *64*(12-14), 1581–1587, doi:10.1016/S1364-6826(02)00095-0.
- Pallamraju, D., S. Chakrabarti, R. Doe, and T. Pedersen (2004a), First ground-based oi 630 nm optical measurements of daytime cusplike and f-region auroral precipitation, *Geophys. Res. Lett.*, *31*(8), doi:10.1029/2003GL019173.
- Pallamraju, D., S. Chakrabarti, and C. E. Valladares (2004b), Magnetic storm-induced enhancement in neutral composition at low latitudes as inferred by O(¹D) dayglow measurements from Chile, *Ann. Geophys.*, *22*(9), 3241–3250, doi:10.5194/angeo-22-3241-2004.
- Pallamraju, D., U. Das, and S. Chakrabarti (2010), Short- and long-timescale thermospheric variability as observed from OI 630.0 nm dayglow emissions from low latitudes, *J. Geophys. Res.*, *115*(A6), doi:10.1029/2009JA015042.
- Pallamraju, D., S. Chakrabarti, and S. C. Solomon (2011), On deriving incident auroral particle fluxes in the daytime using combined ground-based optical and radar measurements, *J. Geophys. Res.*, *116*(A4), doi:10.1029/2010JA015934.
- Pallamraju, D., F. I. Laskar, R. P. Singh, J. Baumgardner, and S. Chakrabarti (2013), MISE: A multiwavelength imaging spectrograph using echelle grating for daytime optical aeronomy investigations , *J. Atmos. Sol. Terr. Phys.*, *103*(0), 176 – 183, doi:10.1016/j.jastp.2012.12.003.
- Pallamraju, D., et al. (2014), Daytime wave characteristics in the mesosphere lower thermosphere region: Results from the Balloon-borne Investigations of Regional-atmospheric Dynamics experiment, *J. Geophys. Res.*, *119*(3), 2229–2242, doi:10.1002/2013JA019368.

- Pallamraju, D., D. K. Karan, and K. A. Phadke (2016), First three dimensional wave characteristics in the daytime upper atmosphere derived from ground-based multiwavelength oxygen dayglow emission measurements, *Geophys. Res. Lett.*, 43(11), 5545–5553, doi:10.1002/2016GL069074.
- Pandey, K., R. Sekar, B. Anandarao, S. Gupta, and D. Chakrabarty (2016), Estimation of nighttime dip-equatorial E-region current density using measurements and models, *J. Atmos. Sol. Terr. Phys.*, 146, 160–170, doi:<https://doi.org/10.1016/j.jastp.2016.06.002>.
- Pant, T. K., and R. Sridharan (1998), A case-study of the low-latitude thermosphere during geomagnetic storms and its new representation by improved MSIS model, *Ann. Geophys.*, 16(11), 1513–1518, doi:10.1007/s00585-998-1513-8.
- Parker, E. N. (1958), Dynamics of the interplanetary gas and magnetic fields., *Astrophys. J.*, 128, 664, doi:10.1086/146579.
- Phadke, K. A., R. Narayanan, R. P. Singh, and D. Pallamraju (2014), An Automated CCD-based multi-wavelength airglow photometer (CMAP) for Optical Aeronomy Studies, *PRL Tech. Note, PRL-TN-2014-107*.
- Phani Chandrasekhar, N., K. Arora, and N. Nagarajan (2014), Characterization of seasonal and longitudinal variability of EEJ in the Indian region, *J. Geophys. Res.*, 119(12), 10,242–10,259, doi:10.1002/2014JA020183.
- Pitteway, M. L. V., and C. O. Hines (1963), The viscous damping of atmospheric gravity waves, *Can. J. Phys.*, 41(12), 1935–1948, doi:10.1139/p63-194.
- Pramitha, M., M. Venkat Ratnam, A. Taori, B. V. Krishna Murthy, D. Pallamraju, and S. Vijaya Bhaskar Rao (2015), Evidence for tropospheric wind shear excitation of high-phase-speed gravity waves reaching the mesosphere using the ray-tracing technique, *Atmos. Chem. Phys.*, 15(5), 2709–2721, doi:10.5194/acp-15-2709-2015.

Prolss, G. W. (1980), Magnetic storm associated perturbations of the upper atmosphere: Recent results obtained by satellite-borne gas analyzers, *Rev. Geophys.*, 18(1), 183–202, doi:10.1029/RG018i001p00183.

Prolss, G. W., M. Roemer, and J. W. Slowey (1988), Dissipation of solar wind energy in the earth's upper atmosphere: The geomagnetic activity effect, *Adv. Space Res.*, 8(5), 215 – 261, doi:[https://doi.org/10.1016/0273-1177\(88\)90043-9](https://doi.org/10.1016/0273-1177(88)90043-9).

Raghavarao, R., and B. G. Anandarao (1980), Vertical winds as a plausible cause for equatorial counter electrojet, *Geophys. Res. Lett.*, 7(5), 357–360, doi:10.1029/GL007i005p00357.

Raghavarao, R., P. Sharma, and M. R. Sivaraman (1978), Correlation of ionization anomaly with the intensity of the electrojet, *Space Res.*, 18, 277–280, doi:10.1016/B978-0-08-022021-5.50063-X.

Raghavarao, R., S. Gupta, R. Sekar, R. Narayanan, J. Desai, R. Sridharan, V. Babu, and V. Sudhakar (1987), In situ measurements of winds, electric fields and electron densities at the onset of equatorial spread-F, *J. Atmos. Terr. Phys.*, 49(5), 485 – 492, doi:[http://dx.doi.org/10.1016/0021-9169\(87\)90042-0](http://dx.doi.org/10.1016/0021-9169(87)90042-0).

Raghavarao, R., R. Sridharan, J. H. Sastri, V. V. Agashe, B. C. N. Rao, P. B. Rao, and V. V. Somayajulu (1988), *The equatorial ionosphere; WITS handbook. World Ionosphere/Thermosphere Study*, vol 1., 48–93 pp., SCOSTEP Secretariat, University of Illinois, Urbana.

Raghavarao, R., L. E. Wharton, N. W. Spencer, H. G. Mayr, and L. H. Brace (1991), An equatorial temperature and wind anomaly (ETWA), *Geophys. Res. Lett.*, 18(7), 1193–1196, doi:10.1029/91GL01561.

Raghavarao, R., W. R. Hoegy, N. W. Spencer, and L. E. Wharton (1993), Neutral temperature anomaly in the equatorial thermosphere- A source of vertical winds, *Geophys. Res. Lett.*, 20(11), 1023–1026, doi:10.1029/93GL01253.

- Rajaram, G. (1977), Structure of the equatorial F region, topside and bottomside-A review, *J. Atmos. Terr. Phys.*, 39, 1125–1177.
- Rees, M. H. (1989), *Physics and Chemistry of the Upper Atmosphere*, 289 pp., Cambridge University Press.
- Richards, P. I. (1967), Computing reliable power spectra, *IEEE Spectrum*, 4, 83–90.
- Richmond, A. D., and S. Matsushita (1975), Thermospheric response to a magnetic substorm, *J. Geophys. Res.*, 80(19), 2839–2850, doi:10.1029/JA080i019p02839.
- Rishbeth, H. (1972), Thermospheric winds and the F-region: A review, *J. Atmos. Terr. Phys.*, 34(1), 1 – 47, doi:[http://dx.doi.org/10.1016/0021-9169\(72\)90003-7](http://dx.doi.org/10.1016/0021-9169(72)90003-7).
- Rishbeth, H. (1997), The ionospheric E-layer and F-layer dynamos: A tutorial review, *J. Atmos. Sol. Terr. Phys.*, 59(15), 1873 – 1880, doi:[http://dx.doi.org/10.1016/S1364-6826\(97\)00005-9](http://dx.doi.org/10.1016/S1364-6826(97)00005-9).
- Rishbeth, H., and O. K. Garriott (1969), *Introduction to Ionospheric Physics*, 331 pp., Academic Press.
- Roble, R. G., and R. E. Dickinson (1973), Is there enough solar extreme ultraviolet radiation to maintain the global mean thermospheric temperature?, *J. Geophys. Res.*, 78(1), 249–257, doi:10.1029/JA078i001p00249.
- Roble, R. G., J. M. Forbes, and F. A. Marcos (1987), Thermospheric dynamics during the march 22, 1979, magnetic storm: 1. model simulations, *J. Geophys. Res.*, 92(A6), 6045–6068, doi:10.1029/JA092iA06p06045.
- Rush, C. M., and A. D. Richmond (1973), The relationship between the structure of the equatorial anomaly and the strength of the equatorial electrojet, *J. Atmos. Terr. Physics*, 35(6), 1171 – 1180, doi:[https://doi.org/10.1016/0021-9169\(73\)90013-5](https://doi.org/10.1016/0021-9169(73)90013-5).

Sagawa, E., T. J. Immel, H. U. Frey, and S. B. Mende (2005), Longitudinal structure of the equatorial anomaly in the nighttime ionosphere observed by IMAGE/FUV, *J. Geophys. Res.*, 110(A11), doi:10.1029/2004JA010848.

Salah, J. E., and J. M. Holt (1974), Midlatitude thermospheric winds from incoherent scatter radar and theory, *Radio Science*, 9(2), 301–313, doi: 10.1029/RS009i002p00301.

Sampath, S., and T. S. G. Sastry (1979), Results from in situ measurements of ionospheric currents in the equatorial region-I, *J. Geomag. Goelect.*, 31(3), 373–379, doi:10.5636/jgg.31.373.

Sastri, J. H. (1990), Equatorial anomaly in F region- A review, *Indian. J. Radio Space Phys*, 19, 225–240.

Sastri, J. H., K. Niranjan, and K. S. V. Subbarao (2002), Response of the equatorial ionosphere in the Indian (midnight) sector to the severe magnetic storm of July 15, 2000, *Geophys. Res. Lett.*, 29(13), 291–294, doi: 10.1029/2002GL015133.

Scargle, J. D. (1982), Studies in astronomical time series analysis. II - Statistical aspects of spectral analysis of unevenly spaced data, *Astrophys. J.*, 263, 835–853, doi:10.1086/160554.

Seaton, M. J. (1956), A possible explanation of the drop in F-region critical densities accompanying major ionospheric storms, *J. Atmos. Terr. Phys.*, 8, 122 – 124.

Sekar, R., and R. Raghavarao (1987), Role of vertical winds on the Rayleigh-Taylor mode instabilities of the night-time equatorial ionosphere, *J. Atmos. Terr. Phys.*, 49(10), 981 – 985, doi:[http://dx.doi.org/10.1016/0021-9169\(87\)90104-8](http://dx.doi.org/10.1016/0021-9169(87)90104-8).

Sekar, R., D. Chakrabarty, and D. Pallamraju (2012), Optical signature of shear in the zonal plasma flow along with a tilted structure associated with equatorial

- spread F during a space weather event, *J. Atmos. Sol. Terr. Phys.*, 75–76, 57 – 63, doi:<https://doi.org/10.1016/j.jastp.2011.05.009>.
- Sharma, P., and R. Raghavarao (1989), Simultaneous occurrence of ionization ledge and counterelectrojet in the equatorial ionosphere: observational evidence and its implications, *Can. J. Phys.*, 67(2-3), 166–172, doi:10.1139/p89-028.
- Shepherd, G. G., W. A. Gault, D. W. Miller, Z. Pasturczyk, S. F. Johnston, P. R. Kosteniuk, J. W. Haslett, D. J. W. Kendall, and J. R. Wimperis (1985), WAMDII: wide-angle Michelson Doppler imaging interferometer for Spacelab, *Appl. Opt.*, 24(11), 1571, doi:10.1364/AO.24.001571.
- Shepherd, G. G., et al. (1993a), WINDII, the wind imaging interferometer on the Upper Atmosphere Research Satellite, *J. Geophys. Res.*, 98(D6), 10,725–10,750, doi:10.1029/93JD00227.
- Shepherd, G. G., et al. (1993b), Longitudinal structure in atomic oxygen concentrations observed with WINDII on UARS, *Geophys. Res. Lett.*, 20(12), 1303–1306, doi:10.1029/93GL01105.
- Shepherd, G. G., N. J. Siddiqi, R. H. Wiens, and S. Zhang (1997), Airglow measurements of possible changes in the ionosphere and middle atmosphere, *Adv. Space Res.*, 20(11), 2127 – 2135, doi:[http://dx.doi.org/10.1016/S0273-1177\(97\)00605-4](http://dx.doi.org/10.1016/S0273-1177(97)00605-4).
- Shepherd, G. G., R. G. Roble, C. McLandress, and W. E. Ward (1997), WINDII observations of the 558 nm emission in the lower thermosphere: the influence of dynamics on composition, *J. Atmos. Sol. Terr. Phys.*, 59, 655–667, doi:10.1016/S1364-6826(96)00142-3.
- Shepherd, G. G., et al. (2012), The Wind Imaging Interferometer (WINDII) on the Upper Atmosphere Research Satellite: A 20 year perspective, *Rev. Geophys.*, 50(2), doi:10.1029/2012RG000390.
- Shiokawa, K., Y. Katoh, M. Satoh, M. K. Ejiri, T. Ogawa, T. Nakamura, T. Tsuda, and R. H. Wiens (1999), Development of Optical Mesosphere Ther-

- mosphere Imagers (OMTI), *Earth, Planets and Space*, 51(7-8), 887–896, doi: 10.5636/eps.51.887.
- Shiokawa, K., et al. (2003), Thermospheric wind during a storm-time large-scale traveling ionospheric disturbance, *J. Geophys. Res.*, 108(A12), doi:10.1029/2003JA010001.
- Shiokawa, K., Y. Otsuka, and T. Ogawa (2006), Quasiperiodic southward moving waves in 630-nm airglow images in the equatorial thermosphere, *J. Geophys. Res.*, 111(A6), doi:10.1029/2005JA011406.
- Shiokawa, K., Y. Otsuka, and T. Ogawa (2009), Propagation characteristics of nighttime mesospheric and thermospheric waves observed by optical mesosphere thermosphere imagers at middle and low latitudes, *Earth, Planets and Space*, 61(4), 479–491, doi:10.1186/BF03353165.
- Singh, R. P., and D. Pallamraju (2015), On the latitudinal distribution of mesospheric temperatures during sudden stratospheric warming events, *J. Geophys. Res.*, 120(4), 2926–2939, doi:10.1002/2014JA020355.
- Singh, R. P., and D. Pallamraju (2016), Effect of cyclone Nilofar on mesospheric wave dynamics as inferred from optical nightglow observations from Mount Abu, India, *J. Geophys. Res.*, 121(6), 5856–5867, doi:10.1002/2016JA022412.
- Singh, R. P., and D. Pallamraju (2017), Near infrared imaging spectrograph (NIRIS) for ground-based mesospheric OH (6-2) and O2 (0-1) intensity and temperature measurements, *J. Earth Syst. Sci.*, 126, doi:10.1007/s12040-017-0865-4.
- Singh, V., I. McDade, G. Shepherd, B. Solheim, and W. Ward (1996), The O(1D) dayglow emission as observed by the WIND Imaging Interferometer on UARS, *Adv. Space Res.*, 17(11), 11 – 14, doi:[http://dx.doi.org/10.1016/0273-1177\(95\)00725-T](http://dx.doi.org/10.1016/0273-1177(95)00725-T).
- Smith, S. M., C. R. Martinis, J. Baumgardner, and M. Mendillo (2015), All-sky imaging of transglobal thermospheric gravity waves generated by the March

- 2011 Tohoku Earthquake, *J. Geophys. Res.*, 120(12), 10,992–10,999, doi:10.1002/2015JA021638.
- Solomon, S. C., and V. J. Abreu (1989), The 630 nm dayglow, *J. Geophys. Res.*, 94(A6), 6817–6824, doi:10.1029/JA094iA06p06817.
- Somayajulu, V. V., L. Cherian, K. Rajeev, G. Ramkumar, and C. R. Reddi (1993), Mean winds and tidal components during counter electrojet events, *Geophys. Res. Lett.*, 20(14), 1443–1446, doi:10.1029/93GL00088.
- Spencer, N. W., L. Wharton, H. Niemann, A. Hedin, G. Carignan, and J. Maurer (1981), The Dynamics Explorer wind and the temperature spectrometer, *Space Science Instrumentation*, 5(4), 417–428.
- Sridharan, R., S. Gurubaran, R. Raghavarao, and R. Suhasini (1991a), Coordinated thermospheric and F-region measurements from low latitudes, *J. Atmos. Terr. Phys.*, 53(6-7), 515–519, doi:10.1016/0021-9169(91)90078-L.
- Sridharan, R., R. Raghavarao, S. Gurubaran, and R. Narayanan (1991b), First results of OI 630.0 nm dayglow measurements from equatorial latitudes, *J. Atmos. Sol.-Terr. Phys.*, 53, 521–528.
- Sridharan, R., R. Narayanan, and N. K. Modi (1992a), Improved chopper mask for the dayglow photometer, *Appl. Opt.*, 31(4), 425–426, doi:10.1364/AO.31.000425.
- Sridharan, R., S. A. Haider, S. Gurubaran, R. Sekar, and R. Narayanan (1992b), OI 630.0-nm dayglow in the region of equatorial ionization anomaly: Temporal variability and its causative mechanism, *J. Geophys. Res.*, 97(A9), 13,715–13,721, doi:10.1029/92JA00674.
- Sridharan, R., R. Narayanan, N. K. Modi, and D. P. Raju (1993a), A Novel mask design for multiwavelength dayglow photometry, *Appl. Opt.*, 32(22), 4178–80, doi:10.1364/AO.32.004178.

Sridharan, R., R. Sekar, and S. Gurubaran (1993b), Two-dimensional high-resolution imaging of the equatorial plasma fountain, *J. Atmos. Terr. Phys.*, *55*(13), 1661 – 1665, doi:[http://dx.doi.org/10.1016/0021-9169\(93\)90170-4](http://dx.doi.org/10.1016/0021-9169(93)90170-4).

Sridharan, R., D. P. Raju, R. Raghavarao, and P. V. S. Ramarao (1994), Precursor to equatorial spread-F in OI 630.0 nm dayglow, *Geophys. Res. Lett.*, *21*(25), 2797–2800, doi:[10.1029/94GL02732](https://doi.org/10.1029/94GL02732).

Sridharan, R., D. Pallam Raju, R. Narayanan, N. K. Modi, B. H. Subbaraya, and R. Raghavarao (1995), Daytime measurements of optical auroral emissions from Antarctica, *Current science*, *68*(8), 830–834.

Sridharan, R., N. K. Modi, D. P. Raju, R. Narayanan, T. K. Pant, A. Taori, and D. Chakrabarty (1998), A multiwavelength daytime photometer - a new tool for the investigation of atmospheric processes, *Meas. Sci. Technol.*, *9*(4), 585.

Sridharan, R., D. P. Raju, V. Somayajulu, A. Taori, D. Chakrabarty, and R. Raghavarao (1999), Imprint of equatorial electrodynamic processes in the OI 630.0 nm dayglow, *J. Atmos. Sol. Terr. Phys.*, *61*(15), 1143 – 1155, doi: [https://doi.org/10.1016/S1364-6826\(99\)00064-4](https://doi.org/10.1016/S1364-6826(99)00064-4).

Stening, R. J., C. E. Meek, and A. H. Manson (1996), Upper atmosphere wind systems during reverse equatorial electrojet events, *Geophys. Res. Lett.*, *23*(22), 3243–3246, doi:[10.1029/96GL02611](https://doi.org/10.1029/96GL02611).

Stolarski, R. S., P. B. Hays, and R. G. Roble (1975), Atmospheric heating by solar EUV radiation, *J. Geophys. Res.*, *80*(16), 2266–2276, doi:[10.1029/JA080i016p02266](https://doi.org/10.1029/JA080i016p02266).

Strickland, D. J., J. S. Evans, and L. J. Paxton (1995), Satellite remote sensing of thermospheric O/N₂ and solar EUV: 1. Theory, *J. Geophys. Res.*, *100*(A7), 12,217–12,226, doi:[10.1029/95JA00574](https://doi.org/10.1029/95JA00574).

Strickland, D. J., R. J. Cox, R. R. Meier, and D. P. Drob (1999), Global O/N₂ derived from DE-1 FUV dayglow data: Technique and examples from two storm periods, *J. Geophys. Res.*, *104*(A3), 4251–4266, doi:[10.1029/98JA02817](https://doi.org/10.1029/98JA02817).

- Sumod, S. G., T. K. Pant, C. Vineeth, and M. M. Hossain (2014), On the ionospheric and thermospheric response of solar flare events of 19 January 2005: An investigation using radio and optical techniques, *J. Geophys. Res.*, 119(6), 5049–5059, doi:10.1002/2013JA019714.
- Sunda, S., and B. M. Vyas (2013), Local time, seasonal, and solar cycle dependency of longitudinal variations of TEC along the crest of EIA over India, *J. Geophys. Res.*, 118(10), 6777–6785, doi:10.1002/2013JA018918.
- Sutton, E. K., J. M. Forbes, R. S. Nerem, and T. N. Woods (2006), Neutral density response to the solar flares of October and November, 2003, *Geophys. Res. Lett.*, 33(22), doi:10.1029/2006GL027737.
- Taori, A., R. Sridharan, D. Chakrabarty, N. Modi, and R. Narayanan (2003), Significant upper thermospheric contribution to the O (1S) 557.7 nm dayglow emission: first ground based evidence, *J. Atmos. Sol. Terr. Phys.*, 65(1), 121 – 128, doi:[https://doi.org/10.1016/S1364-6826\(02\)00289-4](https://doi.org/10.1016/S1364-6826(02)00289-4).
- Taylor, M. J., M. B. Bishop, and V. Taylor (1995), All-sky measurements of short period waves imaged in the OI(557.7 nm), Na(589.2 nm) and near infrared OH and O₂(0,1) nightglow emissions during the ALOHA-93 Campaign, *Geophys. Res. Lett.*, 22(20), 2833–2836, doi:10.1029/95GL02946.
- Taylor, M. J., J.-M. Jahn, S. Fukao, and A. Saito (1998), Possible evidence of gravity wave coupling into the mid-latitude F region ionosphere during the SEEK Campaign, *Geophys. Res. Lett.*, 25(11), 1801–1804, doi:10.1029/97GL03448.
- Teitelbaum, H., M. Massabeuf, J. L. Fellous, M. Petitdidier, J. Christophe, and F. Blanco (1981), Simultaneous measurements of meteor winds and green line intensity variations: Gravity waves and planetary waves, *J. Geophys. Res.*, 86(A9), 7767–7770, doi:10.1029/JA086iA09p07767.
- Thome, G. D., and L. S. Wagner (1971), Electron density enhancements in the E and F regions of the ionosphere during solar flares, *J. Geophys. Res.*, 76(28), 6883–6895, doi:10.1029/JA076i028p06883.

- Tinsley, B. A., A. B. Christensen, J. Bittencourt, H. Gouveia, P. D. Ansgreji, and H. Takahashi (1973), Excitation of oxygen permitted line emissions in the tropical nightglow, *J. Geophys. Res.*, 78(7), 1174–1186, doi:10.1029/JA078i007p01174.
- Torr, M. R., and D. G. Torr (1982), The role of metastable species in the thermosphere, *Rev. Geophys. Sp. Phys.*, 20(1), 91–144.
- Torrence, C., and G. P. Compo (1998), A practical guide to wavelet analysis, *Bull. Amer. Meteor. Soc.*, 79(1), 61–78, doi:10.1175/1520-0477(1998)079<0061:APGTWA>2.0.CO;2.
- Troshichev, O. A. (1982), Polar magnetic disturbances and field-aligned currents, *Space Science Reviews*, 32(3), 275–360, doi:10.1007/BF00167945.
- Tsugawa, T., A. Saito, Y. Otsuka, M. Nishioka, T. Maruyama, H. Kato, T. Nagatsuma, and K. T. Murata (2011), Ionospheric disturbances detected by GPS total electron content observation after the 2011 off the Pacific coast of Tohoku Earthquake, *Earth, Planets and Space*, 63(7), 66, doi:10.5047/eps.2011.06.035.
- Tsunoda, R. T. (1985), Control of the seasonal and longitudinal occurrence of equatorial scintillations by the longitudinal gradient in integrated e region pedersen conductivity, *J. Geophys. Res.*, 90(A1), 447–456, doi:10.1029/JA090iA01p00447.
- Tsurutani, B., et al. (2004), Global dayside ionospheric uplift and enhancement associated with interplanetary electric fields, *J. Geophys. Res.*, 109(A8), doi:10.1029/2003JA010342.
- Tsurutani, B. T., et al. (2005), The October 28, 2003 extreme EUV solar flare and resultant extreme ionospheric effects: Comparison to other Halloween events and the Bastille Day event, *Geophys. Res. Lett.*, 32(3), doi:10.1029/2004GL021475.
- Tyagi, S., and V. Singh (1998), The morphology of oxygen greenline dayglow emission, *Ann. Geophys.*, 16(12), 1599–1606, doi:10.1007/s00585-998-1599-z.

- Upadhyaya, A. K., and V. Singh (2002), Effects of temperature dependence of reaction $N_2(A^3 S^+_u) + O$ on greenline dayglow emission, *Ann. Geophys.*, *20*(12), 2039–2045, doi:10.5194/angeo-20-2039-2002.
- Vadas, S. L., and D. C. Fritts (2005), Thermospheric responses to gravity waves: Influences of increasing viscosity and thermal diffusivity, *J. Geophys. Res.*, *110*(D15), D15,103, doi:10.1029/2004JD005574.
- Walker, G. O., J. H. K. Ma, and E. Golton (1994), The equatorial ionospheric anomaly in electron content from solar minimum to solar maximum for South East Asia, *Ann. Geophys.*, *12*(2/3), 195–209, doi:10.1007/s00585-994-0195-0.
- Wallace, L. (1961), An attempt to observe the day airglow, *J. Geophys. Res.*, *66*(5), 1585–1586, doi:10.1029/JZ066i005p01585.
- Wallace, L. (1963), Observation of the day airglow, *J. Geophys. Res.*, *68*(5), 1559–1560, doi:10.1029/JZ068i005p01559.
- Wallace, L., and M. B. McElroy (1966), The visual dayglow, *Planet. Space Sci.*, *14*(8), 677–708, doi:10.1016/0032-0633(66)90100-0.
- Witasse, O., J. Liliensten, C. Lathuillre, and P.-L. Blelly (1999), Modeling the OI 630.0 and 557.7 nm thermospheric dayglow during EISCAT-WINDII co-ordinated measurements, *J. Geophys. Res.*, *104*(A11), 24,639–24,655, doi:10.1029/1999JA900260.
- Yadav, S., and D. Pallamraju (2015), On the coupled interactions between ring current intensity and high-latitude ionospheric electron density variations, *J. Atmos. Sol. Terr. Phys.*, *125*126, 50–58, doi:<https://doi.org/10.1016/j.jastp.2015.02.006>.
- Yigit, E., A. D. Aylward, and A. S. Medvedev (2008), Parameterization of the effects of vertically propagating gravity waves for thermosphere general circulation models: Sensitivity study, *J. Geophys. Res.*, *113*(D19), D19,106, doi:10.1029/2008JD010135.

- Zhang, S. P., and G. G. Shepherd (2000), Neutral winds in the lower thermosphere observed by WINDII during the April 45th, 1993 storm, *Geophys. Res. Lett.*, 27(13), 1855–1858, doi:10.1029/2000GL000034.
- Zhang, S. P., and G. G. Shepherd (2004), Solar influence on the O(¹D) dayglow emission rate: Global-scale measurements by WINDII on UARS, *Geophys. Res. Lett.*, 31(7), L07,804, doi:10.1029/2004GL019447.
- Zhang, S. P., and G. G. Shepherd (2005), On the response of the O(¹S) dayglow emission rate to the sun's energy input: An empirical model deduced from WINDII/UARS global measurements, *J. Geophys. Res.*, 110(A3), A03,304, doi:10.1029/2004JA010887.
- Zhang, Y., L. J. Paxton, D. Morrison, B. Wolven, H. Kil, C.-I. Meng, S. B. Mende, and T. J. Immel (2004), O/N₂ changes during 14 October 2002 storms: IMAGE SI-13 and TIMED/GUVI observations, *J. Geophys. Res.*, 109(A10), doi:10.1029/2004JA010441.
- Zhang, Y., L. Paxton, D. Morrison, D. Marsh, and H. Kil (2014), Storm-time behaviors of O/N₂ and NO variations, *J. Atmos. Sol. Terr. Phys.*, 114, 42–49, doi:<https://doi.org/10.1016/j.jastp.2014.04.003>.
- Zhao, B., W. Wan, and L. Liu (2005), Responses of equatorial anomaly to the October-November 2003 superstorms, *Ann. Geophys.*, 23(3), 693–706, doi:10.5194/angeo-23-693-2005.

List of Publications

Publications in Journals

1. Pallamraju, D., **D. K. Karan**, K. A. Phadke (2016), First three dimensionsal wave characteristics in the daytime upper atmosphere derived from ground-based multiwavelength oxygen dayglow emission measurements, *Geophys. Res. Lett.*, 42, 5545-5553, doi:10.1002/2016GL069074.
2. **Karan, D. K.**, D. Pallamraju, K. A. Phadke, T. Vijayalakshmi, T. K. Pant, and S. Mukherjee (2016), Electrodynamic influence on the diurnal behaviour of neutral daytime airglow emissions, *Ann. Geophys.*, 34, 1019-1030, doi:10.5194/angeo-34-1019-2016.
3. **Karan, D. K.**, and D. Pallamraju (2017), Small-scale longitudinal variations in the daytime equatorial thermospheric wave dynamics as inferred from oxygen dayglow emissions, *J. Geophys. Res. Space Physics*, 122, 6528-6542, doi:10.1002/2017JA023891.
4. **Karan, D. K.**, and D. Pallamraju (2018), Effect of geomagnetic storms on the daytime low-latitude thermospheric wave dynamics, *J. Atmos. Sol. Terr. Phys.*, <https://doi.org/10.1016/j.jastp.2018.02.003>

Conference Papers

1. Pallamraju, D., **D. K. Karan**, F. I. Laskar, K. A. Phadke, T. Vijaya Lakshmi, M. Anji Reddy, "Zonal behaviour of optical daytime airglow emission intensities from low latitudes." (Paper No.: PS3 - 80) Presented at 18th

National Space Science Symposium held during 29 January - 1 February 2014 at Dibrugarh University, Dibrugarh, Assam. [Poster by DKK]

2. Pallamraju, D., **D. K. Karan**, F. I. Laskar, K. A. Phadke, T. Vijaya Lakshmi, M. Anji Reddy, "Wave dynamical coupling in the daytime as obtained from optical oxygen airglow emission intensities over low latitudes." (Presentation No.: C2.2 - 0052 - 14), 40th COSPAR Scientific Assembly, 2 - 10 August 2014, Moscow, Russia. [Oral by DP]
3. **Karan, D. K.**, D. Pallamraju, K. A. Phadke, T. Vijaya Lakshmi, "Coordinated, optical, radio, and magnetic investigations of wave dynamics in the daytime upper atmosphere." (Session 4: Coupling processes), United Nations / Japan Workshop on Space Weather "Science and Data Products from ISWI Instruments", 2 - 6 March 2015, Fukuoka, Japan. [Oral by DKK]
4. Pallamraju, D., **D. K. Karan**, K. A. Phadke, "Investigations on wave dynamics of daytime upper atmosphere over low-latitude," Session-S4, 14th ISEA meeting, Bahir-Dar, Ethiopia, 19-23 October, 2015. [Oral by DP]
5. Pallamraju, D., **D. K. Karan**, F. I. Laskar, "Upper atmospheric dynamics: influence of solar radiation versus forcing from below," Science for space weather, Goa, 24-29 January, 2016. [Oral by DP]
6. **Karan, D. K.**, D. Pallamraju, K. A. Phadke, T. Vijaya Lakshmi, and M. Anji Reddy, "Effect of equatorial electrodynamic process on the optical neutral dayglow emission intensities over low latitudes." (Paper No.: PS3 - 136). Presented at 19th National Space Science Symposium, Space Physics Laboratory, VSSC, Trivandrum, India, 9-12 February, 2016. [Poster by DKK]
7. Pallamraju, D., **D. K. Karan**, K. A. Phadke, T. Vijaya Lakshmi, and M. Anji Reddy, "Recent results from the investigations of daytime upper atmospheric wave dynamics over low-latitudes." Presented at 19th National Space Science Symposium held during 9-12 February, 2016, Space Physics Laboratory, VSSC, Trivandrum, India. [Oral by DP]

8. Pallamraju, D., **D. K. Karan**, "The changes in the ionospheric-thermospheric behaviour during varying solar activity levels." Presented at 9th IAGA - ICMA/IAMAS-ROSMIC/VarSITI/SCOSTEP workshop on Long-Term Changes and Trends in the Atmosphere, Khlungsborn, 19-23 September, 2016. [Oral by DP]
9. Pallamraju, D., S. Mandal, K. A. Phadke, **D. K. Karan**, R. P. Singh, "Gravity waves in the ionosphere as derived from digisonde measurements at Ahmedabad, India." - 3rd URSI-Regional Conference on Radio Science, NARL, Tirupati, March 1-4, 2017. [Oral by DP]
10. Pallamraju, D., **D. K. Karan**, "Effect Of Equatorial Electrodynamics And Lower Atmospheric Forcing On Optical Neutral Dayglow Emission As A Function Of Solar Activity." - ST08-A007 - Presented at 14th annual meeting Asia Oceania Geosciences Society, 6-11 August 2017. [Oral by DP]
11. Pallamraju, D., **D. K. Karan**, S. Mandal, and R. P. Singh, "Results from the first three dimensional waves in the daytime obtained from dayglow emissions and their comparison with those derived from ionospheric measurements" - ST26-27-A018 - Presented at 14th annual meeting Asia Oceania Geosciences Society, 6-11 August 2017. [Oral by DP]
12. **Karan, D. K.** and D. Pallamraju, "Effect of equatorial electrodynamics on low-latitude thermosphere as inferred from neutral optical dayglow emission observations" - SA34A-07 - Presented at 2017 American Geophysical Union Fall Meeting, 13 December 2017. [Oral by DKK]
13. Pallamraju, D. and **D. K. Karan**, "Small-scale longitudinal variations in the daytime equatorial wave dynamics as inferred from oxygen dayglow emissions" - SA51A-2368 - Presented at 2017 American Geophysical Union Fall Meeting, 15 December 2017. [Poster by DKK]

Publications Attached With Thesis

1. Pallamraju, D., **D. K. Karan**, K. A. Phadke (2016), First three dimensinal wave characteristics in the daytime upper atmosphere derived from ground-based multiwavelength oxygen dayglow emisison measurements, *Geophys. Res. Lett.*, 42, 5545-5553, doi:10.1002/2016GL069074.
2. **Karan, D. K.**, D. Pallamraju, K. A. Phadke, T. Vijayalakshmi, T. K. Pant, and S. Mukherjee (2016), Electrodynamic influence on the diurnal behaviour of neutral daytime airglow emissions, *Ann. Geophys.*, 34, 1019-1030, doi:10.5194/angeo-34-1019-2016.
3. **Karan, D. K.**, and D. Pallamraju (2017), Small-scale longitudinal variations in the daytime equatorial thermospheric wave dynamics as inferred from oxygen dayglow emissions, *J. Geophys. Res. Space Physics*, 122, 6528-6542, doi:10.1002/2017JA023891.