Investigations on Ionospheric Electrodynamics over Low Latitudes in Indian Sector

A thesis submitted in partial fulfilment of

the requirements for the degree of

Doctor of Philosophy

by

Pandey Kuldeep Rambabu

(Roll No. 13330004)

Under the guidance of

Prof. R. Sekar & **Dr. D. Chakrabarty**

Space & Atmospheric Sciences Division

Physical Research Laboratory, Ahmedabad, India

Discipline of Physics

Indian Institute of Technology Gandhinagar

2018

to

my parents

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.

Pandey Kuldeep Rambabu

(Roll No: 13330004)

Certificate

We feel great pleasure in certifying that the thesis entitled "**Investigations on Ionospheric Electrodynamics over Low Latitudes in Indian Sector**" by **Mr. Pandey Kuldeep Rambabu** has been carried out under our supervisions and this work has not been submitted anywhere else for any degree or diploma.

Prof. R. Sekar
(Thesis supervisor)
Physical Research Laboratory
Ahmedabad-380009, Gujarat, India

Dr. D. Chakrabarty
(Thesis co-supervisor)
Physical Research Laboratory
Ahmedabad-380009, Gujarat, India

Acknowledgements

The journey of my doctoral work at Physical Research Laboratory (PRL), Ahmedabad would not be possible without the help and support of many of you. It is a pleasant opportunity to express my sincere gratitude for all that I have received, though a few pages of acknowledgement can never do justice to all.

First and foremost, I express my sincere gratitude to my supervisor, Prof. R. Sekar for his invaluable guidance, patience, and concerns toward my continuous progress during the tenure of thesis work. His unique way of understanding the scientific processes and criticality encourages me to probe deeper into a scientific problem. His valuable suggestions and comments have helped me to improve the scientific outcomes. I express my sincere gratitude to my co-supervisor, Dr. D. Chakrabarty. He has been a guide, friend, critic, motivator throughout these years. His constant guidance and enthusiasm have immensely helped me to explore the new world of ideas. I am thankful to both of them for providing me with unending support, and freedom of independent thinking. The unique opportunity to constantly interact with both of them, with expertise in different areas of research, has immensely improved my scientific understanding in the field of ionospheric studies. I had the luxury to walk-in to their offices at any time or catch them anywhere and start the conversation. I will be forever indebted to both of them.

I had the fortune to interact with Prof. B. G. Anandarao in early days my Ph.D. tenure and started wonderful collaborative works by suitably making use of the equatorial electrojet model developed earlier by him. I'm grateful to him for providing me the Fortran code of the electrojet model and explaining the insights of it. This granted me an opportunity to employ the model to explore the possible answers to a few scientific problems.

I am thankful to Prof. S. P. Gupta for helping me to understand the insights of in-situ measurements of electron density and plasma irregularities that were obtained using sounding rocket flight experiments conducted from Thumba. His important suggestions have improved research outcomes of this thesis work. I am grateful to him for his scientific discussions and keeping the environment lively.

I am obliged to Prof. D. Pallamraju, the then division chairman, for allowing me to join the Space & Atmospherics Sciences Division as a doctoral student. I would also like to thank him for valuable suggestions for the progress of my scientific research throughout these years and being a member of my Doctoral Students Committee.

I am thankful to Mr. R. Naraynan for teaching me the insights of operating the airglow photometer that was built in-house. I am thankful to Dr. Amitava Guharay for the scientific discussions, his friendly and helping nature.

I express my sincere thanks to all the faculty and staff members of Space & Atmospheric Sciences Division. I am grateful to Prof. S. Ramachandran, chairman of the division and student's committee, for his prompt and cooperative help/suggestions in academic and administrative matters.

I thank Prof. R. Sridharan, Prof. H. Chandra, Dr. Y. B. Acharya, Prof. A. K. Patra (NARL), Dr. Smitha Thampi (SPL) for showing interest in my research work and giving encouraging remarks. I thank Dr. T. K. Pant (SPL) for all the help during collaborative airglow campaigns at VSSC, Trivandrum.

I thank the PRLs Director, Dean, Registrar, Academic Committee for their constant help and support. I thank all the PRL faculties for providing an overall view of research works carried out in PRL. My sincere thanks to Prof. J Banerji for teaching communication skills during the coursework. I express my appreciation to the staff members of PRLs Computer center, Library, Canteen, CMD for continuously providing the necessary facilities to smoothly carry out the research work. My special thanks to Mr. Pradeep Kumar for his help and cooperation. I am grateful to staff members of PRL's Mount Abu guest house (Hill View) for their hospitalities during airglow campaigns.

I am thankful to my present/former laboratory colleagues, Dipti, Debrup, Deepak, Sandeep, Sivakandan, Avik, Subir, Nidhi, Ankit and Sovan for their friendly company. I am grateful to Dipti and Debrup for their help, wonderful company and long discussions on numerous academic and non-academic aspects. I thank Atul who is the person I approach first for any issues related to computer and MATLAB. I thank Mitesh, Aditya, Anil for their wonderful company during field campaigns and helpful nature in the lab. I thank Sneha Nair, Pradeep, Surajeet, Mahipath, and others for their extended help and cooperation.

I would like to thank the Director, Dean, Associate Dean and the academic section of IIT Gandhinagar for their support and help. My special thanks to Dr. Nithin V. George, Dr. Vinod Chandra and Mr. Piyush for their prompt responses and helps on official matters.

My sincere gratitude to the Department of Science & Technology (India) for providing me with the funding supports to present my research works at AOGS-2018 meeting held in Hawaii (USA). I am grateful to the organizers of Heliophysics Summer School-2018 for selecting me to attend this prestigious school. I am thankful to the dean of school, Prof. Amitava Bhattacharjee (Princeton University, USA) for his encouraging words and suggestions for my research works.

I am grateful to Indian Institute of Geomagnetism, Navi Mumbai; Coordinated Data Analysis Web, NASA; World Data Center for Geomagnetism, Kyoto and several others for providing the enormous datasets in open source. I would like to acknowledge MATLAB, Google, TexStudio, Getdata, TableCurve2D etc. to make my work simpler.

I feel lucky to join in the wonderful batch-2013: Rukmani, Satish, Navpreet, Prahlad, Kumar, Rupa, Hemant, Ali, Chandan, Jabir, Yasir. I have really enjoyed their company since I entered PRL which is unforgettable. My special thanks to Rukmani for the long discussions, care and helps during these years. I also thank the seasonal friends Santosh, Chandni, and Ashish.

I am thankful to my wonderful seniors/juniors and friends who made my stay at PRL a pleasant and lively experience. To name a few - Sunil Chandra, Sushant, Amrendra, Gavrav Tomar, Waagesh, Arko, Tanmoy, Priyanka, Manojit, Anjali, Naveen, Arun, Girish Kumar, Ikshu, Bivin, Pankaj, Apurva, Chandana, Naman, Vishnu, Niharika, Ashish, Rahul, Subir, Kaustav, Aarthy, Archita, Richa, Arvind, Varun, Shaifali, Randeep, Harish, Sandeep, Priyank, Abdur, Surendra, Deepali, Nisha, Sushree, Kamlesh, Hirdesh, Lijo, Sneha Yadav, Fazlul, Bighnaraj, Piyush, Renuka, Srinivasa, Hrushikesh, Sana, Vipin, Atif and many more... Thanks for making a cooperative, helpful and cheerful environment at Thaltej hostel.

My sincere gratitude to my teachers Mr. Aanand Kumar (Delhi University), Mr. Nitinkumar Bijewar (Mumbai University), Ms. Jyotsna Gandhi (Bhavan's College, Mumbai), Ms. Madhulika Pathak (Rizvi College, Mumbai), Mr. Sanjay Tiwari (B. L. Ruia High School, Mumbai) and several others for their excellent teachings, helps and encouragements at different stages of my educational carrier.

Thanks to my friends Pawan, Ram Singh, Khalid, Dheeraj and others for their constant support and encouragements.

Most importantly, I express my indebtedness, love, and gratitude to my parents (Rambabu & Kanti) and sisters (Shraddha & Vibha). My parents take care of all the things and provide me the luxury to freely focus on my academic carrier. Howsoever I write, words cannot express my gratitude towards them.

Pandey Kuldeep Rambabu

Abstract

The central theme of the present doctoral thesis work is to understand the occurrence of equatorial counter electrojet (CEJ) or reductions in equatorial electrojet (EEJ) strength under geomagnetically quiet and disturbed conditions. Since variation in the ionospheric zonal electric field is central to any meaningful study on EEJ or CEJ, it is important to know the zonal electric field variations to understand these events. Since systematic measurements of electric fields covering all local times and seasons over the Indian sector are not available, the vertical drifts from the presently available global empirical models [*Scherliess and Fejer*, 1999; *Fejer et al.*, 2008a] are used. Detailed investigations on the applicability of these empirical models over the Indian sector are carried out based on the comparisons with the measured and derived drifts. This investigation revealed that *Fejer et al.* [2008a] model drifts represent the quiet time vertical drifts over the Indian sector fairly well barring early morning hours. Therefore, the drifts obtained from *Fejer et al.* [2008a] model are used in the subsequent investigations, whenever applicable.

Observational studies over the Indian longitudes revealed that the occurrence of quiet time CEJ events is most frequent in afternoon hours during June solstice in solar minimum. An investigation carried out to understand the generation mechanism of these CEJ events showed that these CEJ events are caused by westward Sq electric fields and hence are part of the Sq current system extending from pole to equator. Further, the reversal of EEJ due to disturbance dynamo is investigated and it is found that reductions in the daytime electric field can be significantly large (0.7 ± 0.2 to 1.2 ± 0.3 $m\mathrm{Vm}^{-1}$) during disturbance dynamo events. In order to explain such large westward electric field perturbations, additional role of semi-diurnal tides is indicated. Further, the strength of nighttime equatorial E-region current, used as the base level to determine the EEJ strength, are estimated to be about 0.3 - 0.7 $\mu\mathrm{Am}^{-2}$ based on three methods. The corresponding strength of the horizontal component of magnetic field induced at ground is found to be within 6 nT.

Keywords: Low latitude ionosphere, Sq electric field, plasma drifts, equatorial electrojet (EEJ), equatorial counter electrojet (CEJ), disturbance dynamo, D_{dyn}, reversed electrojet, nighttime E-region current.

Contents

Bibliography

Abdu, M. A. (2012), Equatorial spread F/plasma bubble irregularities under storm time disturbance electric fields, *Journal of Atmospheric and Solar-Terrestrial Physics*, *75-76*, 44–56, https://doi.org/10.1016/j.jastp.2011.04.024.

Abdu, M. A., Sobral, J. H. A., Richards, P., deGonzalez, M. M., Huang, Y. N., Reddy, B. M., Cheng, K., Szuszczewicz, E. P., and Batista, I. S. (1996), Zonal/meridional wind and disturbance dynamo electric field control of the low-latitude ionosphere based on the SUNDIAL/ATLAS 1 Campaign, *Journal of Geophysical Research: Space Physics*, *101*(A12), 26,729–26,740, https://doi.org/10.1029/96JA00321.

Abdu, M. A., Sastri, J. H., MacDougall, J., Batista, I. S., and Sobral, J. H. A. (1997), Equatorial disturbance dynamo electric field longitudinal structure and spread F: A case study from GUAR/EITS Campaigns, *Geophysical Research Letters*, *24*(13), 1707–1710, https://doi.org/10.1029/97GL01465.

Abdu, M. A., Batista, I. S., Takahashi, H., MacDougall, J., Sobral, J. H., Medeiros, A. F., and Trivedi, N. B. (2003), Magnetospheric disturbance induced equatorial plasma bubble development and dynamics: A case study in Brazilian sector, *Journal of Geophysical Research: Space Physics*, *108*(A12), https://doi.org/10.1029/2002JA009721.

Abdu, M. A., De Souza, J. R., Sobral, J. H. A., and Batista, I. S. (2006), Magnetic storm associated disturbance dynamo effects in the low and equatorial latitude ionosphere, *Recurrent magnetic storms: corotating solar wind Streams*, pp. 283–304, https://doi.org/10.1029/167GM22.

Aggarwal, M., Joshi, H. P., Iyer, K. N., Kwak, Y. S., Lee, J. J., Chandra, H., and Cho, K. S. (2012), Day-to-day variability of equatorial anomaly in GPS-TEC during low solar activity period, *Advances in Space Research*, *49*(12), 1709–1720, http://dx.doi.org/10.1016/j.asr.2012.03.005.

Akasofu, S., and Chapman, S. (1961), The ring current, geomagnetic disturbance, and the Van Allen radiation belts, *Journal of Geophysical Research*, *66*(5), 1321–1350, https://doi.org/10.1029/JZ066i005p01321.

Alken, P. (2009), A quiet time empirical model of equatorial vertical plasma drift in the Peruvian sector based on 150 km echoes, *Journal of Geophysical Research: Space Physics*, *114*(A2), https://doi.org/10.1029/2008JA013751.

Alken, P., and Maus, S. (2010), Electric fields in the equatorial ionosphere derived from CHAMP satellite magnetic field measurements, *Journal of Atmospheric and Solar-Terrestrial Physics*, *72*(4), 319–326, https://doi.org/10.1016/j.jastp.2009.02.006.

Amory-Mazaudier, C., Bolaji, O. S., and Doumbia, V. (2017), On the historical origins of the CEJ, DP2, and Ddyn current systems and their roles in the predictions of ionospheric responses to geomagnetic storms at equatorial latitudes, *Journal of Geophysical Research: Space Physics*, *122*(7), 7827–7833, https://doi.org/10.1002/2017JA024132.

Anandarao, B. G. (1976), Effects of gravity wave winds and wind shears on equatorial electrojet, *Geophysical Research Letters*, *3*(9), 545–548, http://dx.doi.org/10.1029/GL003i009p00545.

Anandarao, B. G. (1977), Studies on the dynamics of the equatorial ionosphere, Ph.D. thesis, Gujarat University.

Anandarao, B. G., and Raghavarao, R. (1987), Structural changes in the currents and fields of the equatorial electrojet due to zonal and meridional winds, *Journal of Geophysical Research*, *92*(A3), 2514–2526, http://dx.doi.org/10.1029/JA092iA03p02514.

Anandarao, B. G., Desai, J. N., Giles, M., Martelli, G., Raghavarao, R., and Rothwell, P. (1977), Electric field in the equatorial ionosphere, *Journal of Atmospheric and Terrestrial Physics*, *39*(8), 927–931, https://doi.org/10.1016/0021-9169(77)90174-X.

Anderson, D., Anghel, A., Chau, J., and Veliz, O. (2004), Daytime vertical E×B drift velocities inferred from ground-based magnetometer observations at low latitudes, *Space Weather*, *2*(11), http://dx.doi.org/10.1029/2004SW000095.

Anderson, D. N. (1973), A theoretical study of the ionospheric F region equatorial anomaly-I. Theory, *Planetary and Space Science*, *21*(3), 409–419, http://dx.doi.org/10.1016/0032-0633(73)90040-8.

Andriyas, T., and Andriyas, S. (2015), Relevance vector machines as a tool for forecasting geomagnetic storms during years 1996-2007, *Journal of Atmospheric and Solar-Terrestrial Physics*, *125-126*, 10–20, https://doi.org/10.1016/j.jastp.2015.02.005.

Appleton, E. V. (1946), Two Anomalies in the Ionosphere, *Nature*, *157*, 691, https://doi.org/10.1038/157691a0.

Baker, W. G., and Martyn, D. F. (1953), Electric currents in the ionosphere - The conductivity, *Philosophical Transactions of the Royal Society of London A*, *246*(913), 281–294, http://dx.doi.org/10.1098/rsta.1953.0016.

Balan, N., Jayachandran, B., Balachandran Nair, R., Namboothiri, S. P., Bailey, G. J., and Rao, P. B. (1992), HF Doppler observations of vector plasma drifts in the evening F-region at the magnetic equator, *Journal of Atmospheric and Terrestrial Physics*, *54*(1112), 1545–1554, http://dx.doi.org/10.1016/0021-9169(92)90162-E.

Balan, N., Souza, J., and Bailey, G. J. (2018), Recent developments in the understanding of equatorial ionization anomaly: A review, *Journal of Atmospheric and Solar-Terrestrial Physics*, *171*, 3–11, https://doi.org/10.1016/j.jastp.2017.06.020.

Balsley, B. B. (1964), Evidence of a stratified echoing region at 150 kilometers in the vicinity of the magnetic equator during daylight hours, *Journal of Geophysical Research*, *69*(9), 1925–1930, https://doi.org/10.1029/JZ069i009p01925.

Balsley, B. B. (1969), Some characteristics of non-two-stream irregularities in the equatorial electrojet, *Journal of Geophysical Research*, *74*(9), 2333–2347, https://doi.org/10.1029/JA074i009p02333.

Balsley, B. B., and Farley, D. T. (1971), Radar studies of the equatorial electrojet at three frequencies, *Journal of Geophysical Research*, *76*(34), 8341–8351, https://doi.org/10.1029/JA076i034p08341.

Bhardwaj, S. K., and Subba Rao, P. B. V. (2017), The afternoon counter-electrojet current system along the 75°E meridian during the IEEY, *Earth, Planets and Space*, *69*(1), 91, https://doi.org/10.1186/s40623-017-0675-6.

Bhargava, B. N., and Sastri, N. S. (1979), Some Characteristics of the occurrence of the afternoon counter-electrojet events in the India region, *Journal of geomagnetism and geoelectricity*, *31*(2), 97–101, http://dx.doi.org/10.5636/jgg.31.97.

Bhattacharyya, A., and Okpala, K. C. (2015), Principal components of quiet time temporal variability of equatorial and low-latitude geomagnetic fields, *Journal of Geophysical Research*, *120*(10), 8799–8809, http://dx.doi.org/10.1002/2015JA021673.

Bibl, K., and Reinisch, B. W. (1978), The universal digital ionosonde, *Radio Science*, *13*(3), 519–530, https://doi.org/10.1029/RS013i003p00519.

Bilitza, D. (1990), International reference ionosphere 1990, *NSSDC/WDC-A-R&S 90-22. National Space Science Data Center, Greenbelt.*

Bilitza, D., and Reinisch, B. W. (2008), International Reference Ionosphere 2007: Improvements and new parameters, *Advances in Space Research*, *42*(4), 599–609, https://doi.org/10.1016/j.asr.2007.07.048.

Bittencourt, J. A., and Abdu, M. A. (1981), A theoretical comparison between apparent and real vertical ionization drift velocities in the equatorial F region, *Journal of Geophysical Research*, *86*(A4), 2451–2454, http://dx.doi.org/10.1029/JA086iA04p02451.

Blanc, M., and Richmond, A. D. (1980), The ionospheric disturbance dynamo, *Journal of Geophysical Research*, *85*(A4), 1669–1686, http://dx.doi.org/10.1029/JA085iA04p01669.

Bowles, K. L. (1958), Observation of Vertical-Incidence Scatter from the Ionosphere at 41 Mc/sec, *Physical Review Letters*, *1*, 454–455, https://doi.org/10.1103/PhysRevLett.1.454.

Bowles, K. L., Cohen, R., Ochs, R., G., and Balsley, B. B. (1960), Radio echoes from field-aligned ionization above the magnetic equator and their resemblance to auroral echoes, *Journal of Geophysical Research*, *65*(6), 1853–1855, https://doi.org/10.1029/JZ065i006p01853.

Buneman, O. (1963), Excitation of Field Aligned Sound Waves by Electron Streams, *Physical Review Letters*, *10*, 285–287, https://doi.org/10.1103/PhysRevLett.10.285.

Butler, A. H., Sjoberg, J. P., Seidel, D. J., and Rosenlof, K. H. (2017), A sudden stratospheric warming compendium, *Earth System Science Data*, *9*(1), 63–76, https://doi.org/10.5194/essd-9-63-2017.

Cain, J. C., and Sweeney, R. E. (1973), The POGO data, *Journal of Atmospheric and Terrestrial Physics*, *35*(6), 1231–1247, http://dx.doi.org/10.1016/0021-9169(73)90021-4.

Campbell, W. H. (1973), The field levels near midnight at low and equatorial geomagnetic stations, *Journal of Atmospheric and Terrestrial Physics*, *35*, 1127–1146, http://dx.doi.org/10.1016/0021-9169(73)90010-X.

Campbell, W. H. (1979), Occurrence of AE and Dst geomagnetic index levels and the selection of the quietest days in a year, *Journal of Geophysical Research*, *84*(A3), 875–881, http://dx.doi.org/10.1029/JA084iA03p00875.

Chakrabarty, D., Sekar, R., Narayanan, R., Devasia, C. V., and Pathan, B. M. (2005), Evidence for the interplanetary electric field effect on the OI 630.0

nm airglow over low latitude, *Journal of Geophysical Research: Space Physics*, *110*(A11), https://doi.org/10.1029/2005JA011221.

Chakrabarty, D., Sekar, R., Sastri, J. H., and Ravindran, S. (2008), Distinctive effects of interplanetary electric field and substorm on nighttime equatorial F layer: A case study, *Geophysical Research Letters*, *35*(19), https://doi.org/10.1029/2008GL035415.

Chakrabarty, D., Sekar, R., Sastri, J. H., Pathan, B. M., Reeves, G. D., Yumoto, K., and Kikuchi, T. (2010), Evidence for OI 630.0 nm dayglow variations over low latitudes during onset of a substorm, *Journal of Geophysical Research: Space Physics*, *115*(A10), https://doi.org/10.1029/2010JA015643.

Chakrabarty, D., Fejer, B. G., Gurubaran, S., Pant, T. K., Abdu, M. A., and Sekar, R. (2014), On the pre-midnight ascent of F-layer in the June solstice during the deep solar minimum in 2008 over the Indian sector, *Journal of Atmospheric and Solar-Terrestrial Physics*, *121, Part B*, 177–187, http://dx.doi.org/10.1016/j.jastp.2014.01.002.

Chakrabarty, D., Rout, D., Sekar, R., Narayanan, R., Reeves, G. D., Pant, T. K., Veenadhari, B., and Shiokawa, K. (2015), Three different types of electric field disturbances affecting equatorial ionosphere during a long-duration prompt penetration event, *Journal of Geophysical Research: Space Physics*, *120*(6), 4993–5008, https://doi.org/10.1002/2014JA020759.

Chakrabarty, D., Hui, D., Rout, D., Sekar, R., Bhattacharyya, A., Reeves, G. D., and Ruohoniemi, J. M. (2017), Role of IMF By in the prompt electric field disturbances over equatorial ionosphere during a space weather event, *Journal of Geophysical Research: Space Physics*, *122*(2), 2574–2588, https://doi.org/10.1002/2016JA022781.

Chandra, H., Rastogi, R. G., Choudhary, R. K., and Sharma, S. (2016), Equatorial electrojet in the Indian region during the geomagnetic storm of 13 - 14 November 1998, *Journal of Earth System Science*, *125*(3), 669–675, https://doi.org/10.1007/s12040-016-0683-0.

Chapman, S. (1951), The equatorial electrojet as detected from the abnormal electric current distribution above Huancayo, Peru, and elsewhere, *Archiv für Meteorologie, Geophysik und Bioklimatologie, Serie A*, *4*(1), 368–390, https://doi.org/10.1007/BF02246814.

Chau, J. L., and Woodman, R. F. (2004), Daytime vertical and zonal velocities from 150-km echoes: Their relevance to F-region dynamics, *Geophysical Research Letters*, *31*(17), http://dx.doi.org/10.1029/2004GL020800.

Chau, J. L., Fejer, B. G., and Goncharenko, L. P. (2009), Quiet variability of equatorial E×B drifts during a sudden stratospheric warming event, *Geophysical Research Letters*, *36*(5), http://dx.doi.org/10.1029/2008GL036785.

Chau, J. L., Goncharenko, L. P., Fejer, B. G., and Liu, H.-L. (2012), Equatorial and low latitude ionospheric effects during sudden stratospheric warming events, *Space Science Reviews*, *168*(1), 385–417, https://doi.org/10.1007/s11214-011-9797-5.

Cohen, R., and Bowles, K. L. (1963), The association of plane-wave electron density irregularities with the equatorial electrojet, *Journal of Geophysical Research*, *68*(9), 2503–2525, http://dx.doi.org/10.1029/JZ068i009p02503.

Cohen, R., and Bowles, K. L. (1967), Secondary irregularities in the equatorial electrojet, *Journal of Geophysical Research*, *72*(3), 885–894, https://doi.org/10.1029/JZ072i003p00885.

Davis, T. N., and Sugiura, M. (1966), Auroral electrojet activity index AE and its universal time variations, *Journal of Geophysical Research*, *71*(3), 785–801, http://dx.doi.org/10.1029/JZ071i003p00785.

Davis, T. N., Burrows, K., and Stolarik, J. D. (1967), A latitude survey of the equatorial electrojet with rocket-borne magnetometers, *Journal of Geophysical Research*, *72*(7), 1845–1861, http://dx.doi.org/10.1029/JZ072i007p01845.

Deepa, V., Ramkumar, G., Antonita, M., Kumar, K. K., and Sasi, M. N. (2006), Vertical propagation characteristics and seasonal variability of tidal

wind oscillations in the MLT region over Trivandrum (8.5°N, 77°E): First results from SKiYMET meteor radar, *Annales Geophysicae*, *24*(11), 2877–2889, https://www.ann-geophys.net/24/2877/2006/.

Eccles, J. V., St. Maurice, J. P., and Schunk, R. W. (2015), Mechanisms underlying the prereversal enhancement of the vertical plasma drift in the low-latitude ionosphere, *Journal of Geophysical Research*, *120*(6), 4950–4970, http://dx.doi.org/10.1002/2014JA020664.

Egedal, J. (1947), The magnetic diurnal variation of the horizontal force near the magnetic equator, *Terrestrial Magnetism and Atmospheric Electricity*, *52*(4), 449–451, http://dx.doi.org/10.1029/TE052i004p00449.

England, S. L., Maus, S., Immel, T. J., and Mende, S. B. (2006), Longitudinal variation of the E-region electric fields caused by atmospheric tides, *Geophysical Research Letters*, *33*(21), https://doi.org/10.1029/2006GL027465.

Farley, D. T. (1963), A plasma instability resulting in field-aligned irregularities in the ionosphere, *Journal of Geophysical Research*, *68*(22), 6083–6097, https://doi.org/10.1029/JZ068i022p06083.

Farley, D. T. (2009), The equatorial E-region and its plasma instabilities: a tutorial, *Annales Geophysicae*, *27*(4), 1509–1520, http://dx.doi.org/10.5194/angeo-27-1509-2009.

Fejer, B. G. (1981), The equatorial ionospheric electric fields. A review, *Journal of Atmospheric and Terrestrial Physics*, *43*(5), 377–386, https://doi.org/10.1016/0021-9169(81)90101-X.

Fejer, B. G., and Kelley, M. C. (1980), Ionospheric irregularities, *Reviews of Geophysics*, *18*(2), 401–454, http://dx.doi.org/10.1029/RG018i002p00401.

Fejer, B. G., and Scherliess, L. (1995), Time dependent response of equatorial ionospheric electric fields to magnetospheric disturbances, *Geophysical Research Letters*, *22*(7), 851–854, https://doi.org/10.1029/95GL00390.

Fejer, B. G., Paula, E. R., Gonzáez, S. A., and Woodman, R. F. (1991), Average vertical and zonal F region plasma drifts over Jicamarca, *Journal of Geophysical Research: Space Physics*, *96*(A8), 13,901–13,906, https://doi.org/10.1029/91JA01171.

Fejer, B. G., de Paula, E. R., Scherliess, L., and Batista, I. S. (1996), Incoherent scatter radar, ionosonde, and satellite measurements of equatorial F region vertical plasma drifts in the evening sector, *Geophysical Research Letters*, *23*(14), 1733–1736, http://dx.doi.org/10.1029/96GL01847.

Fejer, B. G., Jensen, J. W., and Su, S.-Y. (2008a), Quiet time equatorial F region vertical plasma drift model derived from ROCSAT-1 observations, *Journal of Geophysical Research*, *113*(A5), http://dx.doi.org/10.1029/2007JA012801.

Fejer, B. G., Jensen, J. W., and Su, S.-Y. (2008b), Seasonal and longitudinal dependence of equatorial disturbance vertical plasma drifts, *Geophysical Research Letters*, *35*(20), L20,106, http://dx.doi.org/10.1029/2008GL035584.

Fejer, B. G., Olson, M. E., Chau, J. L., Stolle, C., Lühr, H., Goncharenko, L. P., Yumoto, K., and Nagatsuma, T. (2010), Lunar-dependent equatorial ionospheric electrodynamic effects during sudden stratospheric warmings, *Journal of Geophysical Research*, *115*(A8), http://dx.doi.org/10.1029/2010JA015273.

Fejer, B. G., Hui, D., Chau, J. L., and Kudeki, E. (2014), Altitudinal dependence of evening equatorial F region vertical plasma drifts, *Journal of Geophysical Research: Space Physics*, *119*(7), 5877–5890, http://dx.doi.org/10.1002/2014JA019949.

Fejer, B. G., Blanc, M., and Richmond, A. D. (2017), Post-storm middle and low-latitude ionospheric electric fields effects, *Space Science Reviews*, *206*(1), 407–429, https://doi.org/10.1007/s11214-016-0320-x.

Fesen, C. G., Crowley, G., Roble, R. G., Richmond, A. D., and Fejer, B. G. (2000), Simulation of the pre-reversal enhancement in the low latitude vertical ion drifts, *Geophysical Research Letters*, *27*(13), 1851–1854, http://dx.doi.org/10.1029/2000GL000061.

Forbes, J. M. (1981), The equatorial electrojet, *Reviews of Geophysics*, *19*(3), 469–504, http://dx.doi.org/10.1029/RG019i003p00469.

Forbes, J. M., and Lindzen, R. S. (1976), Atmospheric solar tides and their electrodynamic effects-II. The equatorial electrojet, *Journal of Atmospheric and Terrestrial Physics*, *38*(9), 911–920, http://dx.doi.org/10.1016/0021-9169(76)90074-X.

Francey, R. J. (1970), Electron production in the ionospheric D region by cosmic X rays, *Journal of Geophysical Research*, *75*(25), 4849–4862, https://doi.org/10.1029/JA075i025p04849.

Fuller-Rowell, T. J., Millward, G. H., Richmond, A. D., and Codrescu, M. V. (2002), Storm-time changes in the upper atmosphere at low latitudes, *Journal of Atmospheric and Solar-Terrestrial Physics*, *64*(12), 1383–1391, https://doi.org/10.1016/S1364-6826(02)00101-3.

Gordon, W. E. (1958), Incoherent scattering of radio waves by free electrons with applications to space exploration by radar, *Proceedings of the IRE*, *46*(11), 1824–1829, http://dx.doi.org/10.1109/JRPROC.1958.286852.

Gouin, P. (1962), Reversal of the magnetic daily variation at Addis Ababa, *Nature*, *193*, 1145–1146, https://doi.org/10.1038/1931145a0.

Gouin, P., and Mayaud, P. N. (1967), A propos de l'existence possible d'un contre electrojet aux latitudes magnetiques equatoriales, *Ann. Geophys.*, *23*, 41–47.

Gupta, S. P. (1986), Formation of sporadic E layers at low magnetic latitudes, *Planetary and Space Science*, *34*(11), 1081–1085, http://dx.doi.org/10.1016/0032-0633(86)90019-X.

Gupta, S. P. (1990), Ionisation layers over the magnetic equator during meteor shower days, *Advances in Space Research*, *10*(10), 105–108, http://dx.doi.org/10.1016/0273-1177(90)90016-S.

Gupta, S. P. (1997), Features of E region irregularities at the magnetic equator and in its vicinity, *Advances in Space Research*, *20*(11), 2195–2198, http://dx.doi.org/10.1016/S0273-1177(97)00670-4.

Gupta, S. P. (2000), Two stream instability in E region over magnetic equator during morning hours, *Advances in Space Research*, *26*(8), 1257–1261, http://dx.doi.org/10.1016/S0273-1177(99)01212-0.

Gupta, S. P. (2001), Collected Works. Physical Research Laboratory, India.

Gupta, S. P., and Prakash, S. (1979), Experimental evidence of ion plasma oscillations in the apogee region of the Nike-Apache rocket, *Planetary and Space Science*, *27*(2), 145–150, http://dx.doi.org/10.1016/0032-0633(79)90044-8.

Gupta, S. P., Sekar, R., and Acharya, Y. B. (2004), In situ measurements of sub-meter plasma waves over low-latitude ionosphere during Leonid-99 meteor storm, *Annales Geophysicae*, *22*(6), 2033–2036, https://www.ann-geophys.net/22/2033/2004/.

Gurubaran, S. (2002), The equatorial counter electrojet: Part of a worldwide current system?, *Geophysical Research Letters*, *29*(9), http://dx.doi.org/10.1029/2001GL014519.

Gurubaran, S., Sathishkumar, S., and Veenadhari, B. (2016), On the role of atmospheric tides in the quiet-time variabilities of equatorial electrojet, *Journal of Indian Geophysical Union*, *Special Volume-2*, 87–98.

Haerendel, G., and Eccles, J. V. (1992), The role of the equatorial electrojet in the evening ionosphere, *Journal of Geophysical Research*, *97*(A2), 1181–1192, http://dx.doi.org/10.1029/91JA02227.

Haerendel, G., Lüst, R., and Rieger, E. (1967), Motion of artificial ion clouds in the upper atmosphere, *Planetary and Space Science*, *15*(1), 1–18, https://doi.org/10.1016/0032-0633(67)90062-1.

Hagan, M. E., and Forbes, J. M. (2002), Migrating and nonmigrating diurnal tides in the middle and upper atmosphere excited by tropospheric la-

tent heat release, *Journal of Geophysical Research: Atmospheres*, *107*(D24), https://doi.org/10.1029/2001JD001236.

Hagan, M. E., Maute, A., Roble, R. G., Richmond, A. D., Immel, T. J., and England, S. L. (2007), Connections between deep tropical clouds and the Earth's ionosphere, *Geophysical Research Letters*, *34*(20), https://doi.org/10.1029/2007GL030142.

Hanson, W. B., and Heelis, R. A. (1975), Techniques for measuring bulk gas-motions from satellites, *Space Science Instrumentation*, *1*, 493–524.

Hanson, W. B., and Moffett, R. J. (1966), Ionization transport effects in the equatorial F region, *Journal of Geophysical Research*, *71*(23), 5559–5572, http://dx.doi.org/10.1029/JZ071i023p05559.

Hanson, W. B., Cragin, B. L., and Dennis, A. (1986), The effect of vertical drift on the equatorial F-region stability, *Journal of Atmospheric and Terrestrial Physics*, *48*(3), 205–212, https://doi.org/10.1016/0021-9169(86)90095-4.

Hanuise, C., Mazaudier, C., Vila, P., Blanc, M., and Crochet, M. (1983), Global dynamo simulation of ionospheric currents and their connection with the equatorial electrojet and counter electrojet: A case study, *Journal of Geophysical Research*, *88*(A1), 253–270, http://dx.doi.org/10.1029/JA088iA01p00253.

Henderson, M. G., Reeves, G. D., Belian, R. D., and Murphree, J. S. (1996), Observations of magnetospheric substorms occurring with no apparent solar wind/IMF trigger, *Journal of Geophysical Research: Space Physics*, *101*(A5), 10,773–10,791, https://doi.org/10.1029/96JA00186.

Huang, C. M. (2013), Disturbance dynamo electric fields in response to geomagnetic storms occurring at different universal times, *Journal of Geophysical Research: Space Physics*, *118*(1), 496–501, http://dx.doi.org/10.1029/2012JA018118.

Huang, C. M., and Chen, M. Q. (2008), Formation of maximum electric potential

at the geomagnetic equator by the disturbance dynamo, *Journal of Geophysical Research: Space Physics*, *113*(A3), http://dx.doi.org/10.1029/2007JA012843.

Huang, C.-S. (2012), Statistical analysis of dayside equatorial ionospheric electric fields and electrojet currents produced by magnetospheric substorms during sawtooth events, *Journal of Geophysical Research: Space Physics*, *117*(A2), https://doi.org/10.1029/2011JA017398.

Huang, C.-S., Foster, J. C., Goncharenko, L. P., Reeves, G. D., Chau, J. L., Yumoto, K., and Kitamura, K. (2004), Variations of low-latitude geomagnetic fields and Dst index caused by magnetospheric substorms, *Journal of Geophysical Research: Space Physics*, *109*(A5), https://doi.org/10.1029/2003JA010334.

Huang, C.-S., Foster, J. C., and Kelley, M. C. (2005), Long-duration penetration of the interplanetary electric field to the low-latitude ionosphere during the main phase of magnetic storms, *Journal of Geophysical Research: Space Physics*, *110*(A11), http://dx.doi.org/10.1029/2005JA011202.

Huba, J. D., and Joyce, G. (2007), Equatorial spread F modeling: Multiple bifurcated structures, secondary instabilities, large density bite-outs, and supersonic flows, *Geophysical Research Letters*, *34*(7), https://doi.org/10.1029/2006GL028519.

Huba, J. D., Lyon, J. G., and Hassam, A. B. (1987), Theory and simulation of the Rayleigh-Taylor instability in the limit of large Larmor radius, *Physical Review Letters*, *59*, 2971–2974, https://link.aps.org/doi/10.1103/PhysRevLett.59.2971.

Huba, J. D., Joyce, G., Sazykin, S., Wolf, R., and Spiro, R. (2005), Simulation study of penetration electric field effects on the low- to mid-latitude ionosphere, *Geophysical Research Letters*, *32*(23), https://doi.org/10.1029/2005GL024162.

Huba, J. D., Joyce, G., and Krall, J. (2008), Three-dimensional equatorial spread F modeling, *Geophysical Research Letters*, *35*(10), https://doi.org/10.1029/2008GL033509.

Hui, D., and Fejer, B. G. (2015), Daytime plasma drifts in the equatorial lower ionosphere, *Journal of Geophysical Research*, *120*(11), 9738–9747, http://dx.doi.org/10.1002/2015JA021838.

Hui, D., Chakrabarty, D., Sekar, R., Reeves, G. D., Yoshikawa, A., and Shiokawa, K. (2017), Contribution of storm time substorms to the prompt electric field disturbances in the equatorial ionosphere, *Journal of Geophysical Research: Space Physics*, *122*(5), 5568–5578, https://doi.org/10.1002/2016JA023754.

Hutton, R., and Oyinloye, J. O. (1970), The counter-electrojet in Nigeria, *Ann. Geophys.*, *26*, 921–926.

Immel, T. J., Sagawa, E., England, S. L., Henderson, S. B., Hagan, M. E., Mende, S. B., Frey, H. U., Swenson, C. M., and Paxton, L. J. (2006), Control of equatorial ionospheric morphology by atmospheric tides, *Geophysical Research Letters*, *33*(15), https://doi.org/10.1029/2006GL026161.

Iyer, K. N., Deshpande, M. R., and Rastogi, R. G. (1976), The equatorial anomaly in ionospheric total electron content and the equatorial electrojet current strength, *Proceedings of the Indian Academy of Sciences-Section A*, *84*(4), 129–138, https://doi.org/10.1007/BF03046803.

Jacchia, L. G. (1971), Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles, *Smithsonian Astrophysical Observatory (SAO) Special Report*, *332*.

Jadhav, G., Rajaram, M., and Rajaram, R. (2002), A detailed study of equatorial electrojet phenomenon using Ørsted satellite observations, *Journal of Geophysical Research*, *107*(A8), 1175, http://dx.doi.org/10.1029/2001JA000183.

Janzhura, A., Troshichev, O., and Stauning, P. (2007), Unified PC indices: Relation to isolated magnetic substorms, *Journal of Geophysical Research: Space Physics*, *112*(A9), http://dx.doi.org/10.1029/2006JA012132.

Johnson, J. R., and Wing, S. (2014), External versus internal triggering of sub-

storms: An information-theoretical approach, *Geophysical Research Letters*, *41*(16), 5748–5754, https://doi.org/10.1002/2014GL060928.

Kakad, B., Tiwari, D., and Pant, T. K. (2012), Study of post sunset vertical plasma drift at equatorial F-region using long-term (1990-2003) ionosonde measurements in Indian longitude, *Journal of Atmospheric and Solar-Terrestrial Physics*, *80*, 239–246, http://dx.doi.org/10.1016/j.jastp.2012.02.004.

Kelley, M. C. (2009), The Earth's Ionosphere: Electrodynamics and Plasma Physics, *Academic Press*.

Kelley, M. C., Makela, J. J., Chau, J. L., and Nicolls, M. J. (2003), Penetration of the solar wind electric field into the magnetosphere/ionosphere system, *Geophysical Research Letters*, *30*(4), https://doi.org/10.1029/2002GL016321.

Kikuchi, T., Lühr, H., Kitamura, T., Saka, O., and Schlegel, K. (1996), Direct penetration of the polar electric field to the equator during a DP 2 event as detected by the auroral and equatorial magnetometer chains and the EISCAT radar, *Journal of Geophysical Research: Space Physics*, *101*(A8), 17,161–17,173, http://dx.doi.org/10.1029/96JA01299.

Kikuchi, T., Hashimoto, K. K., Kitamura, T.-I., Tachihara, H., and Fejer, B. (2003), Equatorial counterelectrojets during substorms, *Journal of Geophysical Research*, *108*(A11), http://dx.doi.org/10.1029/2003JA009915.

Kil, H., Oh, S.-J., Kelley, M. C., Paxton, L. J., England, S. L., Talaat, E., Min, W., K., and Su, S.-Y. (2007), Longitudinal structure of the vertical E×B drift and ion density seen from ROCSAT-1, *Geophysical Research Letters*, *34*(14), https://doi.org/10.1029/2007GL030018.

Kil, H., Talaat, E. R., Oh, S.-J., Paxton, L. J., England, S. L., and Su, S.-Y. (2008), Wave structures of the plasma density and vertical E×B drift in low-latitude F region, *Journal of Geophysical Research: Space Physics*, *113*(A9), http://dx.doi.org/10.1029/2008JA013106.

Kil, H., Oh, J., S., Paxton, L. J., and Fang, W., T. (2009), High-resolution vertical E×B drift model derived from ROCSAT-1 data, *Journal of Geophysical Research: Space Physics*, *114*(A10), https://doi.org/10.1029/2009JA014324.

Kivelson, M. G., and Russell, C. (1995), *Introduction to space physics*, Cambridge university press.

Klimenko, M. V., Klimenko, V. V., and Karpachev, A. T. (2012), Formation mechanism of additional layers above regular F2 layer in the near-equatorial ionosphere during quiet period, *Journal of Atmospheric and Solar-Terrestrial Physics*, *90-91*, 179–185, http://dx.doi.org/10.1016/j.jastp.2012.02.011.

Kobea, A. T., Richmond, A. D., Emery, B. A., Peymirat, C., Lühr, H., Moretto, T., Hairston, M., and Amory-Mazaudier, C. (2000), Electrodynamic coupling of high and low latitudes: Observations on May 27, 1993, *Journal of Geophysical Research*, *105*(A10), 22,979–22,989, http://dx.doi.org/10.1029/2000JA000058.

Krishna Murthy, B. V., and Hari, S. S. (1996), Electric fields in the low latitude F-region, *Advances in Space Research*, *18*(6), 93–98, http://dx.doi.org/10.1016/0273-1177(95)00906-X.

Krishna Murthy, B. V., Hari, S. S., and Somayajulu, V. V. (1990), Nighttime equatorial thermospheric meridional winds from ionospheric h'F data, *Journal of Geophysical Research: Space Physics*, *95*(A4), 4307–4310, http://dx.doi.org/10.1029/JA095iA04p04307.

Krishna Murthy, B. V., Ravindran, S., Viswanathan, K. S., Subbarao, K. S. V., Patra, A. K., and Rao, P. B. (1998), Small-scale (∼3 m) E region irregularities at and off the magnetic equator, *Journal of Geophysical Research*, *103*(A9), 20,761–20,773, http://dx.doi.org/10.1029/98JA00928.

Kudeki, E., and Fawcett, C. D. (1993), High resolution observations of 150 km echoes at Jicamarca, *Geophysical Research Letters*, *20*(18), 1987–1990, http://dx.doi.org/10.1029/93GL01256.

Le, G., Slavin, J. A., and Strangeway, R. J. (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, *Journal of Geophysical Research: Space Physics*, *115*(A7), https://doi.org/10.1029/2009JA014979.

Le Huy, M., and Amory-Mazaudier, C. (2005), Magnetic signature of the ionospheric disturbance dynamo at equatorial latitudes: "Ddyn", *Journal of Geophysical Research: Space Physics*, *110*(A10), http://dx.doi.org/10.1029/2004JA010578.

Lin, C. H., Wang, W., Hagan, M. E., Hsiao, C. C., Immel, T. J., Hsu, M. L., Liu, J. Y., Paxton, L. J., Fang, T. W., and Liu, C. H. (2007), Plausible effect of atmospheric tides on the equatorial ionosphere observed by the FORMOSAT-3/COSMIC: Three-dimensional electron density structures, *Geophysical Research Letters*, *34*(11), https://doi.org/10.1029/2007GL029265.

Liu, J.-M., Zhang, B.-C., Kamide, Y., Wu, Z.-S., Hu, Z.-J., and Yang, H.-G. (2011), Spontaneous and trigger-associated substorms compared: Electrodynamic parameters in the polar ionosphere, *Journal of Geophysical Research: Space Physics*, *116*(A1), https://doi.org/10.1029/2010JA015773.

Lühr, H., and Manoj, C. (2013), The complete spectrum of the equatorial electrojet related to solar tides: CHAMP observations, *Annales Geophysicae*, *31*(8), 1315–1331, https://doi.org/10.5194/angeo-31-1315-2013.

Lühr, H., Maus, S., and Rother, M. (2004), Noon-time equatorial electrojet: Its spatial features as determined by the CHAMP satellite, *Journal of Geophysical Research*, *109*(A1), http://dx.doi.org/10.1029/2002JA009656.

Lühr, H., Rother, M., Häusler, K., Alken, P., and Maus, S. (2008), The influence of nonmigrating tides on the longitudinal variation of the equatorial electrojet, *Journal of Geophysical Research: Space Physics*, *113*(A8), https://doi.org/10.1029/2008JA013064.

MacDougall, J. W., Grant, I. F., and Shen, X. (1995), The Canadian advanced

digital ionosonde: design and results, *URSI INAG Ionospheric Station Inf. Bulletin, UAG-104*.

Madhav Haridas, M. K., Manju, G., and Pant, T. K. (2015), On the solar activity variations of nocturnal F region vertical drifts covering two solar cycles in the Indian longitude sector, *Journal of Geophysical Research*, *120*(2), 1445–1451, http://dx.doi.org/10.1002/2014JA020561.

Marcos, F., Bowman, B., and Sheehan, R. (2006), Accuracy of Earth's thermospheric neutral density models, in *AIAA/AAS Astrodynamics Specialist Conference and Exhibit*, p. 6167.

Marriott, R. T., Richmond, A. D., and Venkateswaran, S. V. (1979), The quiet-time equatorial electrojet and counter-electrojet, *Journal of geomagnetism and geoelectricity*, *31*(3), 311–340, doi:https://doi.org/10.5636/jgg.31.311.

Matsushita, S. (1968), Sq and L current systems in the ionosphere, *Geophysical Journal of the Royal Astronomical Society*, *15*(1-2), 109–125.

Matsushita, S. (1971), Interactions Between the Ionosphere and the Magnetosphere for Sq and L Variations, *Radio Science*, *6*(2), 279–294, http://dx.doi.org/10.1029/RS006i002p00279.

Matsushita, S., and Maeda, H. (1965), On the geomagnetic solar quiet daily variation field during the IGY, *Journal of Geophysical Research*, *70*(11), 2535–2558, http://dx.doi.org/10.1029/JZ070i011p02535.

Mayaud, P. N. (1976), Magnetospheric and night-time induced effects in the regular daily variation S_R, *Planetary and Space Science*, *24*, 1049–1057, http://dx.doi.org/10.1016/0032-0633(76)90123-9.

McPherron, R. L., Russell, C. T., and Aubry, M. P. (1973), Satellite studies of magnetospheric substorms on August 15, 1968: 9. Phenomenological model for substorms, *Journal of Geophysical Research*, *78*(16), 3131–3149, https://doi.org/10.1029/JA078i016p03131.

Millward, G. H., Mller-Wodarg, I. C. F., Aylward, A. D., Fuller-Rowell, T. J., Richmond, A. D., and Moffett, R. J. (2001), An investigation into the influence of tidal forcing on F region equatorial vertical ion drift using a global ionosphere-thermosphere model with coupled electrodynamics, *Journal of Geophysical Research*, *106*(A11), 24,733–24,744, http://dx.doi.org/10.1029/2000JA000342.

Mott-Smith, H. M., and Langmuir, I. (1926), The Theory of Collectors in Gaseous Discharges, *Physical Review*, *28*, 727–763, https://doi.org/10.1103/PhysRev.28.727.

Muralikrishna, P. (2006), Electron temperature variations in developing plasma bubbles rocket observations from Brazil, *Advances in Space Research*, *37*(5), 903–909, https://doi.org/10.1016/j.asr.2005.10.017.

Muralikrishna, P., Vieira, L. P., and Abdu, M. A. (2003), Electron density and electric field fluctuations associated with developing plasma bubbles, *Journal of Atmospheric and Solar-Terrestrial Physics*, *65*(14), 1315–1327, https://doi.org/10.1016/j.jastp.2003.08.010.

Nair, R. B., Jayachandran, B., Rao, P. B., and Balan, N. (1993), Seasonal, solar and magnetic activity effects on evening F region vertical plasma drifts, *Indian Journal of Radio & Space Physics*, *22*, 89–93, http://nopr.niscair.res.in/handle/123456789/35973.

Namba, S., and Maeda, K.-I. (1939), Radio wave propagation, *Corona, Tokyo*, p. 86.

Namboothiri, S. P., Balan, N., and Rao, P. B. (1989), Vertical plasma drifts in the F region at the magnetic equator, *Journal of Geophysical Research: Space Physics*, *94*(A9), 12,055–12,060, http://dx.doi.org/10.1029/JA094iA09p12055.

Nicolet, M., and Aikin, A. C. (1960), The formation of the D region of the ionosphere, *Journal of Geophysical Research*, *65*(5), 1469–1483, https://doi.org/10.1029/JZ065i005p01469.

Nishida, A. (1968), Geomagnetic Dp 2 fluctuations and associated magnetospheric phenomena, *Journal of Geophysical Research*, *73*(5), 1795–1803, https://doi.org/10.1029/JA073i005p01795.

Nopper, R. W., and Carovillano, R. L. (1978), Polar-equatorial coupling during magnetically active periods, *Geophysical Research Letters*, *5*(8), 699–702, https://doi.org/10.1029/GL005i008p00699.

Onwumechili, A., and Akasofu, S.-I. (1972), On the abnormal depression of Sq(H) under the equatorial electrojet in the afternoon, *Journal of geomagnetism and geoelectricity*, *24*(2), 161–173, http://dx.doi.org/10.5636/jgg.24.161.

Onwumechili, C. A. (1992a), A study of rocket measurements of ionospheric currents-I. General setting and night-time ionospheric currents, *Geophysical Journal International*, *108*(2), 633–640, http://dx.doi.org/10.1111/j.1365-246X.1992.tb04642.x.

Onwumechili, C. A. (1992b), A study of rocket measurements of ionospheric currents-III. Ionospheric currents at the magnetic dip equator, *Geophysical Journal International*, *108*(2), 647–659, http://dx.doi.org/10.1111/j.1365-246X.1992.tb04644.x.

Onwumechili, C. A., and Agu, C. E. (1981), Longitudinal variation of equatorial electrojet parameters derived from POGO satellite observations, *Planetary and Space Science*, *29*(6), 627–634, http://dx.doi.org/10.1016/0032-0633(81)90111-2.

Onwumechili, C. A., and Ezema, P. O. (1977), On the course of the geomagnetic daily variation in low latitudes, *Journal of Atmospheric and Terrestrial Physics*, *39*(9-10), 1079–1086, http://dx.doi.org/10.1016/0021-9169(77)90016-2.

Oppenheim, M. M., and Dimant, Y. S. (2016), Photoelectron-induced waves: A likely source of 150km radar echoes and enhanced electron modes, *Geophysical Research Letters*, *43*(8), 3637–3644, https://doi.org/10.1002/2016GL068179.

Oyekola, O. S. (2006), Comparison between nighttime ionosonde, incoherent scatter radar, AE-E satellite, and HF Doppler observations of F region vertical electrodynamic plasma drifts in the vicinity of the magnetic equator, *Journal of Geophysical Research*, *111*(A11), http://dx.doi.org/10.1029/2006JA011844.

Oyekola, O. S., Ojo, A., Akinrimisi, J., and dePaula, E. R. (2007), Seasonal and solar cycle variability in F-region vertical plasma drifts over Ouagadougou, *Journal of Geophysical Research*, *112*(A12), http://dx.doi.org/10.1029/2007JA012560.

Pai, G. L., and Sarabhai, V. A. (1964), Periodic fluctuations in the geomagnetic field during magnetic storms, *Planetary and Space Science*, *12*(9), 855–865, https://doi.org/10.1016/0032-0633(64)90045-5.

Pandey, K., Sekar, R., Anandarao, B. G., Gupta, S. P., and Chakrabarty, D. (2016), Estimation of nighttime dip-equatorial E-region current density using measurements and models, *Journal of Atmospheric and Solar-Terrestrial Physics*, *146*, 160–170, http://dx.doi.org/10.1016/j.jastp.2016.06.002.

Pandey, K., Sekar, R., Gupta, S. P., Chakrabarty, D., and Anandarao, B. G. (2017), Comparison of quiet time vertical plasma drifts with global empirical models over the indian sector: Some insights, *Journal of Atmospheric and Solar-Terrestrial Physics*, *157-158*, 42–54, http://dx.doi.org/10.1016/j.jastp.2017.03.012.

Pandey, K., Chakrabarty, D., and Sekar, R. (2018), Critical evaluation of the impact of disturbance dynamo on equatorial ionosphere during daytime, *Journal of Geophysical Research: Space Physics*, https://doi.org/10.1029/2018JA025686.

Pandey, K., Sekar, R., Anandarao, B. G., Gupta, S. P., and Chakrabarty, D. (2018), On the occurrence of afternoon counter electrojet over Indian longitudes during June solstice in solar minimum, *Journal of Geophysical Research: Space Physics*, *123*(3), 2204–2214, http://dx.doi.org/10.1002/2017JA024725.

Patil, A. R., Rao, D. R. K., and Rastogi, R. G. (1990a), Equatorial electrojet strengths in the Indian and American sectors Part I. During Low Solar Activity, *Journal of geomagnetism and geoelectricity*, *42*(7), 801–811, https://doi.org/10.5636/jgg.42.801.

Patil, A. R., Rao, D. R. K., and Rastogi, R. G. (1990b), Equatorial electrojet strengths in the Indian and American sectors Part II. During High Solar Activity, *Journal of geomagnetism and geoelectricity*, *42*(7), 813–823, https://doi.org/10.5636/jgg.42.813.

Patra, A. K., and Rao, N. V. (2006), Radar observations of daytime 150km echoes from outside the equatorial electrojet belt over Gadanki, *Geophysical Research Letters*, *33*(3), https://doi.org/10.1029/2005GL024564.

Patra, A. K., Sripathi, S., Rao, P. B., and Subbarao, K. S. V. (2005), Simultaneous VHF radar backscatter and ionosonde observations of low-latitude E region, *Annales Geophysicae*, *23*(3), 773–779, https://doi.org/10.5194/angeo-23-773-2005.

Patra, A. K., Chaitanya, P. P., Mizutani, N., Otsuka, Y., Yokoyama, T., and Yamamoto, M. (2012), A comparative study of equatorial daytime vertical E×B drift in the Indian and Indonesian sectors based on 150 km echoes, *Journal of Geophysical Research: Space Physics*, *117*(A11), https://doi.org/10.1029/2012JA018053.

Patra, A. K., Chaitanya, P. P., Otsuka, Y., Yokoyama, T., Yamamoto, M., Stoneback, R. A., and Heelis, R. A. (2014), Vertical E×B drifts from radar and C/NOFS observations in the Indian and Indonesian sectors: Consistency of observations and model, *Journal of Geophysical Research*, *119*(5), 3777–3788, http://dx.doi.org/10.1002/2013JA019732.

Patra, A. K., Chaitanya, P. P., St.-Maurice, J.-P., Otsuka, Y., Yokoyama, T., and Yamamoto, M. (2017), The solar flux dependence of ionospheric 150km radar echoes and implications, *Geophysical Research Letters*, *44*(22), 11,257–11,264, https://doi.org/10.1002/2017GL074678.

Pavan Chaitanya, P., Patra, A. K., and Rao, S. V. B. (2014), Quiet time short-period and day-to-day variations in E×B drift studied using 150 km radar echoes from Gadanki, *Journal of Geophysical Research: Space Physics*, *119*(4), 3053–3065, http://dx.doi.org/10.1002/2013JA019668.

Peymirat, C., Richmond, A. D., and Kobea, A. T. (2000), Electrodynamic coupling of high and low latitudes: Simulations of shielding/overshielding effects, *Journal of Geophysical Research: Space Physics*, *105*(A10), 22,991–23,003, http://dx.doi.org/10.1029/2000JA000057.

Pfaff, R. F., Sobral, J. H. A., Abdu, M. A., Swartz, W. E., LaBelle, J. W., Larsen, M. F., Goldberg, R. A., and Schmidlin, F. J. (1997), The Guará Campaign: A series of rocket-radar investigations of the Earth's upper atmosphere at the magnetic equator, *Geophysical Research Letters*, *24*(13), 1663–1666, http://dx.doi.org/10.1029/97GL01534.

Picone, J. M., Hedin, A. E., Drob, D. P., and Aikin, A. C. (2002), NRLMSISE-00 empirical model of the atmosphere: Statistical comparisons and scientific issues, *Journal of Geophysical Research*, *107*(A12), http://dx.doi.org/10.1029/2002JA009430.

Pingree, J. E., and Fejer, B. G. (1987), On the height variation of the equatorial F region vertical plasma drifts, *Journal of Geophysical Research*, *92*(A5), 4763–4766, http://dx.doi.org/10.1029/JA092iA05p04763.

Prabhakaran Nayar, S. R., and Sreehari, C. V. (2004), Investigation of height gradient in vertical plasma drift at equatorial ionosphere using multifrequency HF Doppler radar, *Journal of Geophysical Research*, *109*(A12), http://dx.doi.org/10.1029/2004JA010641.

Prakash, S., and Muralikrishna, P. (1976), The nature of electric field in E-region close to morning and evening reversals, *Geophysical Research Letters*, *3*(8), 445–447, http://dx.doi.org/10.1029/GL003i008p00445.

Prakash, S., and Pal, S. (1985), Electric fields and electron density irregularities

in the equatorial electrojet, *Journal of Atmospheric and Terrestrial Physics*, *47*(8), 853–866, https://doi.org/10.1016/0021-9169(85)90060-1.

Prakash, S., and Subbaraya, B. H. (1967), Langmuir probe for the measurement of electron density and electron temperature in the ionosphere, *Review of Scientific Instruments*, *38*(8), 1132–1136, https://doi.org/10.1063/1.1721035.

Prakash, S., Gupta, S. P., and Subbaraya, B. H. (1969), Irregularities in the equatorial E region over Thumba, *Radio Science*, *4*(9), 791–796, http://dx.doi.org/10.1029/RS004i009p00791.

Prakash, S., Gupta, S. P., and Subbaraya, B. H. (1970), A study of the irregularities in the night time equatorial E-region using a Langmuir probe and plasma noise probe, *Planetary and Space Science*, *18*(9), 1307–1318, http://dx.doi.org/10.1016/0032-0633(70)90141-8.

Prakash, S., Gupta, S. P., Subbaraya, B. H., and Jain, C. L. (1971a), Electrostatic plasma instabilities in the equatorial electrojet, *Nature Physical Science*, *233*(38), 56–58, http://dx.doi.org/10.1038/physci233056a0.

Prakash, S., Gupta, S. P., and Subbaraya, B. H. (1971b), Cross field instability and ionization irregularities in the equatorial E region, *Nature Physical Science*, *230*, 170–171, http://dx.doi.org/10.1038/physci230170a0.

Prakash, S., Subbaraya, B. H., and Gupta, S. P. (1972), Rocket measurements of ionization irregularities in the equatorial ionosphere at Thumba & identification of plasma instabilities, *Indian Journal of Radio & Space Physics*, *01*(1), 72–80, http://nopr.niscair.res.in/handle/123456789/38055.

Prakash, S., Jain, C. L., Balsley, B. B., and Greenwald, R. A. (1974), Evidence of two types of electron density irregularities in the electrojet over Thumba, India, *Journal of Geophysical Research*, *79*(28), 4334–4336, http://dx.doi.org/10.1029/JA079i028p04334.

Prakash, S., Gupta, S. P., Sinha, H. S. S., and Rao, T. R. (1976), Ionization

irregularities in the E region during counter electrojet, *Space Research XVI*, pp. 401–405.

Qian, C., Lei, J., and Wang, W. (2015), A simulation study on the impact of altitudinal dependent vertical plasma drift on the equatorial ionosphere in the evening, *Journal of Geophysical Research*, *120*(4), 2918–2925, http://dx.doi.org/10.1002/2014JA020626.

Rabiu, A. B., Folarin, O. O., Uozumi, T., Abdul Hamid, N. S., and Yoshikawa, A. (2017), Longitudinal variation of equatorial electrojet and the occurrence of its counter electrojet, *Annales Geophysicae*, *35*(3), 535–545, https://doi.org/10.5194/angeo-35-535-2017.

Raghavarao, R., and Anandarao, B. G. (1980), Vertical winds as a plausible cause for equatorial counter electrojet, *Geophysical Research Letters*, *7*(5), 357–360, http://dx.doi.org/10.1029/GL007i005p00357.

Raghavarao, R., and Anandarao, B. G. (1987), Equatorial electrojet and the Counter-Electrojet, *Indian Journal of Radio & Space Physics*, *16*, 54–75.

Raghavarao, R., Sharma, P., and Sivaraman, M. R. (1978), Correlation of ionization anomaly with the intensity of the electrojet, *Space Research*, *XVIII*, 277–280.

Raghavarao, R., Sridharan, R., and Suhasini, R. (1984), The importance of vertical ion currents on the nighttime ionization in the equatorial electrojet, *Journal of Geophysical Research*, *89*(A12), 11,033–11,037, https://doi.org/10.1029/JA089iA12p11033.

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

Raghavarao, R., Sridharan, R., Sastri, J. H., Agashe, V. V., Rao, C. N., Rao, P. B., and Somayajulu, V. V. (1988), The Equatorial Ionosphere, World Ionosphere Thermosphere Study, *WITS Handbook*, *1*, 48–93.

Rajaram, G. (1977), Structure of the equatorial F-region, topside and bottomsidea review, *Journal of Atmospheric and Terrestrial Physics*, *39*(9), 1125–1144, https://doi.org/10.1016/0021-9169(77)90021-6.

Rama Rao, P. V. S., Gopi Krishna, S., Niranjan, K., and Prasad, D. S. V. V. D. (2006), Temporal and spatial variations in TEC using simultaneous measurements from the Indian GPS network of receivers during the low solar activity period of 2004-2005, *Annales Geophysicae*, *24*(12), 3279–3292, https://doi.org/10.5194/angeo-24-3279-2006.

Ramesh, K. B., and Sastri, J. H. (1995), Solar cycle and seasonal variations in F-region vertical drifts over Kodaikanal, India, *Annales Geophysicae*, *13*(6), 633–640, http://dx.doi.org/10.1007/s00585-995-0633-7.

Rastogi, R. G. (1974), Lunar effects in the counter electrojet near the magnetic equator, *Journal of Atmospheric and Terrestrial Physics*, *36*(1), 167–170, http://dx.doi.org/10.1016/0021-9169(74)90074-9.

Rastogi, R. G. (1975), On the criterion of geomagnetic field at the time of disappearance of equatorial Esq layer, *Indian Journal of Radio & Space Physics*, *04*(1), 1–5, http://nopr.niscair.res.in/handle/123456789/37649.

Rastogi, R. G., and Chandra, H. (2012), Response of equatorial ionosphere during the super geomagnetic storm of April 2000, *Indian Journal of Radio & Space Physics*, *41*, 524–535, http://nopr.niscair.res.in/handle/123456789/36904.

Rastogi, R. G., and Iyer, K. N. (1976), Quiet day variation of geomagnetic H-field at low latitudes, *Journal of Geomagnetism and Geoelectricity*, *28*(6), 461–479, http://dx.doi.org/10.5636/jgg.28.461.

Rastogi, R. G., and Patel, V. L. (1975), Effect of interplanetary magnetic field

on ionosphere over the magnetic equator, *Proceedings of the Indian Academy Of Science*, *82*(A), 121–141.

Rastogi, R. G., and Patil, A. (1986), Complex structure of equatorial electrojet current, *Current Science*, *55*(9), 433–436.

Rastogi, R. G., Chandra, H., and James, M. E. (1996), Nocturnal variations of geomagnetic horizontal field at equatorial stations, *Geophysical Research Letters*, *23*(19), 2601–2604, http://dx.doi.org/10.1029/96GL02390.

Rastogi, R. G., Chandra, H., Janardhan, P., and Rahul, S. (2014), Equatorial and mid-latitude ionospheric currents over the Indian region based on 40 years of data at Trivandrum and Alibag, *Indian Journal of Radio & Space Physics*, *43*(4-5), 274–283, http://nopr.niscair.res.in/handle/123456789/30000.

Ravindran, S., and Krishna Murthy, B. V. (1997a), Occurrence of type I plasma waves in the equatorial electrojet during morning and evening hours, *Journal of Geophysical Research*, *102*(A5), 9761–9765, http://dx.doi.org/10.1029/96JA03742.

Ravindran, S., and Krishna Murthy, B. V. (1997b), Up-down asymmetry of type I plasma waves in the equatorial electrojet region, *Annales Geophysicae*, *15*(6), 774–778, http://dx.doi.org/10.1007/s00585-997-0774-y.

Reddy, C. A. (1989), The equatorial electrojet, *Pure and Applied Geophysics*, *131*(3), 485–508, https://doi.org/10.1007/BF00876841.

Reddy, C. A., Vikramkumar, B. T., and Viswanathan, K. S. (1987), Electric fields and currents in the equatorial electrojet deduced from VHF radar observations-I. A method of estimating electric fields, *Journal of Atmospheric and Terrestrial Physics*, *49*(2), 183–191, https://doi.org/10.1016/0021-9169(87)90053-5.

Reeves, G. D., Belian, R. D., and Fritz, T. A. (1991), Numerical tracing of energetic particle drifts in a model magnetosphere, *Journal of Geophysical Research: Space Physics*, *96*(A8), 13,997–14,008, https://doi.org/10.1029/91JA01161.

Reeves, G. D., Henderson, M. G., Skoug, R. M., F., T. M., Borovsky, J. E., Funtsen, H. O., C:Son Brandt, P., Mitchell, D. J., Jahn, J.-M., Pollock, C. J., McComas, D. J., and Mende, S. B. (2013), IMAGE, POLAR, and Geosynchronous Observations of Substorm and Ring Current Ion Injection, *American Geophysical Union*, pp. 91–101, https://doi.org/10.1029/142GM09.

Reinisch, B. W., Abdu, M., Batista, I., Sales, G. S., Khmyrov, G., Bullett, T. A., Chau, J., and Rios, V. (2004), Multistation digisonde observations of equatorial spread F in South America, *Annales Geophysicae*, *22*(9), 3145–3153, https://doi.org/10.5194/angeo-22-3145-2004.

Ren, Z., Wan, W., Xiong, J., and Liu, L. (2010), Simulated wave number 4 structure in equatorial F-region vertical plasma drifts, *Journal of Geophysical Research: Space Physics*, *115*, A05,301, https://doi.org/10.1029/2009JA014746.

Richmond, A. D. (1973), Equatorial electrojet-I. Development of a model including winds and instabilities, *Journal of Atmospheric and Terrestrial Physics*, *35*(6), 1083–1103, http://dx.doi.org/10.1016/0021-9169(73)90007-X.

Richmond, A. D., Peymirat, C., and Roble, R. G. (2003), Long-lasting disturbances in the equatorial ionospheric electric field simulated with a coupled magnetosphere-ionosphere-thermosphere model, *Journal of Geophysical Research: Space Physics*, *108*(A3), http://dx.doi.org/10.1029/2002JA009758.

Rishbeth, H. (1981), The F-region dynamo, *Journal of Atmospheric and Terrestrial Physics*, *43*(5), 387–392, https://doi.org/10.1016/0021-9169(81)90102-1.

Rishbeth, H., and Garriott, O. K. (1969), Introduction to ionospheric physics, *New York, Academic Press.*

Rodrigues, F. S., Nicolls, M. J., Milla, M. A., M., S. J., Varney, R. H., Strømme, A., Martinis, C., and Arratia, J. F. (2015), AMISR-14: Observations of equatorial spread F, *Geophysical Research Letters*, *42*(13), 5100–5108, https://doi.org/10.1002/2015GL064574.

Rout, D., Chakrabarty, D., Janardhan, P., Sekar, R., Maniya, V., and Pandey, K. (2017), Solar wind flow angle and geoeffectiveness of corotating interaction regions: First results, *Geophysical Research Letters*, *44*(10), 4532–4539, https://doi.org/10.1002/2017GL073038.

Rout, D., Chakrabarty, D., Sarkhel, S., Sekar, R., Fejer, B. G., Reeves, G. D., Kulkarni, A. S., Aponte, N., Sulzer, M. P., Mathews, J. D., Kerr, R. B., and Noto, J. (2018), The ionospheric impact of an ICME driven sheath region over Indian and American sectors in the absence of a typical geomagnetic storm, *Journal of Geophysical Research: Space Physics*, *123*, 4298–4308, https://doi.org/10.1029/2018JA025334.

Rush, C. M., and Richmond, A. D. (1973), The relationship between the structure of the equatorial anomaly and the strength of the equatorial electrojet, *Journal of Atmospheric and Terrestrial Physics*, *35*(6), 1171–1180, http://dx.doi.org/10.1016/0021-9169(73)90013-5.

Sagawa, E., Immel, T. J., Frey, H. U., and Mende, S. B. (2005), Longitudinal structure of the equatorial anomaly in the nighttime ionosphere observed by IMAGE/FUV, *Journal of Geophysical Research: Space Physics*, *110*, A11,302, https://doi.org/10.1029/2004JA010848.

Sampath, S., and Sastry, T. S. G. (1979), AC electric fields associated with the plasma instabilities in the equatorial electrojet-III, *Journal of Geomagnetism and Geoelectricity*, *31*(3), 391–400, http://doi.org/10.5636/jgg.31.391.

Sanatani, S. (1966), Electron density distribution in the ionosphere, Ph.D. thesis, Gujarat University.

Sastri, J. H. (1984), Duration of equatorial spread-F, *Annales Geophysicae*, *2*(3), 353–358.

Sastri, J. H. (1988), Equatorial electric-fields of ionospheric disturbance dynamo orgin, *Annales Geophysicae*, *6*(6), 635–642.

Sastri, J. H. (1990), Equatorial anomaly in F-region - A Review, *Indian Journal of Radio & Space Physics*, *19*(4), 225–240, http://nopr.niscair.res.in/handle/123456789/36285.

Sastri, J. H. (1996), Longitudinal dependence of equatorial F region vertical plasma drifts in the dusk sector, *Journal of Geophysical Research*, *101*(A2), 2445–2452, http://dx.doi.org/10.1029/95JA02759.

Sastri, J. H., Ramesh, K. B., Somayajulu, V. V., and Rao, J. V. S. V. (1991), Origin of short-period (30-300 s) Doppler frequency fluctuations of lower F region reflections in the equatorial electrojet region, *Radio Science*, *26*(6), 1403–1413, http://dx.doi.org/10.1029/91RS02021.

Sastri, J. H., Varma, V. K. M., and Prabhakaran Nayar, S. R. (1995), Height gradient of F region vertical drift in the evening equatorial ionosphere, *Geophysical Research Letters*, *22*(19), 2645–2648, http://dx.doi.org/10.1029/95GL02668.

Sastri, J. H., Lühr, H., Tachihara, H., Kitamura, T.-I., and Rao, J. V. S. V. (2000), Electric field fluctuations (25-35 min) in the midnight dip equatorial ionosphere, *Annales Geophysicae*, *18*(2), 252–256, https://doi.org/10.1007/s00585-000-0252-2.

Sastri, J. H., Kamide, Y., and Yumoto, K. (2003), Signatures for magnetospheric substorms in the geomagnetic field of dayside equatorial region: Origin of the ionospheric component, *Journal of Geophysical Research: Space Physics*, *108*(A10), https://doi.org/10.1029/2003JA009962.

Sastry, T. S. G. (1970), Diurnal changes in the parameters of the equatorial electrojet as observed by rocket-borne magnetometers, *Space Research X*, pp. 778–785.

Savitzky, A., and Golay, M. J. E. (1964), Smoothing and differentiation of data by simplified least squares procedures, *Analytical Chemistry*, *36*(8), 1627–1639, http://dx.doi.org/10.1021/ac60214a047.

Scherliess, L., and Fejer, B. G. (1997), Storm time dependence of equatorial disturbance dynamo zonal electric fields, *Journal of Geophysical Research: Space Physics*, *102*(A11), 24,037–24,046, http://dx.doi.org/10.1029/97JA02165.

Scherliess, L., and Fejer, B. G. (1999), Radar and satellite global equatorial F region vertical drift model, *Journal of Geophysical Research*, *104*(A4), 6829–6842, http://dx.doi.org/10.1029/1999JA900025.

Schoeberl, M. R. (1978), Stratospheric warmings: Observations and theory, *Reviews of Geophysics*, *16*(4), 521–538, http://dx.doi.org/10.1029/RG016i004p00521.

Sekar, R. (1990), Plasma instabilities and the dynamics of the equatorial F-region, Ph.D. thesis, Gujarat University.

Sekar, R., and Chakrabarty, D. (2008), Role of overshielding electric field on the development of pre-midnight plume event: Simulation results, *Journal of Atmospheric and Solar-Terrestrial Physics*, *70*(17), 2212–2221, https://doi.org/10.1016/j.jastp.2008.04.015.

Sekar, R., and Kelley, M. C. (1998), On the combined effects of vertical shear and zonal electric field patterns on nonlinear equatorial spread F evolution, *Journal of Geophysical Research: Space Physics*, *103*(A9), 20,735–20,747, https://doi.org/10.1029/98JA01561.

Sekar, R., and Raghavarao, R. (1987), Role of vertical winds on the Rayleigh-Taylor mode instabilities of the night-time equatorial ionosphere, *Journal of Atmospheric and Terrestrial Physics*, *49*(10), 981–985, https://doi.org/10.1016/0021-9169(87)90104-8.

Sekar, R., Chakrabarty, D., Narayanan, R., Sripathi, S., Patra, A. K., and Subbarao, K. S. V. (2004), Characterization of VHF radar observations associated with equatorial Spread F by narrow-band optical measurements, *Annales Geophysicae*, *22*(9), 3129–3136, https://doi.org/10.5194/angeo-22-3129-2004.

Sekar, R., Chakrabarty, D., and Pallamraju, D. (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, *Journal of Atmospheric and Solar-Terrestrial Physics*, *75-76*, 57–63, https://doi.org/10.1016/j.jastp.2011.05.009.

Sekar, R., Gupta, S. P., Acharya, Y. B., Chakrabarty, D., Pallamraju, D., Pathan, B. M., Tiwari, D., and Choudhary, R. K. (2013), Absence of streaming plasma waves around noontime over Thumba in recent times: Is it related to the movement of the dip equator?, *Journal of Atmospheric and Solar-Terrestrial Physics*, *103*, 8–15, http://dx.doi.org/10.1016/j.jastp.2013.02.005.

Sekar, R., Gupta, S. P., and Chakrabarty, D. (2014), On the altitude of initiation of the gradient drift waves at different longitude sectors in the vicinity of the dip equator, *Journal of Atmospheric and Solar-Terrestrial Physics*, *121*, 59–62, http://dx.doi.org/10.1016/j.jastp.2014.10.004.

Senior, C., and Blanc, M. (1984), On the control of magnetospheric convection by the spatial distribution of ionospheric conductivities, *Journal of Geophysical Research*, *89*(A1), 261–284, https://doi.org/10.1029/JA089iA01p00261.

Shuman, B. M. (1970), Rocket measurement of the equatorial electrojet, *Journal of Geophysical Research*, *75*(19), 3889–3901, http://dx.doi.org/10.1029/JA075i019p03889.

Simi, K. G., Thampi, S. V., Chakrabarty, D., Pathan, B. M., Prabhakaran Nayar, S. R., and Pant, T. K. (2012), Extreme changes in the equatorial electrojet under the influence of interplanetary electric field and the associated modification in the low-latitude F region plasma distribution, *Journal of Geophysical Research: Space Physics*, *117*(A3), http://dx.doi.org/10.1029/2011JA017328.

Singh, D., Gurubaran, S., and He, M. (2018), Evidence for the influence of DE3 tide on the occurrence of equatorial counter electrojet, *Geophysical Research Letters*, *45*, 21452150, http://dx.doi.org/10.1002/2018GL077076.

Smith, L. G. (1964), Langmuir probes for measurements in the ionosphere, *COSPAR Information Bull. No. 17, edited by K. Maeda*, pp. 37–81.

Somayajulu, V. V., Reddy, C. A., and Viswanathan, K. S. (1987), Penetration of magnetospheric convective electric field to the equatorial ionosphere during the substorm of March 22, 1979, *Geophysical Research Letters*, *14*(8), 876–879, https://doi.org/10.1029/GL014i008p00876.

Spencer, N. W., Brace, L. H., and Carignan, G. R. (1962), Electron temperature evidence for nonthermal equilibrium in the ionosphere, *Journal of Geophysical Research*, *67*(1), 157–175, https://doi.org/10.1029/JZ067i001p00157.

Spiro, R. W., Wolf, R. A., and Fejer, B. G. (1988), Penetrating of high-latitude-electric-field effects to low latitudes during SUNDIAL 1984, *Annales Geophysicae*, *6*, 39–49.

Sridharan, R., Pallam Raju, D., Somayajulu, V. V., Taori, A., Chakrabarty, D., and Raghavarao, R. (1999), Imprint of equatorial electrodynamical processes in the OI 630.0 nm dayglow, *Journal of Atmospheric and Solar-Terrestrial Physics*, *61*(15), 1143–1155, https://doi.org/10.1016/S1364-6826(99)00064-4.

Sridharan, S., Gurubaran, S., and Rajaram, R. (2002), Structural changes in the tidal components in mesospheric winds as observed by the MF radar during afternoon counter electrojet events, *Journal of Atmospheric and Solar-Terrestrial Physics*, *64*(12-14), 1455–1463, http://dx.doi.org/10.1016/S1364-6826(02)00109-8.

Sridharan, S., Sathishkumar, S., and Gurubaran, S. (2009), Variabilities of mesospheric tides and equatorial electrojet strength during major stratospheric warming events, *Annales Geophysicae*, *27*(11), 4125–4130, https://doi.org/10.5194/angeo-27-4125-2009.

Sripathi, S., Singh, R., Banola, S., Sreekumar, S., Emperumal, K., and Selvaraj, C. (2016), Characteristics of the equatorial plasma drifts as obtained by using Canadian Doppler ionosonde over southern tip of India, *Journal of Geophysical Research: Space Physics*, *121*(8), 8103–8120, https://doi.org/10.1002/2016JA023088.

Stening, R. J. (1977), Magnetic variations at other latitudes during reverse equatorial electrojet, *Journal of Atmospheric and Terrestrial Physics*, *39*(9), 1071–1077, http://dx.doi.org/10.1016/0021-9169(77)90015-0.

Stening, R. J. (1985), Modeling the equatorial electrojet, *Journal of Geophysical Research*, *90*(A2), 1705–1719, http://dx.doi.org/10.1029/JA090iA02p01705.

Stening, R. J. (1989a), A diurnal modulation of the lunar tide in the upper atmosphere, *Geophysical Research Letters*, *16*(4), 307–310, http://dx.doi.org/10.1029/GL016i004p00307.

Stening, R. J. (1989b), A calculation of ionospheric currents due to semidiurnal antisymmetric tides, *Journal of Geophysical Research*, *94*(A2), 1525–1531, http://dx.doi.org/10.1029/JA094iA02p01525.

Stening, R. J. (1992), The enigma of the counter equatorial electrojet and lunar tidal influences in the equatorial region, *Advances in Space Research*, *12*(6), 23–32, https://doi.org/10.1016/0273-1177(92)90036-W.

Stening, R. J., and Winch, D. E. (1987), Night-time geomagnetic variations at low latitudes, *Planetary and Space Science*, *35*(12), 1523–1539, http://dx.doi.org/10.1016/0032-0633(87)90078-X.

Stoneback, R. A., Heelis, R. A., Burrell, A. G., Coley, W. R., Fejer, B. G., and Pacheco, E. (2011), Observations of quiet time vertical ion drift in the equatorial ionosphere during the solar minimum period of 2009, *Journal of Geophysical Research*, *116*, A12,327, http://dx.doi.org/10.1029/2011JA016712.

Strobel, D. F., Young, T. R., Meier, R. R., Coffey, T. P., and Ali, A. W. (1974), The nighttime ionosphere: E region and lower F region, *Journal of Geophysical Research*, *79*(22), 3171–3178, https://doi.org/10.1029/JA079i022p03171.

Subbarao, K. S. V., and Krishna Murthy, B. V. (1994), Seasonal variations of equatorial spread-F, *Annales Geophysicae*, *12*(1), 33–39, https://doi.org/10.1007/s00585-994-0033-4.

Subbaraya, B. H., Muralikrishna, P., Sastry, T. S. G., and Prakash, S. (1972), A study of the structure of electrical conductivities and the electrostatic field within the equatorial electrojet, *Planetary and Space Science*, *20*(1), 47–52, http://dx.doi.org/10.1016/0032-0633(72)90139-0.

Subbaraya, B. H., Prakash, S., and Gupta, S. P. (1983), Electron densities in the equatorial lower ionosphere from the Langmuir probe experiments conducted at Thumba during 1966-1978, *Scientific report*, ISRO-PRL-SR-15-83.

Subbaraya, B. H., Prakash, S., and Gupta, S. P. (1985), Structure of the equatorial lower ionosphere from the Thumba Langmuir probe experiments, *Advances in Space Research*, *5*(7), 35–38, http://dx.doi.org/10.1016/0273-1177(85)90352-7.

Sudan, R. N., Akinrimisi, J., and Farley, D. T. (1973), Generation of small-scale irregularities in the equatorial electrojet, *Journal of Geophysical Research*, *78*(1), 240–248, http://dx.doi.org/10.1029/JA078i001p00240.

Sugiura, M., and Cain, J. C. (1966), A model equatorial electrojet, *Journal of Geophysical Research*, *71*(7), 1869–1877, http://dx.doi.org/10.1029/JZ071i007p01869.

Sugiura, M., and Poros, D. J. (1969), An improved model equatorial electrojet with a meridional current system, *Journal of Geophysical Research*, *74*(16), 4025–4034, http://dx.doi.org/10.1029/JA074i016p04025.

Takeda, M., and Araki, T. (1985), Electric conductivity of the ionosphere and nocturnal currents, *Journal of Atmospheric and Terrestrial Physics*, *47*(6), 601–609, http://dx.doi.org/10.1016/0021-9169(85)90043-1.

Tarpley, J. D. (1970), The ionospheric wind dynamo-II: Solar tides, *Planetary and Space Science*, *18*(7), 1091–1103, https://doi.org/10.1016/0032-0633(70)90110-8.

Thampi, S. V., Shreedevi, P. R., Choudhary, R. K., Pant, T. K., Chakrabarty, D., Sunda, S., Mukherjee, S., and Bhardwaj, A. (2016), Direct observa-

tional evidence for disturbance dynamo on the daytime low-latitude ionosphere: A case study based on the 28 June 2013 space weather event, *Journal of Geophysical Research: Space Physics*, *121*(10), 10,064–10,074, https://doi.org/10.1002/2016JA023037.

Thébault, E., et al. (2015), International Geomagnetic Reference Field: the 12th generation, *Earth, Planets and Space*, *67*(1), 1–19, http://dx.doi.org/10.1186/s40623-015-0228-9.

Tiwari, D., Patra, A. K., Viswanathan, K. S., Jyoti, N., Devasia, C. V., Subbarao, K. S. V., and Sridharan, R. (2003), Simultaneous radar observations of the electrojet plasma irregularities at 18 and 54.95 MHz over Trivandrum, India, *Journal of Geophysical Research*, *108*, 1368, http://dx.doi.org/10.1029/2002JA009698.

Untiedt, J. (1967), A model of the equatorial electrojet involving meridional currents, *Journal of Geophysical Research*, *72*(23), 5799–5810, http://dx.doi.org/10.1029/JZ072i023p05799.

Vasyliunas, V. M. (1970), Mathematical models of magnetospheric convection and its coupling to the ionosphere, in *Particles and Fields in the Magnetosphere*, pp. 60–71, https://doi.org/10.1007/978-94-010-3284-1_6.

Venkatesh, K., Fagundes, P. R., Prasad, D. S. V. V. D., Denardini, C. M., de Abreu, A. J., de Jesus, R., and Gende, M. (2015), Day-to-day variability of equatorial electrojet and its role on the day-to-day characteristics of the equatorial ionization anomaly over the Indian and Brazilian sectors, *Journal of Geophysical Research: Space Physics*, *120*(10), 9117–9131, http://dx.doi.org/10.1002/2015JA021307.

Vichare, G., and Rajaram, R. (2011), Global features of quiet time counterelectrojet observed by Ørsted, *Journal of Geophysical Research: Space Physics*, *116*, A04,306, http://dx.doi.org/10.1029/2009JA015244.

Vichare, G., Rawat, R., Jadhav, M., and Sinha, A. K. (2017), Seasonal variation

of the Sq focus position during 2006-2010, *Advances in Space Research*, *59*(2), 542–556, http://dx.doi.org/10.1016/j.asr.2016.10.009.

Viswanathan, K. S., Vikramkumar, B. T., and Reddy, C. A. (1987), Electric fields and currents in the equatorial electrojet deduced from VHF radar observations-II. Characteristics of electric fields on quiet and disturbed days, *Journal of Atmospheric and Terrestrial Physics*, *49*(2), 193–200, https://doi.org/10.1016/0021-9169(87)90054-7.

Wei, Y., Hong, M., Wan , A., W.and Du, Lei, J., Zhao, B., Wang, W., Ren, Z., and Yue, X. (2008), Unusually long lasting multiple penetration of interplanetary electric field to equatorial ionosphere under oscillating imf bz, *Geophysical Research Letters*, *35*(2), L02,102, http://dx.doi.org/10.1029/2007GL032305.

Wolf, R. A. (1970), Effects of ionospheric conductivity on convective flow of plasma in the magnetosphere, *Journal of Geophysical Research*, *75*(25), 4677–4698, https://doi.org/10.1029/JA075i025p04677.

Wolf, R. A., Spiro, R. W., Sazykin, S., and Toffoletto, F. R. (2007), How the Earth's inner magnetosphere works: An evolving picture, *Journal of Atmospheric and Solar-Terrestrial Physics*, *69*(3), 288–302, https://doi.org/10.1016/j.jastp.2006.07.026.

Woodman, R. F. (1970), Vertical drift velocities and east-west electric fields at the magnetic equator, *Journal of Geophysical Research*, *75*(31), 6249–6259, http://dx.doi.org/10.1029/JA075i031p06249.

Woodman, R. F. (2009), Spread F - an old equatorial aeronomy problem finally resolved?, *Annales Geophysicae*, *27*(5), 1915–1934, https://doi.org/10.5194/angeo-27-1915-2009.

Woodman, R. F., and La Hoz, C. (1976), Radar observations of F region equatorial irregularities, *Journal of Geophysical Research*, *81*(31), 5447–5466, https://doi.org/10.1029/JA081i031p05447.

Yadav, S., Dabas, R. S., Rupesh, M. D., Upadhayaya, A. K., and Gwal, A. K. (2013), Temporal and spatial variation of equatorial ionization anomaly by using multistation ionosonde data for the 19th solar cycle over the Indian region, *Advances in Space Research*, *51*(7), 1253–1265, http://dx.doi.org/10.1016/j.asr.2012.11.009.

Yamazaki, Y., and Kosch, M. J. (2015), The equatorial electrojet during geomagnetic storms and substorms, *Journal of Geophysical Research: Space Physics*, *120*(3), 2276–2287, http://dx.doi.org/10.1002/2014JA020773.

Yamazaki, Y., and Maute, A. (2017), Sq and EEJ - A review on the daily variation of the geomagnetic field caused by ionospheric dynamo currents, *Space Science Reviews*, *206*(1), 299–405, https://doi.org/10.1007/s11214-016-0282-z.

Zaka, K. Z., Kobea, A. T., Assamoi, P., Obrou, O. K., Doumbia, V., Boka, K., Adohi, B. J.-P., and Mene, N. M. (2009), Latitudinal profile of the ionospheric disturbance dynamo magnetic signature: comparison with the DP2 magnetic disturbance, *Annales Geophysicae*, *27*(9), 3523–3536, https://doi.org/10.5194/angeo-27-3523-2009.

List of Publications

Publications included in the thesis

1. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, and D. Chakrabarty (2016), Estimation of nighttime dip-equatorial E-region current density using measurements and models, *Journal of Atmospheric and Solar-Terrestrial Physics, 146*, 160 - 170.
   http://dx.doi.org/10.1016/j.jastp.2016.06.002

2. **Kuldeep Pandey**, R. Sekar, S. P. Gupta, D. Chakrabarty, B. G. Anandarao (2017), Comparison of quiet time vertical plasma drifts with global empirical models over the Indian sector: Some insights, *Journal of Atmospheric and Solar-Terrestrial Physics, 157 - 158*, 42 - 54.
   http://dx.doi.org/10.1016/j.jastp.2017.03.012

3. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, and D. Chakrabarty (2018), On the occurrence of afternoon counter electrojet over Indian longitudes during June solstice in solar minimum, *Journal of Geophysical Research: Space Physics, 123(3)*, 2204 - 2214.
   http://dx.doi.org/10.1002/2017JA024725

4. **Kuldeep Pandey**, D. Chakrabarty and R. Sekar (2018), Critical evaluation of the impact of disturbance dynamo on equatorial ionosphere during daytime, *Journal of Geophysical Research: Space Physics, 123*.
   https://doi.org/10.1029/2018JA025686

Publications not included in the thesis

1. Rout, D., D. Chakrabarty, P. Janardhan, R. Sekar, V. Maniya, and **Kuldeep Pandey** (2017), Solar wind flow angle and geoeffectiveness of corotating interaction regions: First results, *Geophysical Research Letters, 44*, 45324539. http://dx.doi.org/10.1002/2017GL073038

2. Rout, D., **Kuldeep Pandey**, D. Chakrabarty, and R. Sekar, Significant electric field perturbations in low latitude ionosphere due to the passage of two consecutive ICMEs during 6 - 8 September 2017, *under revision in Journal of Geophysical Research: Space Physics.*

Presentations at International/National Conferences

1. **Kuldeep Pandey**, D. Chakrabarty, R. Sekar, "Effect of disturbance dynamo on equatorial ionosphere during daytime" presented in the 15th International Symposium on Equatorial Aeronomy (ISEA-15) held at Physical Research Laboratory, India during 22 - 26 October 2018 [*Poster presentation - Best Young Scientist Paper Award*].

2. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, and D. Chakrabarty, "Afternoon counter electrojet over Indian longitudes during June solstice in solar minimum" presented in the 15th International Symposium on Equatorial Aeronomy (ISEA-15) held at Physical Research Laboratory, India during 22 - 26 October 2018 [*Oral presentation*].

3. **Kuldeep Pandey**, D. Chakrabarty, R. Sekar, "Significantly Large Impact of Disturbance Dynamo on Equatorial Ionosphere: Case Studies" presented in the 15th Annual Meeting of Asia Oceania Geosciences Society (AOGS) held at Hawaii, USA during 3 - 8 June 2018 [*Oral presentation*].

4. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, and D. Chakrabarty, "On the Occurrence of Afternoon Counter Electrojet Over Indian Longitudes During June Solstice in Solar Minimum" presented in the 15th Annual Meeting of Asia Oceania Geosciences Society (AOGS) held at Hawaii, USA during 3 - 8 June 2018 [*Oral presentation*].

5. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, D. Chakrabarty, "Estimation of nighttime current density and daytime zonal electric field over the dip-equatorial E-region" presented in the 3rd URSI-Regional Conference on Radio Science (URSI-RCRS-2017) held at National Atmospheric Research Laboratory, India during 1 - 4 March 2017 [*Poster presentation*].

6. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, and D. Chakrabarty, "Estimation of nighttime equatorial E-region current densities using electrojet model" presented in the 19th National Space Science Symposium (NSSS-2016) held at Vikram Sarabhai Space Centre, India during 9 - 12 February 2016 [*3rd Prize in Students' Poster Presentation*].

7. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, D. Chakrabarty, "Estimations of Nighttime Equatorial E-region Currents", presented in the 2nd URSI-Regional Conference on Radio Science (URSI-RCRS-2015) held at Jawaharlal Nehru University, India during 16 - 19 November 2015 [*2nd Prize in Students' Poster Presentation*].

International School Attended

Heliophysics Summer School (Year 12) held at High Altitude Observatory, Boulder, Colorado, USA during 24 - 31 July, 2018.

Publications attached with thesis

1. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, and D. Chakrabarty (2016), Estimation of nighttime dip-equatorial E-region current density using measurements and models, *Journal of Atmospheric and Solar-Terrestrial Physics, 146*, 160 - 170.
   http://dx.doi.org/10.1016/j.jastp.2016.06.002

2. **Kuldeep Pandey**, R. Sekar, S. P. Gupta, D. Chakrabarty, B. G. Anandarao (2017), Comparison of quiet time vertical plasma drifts with global empirical models over the Indian sector: Some insights, *Journal of Atmospheric and Solar-Terrestrial Physics, 157 - 158*, 42 - 54.
   http://dx.doi.org/10.1016/j.jastp.2017.03.012

3. **Kuldeep Pandey**, R. Sekar, B. G. Anandarao, S. P. Gupta, and D. Chakrabarty (2018), On the occurrence of afternoon counter electrojet over Indian longitudes during June solstice in solar minimum, *Journal of Geophysical Research: Space Physics, 123(3)*, 2204 - 2214.
   http://dx.doi.org/10.1002/2017JA024725

4. **Kuldeep Pandey**, D. Chakrabarty and R. Sekar (2018), Critical evaluation of the impact of disturbance dynamo on equatorial ionosphere during daytime, *Journal of Geophysical Research: Space Physics, 123*.
   https://doi.org/10.1029/2018JA025686