AFRL-AFOSR-VA-TR-2024-0159

Investigating the Range of Response of Auroral Electron Precipitation in High Latitude Electrodynamics

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02/14/2024
Final Technical Report

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Air Force Research Laboratory
Air Force Office of Scientific Research
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

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1. REPORT DATE	**2. REPORT TYPE**	**3. DATES COVERED**	
20240214	Final	**START DATE** 20190502	**END DATE** 20220501

4. TITLE AND SUBTITLE
Investigating the Range of Response of Auroral Electron Precipitation in High Latitude Electrodynamics

5a. CONTRACT NUMBER	**5b. GRANT NUMBER**	**5c. PROGRAM ELEMENT NUMBER**
	FA9550-19-1-0130	61102F
5d. PROJECT NUMBER	**5e. TASK NUMBER**	**5f. WORK UNIT NUMBER**

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
CLEMSON UNIVERSITY 201 SIKES HALL CLEMSON, SC 29634 USA	

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSOR/MONITOR'S ACRONYM(S)**	**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**
Air Force Office of Scientific Research 875 N. Randolph St. Room 3112 Arlington, VA 22203	AFRL/AFOSR RTB1	AFRL-AFOSR-VA-TR-2024-0159

12. DISTRIBUTION/AVAILABILITY STATEMENT
A Distribution Unlimited: PB Public Release

13. SUPPLEMENTARY NOTES

14. ABSTRACT
Understanding how energy flows from the plasma trapped in the Earth’s magnetic field, the magnetosphere, into the Earth’s upper atmosphere, the ionosphere-thermosphere, is a fundamental process in space weather. Within the ionosphere-thermosphere, energy from the magnetosphere is dissipated by friction between the ionized plasma and the atmospheric neutral gas, which is driven by the interaction of electrical currents, electric fields, neutral winds, and conductivity through Ohm’s law. The ionosphere acts like a resistor in the magnetosphere-ionosphere electrical circuit. The conductivity is difficult to specify since it is not directly observed by ground- or space-based instrumentation. Conductivities driven by auroral precipitation are particularly challenging to quantify due to rapid temporal changes, significant magnitudes, and the localized nature of phenomena. Space weather models do not produce satisfactory agreement with data, which is thought to be due to an inadequate specification of conductivity associated with auroral phenomena. We will investigate and quantify the full range of response of the ionospheric E-region electron density and conductivity caused by auroral electron precipitation. We will analyze a 10+ year (2008-2018) database of nearly continuously sampled incoherent scatter radar observations provided by the Poker Flat Incoherent Scatter Radar to quantify the E-region electron density and conductivity
enhancements caused auroral electron precipitation. We will statistically analyze a database of auroral events. We will also undertake a much-needed update to empirical models of the Hall and Pedersen conductance, and we will develop an empirical orthogonal function model for the altitude-resolved conductivity and E-region electron density. We will evaluate the performance these empirical conductance and conductivities models within mesoscale and global ionosphere-thermosphere models.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**	UU	4
U	U	U		

19a. NAME OF RESPONSIBLE PERSON	**19b. PHONE NUMBER** *(Include area code)*
JULIE MOSES	426-9586

Standard Form 298 (Rev.5/2020)
Prescribed by ANSI Std. Z39.18

Award Number:
FA9550-19-1-0130

Report Type:
Final Report

Reporting Period:
5/1/2019 – 07/01/2023

Distribution Statement:
Distribution A: Approved for Public Release

Program Officer:
Dr. Julie Moses

Principal Investigator Name:
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Project Title:
Investigating the Range of Response of Auroral Electron Precipitation

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Understanding how energy flows from the plasma trapped in the Earth's magnetic field, the magnetosphere, into the Earth's upper atmosphere, the ionosphere-thermosphere, is a fundamental process in space weather. Within the ionosphere-thermosphere, energy from the magnetosphere is dissipated by friction between the ionized plasma and the atmospheric neutral gas, which is driven by the interaction of electrical currents, electric fields, neutral winds, and conductivity through Ohm's law. The ionosphere acts like a resistor in the magnetosphere-ionosphere electrical circuit. The conductivity is difficult to specify since it is not directly observed by ground- or space-based instrumentation. Conductivities driven by auroral precipitation are particularly challenging to quantify due to rapid temporal changes, significant magnitudes, and the localized nature of phenomena. Space weather models do not produce satisfactory agreement with data, which is thought to be due to an inadequate specification of conductivity associated with auroral phenomena.

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ACCOMPLISHMENTS

ACTIVITIES:

Year 2019:

1. Project initiation and getting original codes up and running.

Year 2020:

1. Undergraduate student William Youngblood has been manually categorizing auroral morphology using all sky imager data. He is categorizing based on discrete, diffuse, and pulsating aurora for the year 2015.
2. Presented an invited presentation (poster due to COVID) at AGU 2020. As part of this effort, I wrote the code to run the Levenberg Marquardt fitting on the "fitted" electron density data in the E-region, similar to Kaeppler et al., 2015. That code is working and I ran it for ALL data from the year 2016. This is a 2-parameter fit, given ~11 data points (when I assume a Maxwellian distribution). This is effectively Example 1 from the slides presented at the AFOSR program review in January 2021.

Year 2021:

1. Changed focus away from Levenberg-Marquardt fitting method used in Kaeppler et al., 2015. Given the coarse resolution of the PFISR data, it may be hard to distinguish, for example, 1 keV electron fluxes from 2 keV electron fluxes, since their altitude peak may be between two altitude grid points. Second, developed a more direct inversion that relaxed the requirements on the type of flux being used.
2. Code developed by Riley Troyer was able to perform maximum entropy inversion of the energy flux and average energy using Rees, 1963 precipitation model. Implemented this code as part of the effort for performing the inversions. Issues remained in implementing the more recent Fang et al., 2010 ionization model.
3. Assisted with the co-authorship of Troyer et al., 2022.

Year 2022:

1. Danielle Markowski performed manual identification of auroral morphology in all sky imager data from Poker Flat Research Range at same time as ISR observations. Developed databased that spanned the years 2012-2016 for spring, fall, and winter months.
2. Reprocessed PFISR data so that calibrated electron density could be produced at 1.5 km range resolution from alternating code data. This data product is a "one off" and not what is typically available from AMISR.com. Data are still available to scientific community. Reprocessed all ISR data for the years 2012-2016 for the same time intervals as the all sky imager data.
3. Streamlined implementing the maximum entropy inversion using the Rees electron transport model. Had issues implementing Fang et al., 2010 model, but ran all results using the Rees model.
4. Presented statistical study at AGU 2022 in Chicago that used the Rees model.
5. Published Frontiers paper on the pyGPI5 code which included E-region chemistry algorithms developed as part of this effort.

6. Undergraduate Stephen (Arun) Chandler, Casey King, and Fermin Redondo develop a Langmuir probe to measure electron densities which are essential for understanding conductivity.

Year 2023:

1. Corrected problem with implementation of Fang et al., 2010 code and was able to rapidly rerun all of the 2022 results using Rees now using the Fang model.
2. Published conductance results using Fang et al., 2010 model in JGR-Space Physics.

IMPACT:

The primary purpose of this investigation was to develop empirical conductance models associated with auroral precipitation that could be implemented into magnetosphere-ionosphere models. We have accomplished this objective by developing easy-to-calculate conductance models associated with different auroral morphologies. There is a strong need within the community currently for such models and especially to improve space weather forecasting capabilities.

This investigation also included contributions to 4 peer authored publications, 1 book chapter and 3 presentations at a major national conference in the field. Two graduate students participated in this investigation and several undergraduates also contributed to this effort. This effort contributed significantly to the PI's tenure portfolio.

Publications and Presentations:

1. Gabrielse C, Nishimura T, Chen M, Hecht JH, Kaeppler SR, Gillies DM, Reimer AS, Lyons LR, Deng Y, Donovan E and Evans JS (2021) Estimating Precipitating Energy Flux, Average Energy, and Hall Auroral Conductance From THEMIS All-Sky-Imagers With Focus on Mesoscales. *Front. Phys.* 9:744298. doi: 10.3389/fphy.2021.744298
2. Gabrielse, C., **Kaeppler, S.R.**, Lu G., Yu, Y., Wang W., (2022) " Chapter 4- Energetic particle dynamics, precipitation and conductivity" in *Cross-Scale Coupling and Energy Transfer in the Magnetosphere-Ionosphere-Thermosphere System* edited by Toshi Nishimura, Olga Verkhogladova, Yue Deng, Cheryl Huang and Shunrog Zhang, Elsevier., pp. 217-300, https://doi.org/10.1016/B978-0-12-821366-7.00002-0
3. **Kaeppler S.R.**, Marshall R., Sanchez E.R., Juarez Madera D.H., Troyer R. and Jaynes A.N. (2022) pyGPI5: A python D- and E-region chemistry and ionization model. *Front. Astron. Space Sci.* 9:1028042. doi: 10.3389/fspas.2022.1028042
4. Troyer R.N., Jaynes A.N., **Kaeppler S.R.,** Varney RH, Reimer AS and Jones SL (2022) Substorm activity as a driver of energetic pulsating aurora. *Front. Astron. Space Sci.* 9:1032552. https://doi.org/10.3389/fspas.2022.1032552
5. **Kaeppler, S. R.,** Markowski, D. G., Pepper, A. M., Troyer, R., Jaynes, A. N., Varney, R. H., & Hampton, D. (2023). Data-driven empirical conductance relations during auroral precipitation using incoherent scatter radar and all sky imagers. *Journal of Geophysical Research: Space Physics*, 128, e2023JA031764. https://doi.org/10.1029/2023JA031764

Presentations:

1. Kaeppler, S.R., Zhan W., Varney R.H., Reimer A.S., “Toward Development of Empirical Conductance Relations using Incoherent Scatter Radar Data”, AGU Fall Meeting 2020, SA030-0002 (Invited), https://ui.adsabs.harvard.edu/abs/2020AGUFMSA0300002K/abstract
2. Andrew Pepper, Austin Smith, Stephen R. Kaeppler., “Statistics of High Latitude Sporadic E Layer Occurrence derived using Incoherent Scatter Radar Observations”, AGU Fall Meeting 2021, SA45D-2250 (contributed), https://ui.adsabs.harvard.edu/abs/2021AGUFMSA45D2250P/abstract
3. Kaeppler S.R., Markowski, D.G., Pepper, A.M., Troyer, R., Jaynes, A.N., Varney, R.H., Hampton D.L., “An Incoherent Scatter Radar and All Sky Imager Derived Empirical Conductance Model,” AGU Fall Meeting 2022, SM35C-1766, https://ui.adsabs.harvard.edu/abs/2022AGUFMSM35C1766K/abstract

Dataset:

1. Stephen Kaeppler. (2023). Dataset for "Data-driven empirical conductance relations during auroral precipitation using incoherent scatter radar and all sky imagers" JGR-Space Physics [Data set]. Zenodo. https://doi.org/10.5281/zenodo.8329371

CHANGES:

Nothing to report.

TECHNICAL UPDATES:

Nothing to report.