Assimilative Mapping of Geospace Observations (AMGeO): Data Science Tools for Collaborative Geospace Systems Science

TOMOKO MATSUO[1]

[1]University of Colorado Boulder

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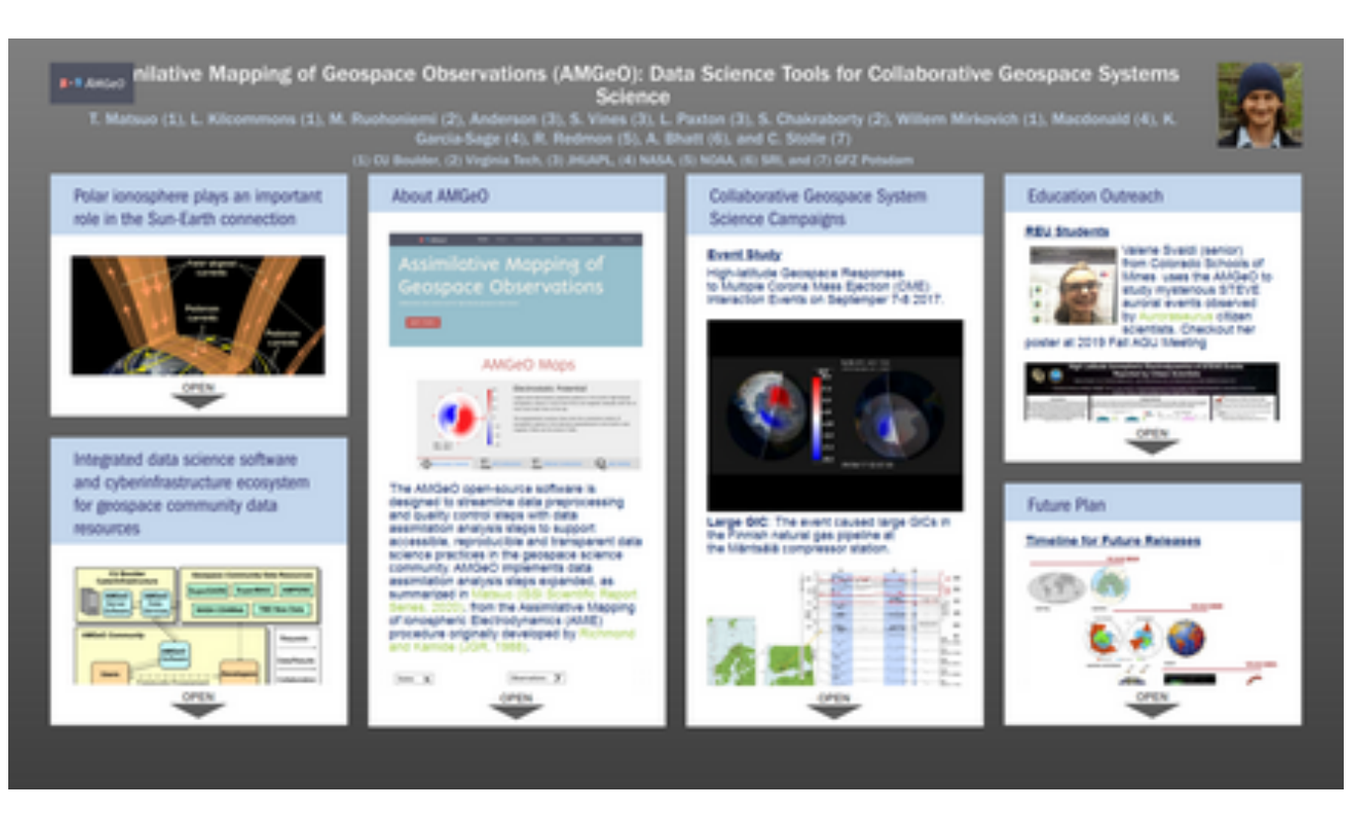
Abstract

The most dynamic electromagnetic energy and momentum exchange processes between the upper atmosphere and the magnetosphere take place in the polar ionosphere, as evidenced by the aurora. Accurate specification of the constantly changing conditions of high-latitude ionospheric electrodynamics has been of paramount interest to the geospace science community. In response this community's need for research tools to combine heterogeneous observational data from distributed arrays of small ground-based instrumentation operated by individual investigators with global geospace data sets, an open-source Python software and associated web-applications for Assimilative Mapping of Geospace Observations (AMGeO) are being developed and deployed (https://amgeo.colorado.edu). AMGeO provides a coherent, simultaneous and inter-hemispheric picture of global ionospheric electrodynamics by optimally combining diverse geospace observational data in a manner consistent with first-principles and with rigorous consideration of the uncertainty associated with each observation. In order to engage the geospace community in the collaborative geospace system science campaigns and a science-driven process of data product validation, AMGeO software is designed to be transparent, expandable, and interoperable with established geospace community data resources and standards. This paper presents an overview of the AMGeO software development and deployment plans as part of a new NSF EarthCube project that has started in September 2019.

Assimilative Mapping of Geospace Observations (AMGeO): Data Science Tools for Collaborative Geospace Systems Science

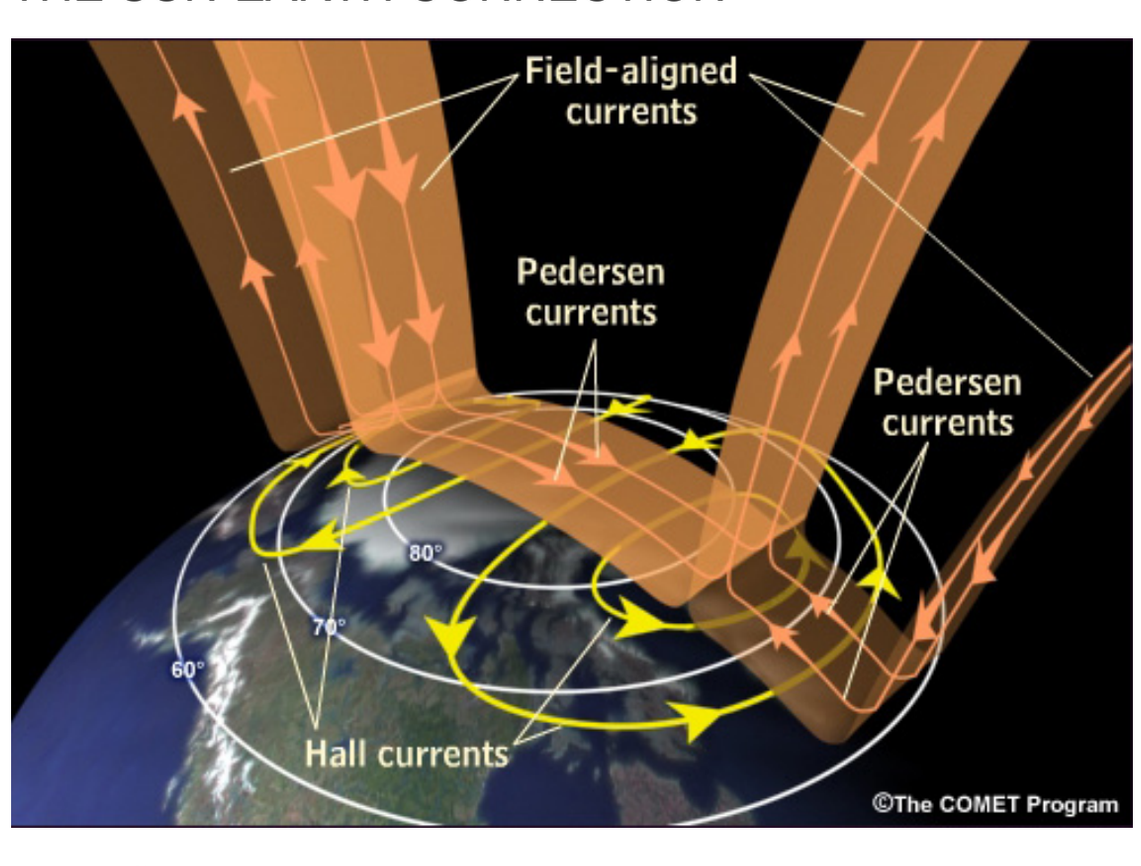

Assimilative Mapping of Geospace Observations (AMGeO): Data Science Tools for Collaborative Geospace Systems Science
Polar ionosphere plays an important role in the Sun-Earth connection
Integrated data science software and cyberinfrastructure ecosystem for geospace community data resources
About AMGeO
Collaborative Geospace System Science Campaigns
Education Outreach
Future Plan
OPEN

T. Matsuo (1), L. Kilcommons (1), M. Ruohoniemi (2), Anderson (3), S. Vines (3), L. Paxton (3), S. Chakraborty (2), Willem Mirkovich (1), Macdonald (4), K. Garcia-Sage (4), R. Redmon (5), A. Bhatt (6), and C. Stolle (7)

(1) CU Boulder, (2) Virginia Tech, (3) JHUAPL, (4) NASA, (5) NOAA, (6) SRI, and (7) GFZ Potsdam

PRESENTED AT:

POLAR IONOSPHERE PLAYS AN IMPORTANT ROLE IN THE SUN-EARTH CONNECTION



Why We Care

Polar ionospheric electrodynamics play an important role in the Sun-Earth connection chain, acting as one of the major driving forces of the upper atmosphere and providing us with a means to probe physical processes in the distant magnetosphere. Accurate specification of the constantly changing conditions of high-latitude geospace has been of paramount interest to the geospace science community. Also they also affects our everyday life for example by disturning radio communication and navigation systems and causing geomagnetically induced currents (GIC) that can damage electric powertransmission grids, oil and gas pipelines.

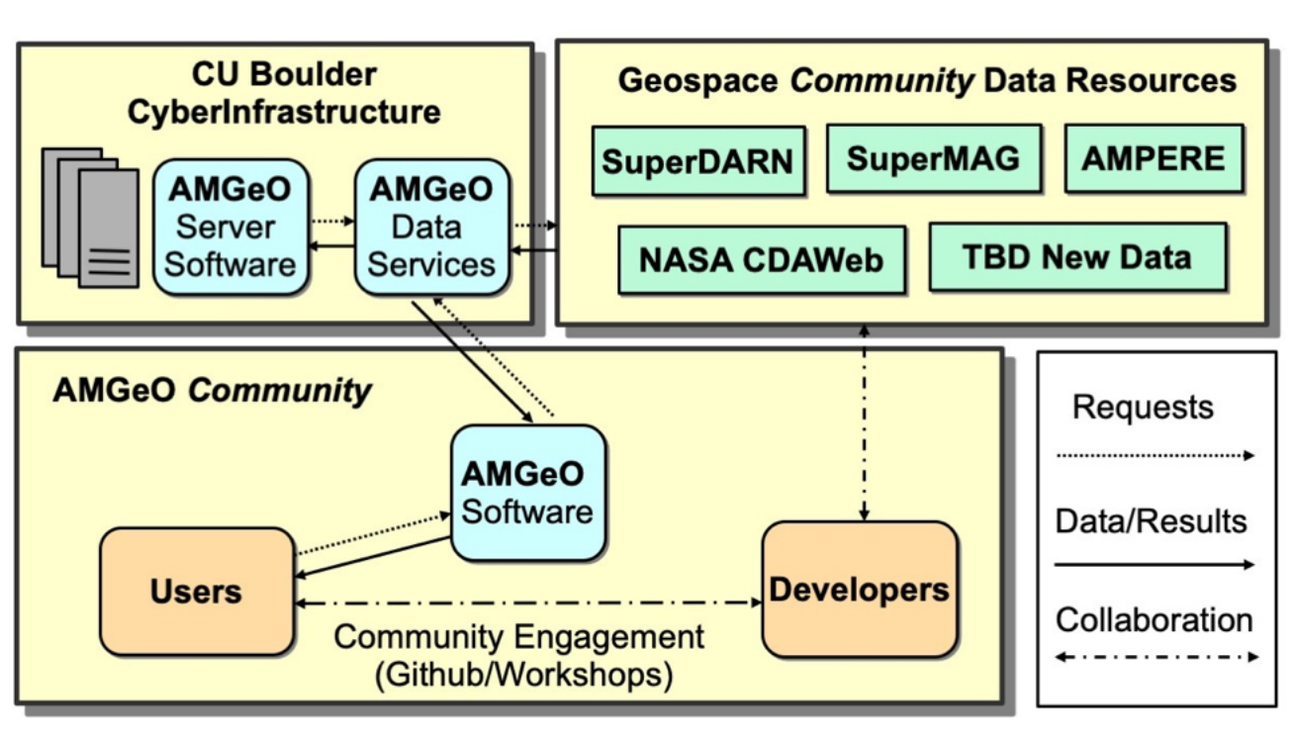
What We Want

Inspired by recent advancements in geospace observing capabilities and the opportunities of Big Data, **the goals of our NSF EarthCube Data Capabilities: Assimilative Mapping of Geospace Observations (AMGeO) project (Sep 2019-Aug 2022, ICER-1928403, ICER-1928358, ICER-1928327)** are (1) to develop and deploy an open-source Python software and associated web-applications are interoperable with established geospace community data resources and standards, and (2) to create fully reproduceable, validated reanalysis data products that can be accessed from established data repositories to maximize the scientific return on the NSF, DOD and NASA program investments, such as AMPERE, SuperDARN, SuperMAG, DMSP and TIMED. The capabilities of existing data assimilation and data analysis tools, developed as part of the PI's earlier EarthCube pilot project, will be extended to take advantage of the latest development and findings in the geospace sciences.

Give it a Try!

We released AMGeO v1.0.0 in December 2019, and the latest version can be downloaded frorm GitHub after registering at AMGeO Website.

INTEGRATED DATA SCIENCE SOFTWARE AND CYBERINFRASTRUCTURE ECOSYSTEM FOR GEOSPACE COMMUNITY DATA RESOURCES


CU Boulder CyberInfrastructure
AMGeO Server Software
AMGeO Data Services
Geospace Community Data Resources
SuperDARN
SuperMAG
AMPERE
NASA CDAWeb
TBD New Data
AMGeO Community
AMGeO Software
Users
Developers
Community Engagement (Github/Workshops)
Requests
Data/Results
Collaboration

CU Boulder Cyberinfrastructure

- **AMGeO Data Services** interface directly with geospace community data resources (see below) and routes the required data to the AMGeO Core Software installed on users' computers. AMGeO Data Services furthermore track the number and frequency of data requests, handle user authentication with various data services, and format data appropriately. *Note that AMGeO Data Services do not redistribute geospace community data.*
- **AMGeO Server Software** include an informative web site about the project and software (amgeo.colorado.edu).

Geospace Community Data Resources

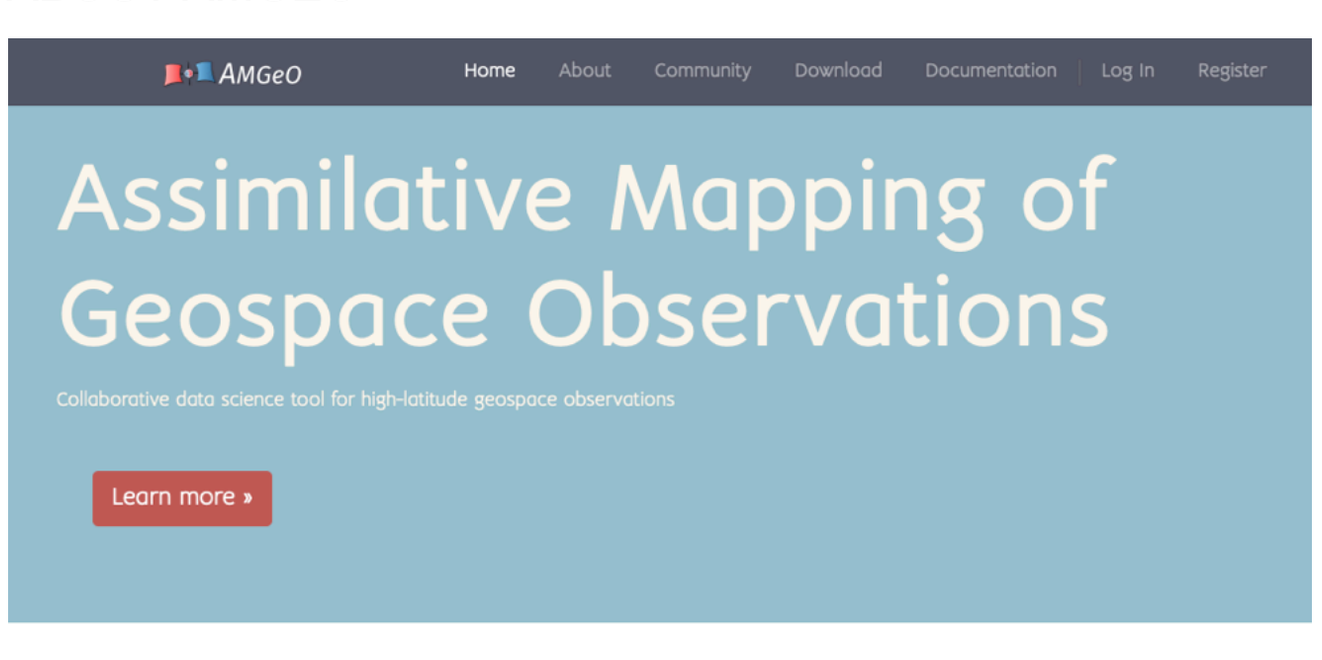
- **SuperDARN** stands for Super Dual Auroral Radar Network. The network consists of more than 30 HF radars that look into Earth's upper atmosphere at mid- and high-latitudes. AMGeO v1 assimilates SuperDARN line-of-sight plasma drifts.
- **AMPERE** stands for Active Magnetosphere and Planetary Electrodynamics Response Experiment. AMPERE repuporses magnetometer data used for navagation of the Iridium satellite constellation (66+spares LEO satellites) for monitoring of field-aligned currents. AMGeO v2 (planed to be released in December 2020) will assimilate AMPERE's Iridium magnetometer data products.
- **SuperMAG** provides easy access to validated and standardized ground magnetic field perturbations frrom more than 300 worldwide ground based magnetometers. AMGeO v1 assimilates magnetometer data provided by the SuperMAG data service.
- **NASA CDAWeb** is the NASA/GSFC Space Physics Data Facility's data service that makes data from current and past space physics missions accessible to public. AMGeO v1 uses data from CDAWeb to drive the prior background models.

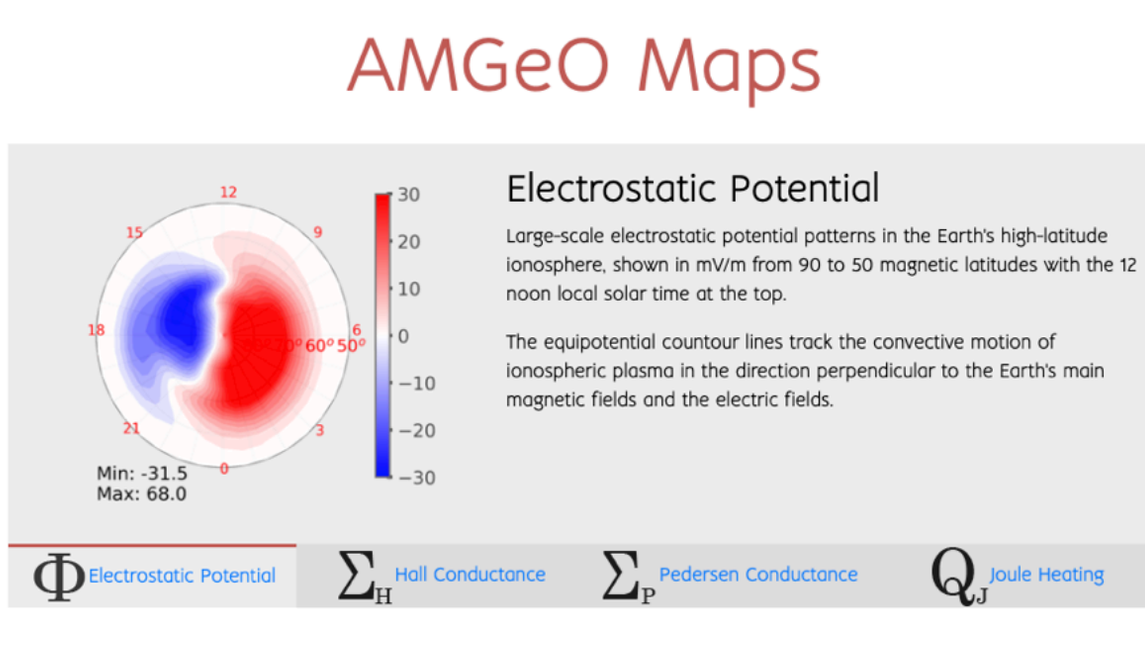
AMGeO Community

AMGeO Community is the place to share users' experience and analysis results using AMGeO, and to contribute users' ideas and software to AMGeO Core Software.

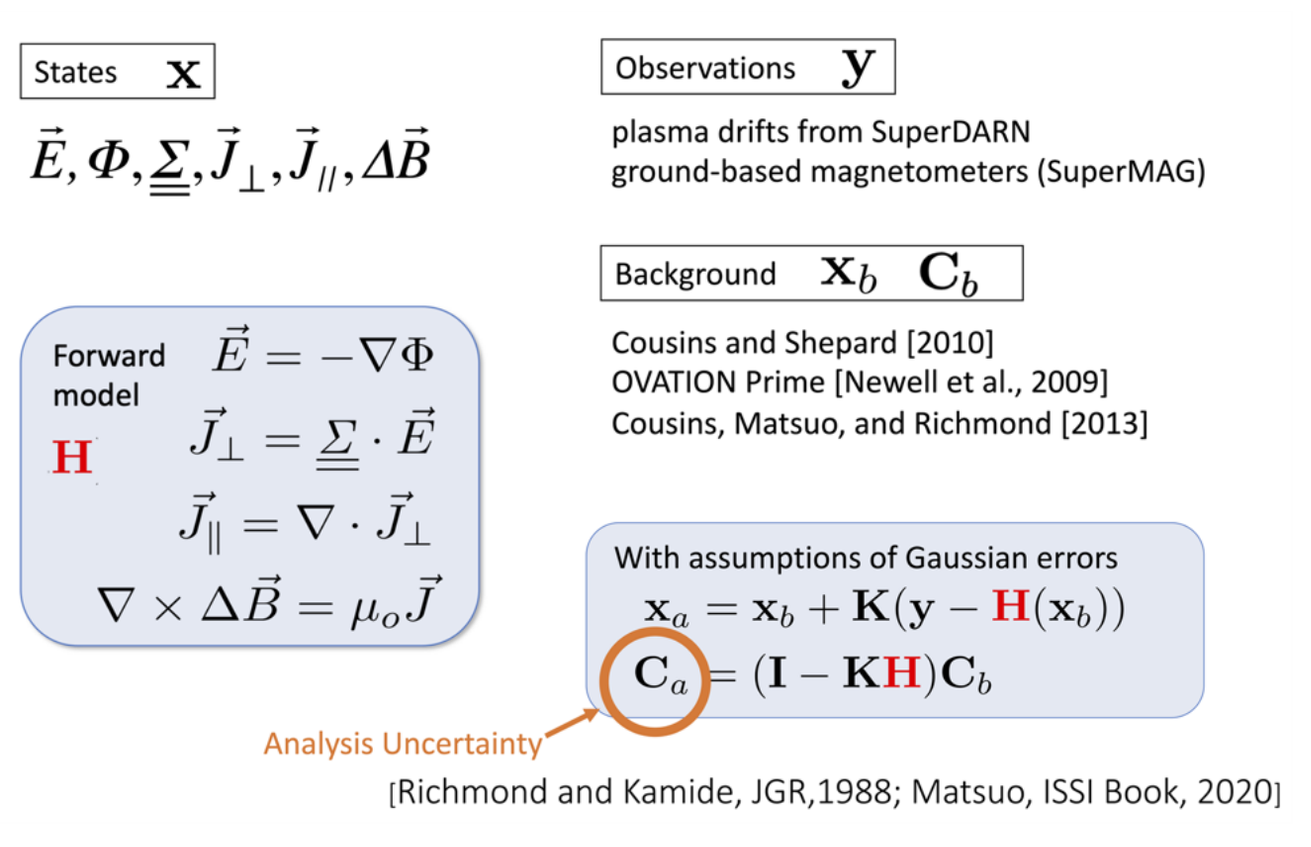
- **AMGeO (Core) Software** is a well documented, accessible, expandable open-source geospace data assimilation Python tool package that is fully interoperable with established geospace community data resources and standards.
- **AMGeO's Collaboration** among developers and individual users and the eventual formation of an AMGeO Community will be facilitated by the GitHub Education program.

ABOUT AMGEO

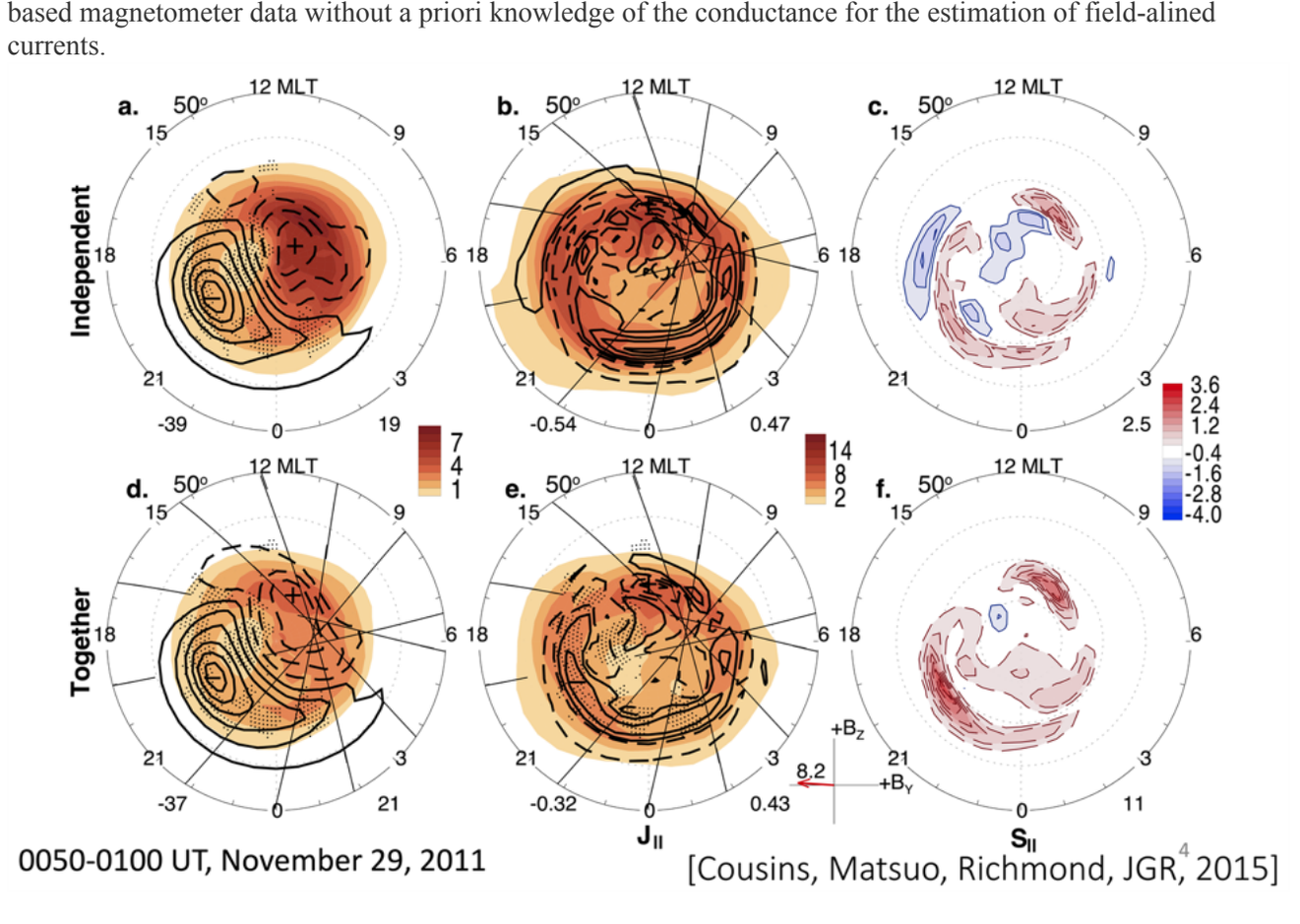



AMGeO Maps
Electrostatic Potential
Large-scale electrostatic potential patterns in the Earth's high-latitude ionosphere, shown in mV/m from 90 to 50 magnetic latitudes with the 12 noon local solar time at the top.
The equipotential countour lines track the convective motion of ionospheric plasma in the direction perpendicular to the Earth's main magnetic fields and the electric fields.
Min: -31.5
Max: 68.0
Electrostatic Potential
Hall Conductance
Pedersen Conductance
Joule Heating

The AMGeO open-source software is designed to streamline data preprocessing and quality control steps with data assimilation analysis steps to support accessible, reproducible and transparent data science practices in the geospace science community. AMGeO implements data assimilation analysis steps expanded, as summarized in Matsuo (ISSI Scientific Report Series, 2020), from the Assimilative Mapping of Ionospheric Electrodynamics (AMIE) procedure originally developed by Richmond and Kamide (JGR, 1988).


States x
Observations y
plasma drifts from SuperDARN
ground-based magnetometers (SuperMAG)
Background
Cousins and Shepard [2010]
OVATION Prime [Newell et al., 2009]
Cousins, Matsuo, and Richmond [2013]
Forward model
H
With assumptions of Gaussian errors
Analysis Uncertainty
[Richmond and Kamide, JGR,1988; Matsuo, ISSI Book, 2020]

A recent extension of the assimilation technique (Matsuo et al., JGR, 2015) allows direct assimilation of space-based magnetometer data without a priori knowledge of the conductance for the estimation of field-alined currents.



Cousins et al. (JGR, 2015) demonstrated the benefit of incorporating both SuperDARN and AMPERE's Irridium observations into the estimation of the electrostatic and magnetic potential. For example, as shown in filled-colored contours in Panel a and Panel d, uncertainties for electrostatic potential distributions estimated from SuperDARN data alone decrease when both data are assimilated. This is particularly evident in the dawn cell where there is no SuperDARN data.

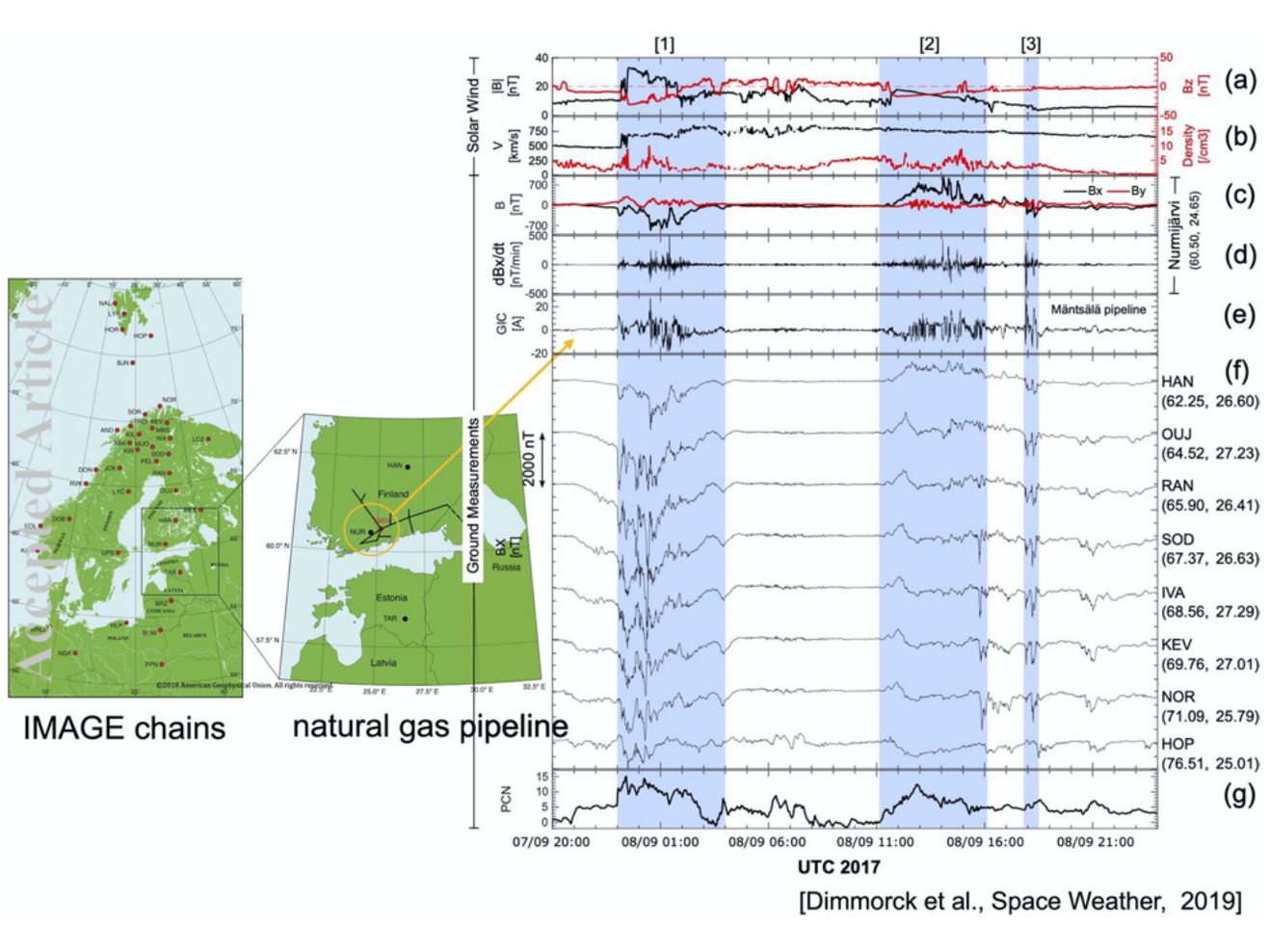
COLLABORATIVE GEOSPACE SYSTEM SCIENCE CAMPAIGNS

Event Study

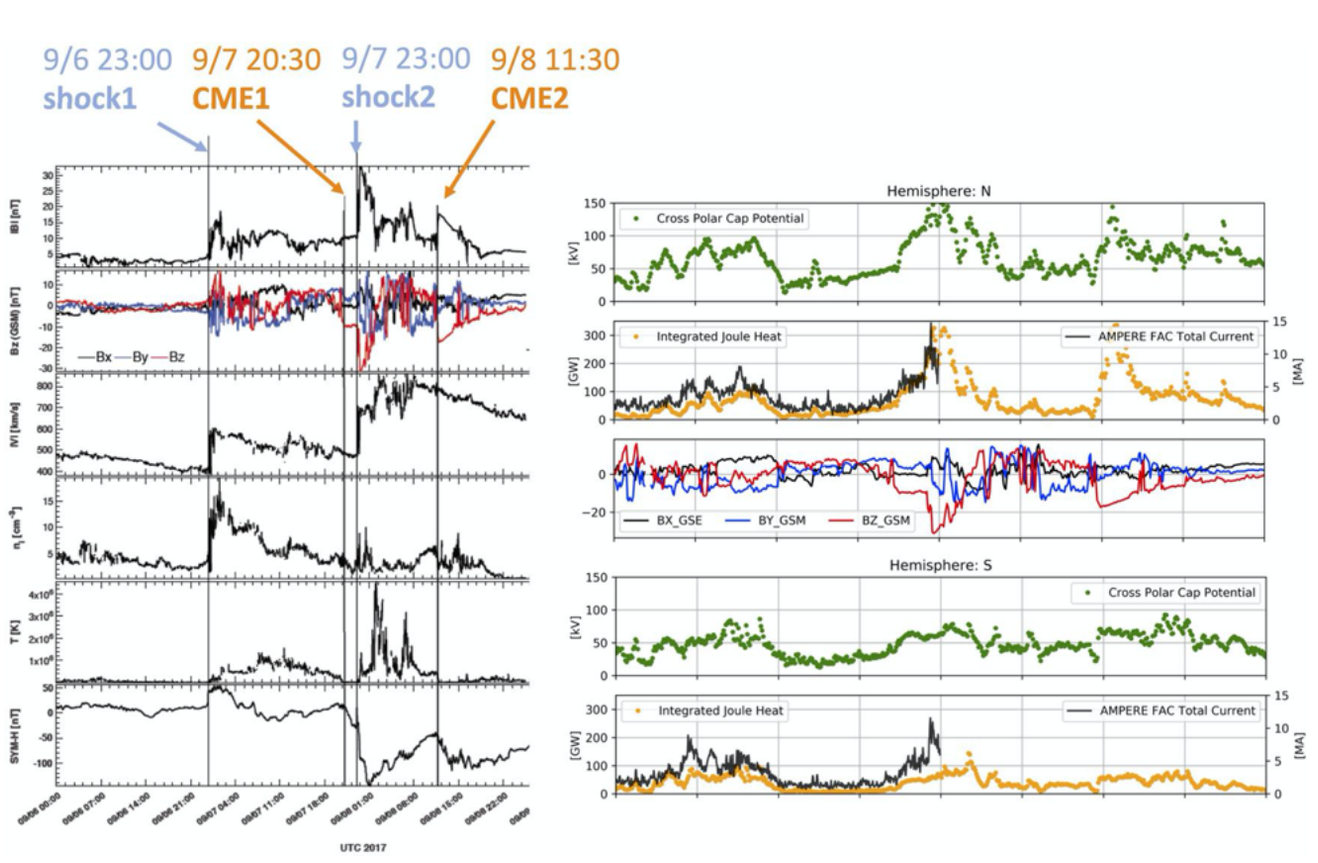
High-latitude Geospace Responses to Multiple Corona Mass Ejection (CME) Interaction Events on Septemper 7-8 2017.

[VIDEO] https://www.youtube.com/embed/FHwj8X4h9Ag?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0

Large GIC: The event caused large GICs in the Finnish natural gas pipeline at the Mäntsälä compressor station.



Geospace Responses to Solar Wind Drivers: AMGeO analysis is produced with SuperDARN, SuperMAG and AMPERE data.



Shock2 Response: After 2-3 hours of southward IMF following CME1, solar wind shock2 arrives at 23:07 on September 7 and a typical shock response propagates from dayside to night over 4-6 minutes. A R0 or new current system is formed in the northward of R1 currents and decays quickly which followed by an intensification of R1 currents.

[VIDEO] https://www.youtube.com/embed/X5e6ExLWbbo?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0

CME2 Response: CME2 arrives at 11:27 on Septermber 8. A typical 2-cell convection patterns develop and extend toward equatorward.

[VIDEO] https://www.youtube.com/embed/5owXxyrgDAQ?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0

Rarefication Response: Substorm without any obvious solar wind trigers. Westward auroral electric current surges produced uncommondly large GIC in Finland as observed by IMAGE magnetometer chains.

[VIDEO] https://www.youtube.com/embed/gaP9MRE-0PU?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0

Science-Driven AMGeO Data Product Validation

In partnership with community science working groups, we plan to engage the community in the process of AMGeO data product validation and participating in collaborative geospace system sicnece campains.

We are interested in learning the community's interests. Candidate events include GEM Conductance Challenge events such as

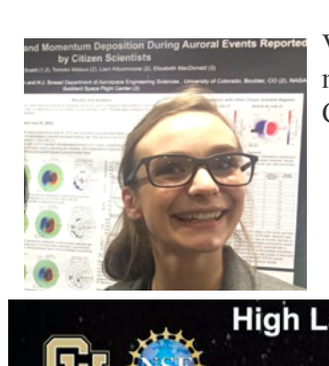
- ICME event on October 13-15 2016
- St. Patrick's Day storm on March 17 2013
- AuroraPHILE events on June 21-24 2015 and March 9 2012

Other events under investigation include

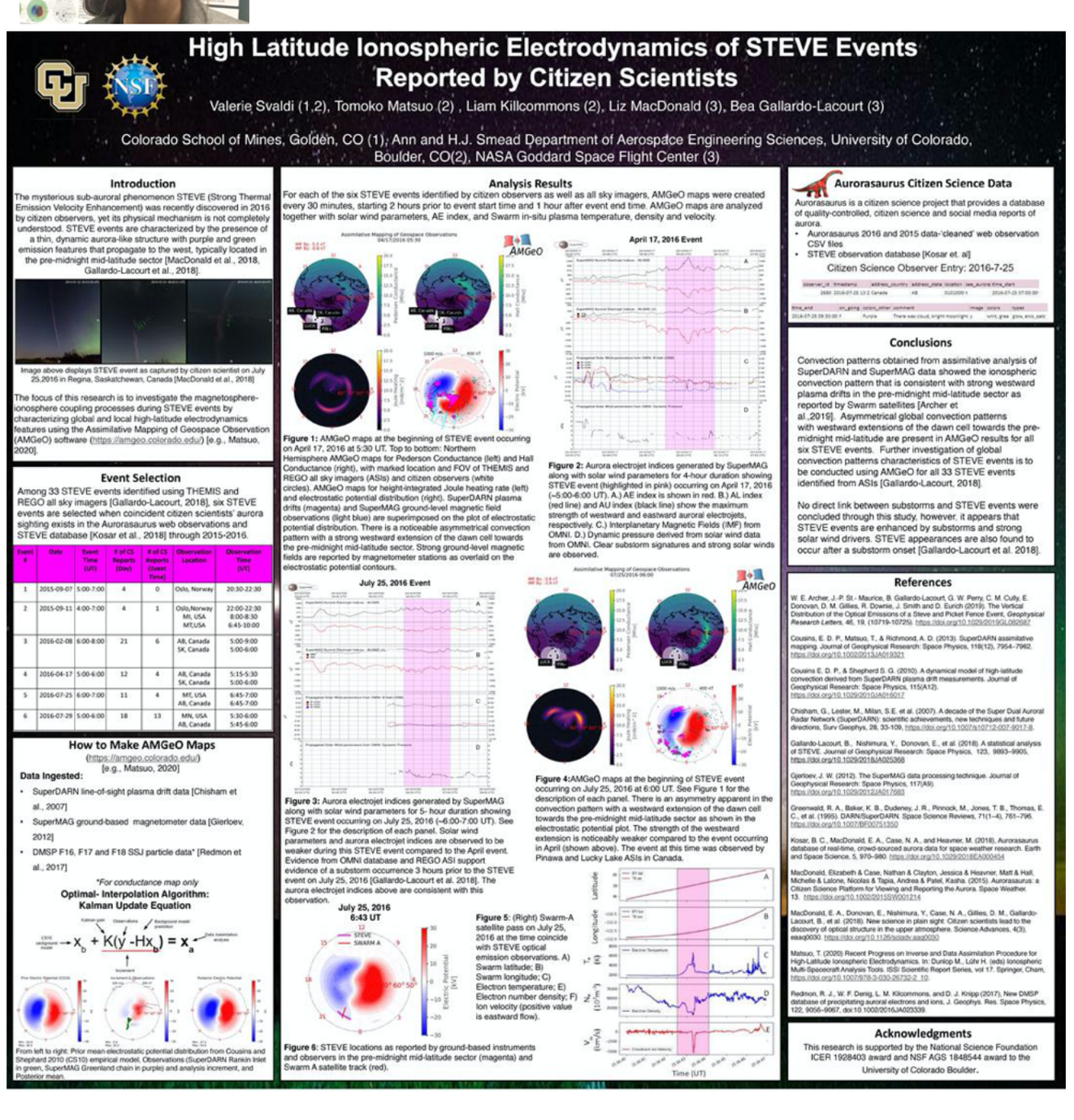
- Multiple CME interaction events on Septemper 7-8 2017 (see above)
- St. Patrick's Day storm on March 17 2015

EDUCATION OUTREACH

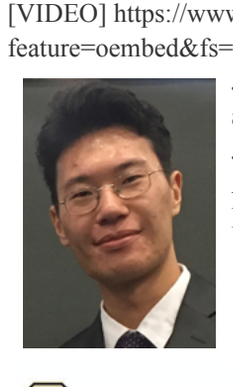
REU Students



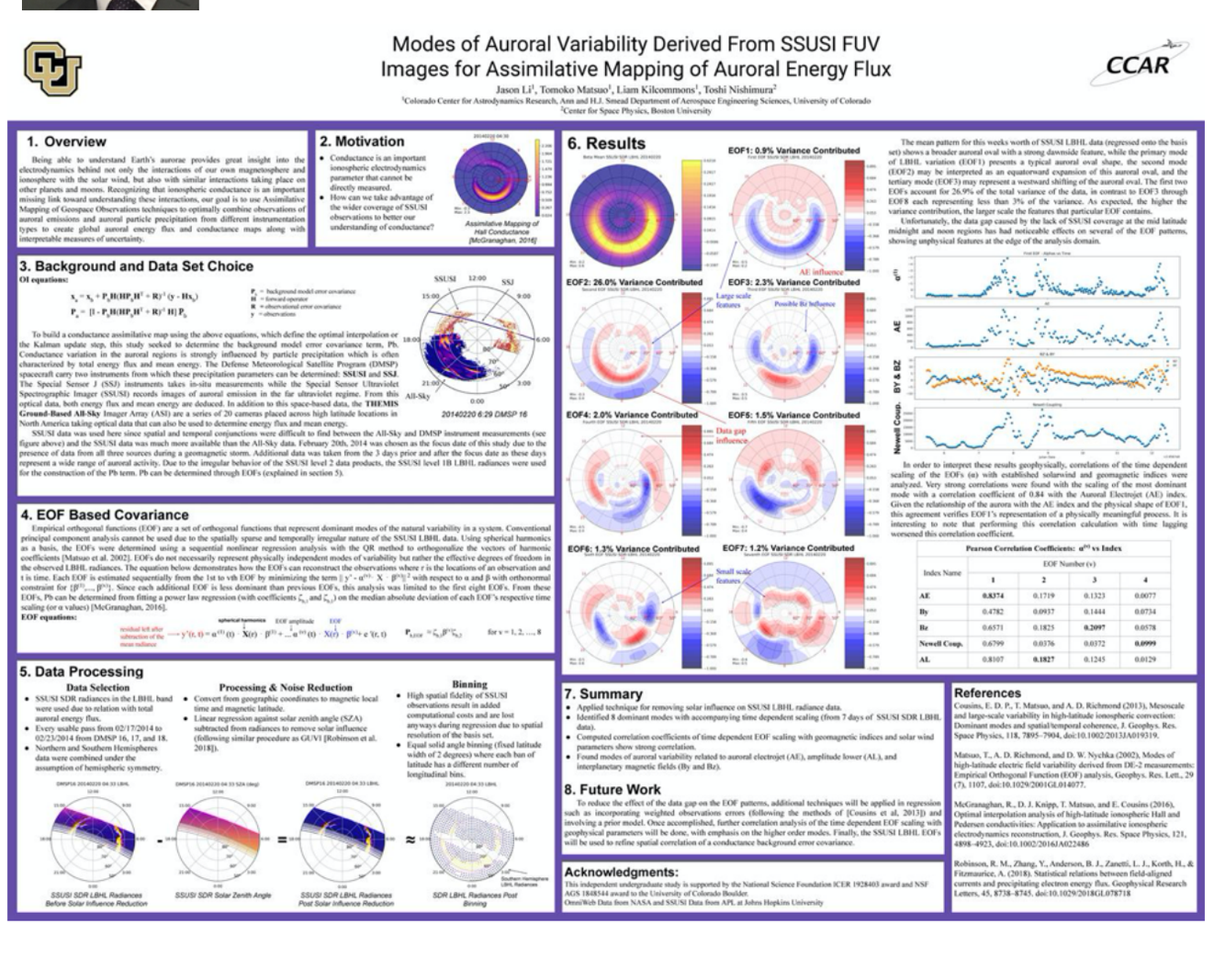
Valerie Svaldi (senior) from Colorado Schools of Mines uses the AMGeO to study mysterious STEVE auroral events observed by Aurorasaurus citizen scientists. Checkout her poster at 2019 Fall AGU Meeting


High Latitude Ionospheric Electrodynamics of STEVE Events Reported by Citizen Scientists
Valerie Svaldi (1,2), Tomoko Matsuo (2), Liam Kilcommons (2), Liz MacDonald (3), Bea Gallardo-Lacourt (3)
Colorado School of Mines, Golden, CO (1), Ann and H.J. Smead Department of Aerospace Engineering Sciences, University of Colorado, Boulder, CO(2), NASA Goddard Space Flight Center (3)
Introduction
Analysis Results
Aurorasaurus Citizen Science Data
Event Selection
How to Make AMGeO Maps
Conclusions
References
Acknowledgments

[VIDEO] https://www.youtube.com/embed/0I4rEwhGSHo?feature=oembed&fs=1&modestbranding=1&rel=0&showinfo=0

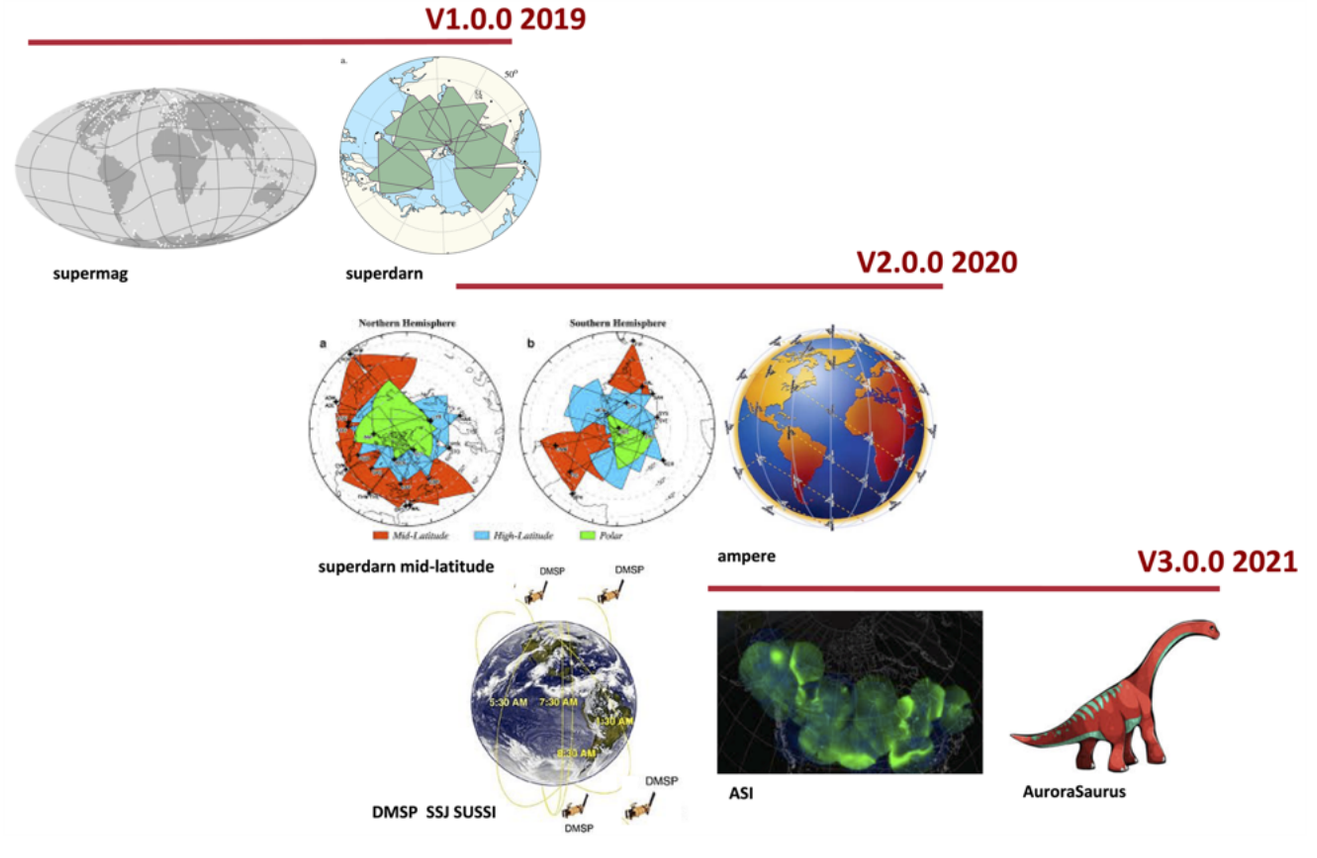


Jason Li (BS, May 2020) from CU Boulder is analyzing DMSP SUSSI data. Conductance is an important ionospheric electrodynamics parameter that cannot be directly measured, and Jason's work will help improve auroral conductance specification in the future version of AMGeO by using the SSUSI FUV images of aurora. Check out his poster at 2019 Fall AGU Meeting.


Modes of Auroral Variability Derived From SSUSI FUV Images for Assimilative Mapping of Auroral Energy Flux
Jason Li, Tomoko Matsuo, Liam Kilcommons, Toshi Nishimura
CCAR
1. Overview
2. Motivation
3. Background and Data Set Choice
4. EOF Based Covariance
5. Data Processing
6. Results
7. Summary
8. Future Work
Acknowledgments:
References

FUTURE PLAN

Timeline for Future Releases



While the AMGeO v1.0 open-source software released in December 2019 have the capability of assimilating the SuperDARN and SuperMAG data, the additional capability of assimilating AMPERE's Iridium magnetometer data will be released as version 2.0 in December 2020. The AMGeO v2.0 software will be able to handle mid-latitude SuperDARN data better. The AMGeO v3 software will include a new module for handling additional data such as DMSP particle and imager data as well as Aurorasaurus citizen science data to help improve the AMGeO's conductance estimation.

Interoperability with the Geospace Community Data Resources

The AMGeO Data Sevices' API access to SuperDARN and SuperMAG has been already established. Similar access to AMPERE, TIMED-GUVI, and DMSP-SUSSI data servers will be established. AMGeO Software and Data Service will be interoperable with the EarthCube Integrative Activity InGeO project and the new NASA CCMC's Kamodo Python-based analysis suite.

Reanalysis SpWx Data Product

We plan to serve the AMGeO data products resulting from our project activities as an update to NOAA-NCEI's existing AMIE SpWx reanalysis accessible archive, the outcomes of this project will become part of accessible long-term archival data for the community.

Data Science Course Unit

The AMGeO will be integrated into a modularized data science course unit that can be offered as part of general space physics course to facilitate the community adoption by university communities.