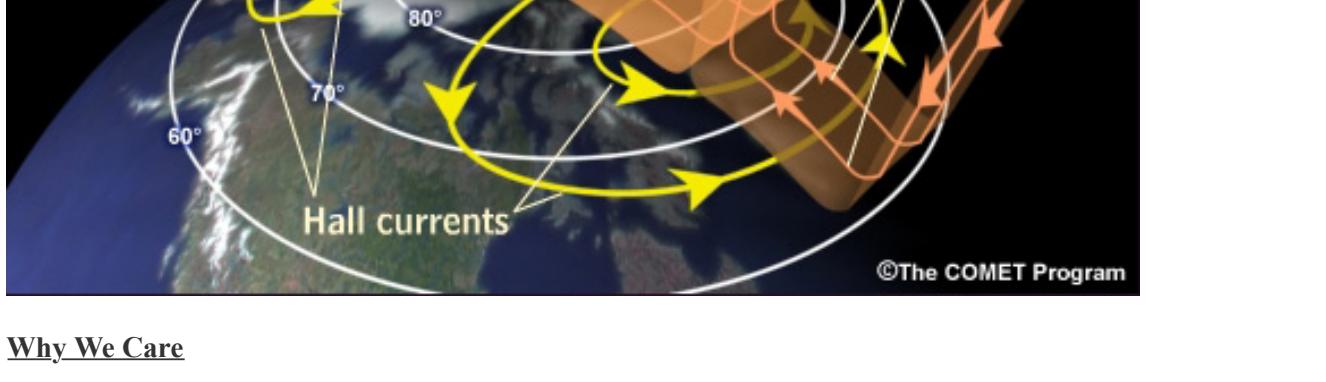
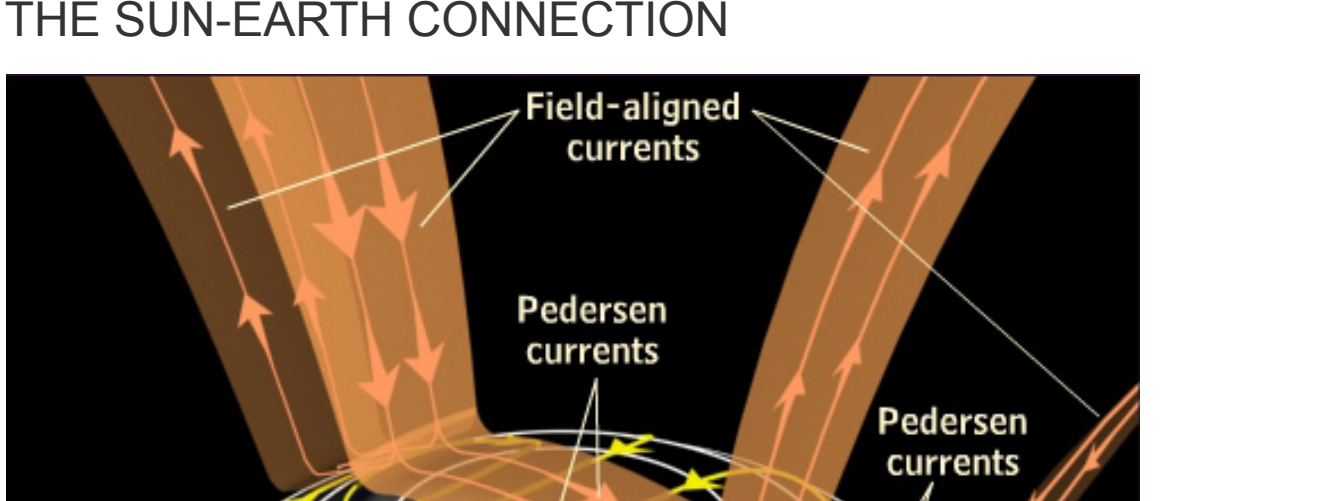


Assimilative Mapping of Geospace Observations (AMGeO): Data Science Tools for Collaborative Geospace Systems Science

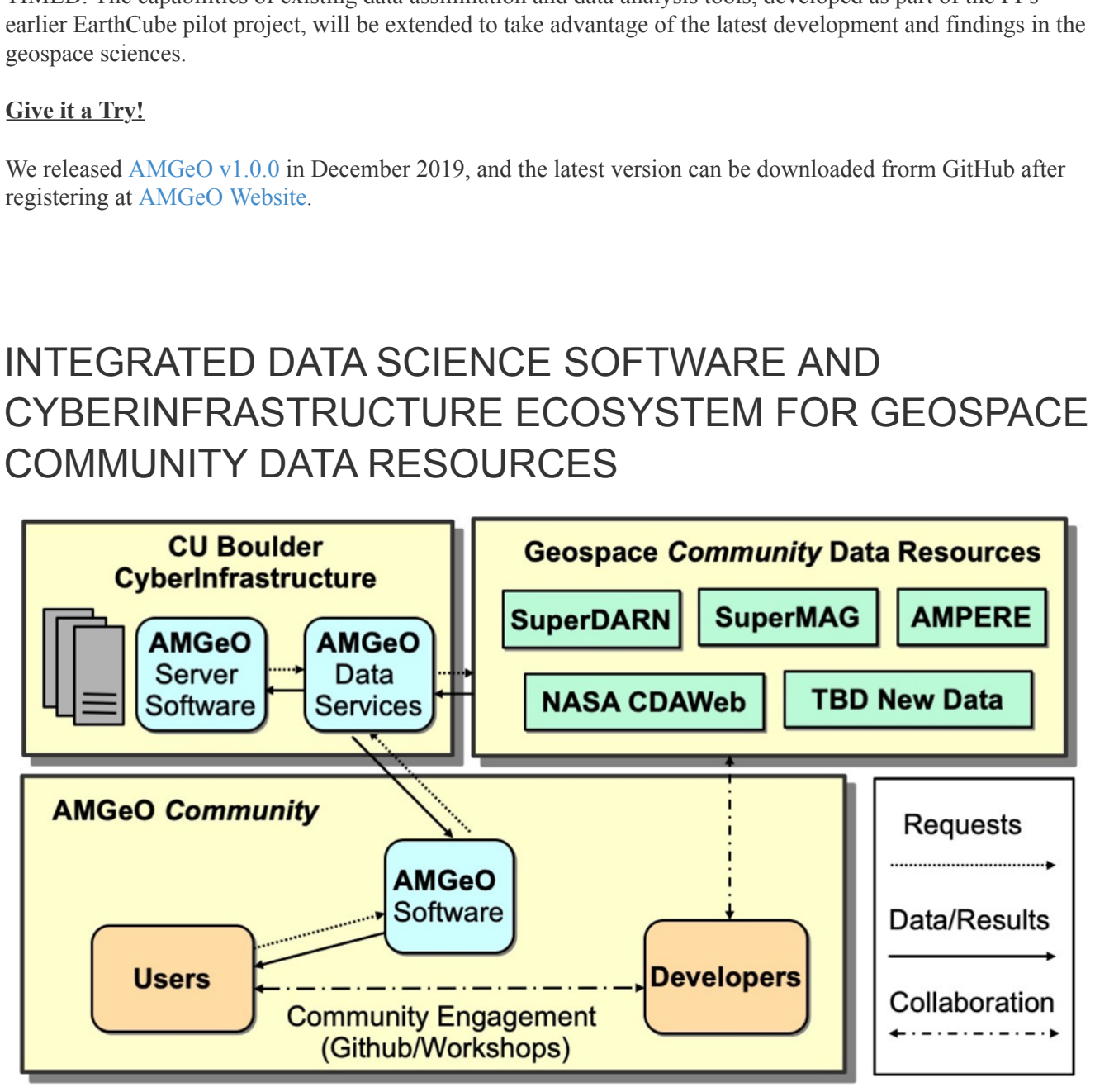


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(1) CU Boulder, (2) Virginia Tech, (3) JHAPL, (4) NASA, (5) NOAA, (6) SRI, and (7) GFZ Potsdam



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 disturbing radio communication and navigation systems and causing geomagnetically induced currents (GIC) that can damage electric power transmission grids, oil and gas pipelines.

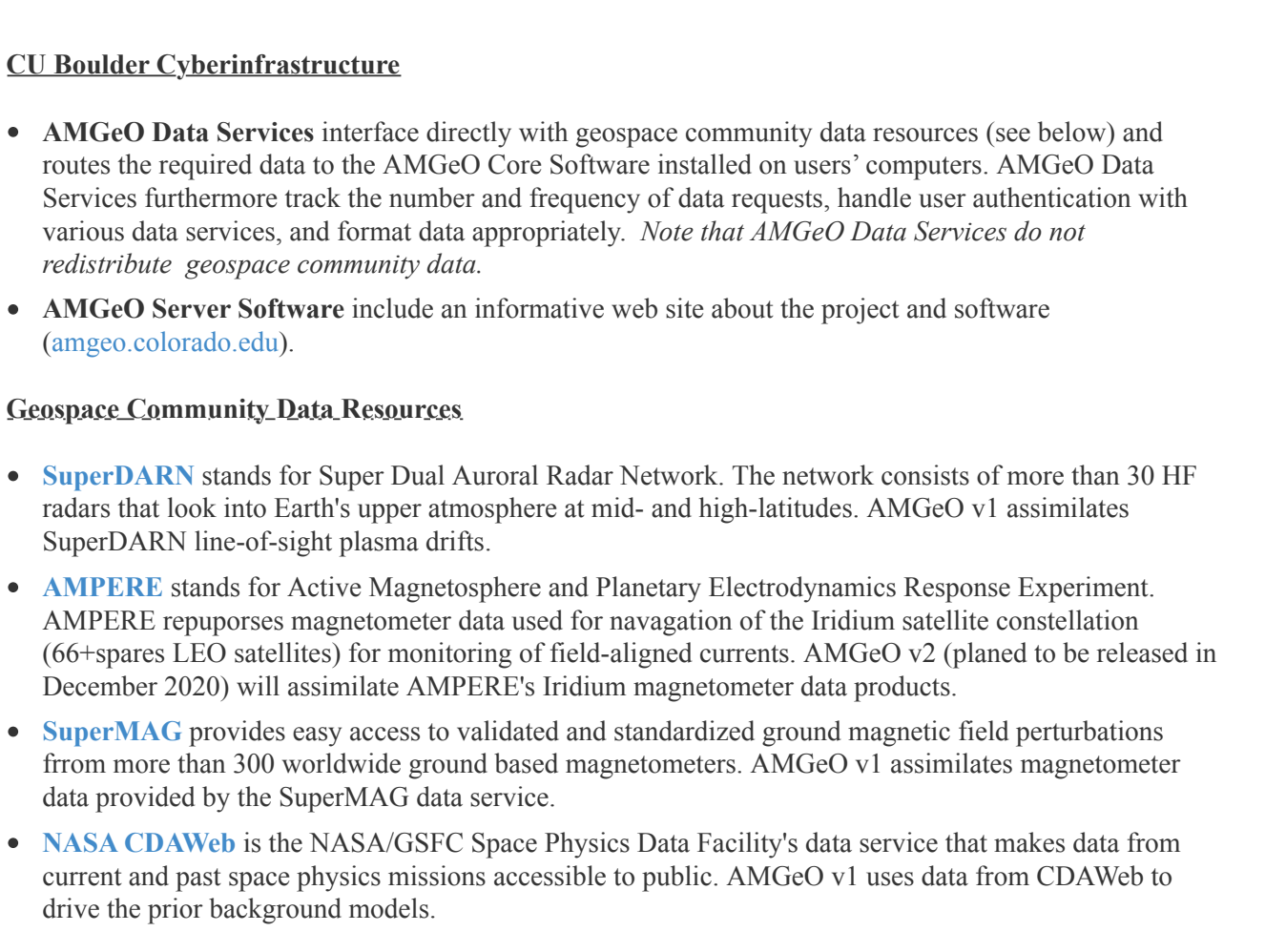
What We Want

Inspired by recent advancements in geospace observing capabilities and the opportunities of Big Data, the goal of our NSF EarthCube Data Capabilities: Assimilative Mapping of Geospace Observations (AMGeO) project (Sep 2019-Aug 2022, ICR-1928463, ICR-1928356, ICR-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 reproducible, validated analysis data products that can be accessed from established data repositories to maximize the scientific return on the NSF, EOD and NASA program investments, such as AMPERE, SuperDARN, SuperMAG, DMSF 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 from GitHub after registering at AMGeO Website.

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



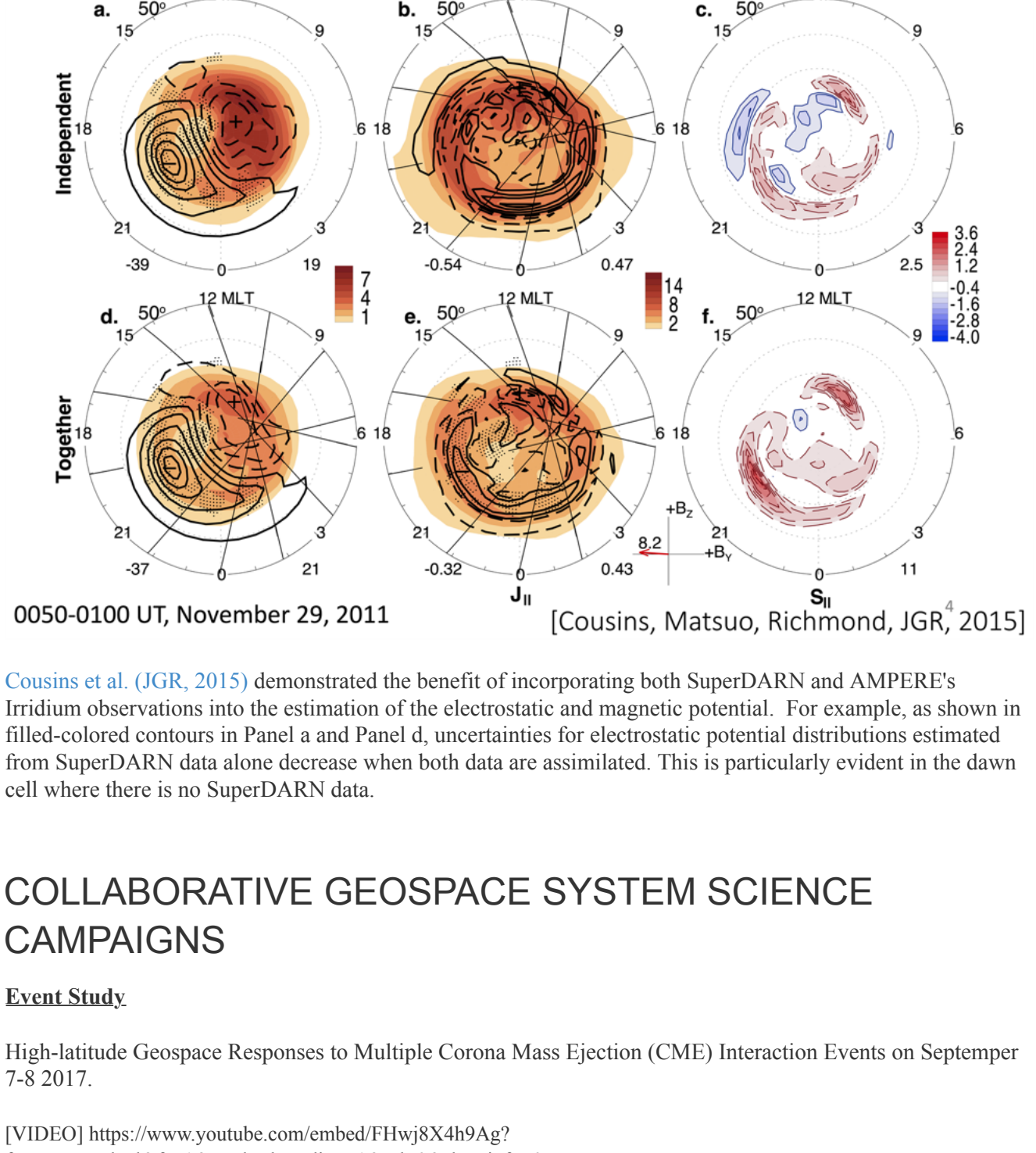
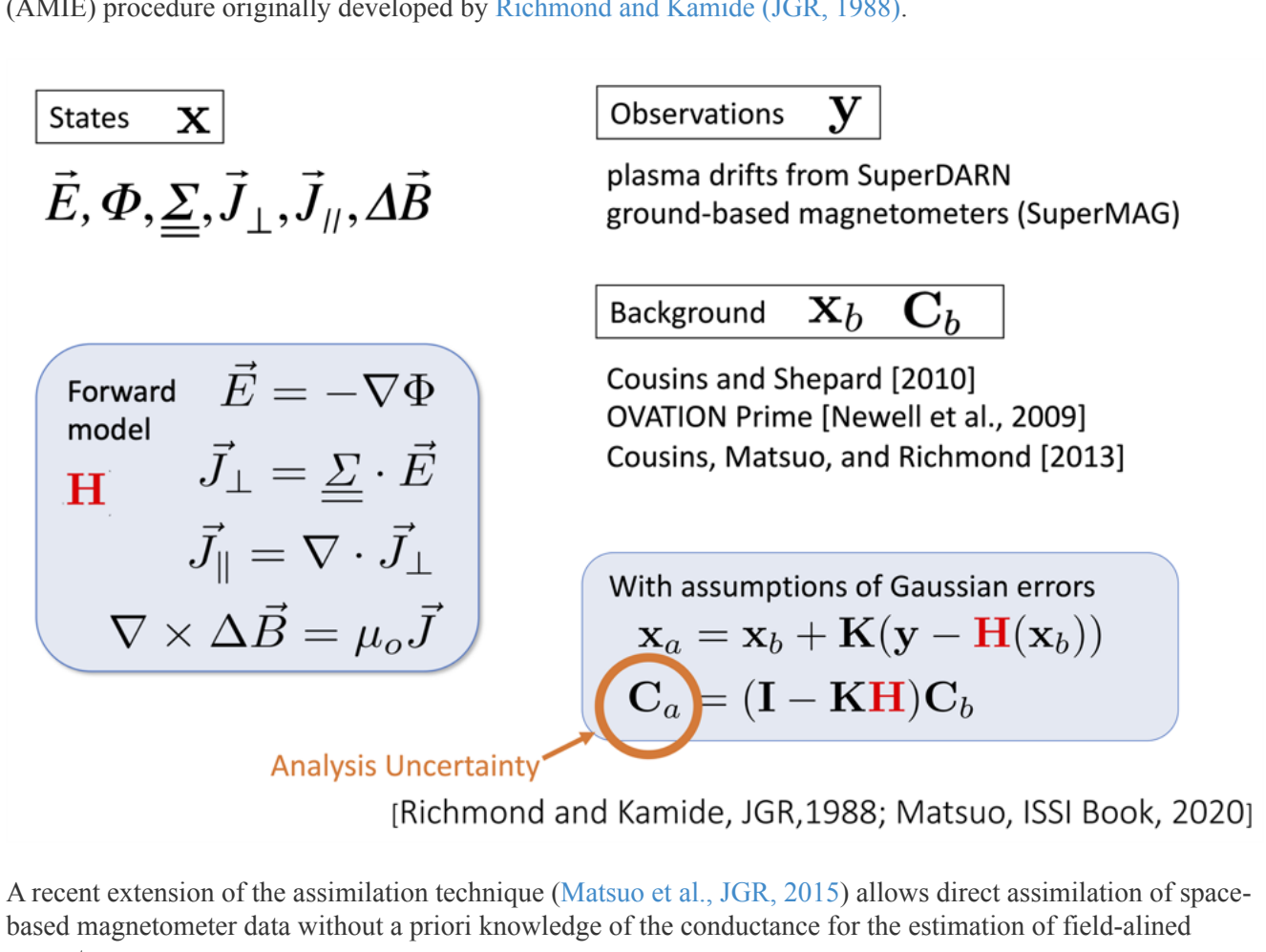
- CU Boulder Cyberinfrastructure**
- AMGeO Data Services interface directly with geospace community data resources (see below) and routes the required data to the AMGeO Core Software installed on users' computers. AMGeO Data Services furthermore track the number and frequency of data requests, handle 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 (<https://amgeo.org>).
- Geospace Community Data Resources**
- SuperDARN stands for Super Dual Auroral Radar Network. The network consists of more than 50 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 responds magnetometer data used for navigation of the Indian satellite constellation (66+space LEO satellites) for monitoring of field-aligned currents. AMGeO v2 (planned to be released in December 2020) will assimilate AMPERE's Indium magnetometer data products.
 - SuperMAG provides easy access to validated and standardized ground magnetic field perturbations from 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

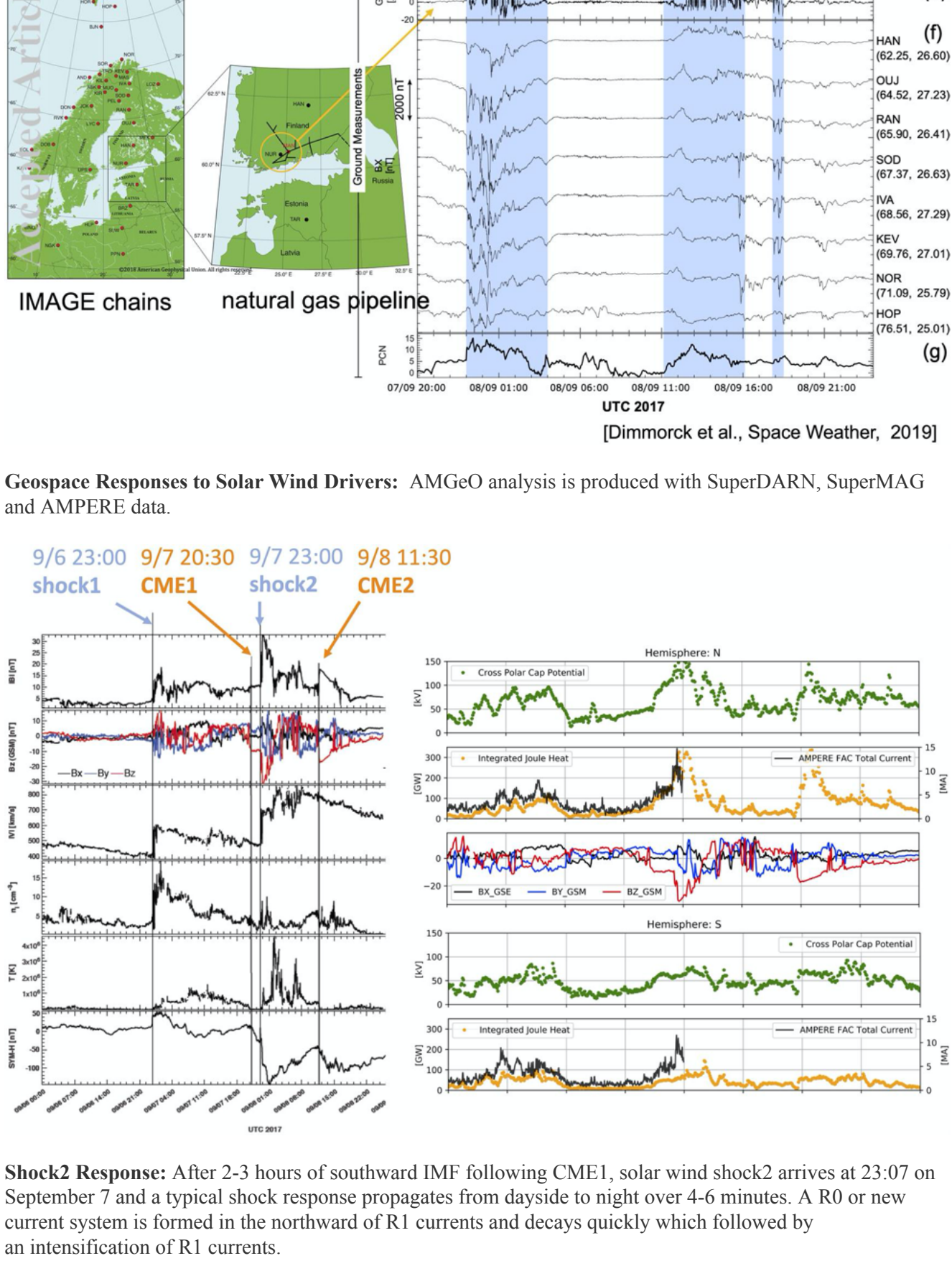
AMGeO Community is the place to share users' experience and analysis results using AMGeO, and to contribute users' ideas and software to AMGeO Core Software.

- 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.

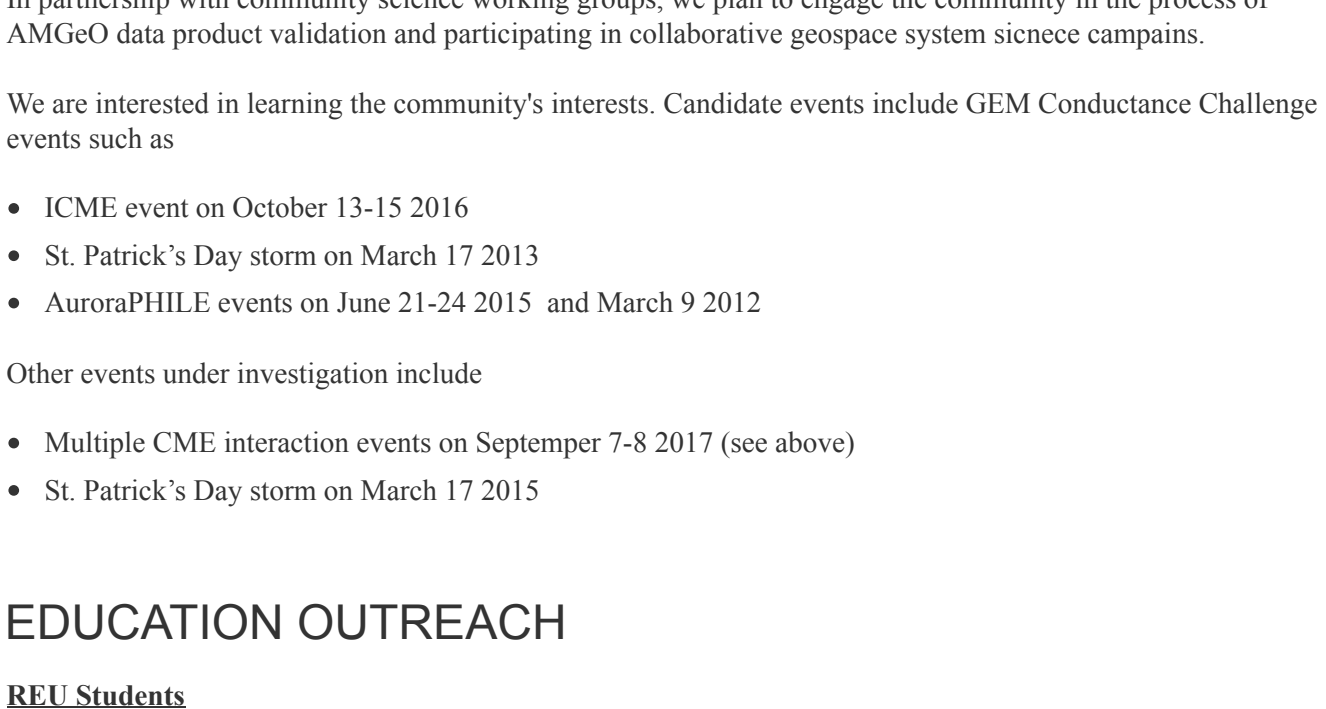
ABOUT AMGeO



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).



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-aligned currents.



Cousins et al. (JGR, 2015) demonstrated the benefit of incorporating both SuperDARN and AMPERE's Indium 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.

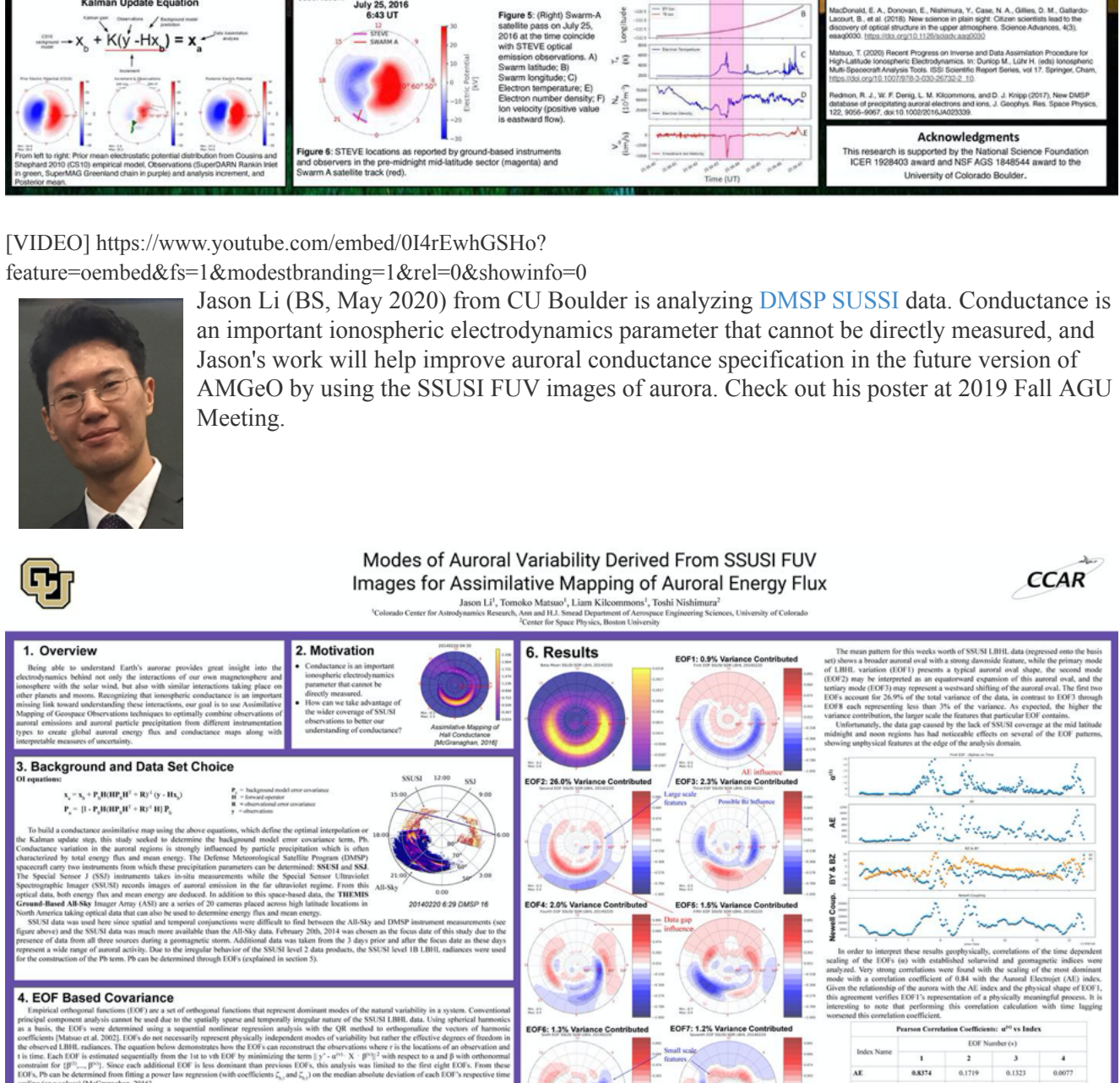
COLLABORATIVE GEOSPACE SYSTEM SCIENCE CAMPAIGNS

Event Study

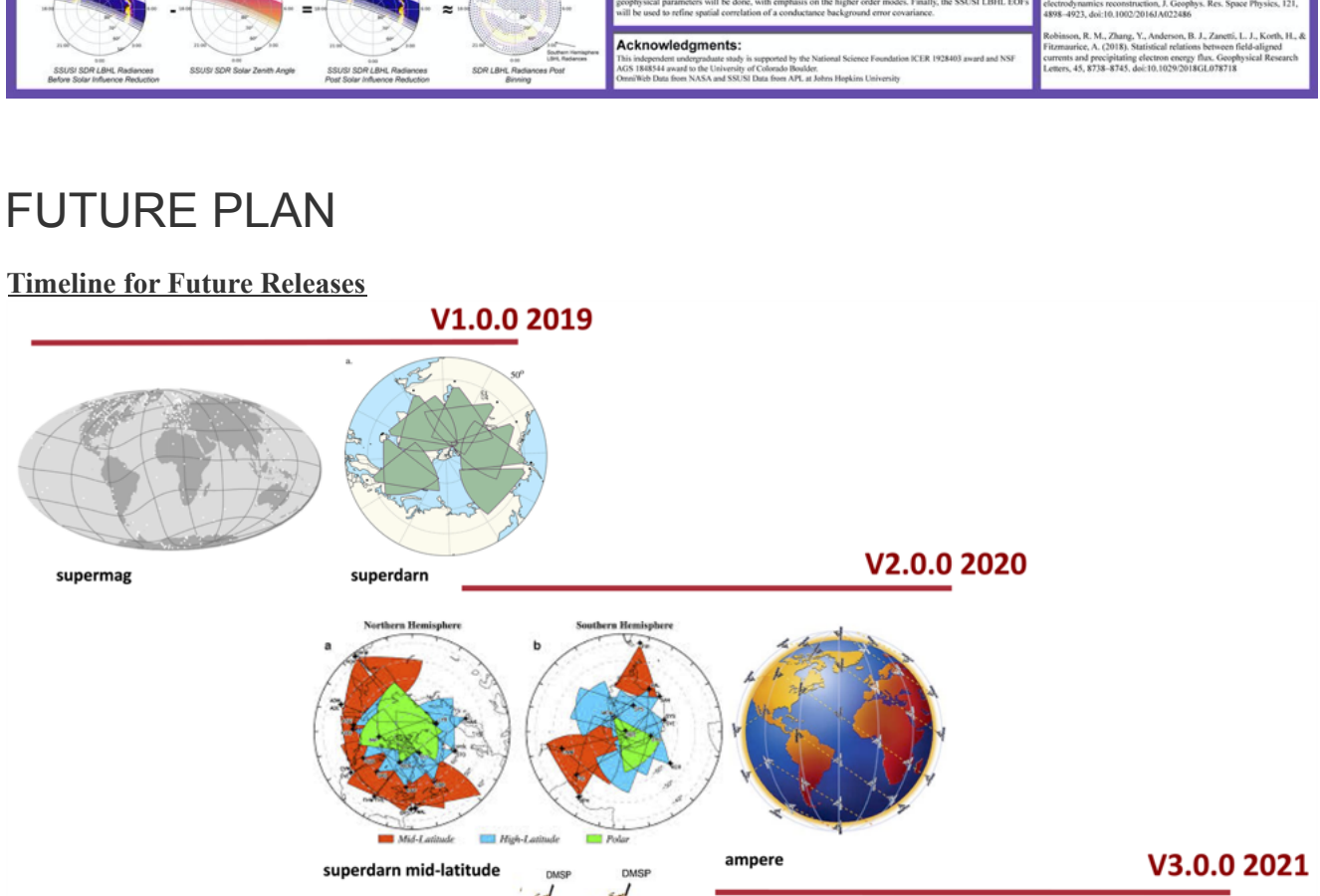
High-latitude Geospace Responses to Multiple Corona Mass Ejection (CME) Interaction Events on September 7-8 2017.

[VIDEO] <https://www.youtube.com/embed/PHy8X8WAg?feature=embdd&f=1&modestbranding=1&rel=0&showinfo=0>

Large GIC: The event caused large GICs in the Finnish natural gas pipeline at the Mantsala 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 southward of R1 currents and decays quickly which followed by an intensification of R1 currents.

[VIDEO] <https://www.youtube.com/embed/X56fclWb8?feature=embdd&f=1&modestbranding=1&rel=0&showinfo=0>

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

[VIDEO] <https://www.youtube.com/embed/5onXcygDAP?feature=embdd&f=1&modestbranding=1&rel=0&showinfo=0>

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

[VIDEO] <https://www.youtube.com/embed/gaPMRE-0P1?feature=embdd&f=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 science campaigns.

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 September 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 is using AMGeO to study mysterious STEVE auroral events observed by *Aurorasaurus* citizen scientists. Check out her poster at 2019 Fall AGU Meeting.

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

Model of Auroral Variability Derived from SSUSI FLV Images for Assimilative Mapping of Auroral Energy Flux

CCAR

Future Plan

Timeline for Future Releases

V1.0.0 2019

V2.0.0 2020

V3.0.0 2021

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 Indium 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 DMSF particle and imager data as well as *Aurorasaurus* citizen science data to help improve the AMGeO conductance estimation.

Interoperability with the Geospace Community Data Resources

The AMGeO Data Services' API access to SuperDARN and SuperMAG has been already established. Similar access to AMPERE, TIMED-GUVI, and DMSF-SSUSI data servers will be established. AMGeO Software and Data Services will be interoperable with the EarthCube Integrative Activity InTeGrO project and the new NASA CCMC's Kamado 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-NCCE'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.