Assimilative Mapping of Geospace Observations

Building Community for Collaborative CEDAR Data Science

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Connection of Data

Community

Culture Change
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The properties of electric field (or equivalently, velocity) fluctuations have been the subject of many studies [e.g., Kintner, 1976; Weimer et al., 1985; Ishii et al., 1992; Earle and Kelley, 1993; Heppner et al., 1993; Tam et al., 2005; Golovchanskaya et al., 2006; Parkinson, 2006; Abel et al., 2007]. To estimate the contribution to the total electric field in the ionosphere and to the amount of energy input to the atmosphere, several statistical studies have also investigated the absolute magnitudes of small-scale electric field variability observed in the ionosphere [Heppner et al., 1993; Johnson and Heelis, 2005; Golovchanskaya et al., 2006; Golovchanskaya, 2007; Matsuo and Richmond, 2008]. These statistical studies were all based on data from the Dynamics Explorer (DE) 2 spacecraft, which operated for 1.5 years (August, 1981 to February, 1983) during the declining phase of solar cycle 21.

This paper seeks to characterize the statistical properties of small-scale spatial and temporal variability observed by the Super Dual Auroral Radar Network (SuperDARN) high-frequency (HF) radars in order to better understand the nature and possible drivers of electric field variability in the ionosphere, thereby enabling improved representation of this small-scale component in empirical or statistical models of ionospheric convection electric fields.

Section 2 describes the method used to calculate small-scale electric field variability, section 3 describes the statistical characteristics of this small-scale variability and section 4 discusses possible implications of the results in context of previous studies.

2. Technique

We first describe the selection of velocity data, the technique of calculating small-scale variability, and the selection of other geophysical and interplanetary data for organizing the variability data.

2.1. Velocity Data

Velocity data are obtained from the SuperDARN HF coherent backscatter radars located in the high-latitude regions of both hemispheres. These radars provide measurements of the line-of-sight (LOS) component of the bulk E\textsubscript{B}/E\textsubscript{B} drift of F\textsubscript{B}-region ionospheric plasma in the regions sampled by their fields of view (FOVs). All the radars included in this study transmit along 16 (electronically steered) beams within 50 FOVs. In the typical radar operating mode (the only mode used in this study), the velocity data have a spatial resolution of 45 km in the LOS direction and the entire FOV is sampled once every 2 min. Because the velocity determination relies on Doppler shift information, velocities above a maximum magnitude of 2000 m/s (dependent on the operating frequency) are aliased, limiting the range of velocity fluctuation magnitudes that can be accurately measured.

For this study, 48 months of data (8 months per year) are used from 1999–2004, encompassing the maximum of solar cycle 23. In the Northern Hemisphere, data from February, April, May, June, July, August, October and December are included from each year, while in the Southern Hemisphere, January, February, April, June, August, October, November and December are included. This selection results in a more equal distribution of data across seasons, because generally less backscatter is observed during summer months [cf. Ruohoniemi and Greenwald, 1997]. During the years considered in this study, 6–9 radars in the Northern Hemisphere and 4–7 radars in the Southern Hemisphere were operational. The locations of these radars and their FOVs are shown in Figure 1.
What We Did

Why It’s Important
Assimilative Mapping of Geospace Observations

Collaborative data science tool for high-latitude geospace observations

Learn more »
https://amgeo.colorado.edu

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 contour lines track the convective motion of ionospheric plasma in the direction perpendicular to the Earth's main magnetic fields and the electric fields.

<table>
<thead>
<tr>
<th>Electrostatic Potential</th>
<th>$\Sigma_H$ Hall Conductance</th>
<th>$\Sigma_P$ Pedersen Conductance</th>
<th>$J$ Field-Aligned Current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Min: -31.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Max: 68.0</td>
<td></td>
<td></td>
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</tbody>
</table>
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Making AMGeO Maps

SuperDARN Assimilation  SuperMAG Assimilation  SuperDARN & SuperMAG  Iridium Assimilation

Prior Model + Data Impact = AMGeO Map
### AMGeO v2beta – algorithm

#### States $\mathbf{X}$

$\vec{E}, \Phi, \Sigma, \vec{J}_\perp, \vec{J}_\parallel, \Delta \vec{B}$

#### Observations $\mathbf{Y}$

- Plasma drifts from SuperDARN ground-level magnetic fields (SuperMAG)
- Iridium magnetic fields (AMPERE)

#### Background $\mathbf{X}_b$

- Cousins and Shepard [2010]
- OVATION Prime [Newell et al., 2009]

#### Background Covariance $\mathbf{C}_b$

- Cousins et al. [2013]
- Shi et al. [2019]

$$\mathbf{C}_b \approx \mathbf{Q}\Gamma\mathbf{Q}^T$$

#### Forward model

- $\vec{E} = -\nabla \Phi$
- $\vec{J}_\perp = \Sigma \cdot \vec{E}$
- $\vec{J}_\parallel = \nabla \cdot \vec{J}_\perp$
- $\nabla \times \Delta \vec{B} = \mu_0 \vec{J}$

#### Analysis Uncertainty

$$\mathbf{C}_a = (\mathbf{I} - \mathbf{K}\mathbf{H})\mathbf{C}_b$$

[Richmond and Kamide, JGR, 1988; Matsuo, ISSI Book, 2020]
AMGeO v2beta – software & web application

Collaborative Data Science Platform

[AMGeO Collaboration, 10.5281/zenodo.3564913, 2019]
Going Beyond Event Studies with AMGeO

From 64 events
Characterizing global electrodynamics during STEVE vs Non-STEVE substorms

[Svaldi, Matsuo, Kilcommons, Gallardo-Lacourt, Under Preparation, 2021]
Going Beyond Event Studies with AMGeO

From 64 events
Characterizing global electrodynamics during STEVE vs Non-STEVE substorms

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 Recent EarthCube Efforts
Auroral Conductance

Neural Network + PCA + Assimilative Mapping

[Li, Matsuo and Kilcommons, Under Review, 2021]
Recent EarthCube Efforts
SuperDARN + AMGeO

FitACF++ from Ruohoniemi and Chakraborty
AMGeO v1 and v2beta is Available to Support Transparent, Reproducible, & Open Research

- Capability to ingest SuperDARN, SuperMAG, AMPERE
- Improving uncertainty quantification through close collaboration with data providers
- Improving conductance analysis
- CEDAR workshop session on AMGeO Tutorial and Interactive Demos at 1-3pm on June 25 (Friday)

Sign up!
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What’s Next?

• Interoperability with CCMC and InGeO cyberinfrastructures

• Collaborative geospace data science campaigns to produce reanalysis data product

Sign up!
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