Improving Covariance Matrix for Aurora Data Assimilation

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1. Abstract

Recent advancements in Ionosphere-Thermosphere (IT) system simulations have seen significant improvements by integrating data assimilation methods. Traditional models use covariance matrices based on Markov random fields, which inaccurately represent spatial correlations among auroral drivers like auroral precipitation. Utilizing auroral energy flux data from Special Sensor Ultraviolet Spectrographic Imagers (SSUSI), we analyzed correlations across geomagnetic latitudes from 50º to the pole and found that within the auroral oval, fluxes are positively correlated, decreasing with distance at an e-folding length of approximately 500 km. Notably, a secondary correlation peak occurs around 4500 km from the reference point on the opposite side of the oval, highlighting interconnected magnetospheric processes driving auroral variability. We developed a new correlation matrix reflecting these findings, which better captures the observed spatial correlations. This matrix will be used in Lattice Kriging data assimilation approach for aurora and will extend to examine the differences in the data assimilation products introduced by the new correlation matrix simulating the TIEGCM model.

2. Introduction

Lattice Kriging (LK) data assimilation

- Spatial field is decomposed into spatially varying mean (μ(x)), spatially correlated field g(x), and a spatially uncorrelated error term (ε(x))

$$Y(x) = \mu(x) + g(x) + \varepsilon(x)$$

- **μ(x)** is obtained from empirical model z(x), where μ(x)= z(x)d, d is scaling factor.
- **g(x):** $\sum c_j \phi_j(x)$, $\phi_j(x)$, $1 \leq j \leq m$ are predefined basis function. Here c follow multivariate normal distribution with mean zero and covariance Q^{-1}
- Staking all observations, empirical data and error at each location, The model equation takes the form

$$Y = Zd + \phi c + \varepsilon$$

Spatial Covariance

- Provides information about the degree to which data points influence each other
- Previously used covariance matrix in Lattice Kriging data assimilation for auroras doesn't represent reality.

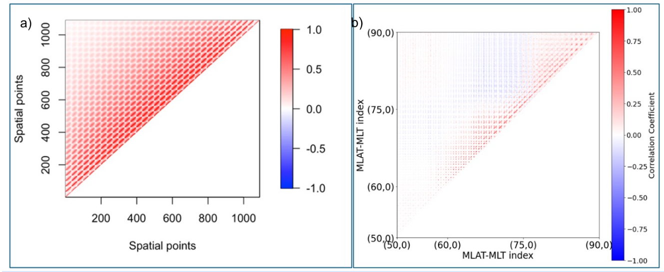

Figure 2.1: (a) Arbitrary correlation matrix structure used for Lattice Kriging data assimilation of auroral energy flux (b) SSUSI observed spatial correlation matrix structure

3. Data Sources

- SSUSI:
- Remote-sensing instrument which measures ultraviolet (UV) emissions in five different wavelength bands which is used to calculate electron energy flux(0.15 spatial and 20 minutes temporal resolution data is used as input data for this work)
- Incorporated in D16, D17, D18, and D19 DMSP satellites and covers auroral zones

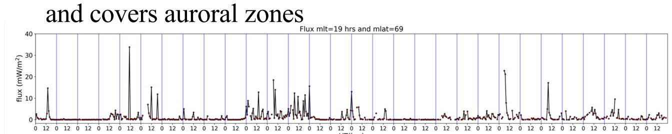

Figure 3.1: Hourly averaged auroral energy flux during July 2015 (69 MLAT and 19 MLT).

4. Methodology

- The correlation coefficient of SSUSI-derived auroral energy flux at 69° MLAT and 19 hours MLT with energy flux of all other locations are obtained for July 2015.
- The obtained structure is fitted as a function of MLT, MLAT and distance

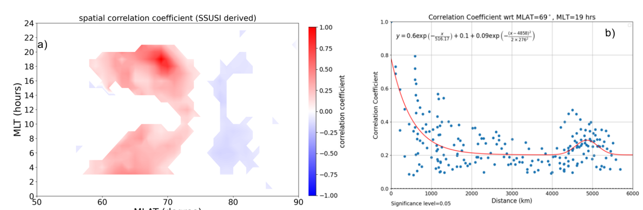

Figure 4.1: Spatial correlation coefficient, with respect to 69 MLAT and 19 MLT as observed from SSUSI data a) function of MLAT and MLT b) function of distance

5. Results and Discussion

- Auroral energy fluxes are positively correlated with fluxes within auroral oval (60-70MLAT) while negative correlation with those on sub-auroral (50-60 MLAT) and polar cap region.
- Correlation coefficient decreases with distance at an e-folding length of approximately 500 km.
- A secondary correlation peak occurs around 4500 km from the reference point on the opposite side of the oval.

Derived Correlation Function

$$0.35\cos(0.19(\mathrm{MLAT} - \mathrm{X}) + 0.6\times e^{\left(\frac{-d}{216}\right)} + 0.1 + 0.09e^{\frac{-(d-4800)^2}{2\times 276^2}}$$

$$\mathrm{X} = \mathrm{refMLAT} - 0.15\|\mathrm{MLT} - \mathrm{refMLT}\|$$

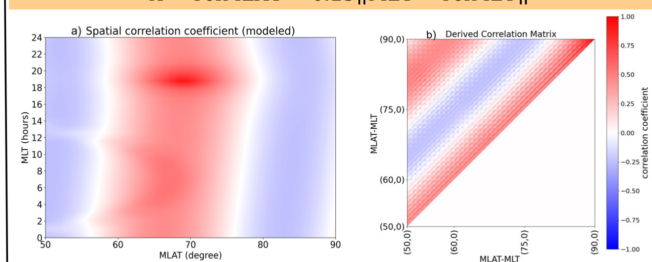

Figure 5.1: a) Modeled spatial correlation structure with respect to auroral electron energy flux at MLAT= 69° and MLT= 19 hours. b) Correlation matrix structure constructed using correlation function

- The correlation matrix constructed from the derived correlation function is able to capture the negative correlation pattern as seen in the real structure.

6. Conclusion

- We can improve the covariance matrix structure for auroral data assimilation using the real observation.

7. Future Work

- The derived correlation function will be used for data assimilation of aurora and produce auroral maps to simulate the TIEGCM model to study the ionospheric responses in different geomagnetic conditions..

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