Abstract

We discuss our approach to high spatial and temporal resolution auroral tomography, along with an exploration of the observation tradespace in time and space of ground-based observations. We discuss the modeling and processing effort relevant to answering science questions on small and large time scales via 100+ frame-second optical auroral observations. Tightly time synchronized observations from two or more sensitive cameras enable tomographic reconstruction using a first principles physical model yielding new insight into the fine dynamics of primary electron precipitation into the ionosphere down to the ten millisecond scale. The High Speed Tomography (HiST) rapidly redeployable instrument contributes to the global synthetic perspective by providing multi-year persistent observations with little user intervention needed due to our OpenCV-based algorithms. Transformative heliophysics system observations over solar cycle scales requires systems that take a different approach to systems engineering than legacy systems that assumed frequent human interaction or maintenance. The techniques we use to study the fine scale spatio-temporal dynamics of the magnetospheric drivers of the aurora can be adapted to other instruments and metamachines studying magnetosphere-ionosphere coupling.

Introduction

The HiST system is part of the leading edge of ionospheric data collection and analysis. Joint sensing of the ionosphere by use of diverse coordinated distributed sensing create metamaschines where far more can be learned about the ionosphere than by simply taking the “sum” of isolated measurements. The rapidly relocatable HiST system contributes to auronomy observations of the finest ground-observable auroral features.

Auroral tomography is carried out by two or more cameras pointed at a common auroral altitude region, typically set to overlap as much as geometrically possible in the altitude range of \( z = 90 \)–300 km.

\[ \hat{B} \perp \text{error vs. time & position} \]

\[ \hat{E}_0 \perp \text{error vs. time & position} \]

\[ \text{LT} \Phi_{\text{top}} = \hat{B} \]

(1)

We estimate particular characteristics of \( \Phi_{\text{top}} \) based on observed brightness \( B \) using the L-BFGS-B algorithm with criteria:

\[ \Phi_{\text{top}}(B, E) = \arg \min \[ | B - \text{LT} \Phi_{\text{top}} |^2 = \arg \min \| B - \hat{B} \| \] \]

(2)

\( \Phi_{\text{top}} \) is the location of peak electron precipitation intensity in the direction perpendicular to the geomagnetic field and the characteristic energy. Our simulated camera has an exposure of 10 ms corresponding to a 100 Hz frame rate. The simulation forward model runs at 2 ms step, based on known characteristics of dispersive Alfvénic aurora as confirmed by previous ground observations. The result of the 2 ms forward model with a 10 ms exposure is a smeared brightness observed, from which we use a 2-D fitter to estimate \( \Phi_{\text{top}}(B, E) \) on 10 ms scale.

Inversion

The inversion algorithm has been described in [Hirsch 2015]. Assuming the observation process can be described and discretized with the Fredholm Integral of the First Kind, we use the viewing geometry of Fig. 1 in the projection matrix \( \mathbf{L} \). The particle precipitation model generating filtered excitation rates is encapsulated in kernel \( \mathbf{T} \). The unknown precipitation intensity at the top of the ionosphere that we seek is \( \Phi_{\text{top}} \). The ground-observable brightness \( B \) is inverted to obtain estimated precipitation intensity \( \Phi_{\text{top}} \)

\[ \text{LT} \Phi_{\text{top}} = B \]

(1)

We estimate particular characteristics of \( \Phi_{\text{top}} \) based on observed brightness \( B \) using the L-BFGS-B algorithm with criteria:

\[ \Phi_{\text{top}}(B, E) = \arg \min \| B - \text{LT} \Phi_{\text{top}} \|^2 = \arg \min \| B - \hat{B} \| \]

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Machine Vision Algorithm

This algorithm (manuscript in preparation) allows filtering many terabytes per day to detect the highly time dynamic auroral events of interest.

Simulation Error

The amount of error in the data inversion is currently estimated by using a Gaussian fit to the data in the neighborhood of the precipitation intensity peak. The peak is detected as the maximum of the precipitation intensity.

Figure 1: Viewing geometry for three cameras at \( z \in (0, 3, 10) \) km.

Figure 2: Simulation error as measured by 2-D Gaussian Levenberg-Marquardt fitter, for \( E_0 = 3keV \).

Figure 3: Auroral detection algorithm block diagram.

Key Result

Our inversions of ground-observed auroral optical intensity estimate the characteristic energy \( E_0 \) and the location in the direction perpendicular to the geomagnetic field \( B_0 \) with error on the order of 15%. Our observations are carried out with a network of two or more tightly GPS/DO synchronized Electron Multiplying CCD (EMCCD) cameras.

Conclusion and Future Work

These preliminary results show that tightly time-synchronized cameras can provide access to primary electron precipitation characteristics with spatial and temporal resolution not otherwise readily available. As shown in [Semeter 2012], a high-resolution auroral network must be sufficiently close spaced to allow resolving fine \( B_0 \) structure, and as shown in [Hirsch 2015], a \( B_0 \) physics model such as TRANSIOR can be used to regularize the inherently poorly-observed direction parallel to the geomagnetic field. Our current results and constraints inherent to the Poker Flat Research Range indicate that sites at 3 km and 10 km spacing give servicable estimates of the peak in precipitation intensity with regard to the \( B_0 \) and \( E_0 \) characteristic energy. The system is in preparation for redeployment in Fall 2015 in ruggedized, self-contained outdoor cabinets with integral environmental control. We have work in progress on enhancing the data inversion by incorporation of data from other optical and radar sensors.

References


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