Studying Magnetosphere-Ionosphere Plasma Convection Using Optical Flow

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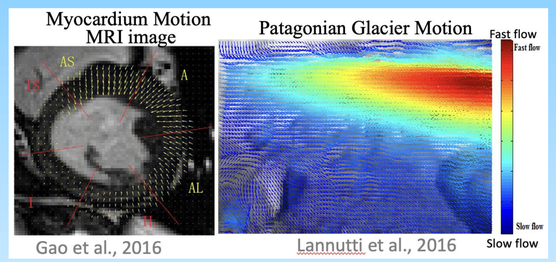
Abstract

Plasma convection is a fundamental process governing mass and energy transport within Earth's magnetosphere-ionosphere system and throughout the solar system. However, conventional convection models often fail to capture or underestimate the contributions of dynamic mesoscale (10s–100s of kilometers) structures that play a crucial role in energy transfer within this coupled system. Modern red-line all-sky cameras offer a transformative approach to studying mesoscale convection. With spatial resolutions on the order of 1 km and temporal resolutions as fine as 3 seconds, these cameras are sensitive to low-energy precipitating electrons, making them excellent tracers of magnetospheric convection.

This work presents initial results from optical flow calculations applied to red-line all-sky camera observations. Optical flow techniques track the apparent motion of objects in consecutive frames, producing two-dimensional flow fields that reveal the dynamics of ionospheric convection. Our analysis demonstrates the capability of this technique to enhance understanding of ionospheric electric fields and the role of mesoscale structures in plasma transport.

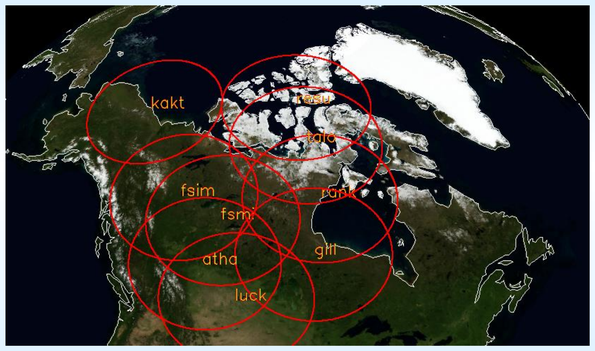
Introduction and Methodology

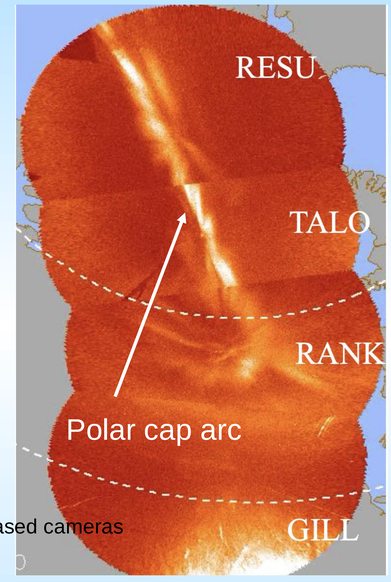


- Optical flow used here (also called gradient or differential method) is the representation of the apparent two-dimensional motion of an "object"
- We calculate the motion between two image frames
- We use the Horn and Schunk, 1981, method to determine optical flow
- The technique has been successfully used in many fields

- Auroral optical data is a great data set to apply the optical flow technique
- Several arrays of optical instruments are available for the analysis

The REGO Array



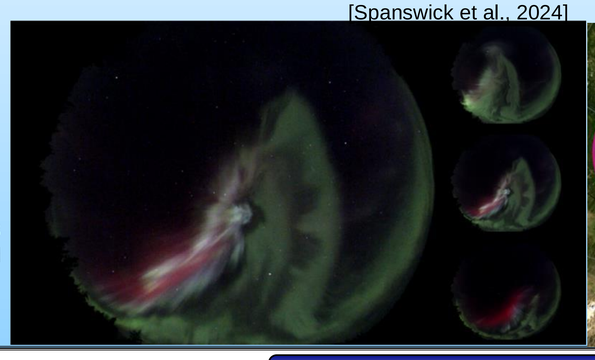


- REGO (Redline Geospace Observatory) is composed of nine ground-based cameras
- These imagers measure the 630.0 nm emission
- Calibrated to obtain luminosities in Rayleigh
- The 630.0 nm emission is particularly sensitive to low-energy precipitation, allowing us to study dim features

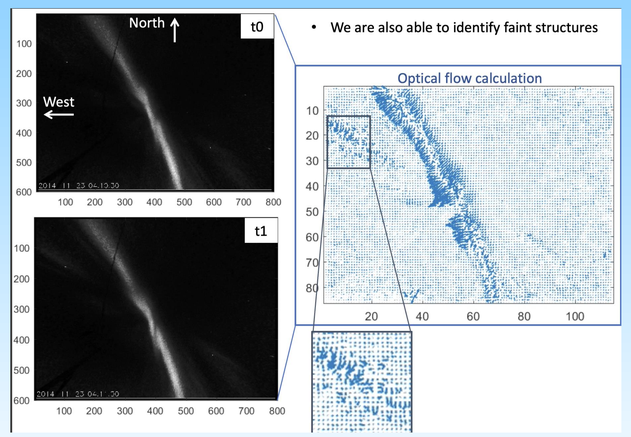
[Spanswick et al., 2024]

The TREx RGB Array

- TREx (Transition Region Explorer) is composed of seven ground-based cameras
- These imagers measure in true RGB color
- The cameras operates in 3 second time resolution and a 3Hz burst mode as a campaign mode for certain events



Discussion and Applications



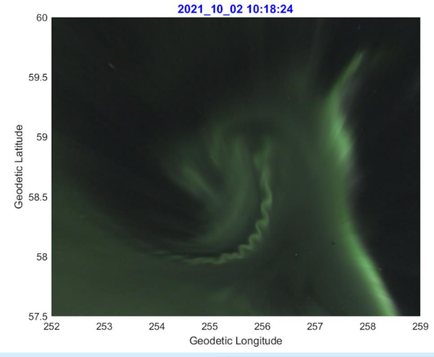
- Using optical flow, we have been able to track the motion of auroral structures, even when they are dim
- This is an example of a polar cap arc motion

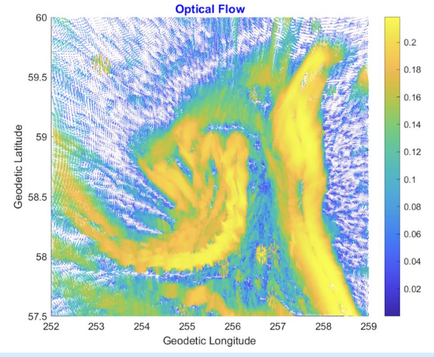
Some Issues

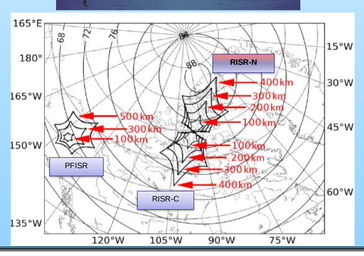
- The code used for optical flow analysis was originally developed in MATLAB; however, for years, processing tools for optical auroral data have been exclusively developed in IDL
- Optical data analysis tools include geolocation information, enabling distance calculations
- Code conversion was not available but necessary for this analysis

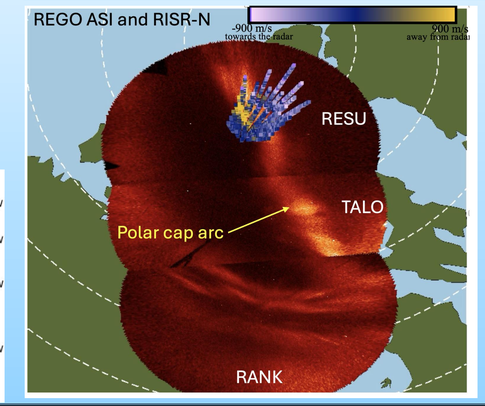
[Gillies et al., in progress]

- Collaborator D. M. Gillies made tools for analysis of optical auroral data in MATLAB
- Calculating the velocities of optical structures within the oval and polar cap is now possible









Technique validation

- Incoherent Scatter Radars (ISR) overlap with auroral imagers
- These radars provide electron density, line-of-sight flow velocity, electron and ion temperature
- For structures that move with plasma convections, velocities measured with ISRs can be compared with optical flow calculations

Summary and Conclusions

- Optical flow is an effective technique for quantitatively analyzing the motion of auroral structures.
- We have successfully developed a new MATLAB code for auroral structure analysis.
- This code is well-suited for integration with optical flow calculations, enabling efficient tracking of auroral and polar cap arcs.
- Radars provide valuable data for validating this technique in different ionospheric regions.
- Incoherent scatter radar data is currently being analyzed for validation.

Acknowledgements

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- The Transition Region Explorer RGB (TREx RGB) is a joint Canada Foundation for Innovation and Canadian Space Agency project developed by the University of Calgary. TREx RGB is operated and maintained by Space Environment Canada with the support of the Canadian Space Agency (CSA) [23SUGOSEC]. TREx RGB data is openly available. Users must, at a minimum, acknowledge usage of the data using the below citation for the data set. The TREx team welcomes opportunities to collaborate on usage of the data and may assist in aspects of data processing and/or interpretation.
- The REGO and TREx datasets are available from the University of Calgary data website at https://data.phys.ucalgary.ca/
- ISR data can be obtain from https://madrigal.haystack.mit.edu/