2025 Workshop: What are the polar cap patches?

Long title
Redefining Polar Cap Patches: Understanding High-Latitude Irregularities, and their implications for the coupled MIT system
Grand Challenge
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Description

Polar cap patches have long been discussed as F-region plasma density enhancements at least twice the background density, typically ~100-1000 km across. However, debate persists on whether this definition is accurate, helpful, or if "patches" encompass multiple phenomena, given that soft precipitation, Traveling Ionospheric Disturbances (TIDs), and Tongues of Ionization (TOIs) can also produce localized plasma density enhancements. Observational biases further complicate classification. It is therefore argued that in modern high-latitude research this definition is more confusing rather than clarifying. This grand challenge seeks to evaluates “patches” from modeling, theory, and observational perspectives, by bringing together experts not only in polar cap structuring, but also waves and other high-latitude phenomena to see evidence of similarities and differences in different

identified structuring in the polar cap and come to some consensus about whether or not present categorization makes physical sense, or if it should be reconsidered. These are now achievable with the availability of the long-term observations in the polar cap, and the recent advances in numerical simulations such as MAGE, GITM and GEMINI. This grand challenge will feature talks providing background and an extended discussion period, with a focus on keeping the session structured. We encourage submissions contributing to this debate and especially welcome participation from students and early-career researchers, as evolving definitions will shape future studies of the polar cap.

Virtual Link

https://umich.zoom.us/j/98614457228

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Agenda

Tuesday 6-24-2025 13:30-15:30

13:30 - Shasha Zou: Tutorial

13:50 - Taylor Cameron: Polar Cap Patch Impacts on HF Radio Propagation

14:00 - Waqar Younas: Ionospheric Irregularities and Their Impact on Position Accuracy in the Antarctic Region

14:10 - Sophie Maguire: Observations of structures in the high-latitude ionosphere and their effects for GNSS

14:50 - Amelia Lee: Meso-scale Polar Cap Flows and their Impact on Polar Cap Patch Evolution

14:20 - Aidan Thayer: A Statistical Background Study of Polar Latitudes Using Longterm AMISR Data

14:40 - Olu Jonah: Long-term variability of polar cap patches using Advanced Modular Incoherent Scatter Radars (AMISRs)

14:50 - Braeden Peterson: Correlation Analysis of Ionospheric Drivers on Scintillations

15:00 - Roger Varney: No Pinching: Topological Constraints on Polar Cap Patch Formation Mechanisms

Wednesday 6-25-2025 10:00-12:00

10:00 - Shunrong Zhang: GNSS TEC measurements of polar cap patches and TIDs during recent storms

10:10 - Gareth Perry: A case study of HF scintillation during a polar-cap patch event

10:20 - Larry Lyons: Importance of flow channels in greatly structuring the polar cap, including on large temporal and spatial scales

10:30 - Ying Zou: Polar cap patches traced by PMRAFs: hemispheric symmetry and asymmetry

Justification

Introduction
Descriptions of polar cap patches in the high-latitude ionosphere have percolated the literature for 75 years. They are traditionally defined as enhancements in plasma density at least twice the background plasma density. Less formally, the term is typically used to describe enhancements ~100-1000 km across that move with the background plasma convection. Over the decades, many studies have described different and often contradictory properties of polar cap patches, including:
Internal temperature (hotter or colder than surrounding plasma)
Propagation direction (generally antisunwards but sometime not)
Morphology and development (cigar shaped, circular, or amorphous)
Generation mechanism (segmented TOI, bursty reconnection, soft precipitation, Traveling Ionospheric Disturbance, gravity waves, etc)
Destruction mechanism (break apart, join nightside aurora as “blob”, enhanced recombination)
Small-scale structuring (trailing edge, leading edge, or internal)

With this in mind, there has recently been increased debate over whether the definition, or even the idea of patches as a unique and unambiguous phenomena, is appropriate. High-density plasma may arise from various sources, but it is unclear if “patches” defined in individual studies are truly patches. For instance, many plasma

structures that would typically be described as patches appear similar to wave-like structures, such as traveling ionospheric disturbances (TIDs). Similarly, there is debate as to the extent that patches and TOIs are actually independent phenomena vs the same thing observed with different techniques or at different stages in its life cycle.

Justification
A stand-alone workshop on this topic was convened at the 2024 CEDAR workshop, which generated excellent community discussion about this dilemma and allowed us to more clearly define “patches”, as well as discuss some of the competing theories and observations associated with them. However, the consensus was that there is still significant, focused work that needs to be done to actually resolve these open questions, requiring more than a standalone session. We are therefore proposing this as a Grand Challenge topic so we can devote sufficient time and attention to different aspects of the question. In particular, in order to allow time for healthy community discussion during last year’s session, there were very limited opportunities for the community to present new research and results, which we believe are also an important part of the discussion.

Patches are an important phenomenon for understanding plasma transport, ion-neutral coupling, and currents in the polar region. The high-density plasma is a source of ion upflow/outflow, and manifests as a tracer of multi-scale flow structures. Patches also have Space Weather impacts particularly regarding radio communication and navigation, since the high density plasma and associated irregularities alter HF wave propagation and cause scintillation. The origin of the polar cap patches is one of the objectives of the Priority Science Goal 3 in the 2024 Decadal Survey. The driver of ion outflows is one of the objectives of the Priority Science Goal 2. The HF signal propagation is recognized as one of the Space Weather impacts.

Science Questions
Definition of Patches:
How should we define polar cap patches?
How do we differentiate between polar cap patches and other important density enhancements, such as polar cap arcs and TIDs?
Is more specific terminology required for polar cap density structures?

Properties of Patches:
What are the properties of patches (e.g., generation mechanism, propagation and decay patterns)?
How are these distinct from other density enhancements in the polar cap?

Impact of Patches:
How do patches as observed from different modalities (e.g. ISR, TEC, in-situ, ASI and SuperDARN) compare to each other?
How do patches impact cross-scale coupling in the ionosphere?
What are the impacts of patches in the M-I-T system?
What are the space weather effects of patches? What is their societal impact?

These questions will be addressed through the collection of relevant publications and presentations produced during the GC period. We will also create action items or research objectives to be evaluated in the following years. These items can be fulfilled by group research efforts. Progress on this GC will be through the development of new and/or clarified definition(s) of polar cap patches that respect phenomenological differences.

Community Research Resources
Several polar cap observing facilities have been collecting data for over a full solar cycle, including RISR-N and CHAIN. There are additional satellite datasets such as Swarm and e-POP. All of these can be used to study various patch phenomena, both through case studies and statistical investigations.
Recent advances in sophisticated coupled MI models (ie, MAGE, GITM) have improved their ability to resolve patch-scale structuring. Many of these are available on CCMCTo address questions about TID behavior in the polar cap and how these waves interact with patches, we need fully coupled ionosphere-neutral atmosphere models that can resolve patch-scale dynamics.
Additional measurements of neutral dynamics would significantly enhance our ability to study how patches are involved in IT copling, both through interactions with TIDs in the neutral atmosphere and chemistry effects.

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Keywords
polar cap, patch, high latitude

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