Analysis of Ionospheric Patches Based on Swarm Langmuir Probe and TEC Data

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Outline

What is a patch?

Patch detection algorithms using Swarm GPS and LP

Occurrence rates across both hemispheres

Correlation with IMF

What is a patch?

- Dense, fast-moving regions of ionization at high latitudes
- >2x background density, km/s velocities, approx. 100 – 1000 km diameter
- Patches contain plasma irregularities that affect RF signals
- Patches are made up of photo-ionized plasma, convected across the Polar caps through the action of the magnetosphere
- Proposed formation mechanisms include:
  - Transient magnetopause reconnection
  - IMF B_y and B_z variations
  - Mesoscale Flow Channel Events

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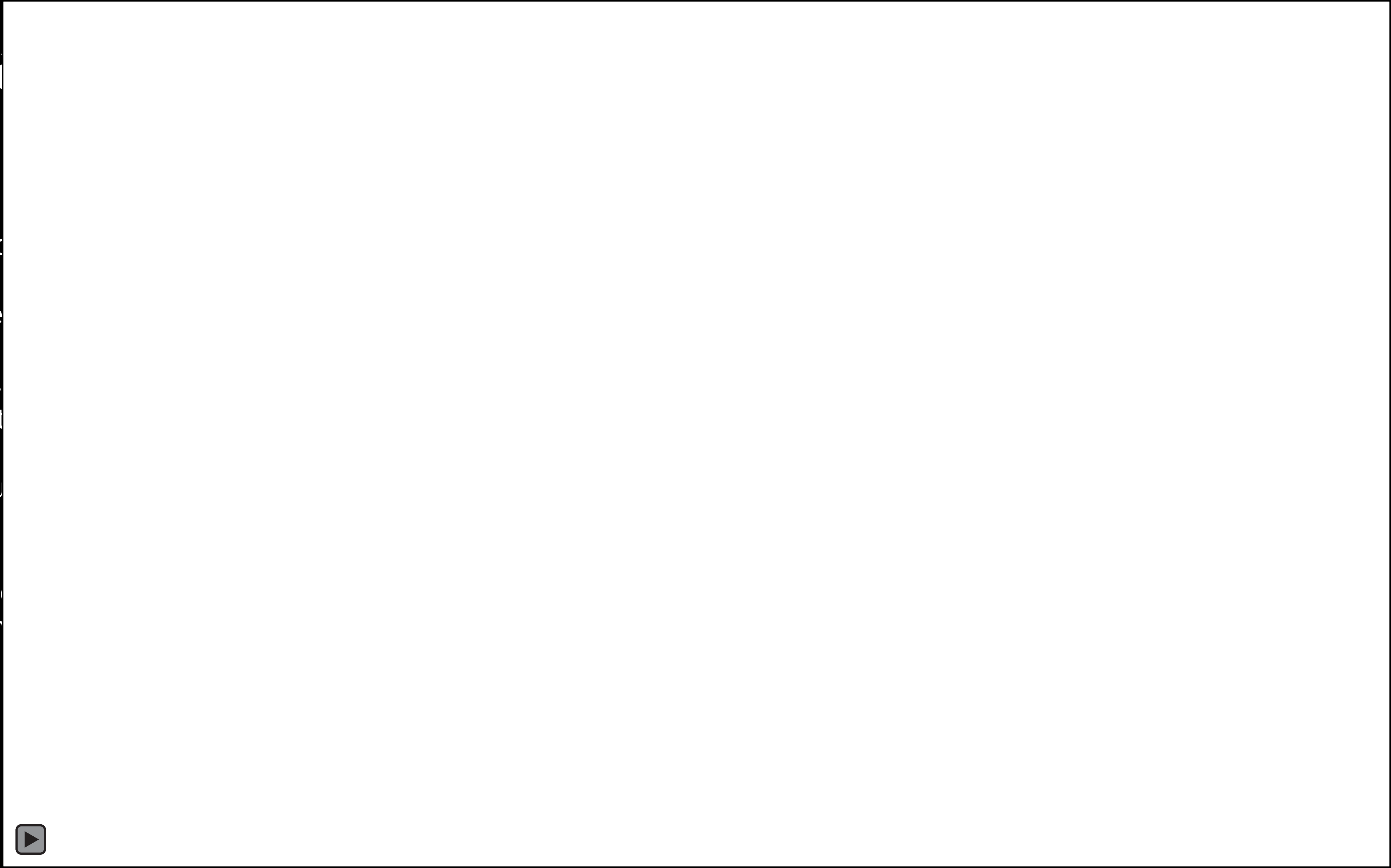


Swarm instruments

- Swarm consists of three satellites in Polar orbits, allowing for systematic patch detection with even coverage across both hemispheres
- A and C fly side by side at 87.4^{o} at <460km, B is at 88^{o} at <530 km
- Langmuir Probe and upward-looking GPS receiver among instruments onboard
- Observed *in situ* F-region densities and upward-looking TEC can both be employed to detect patches [*Coley and Heelis,* 1995; *Noja et al.*, 2013]

Patch detection algorithms

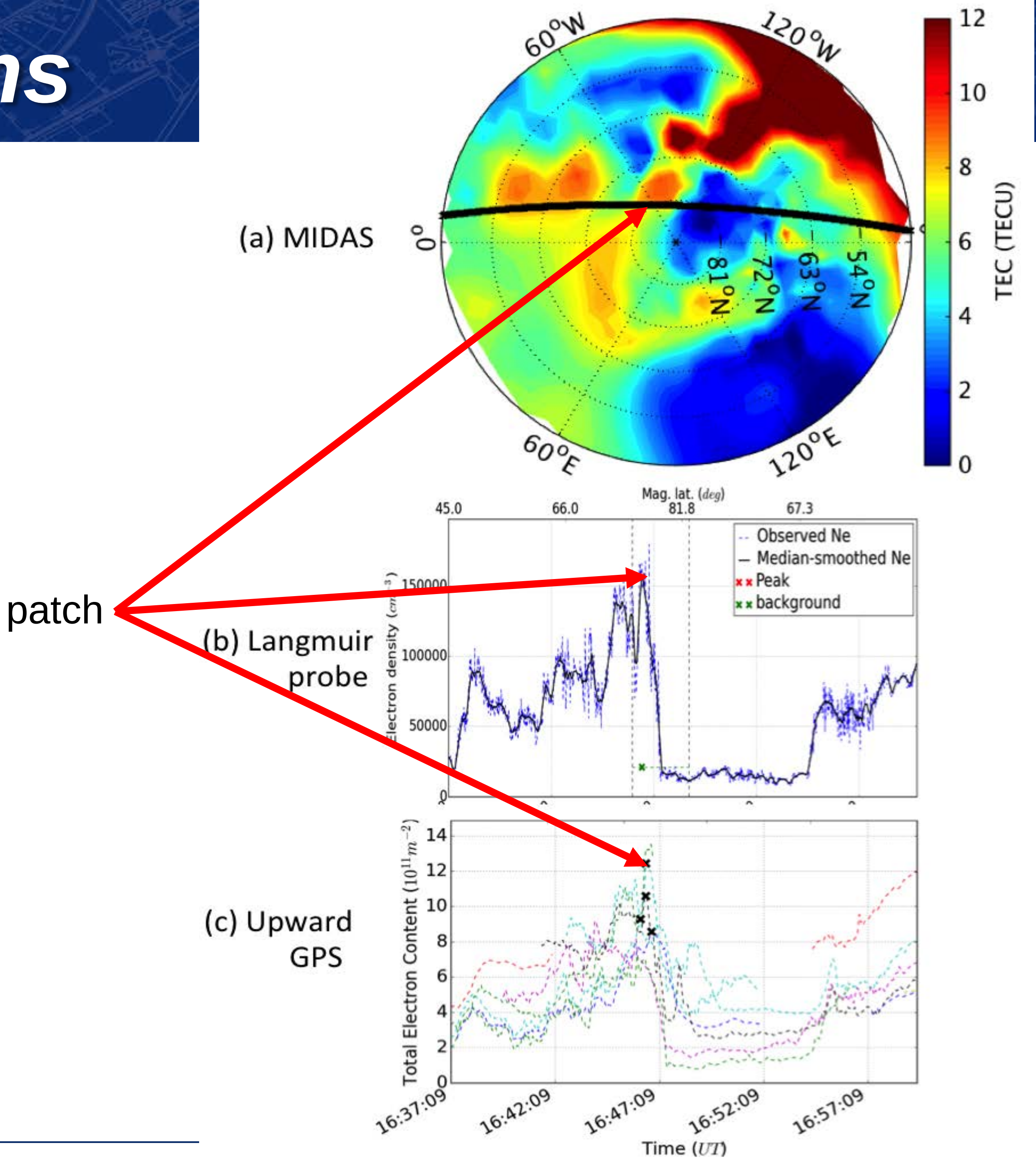
Swarm B passed through the Polar cap during the movie shown earlier. Frame at 16:40 UT is rotated and shown here.

Langmuir Probe Filter (similar to *Coley and Heelis* [1995]:

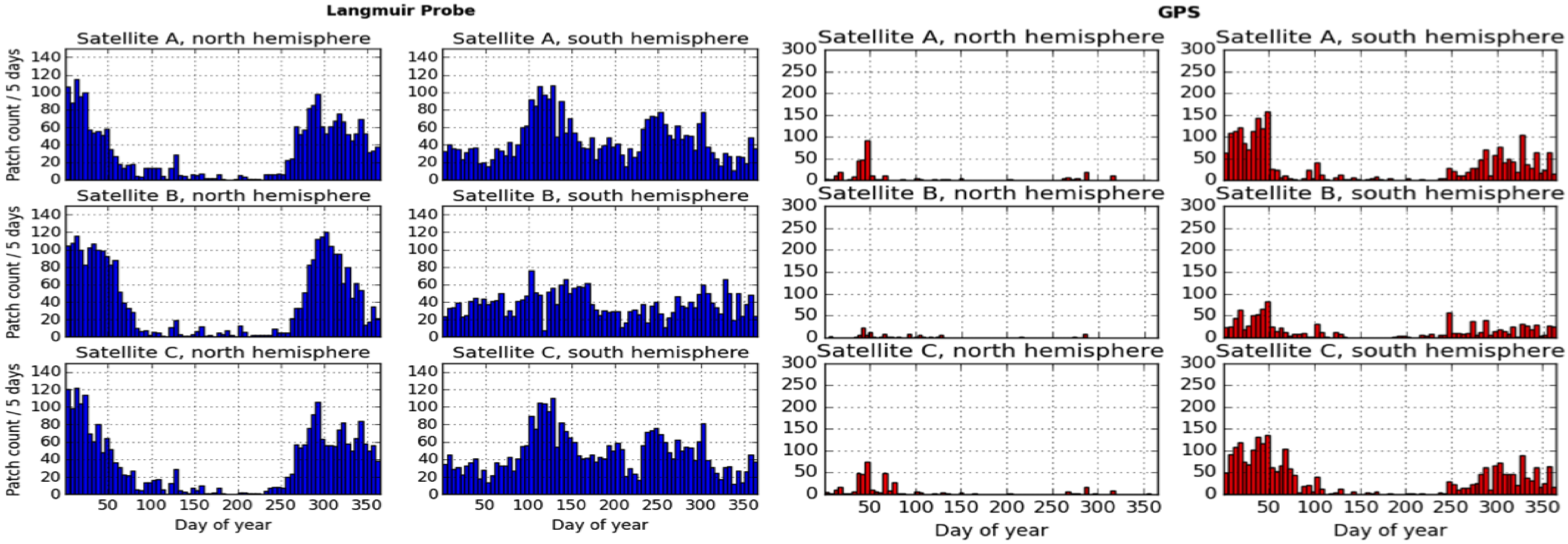
- 120 km median smoothed 2 Hz data
- 1250 km sliding window
- Edges must increase and then degrease >40% within 140 km
- Peak density > double median value in window
- 70º MLAT cutoff

Upward GPS, following *Noja et al.* [2013]:

- 1 Hz data
- 1500 km sliding window
- Positive gradient followed by negative gradient
- $(TEC_P - TEC_{BG})^2 / TEC_{BG} \geq 1.2$ TECU
- $TEC_P - TEC_{start} \geq 4$ TECU
- $TEC_P - TEC_{end} \geq 4$ TECU
- 55º MLAT cutoff



Results: 2016 occurrence rates



Despite double-counting problems, upward GPS detects fewer patches than Langmuir Probe.

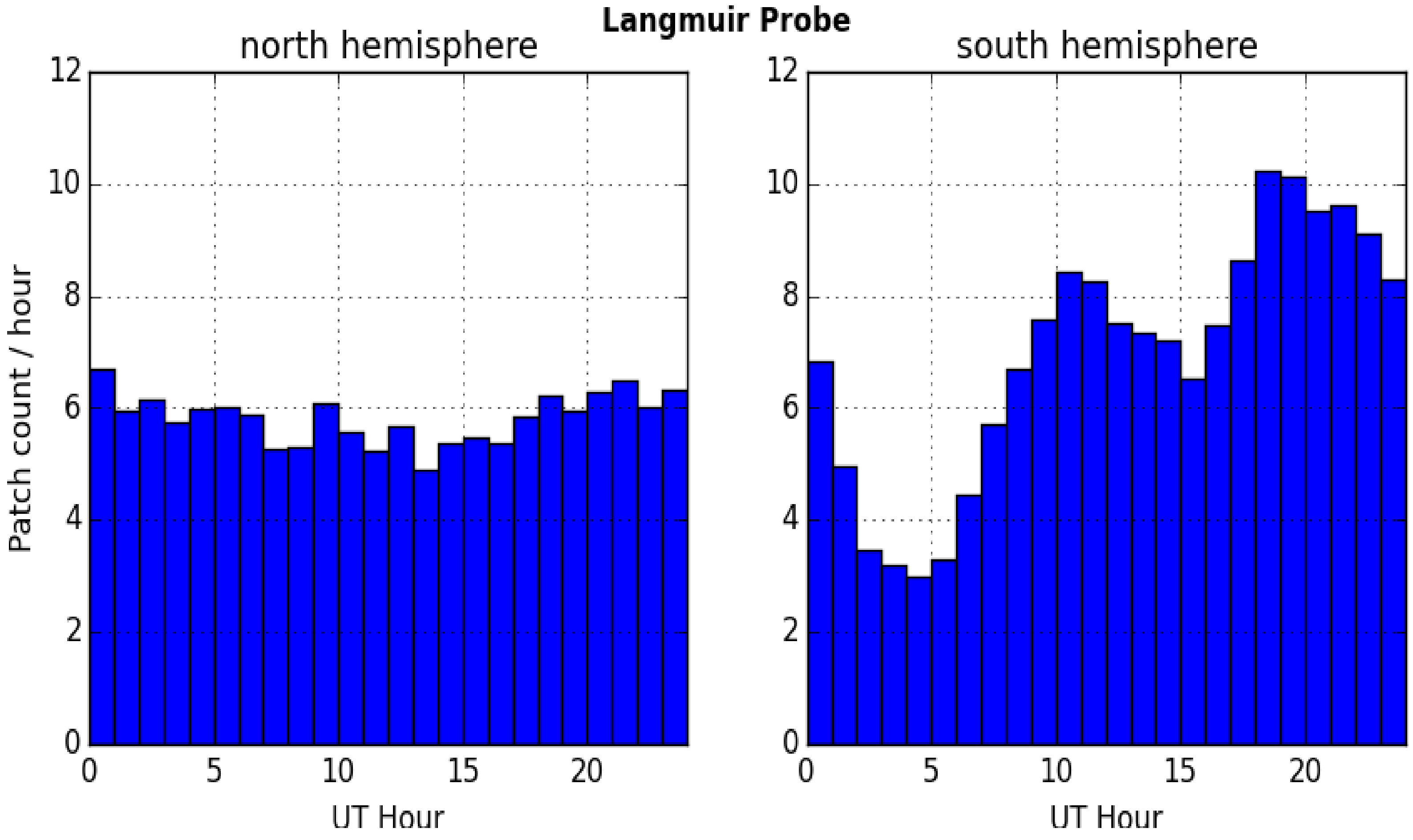
Both methods show hemispheric and seasonal asymmetry

Northern hemisphere peaks in local winter. Southern hemisphere peaks either at equinox or in local summer.

A and C results very similar, so these are genuine large-scale (100s of km) structures.

Only use A and B Langmuir probe from here on

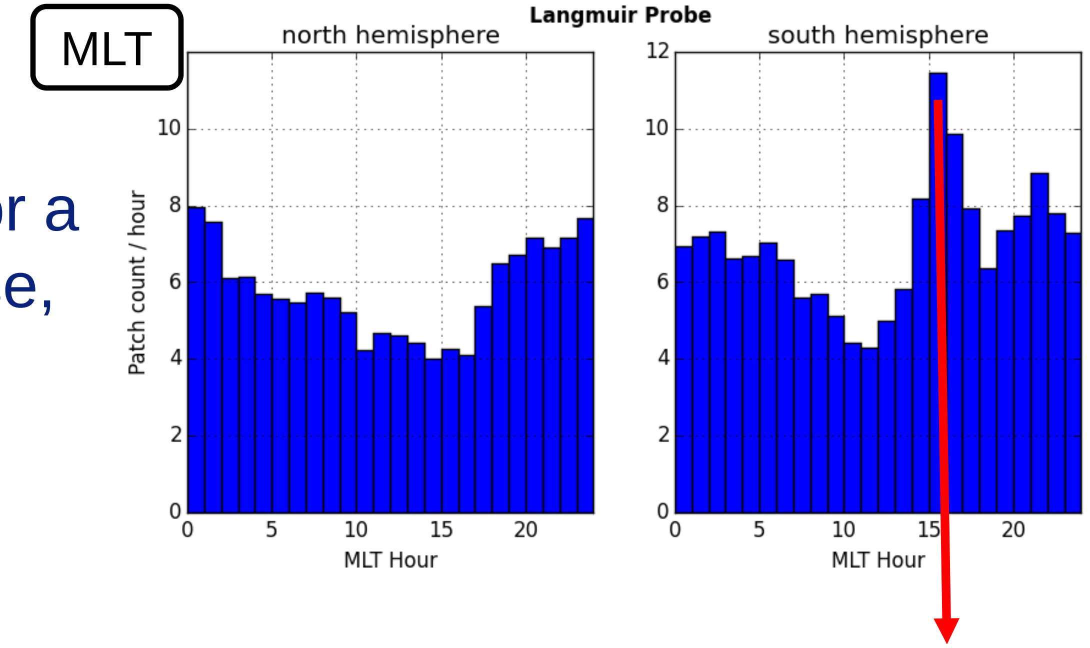
Results: UT occurrence rates



- UT occurrence rates from satellites A and B.
- Normalized according to satellite hours spent in each UT bin
- Northern hemisphere approximately invariant in UT
- Southern hemisphere max. at 18 UT, min. at 4 UT
- South mag. pole is at 64º S, North mag. pole is at 86º N
- South occurrence rate peaks when mag. pole is close to midnight

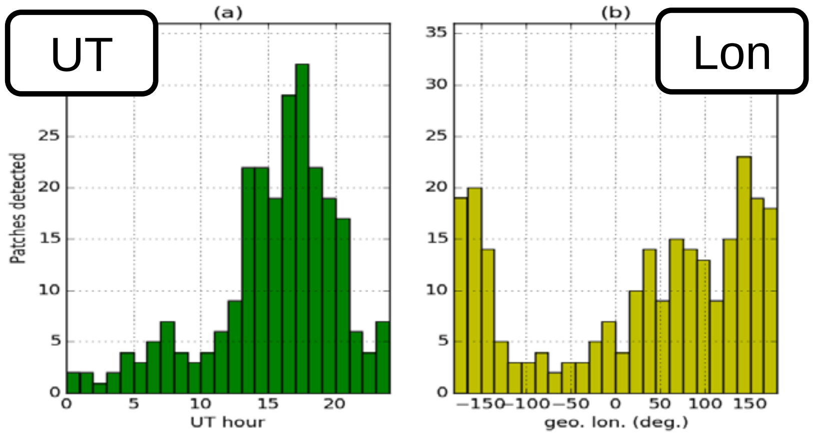
Results: MLT occurrence rates

Normalized MLT occurrence rates are similar in both hemispheres, except for a spike at 15-16 UT in the SH. Otherwise, more patches are found on the nightside.



15-16 UT SH patches strongly associated with the mag. pole near midnight effect.

Most commonly found in the 135-150° E sector. The mag. pole is at 137° E.



Space Exploration

Occurrence rate correlations

Pearson (linear) correlations are calculated between normalized hourly occurrence rates and all the hourly parameters from NASA's OMNI service (not all shown). IMF data are propagated to Earth at the Solar Wind speed from the L1 point.

Hours when neither satellite A or C passed above 70º MLAT are excluded.

OMNI parameter	*r* correlation coefficient	*p* factor
D_{st} ring current	-0.19	0.000
a_p magnetic disturbance	0.18	0.000
UT hour	0.14	0.000
E electric field (V)	0.11	0.000
B_z (nT)	-0.10	0.000
RMS Bz (nT)	0.08	0.000
RMS By (nT)	0.08	0.000

$p < 0.05$ is significant

$|r| < 0.25$ is uncorrelated

No global hourly parameter is found to correlate with patch occurrence rate, probably due to sampling error (patches that occurred unseen by Swarm).

The parameters all have the predicted signs (e.g. B_z southward, D_{st} negative).

Better observational coverage is required to identify patch occurrence rate drivers, or to rule out macro-scale mechanisms

Summary

- Patches can be detected using Swarm's Langmuir Probe and upward-looking GPS receiver. However, MIDAS validation indicates the upward GPS can count the same patch multiple times.

- Seasonal occurrence rates show strong hemispheric asymmetry. Northern patches occur primarily in winter. Southern patches are seen year-round, peaking at the equinoxes.

- A spike in the southern MLT occurrence rate is linked to the location of the Magnetic pole, and its presence on the nightside of the Earth at that time

- No statistical correlations found between patch occurrence with IMF parameters and global indices

Future work

We plan to deploy a bistatic HF array to Antarctica (TX: McMurdo, RX: South Pole) to further this line of inquiry. Observations of velocity, seasonal occurrence rate, structuring and magnitude will be instrumental in determining the physical mechanisms responsible for Antarctic patch occurrence.

Given enough receiver coverage, a patch counting algorithm could be developed and applied to GPS tomographic images. This provides one method of overcoming the sampling deficiencies of a sparse satellite observing network such as Swarm.

Swarm's Electric Field Instrument has recently been released. This, in combination with ground-based SuperDARN data, may be useful in identifying whether mesoscale convective features are responsible for patches.

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