Probing the polar ionosphere in-situ and remotely

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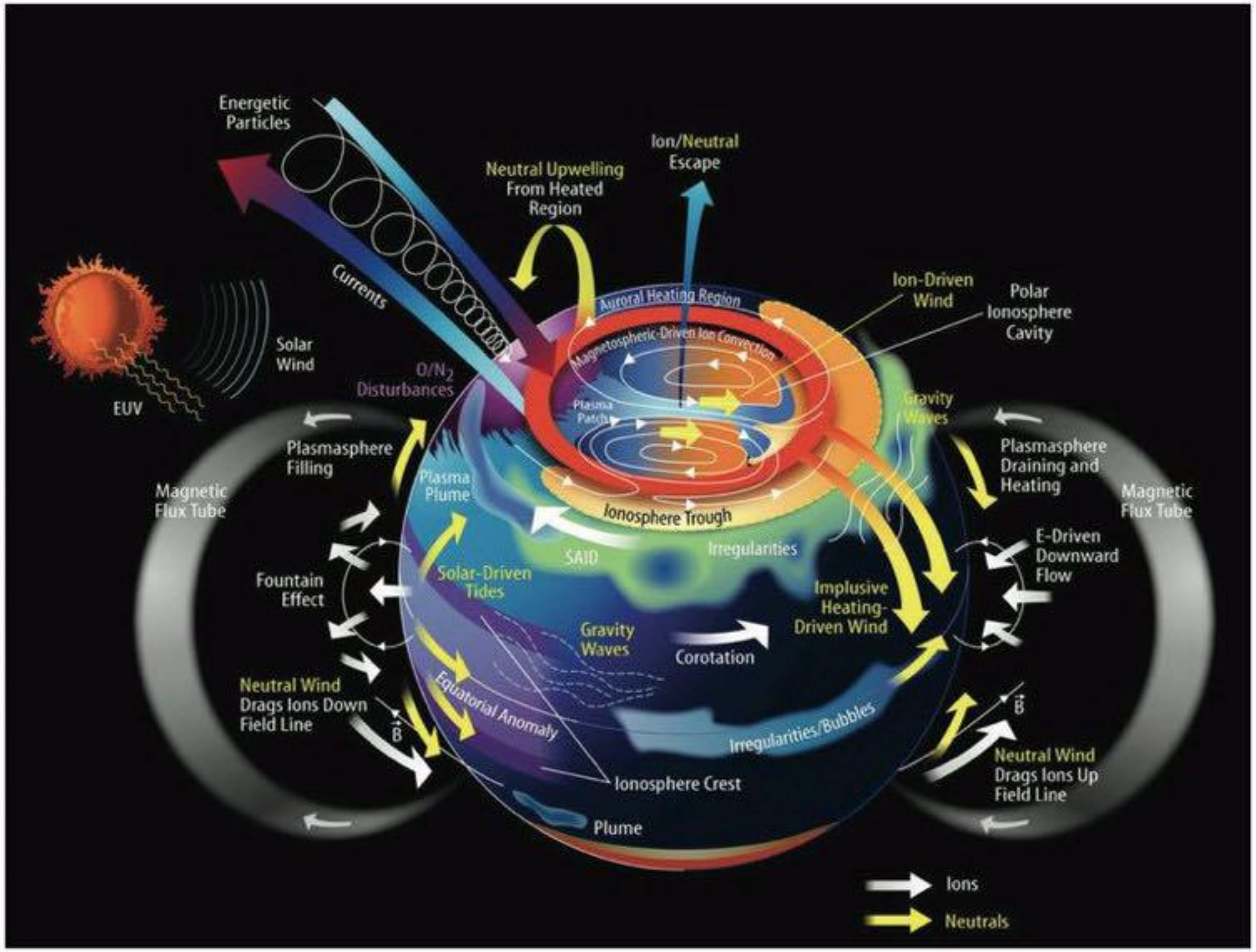
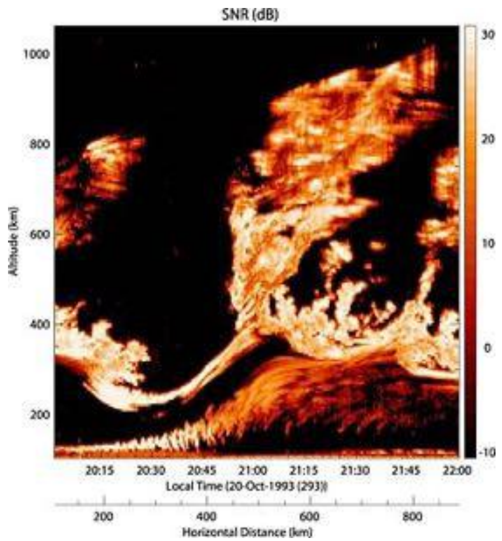
Magnetosphere – Ionosphere – Thermosphere coupling



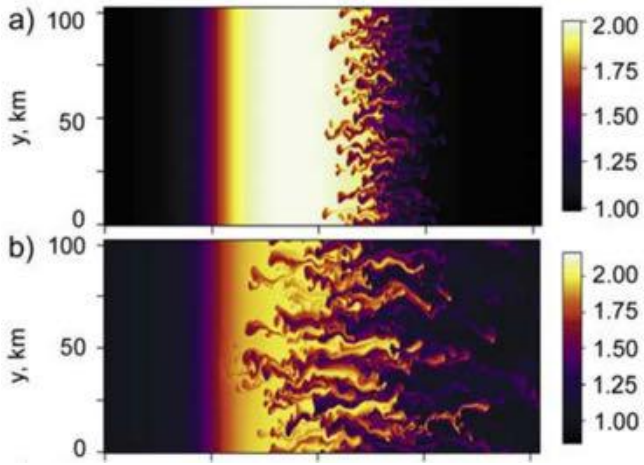
NASA/J. Grobowsky

- Interaction between the Sun and the Earth (not only magnetically) drives a multitude of physical phenomena
- The MIT coupling and associated effects are most pronounced at high latitudes.

Magnetosphere – Ionosphere – Thermosphere coupling



ESF, Echoes of Jicamarca radar
(Woodman and Chau, GRL 28, 207, 2001)



Evolution of the Gradient Drift Instability
Gondarenko & Guzdar 2004

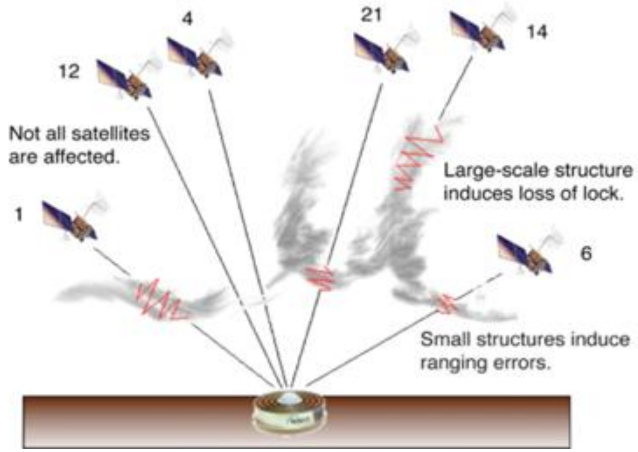


Illustration of irregularities affectinng GNSS signals.
Ahmed, W. A. et al. Proc. SPIE 10425, 104250A, 2017

Plasma instabilities in the ionosphere lead to irregularities at various scales.

Some of phenomena in the ionosphere affect technological systems, such as the Global Navigation Satellite Systems (GNSS) or power grids.

How to study the ionosphere?

Cluster, Swarm, ACE etc.

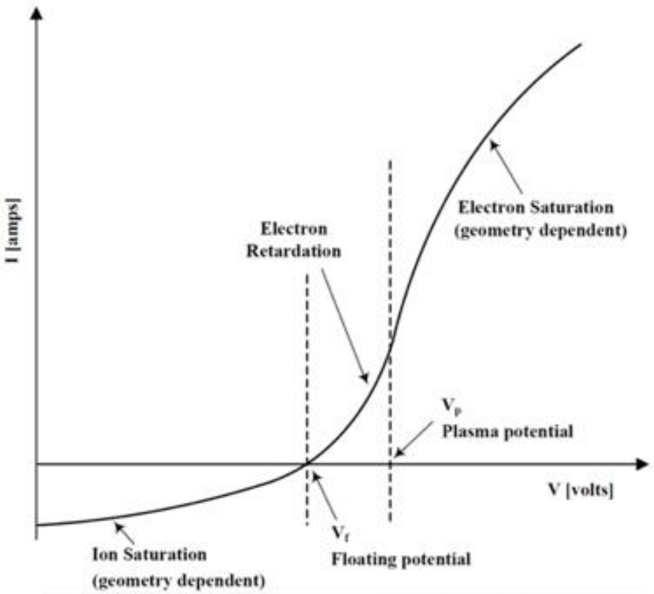
IONOSPHERE

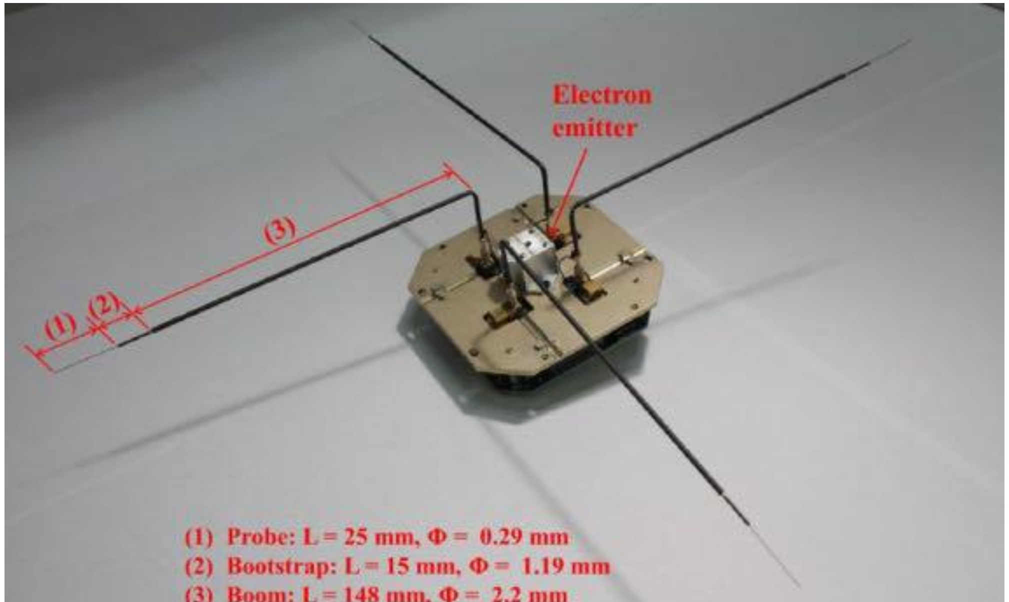
EISCAT – radar, Superdarn, Optical studies, TEC receivers

(Svalbard: Ny Alesund, Longyearbyen, Hornsund; Skibotn; Antarctica)

Arctic – sounding rockets

Langmuir probes – m-NLP system





m-NLP system for a cubesat

Space simulator at UiO

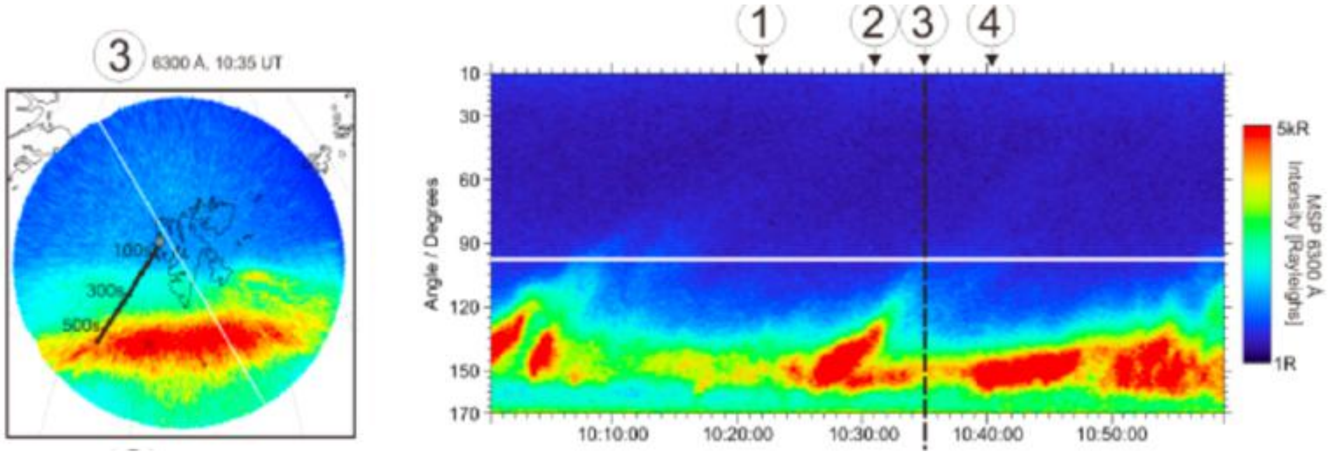
NORSAT1 - satellite

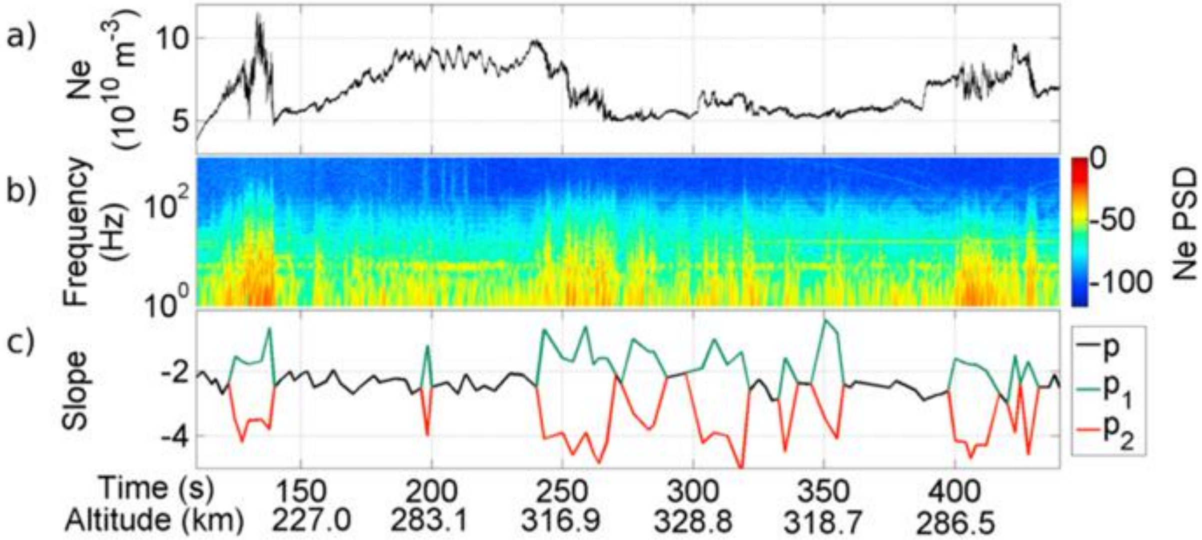
Arctic – sounding rockets

https://www.grandchallenge.no/

Arctic – sounding rockets

ICI-2 05. Dec 2008, 1037 UTC





Spicher et al. *JGR* 120, 10959, 2015

Arctic – sounding rockets

ICI-2 05. Dec 2008, 1037 UTC

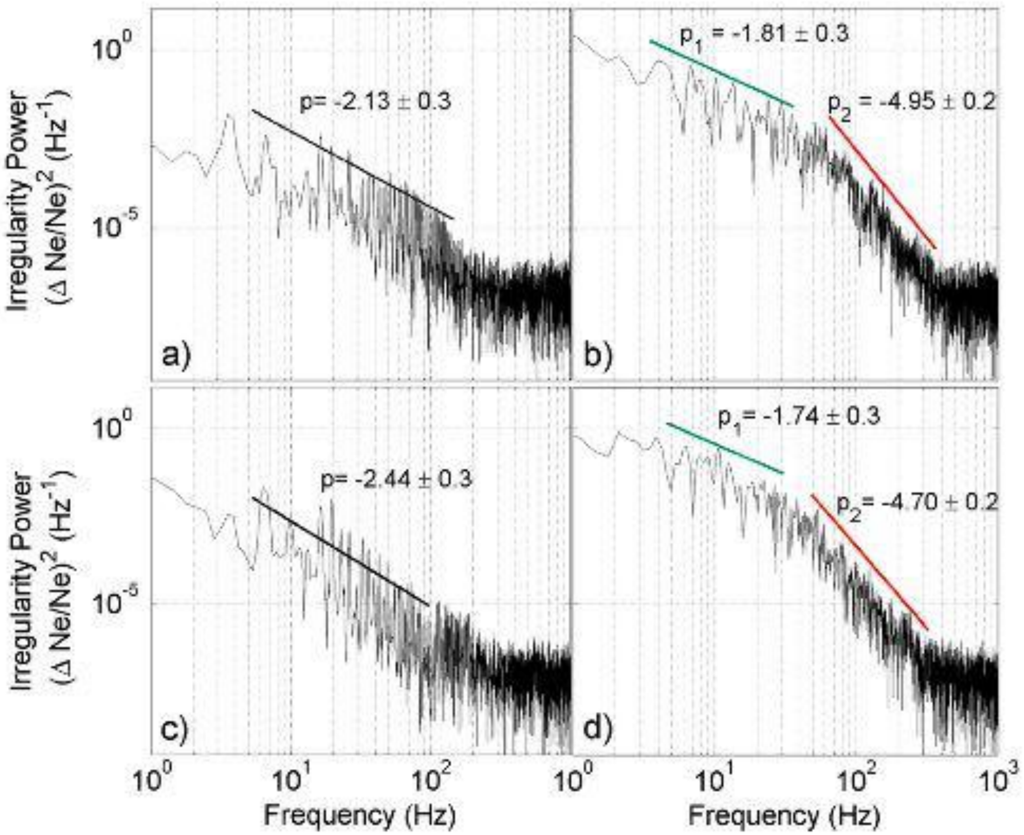
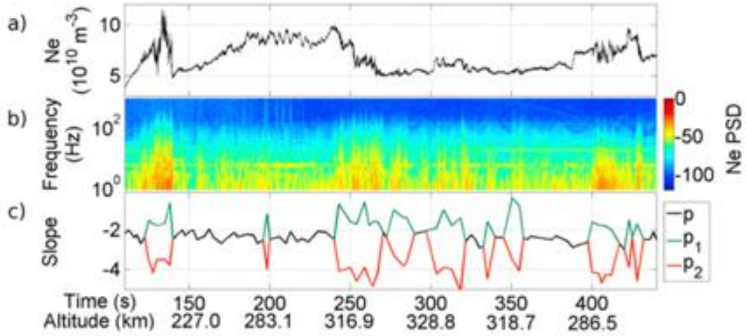
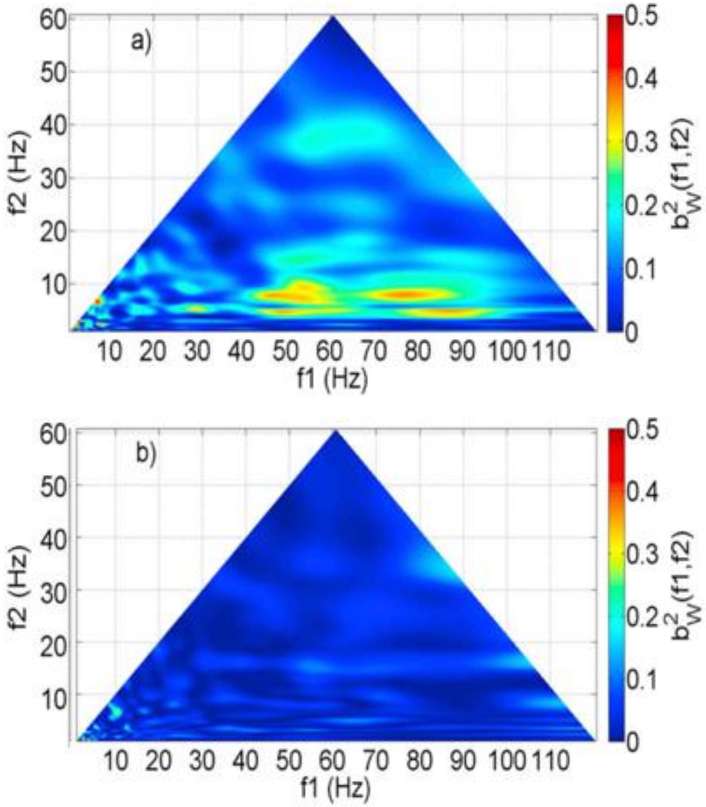


Figure 2. Power spectra and the fits of the slopes for (a) $t_{of} \in (271.5, 273.5)$ s just after strong fluctuations with no significant precipitation, (b) $t_{of} \in (265, 267)$ s for strong fluctuations with no significant precipitation, (c) $t_{of} \in (425, 427)$ s just before strong fluctuations with a significant electron precipitation, and (d) $t_{of} \in (428, 430)$ s for fluctuations with precipitating electrons. For visualization, the fits are shifted above the data.

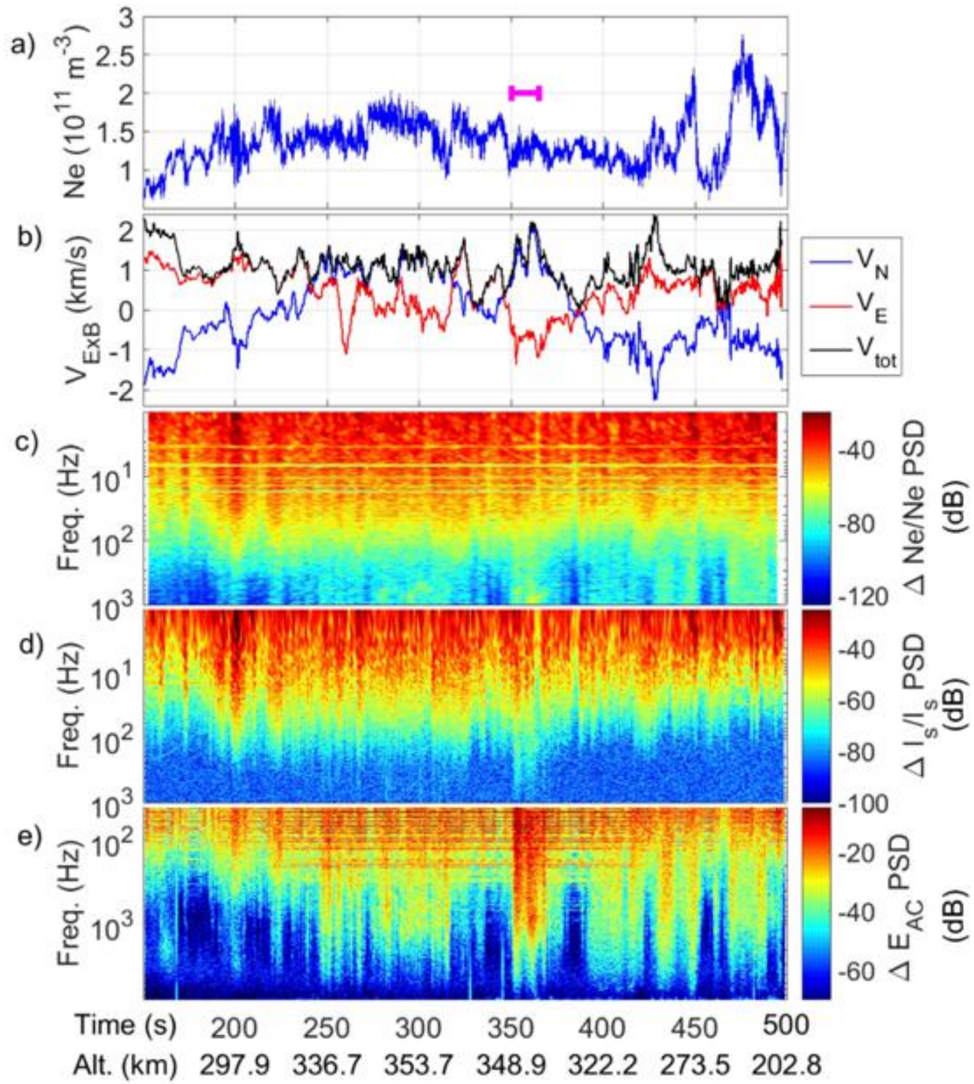


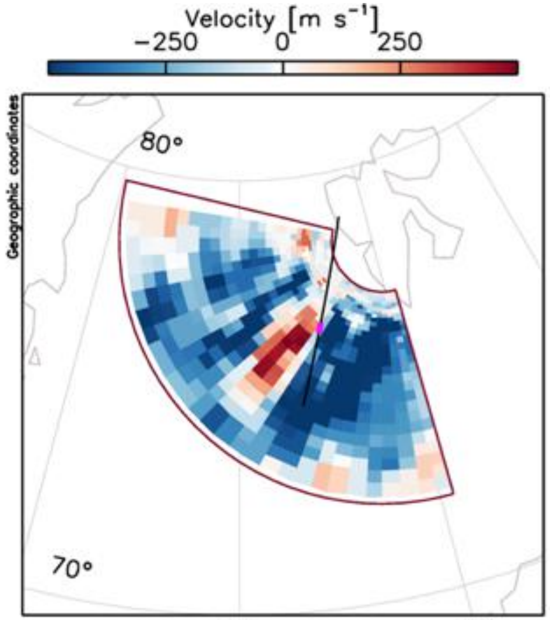


Spicher et al. *JGR* 120, 10959, 2015

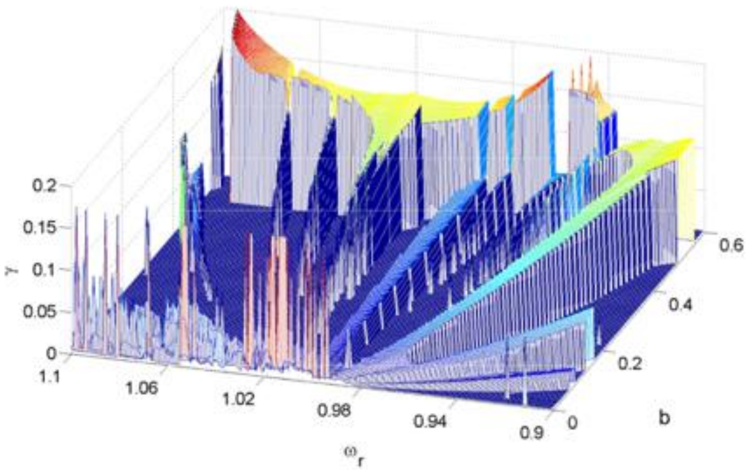
Arctic – sounding rockets

ICI-3 03. Dec 2011, 0721 UTC





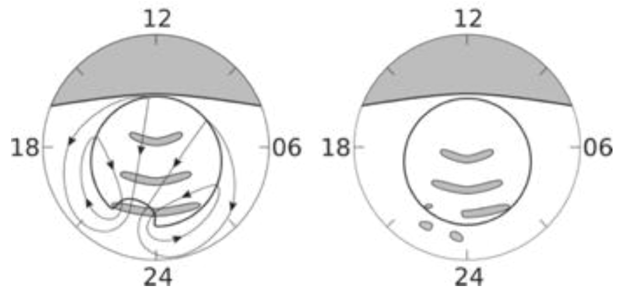
EISCAT results

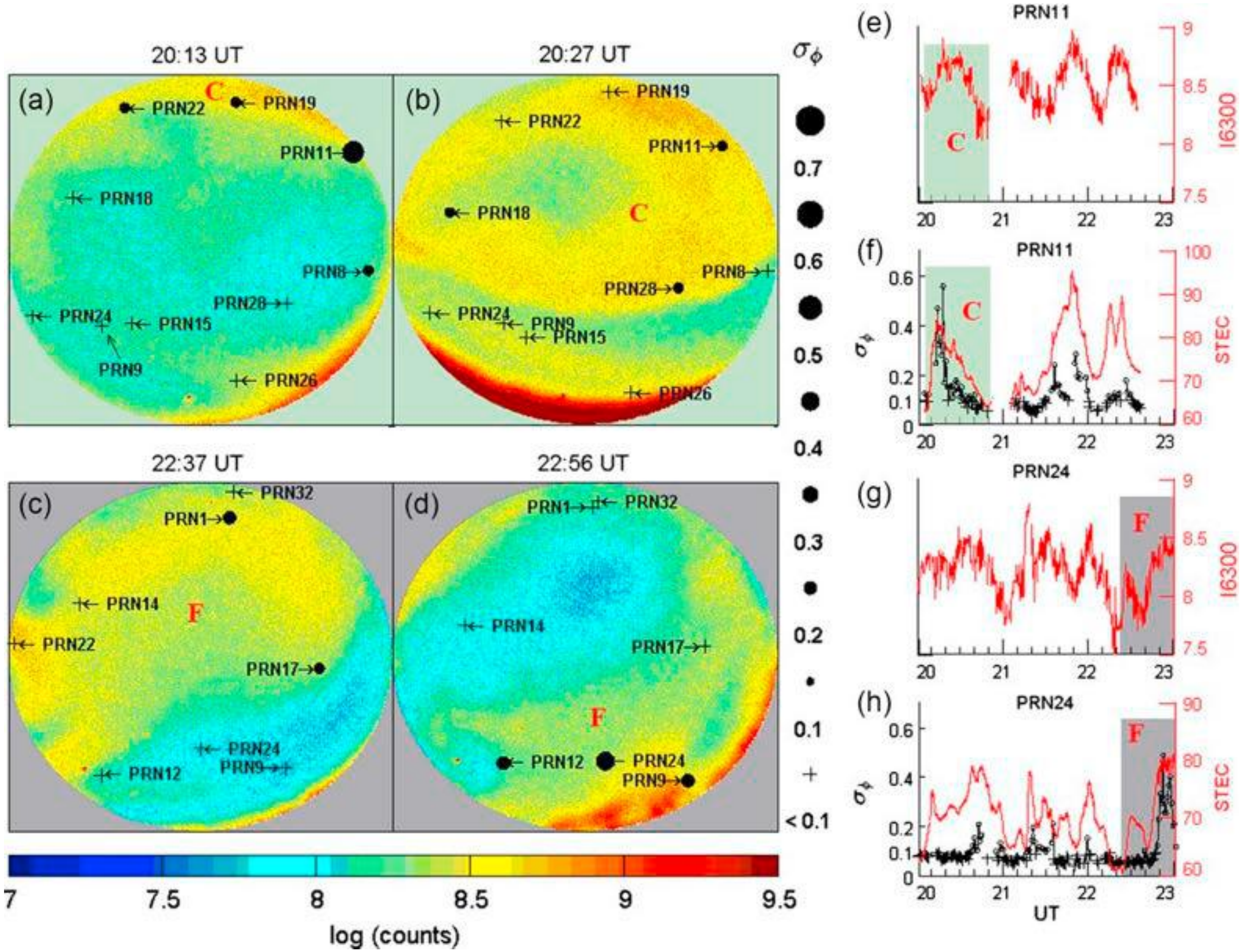


Growth rate of the inhomogeneous energy-density-driven instability (IEDDI)

Spicher et al., *JGR* 121, 10446 (2016)

Polar cap patches – ground based observations



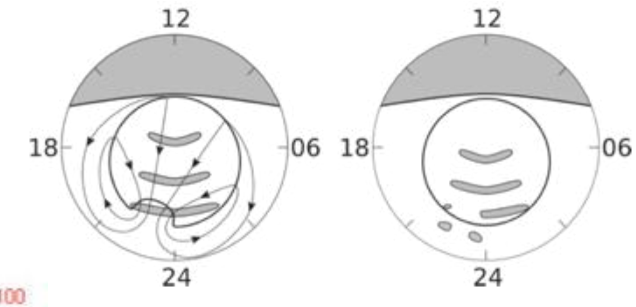


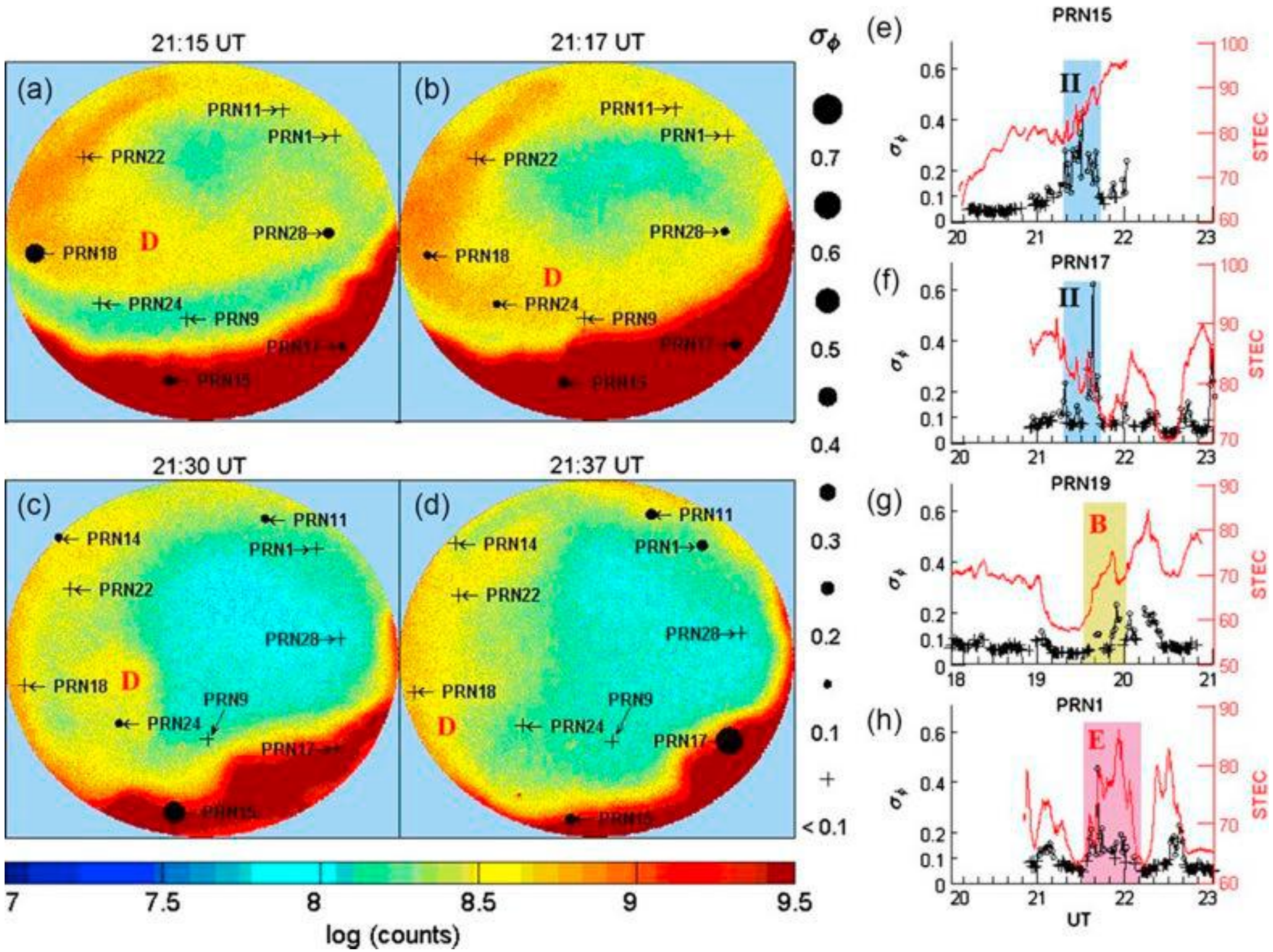
Edges of polar cap patches are associated with higher values of sigma_phi scintillation indices

All-sky-imager and GISTM data from Svalbard / NYA – Jan 13, 2013

Jin et al, SWSC, 2014

Polar cap patches – ground based observations



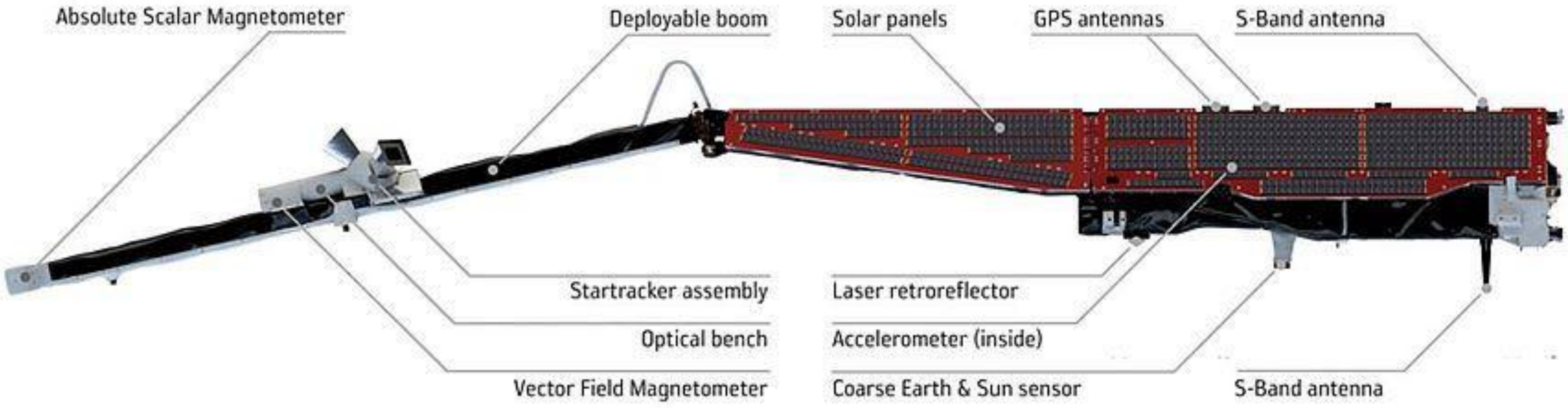


When a PCP enters auroral oval the structuring is largest.

All-sky-imager and GISTM data from Svalbard / NYA – Jan 13, 2013

Jin et al, SWSC, 2014

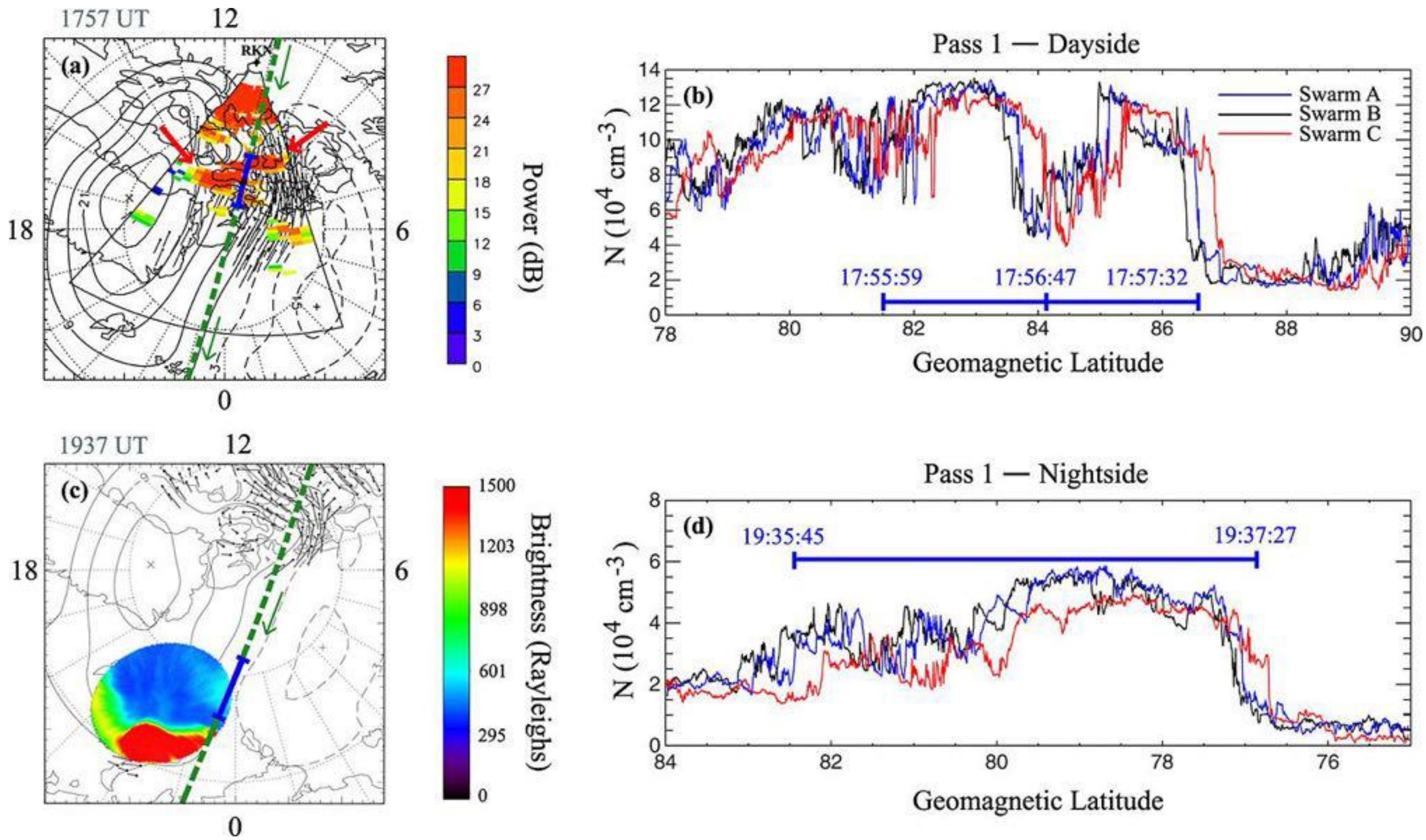
Swarm – long term in-situ monitoring



All the three Swarm satellite are equipped with a set of six instruments:

Absolute Scalar Magnetometer (ASM)
Vector Field Magnetometer (VFM)
Star Tracker (STR)
Electric Field Instrument (EFI)
GPS Receiver (GPSR)
Accelerometer (ACC)

Polar cap patches detected by Swarm

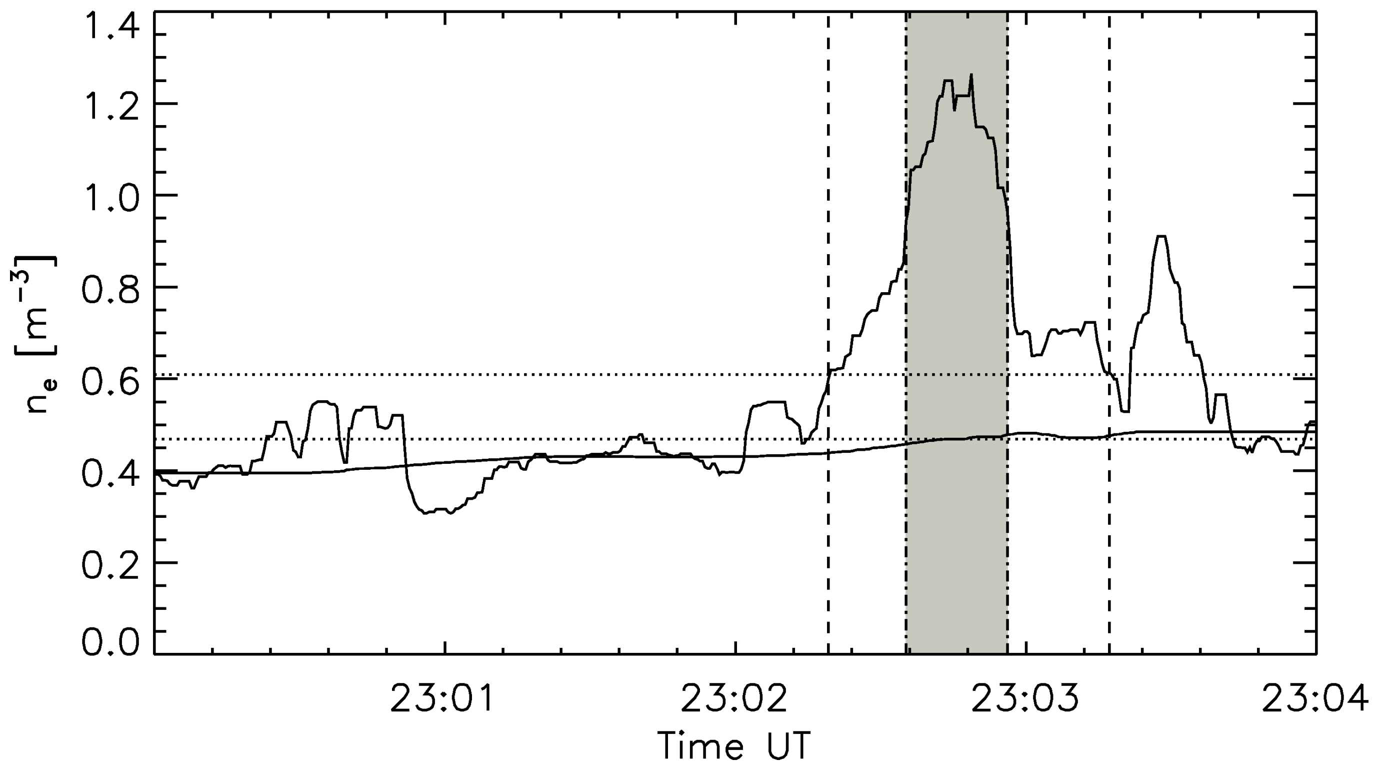


LYR ASI

Swarm passes, 29 Dec. 2013

Spicher et al. GRL 42, 201, 2014

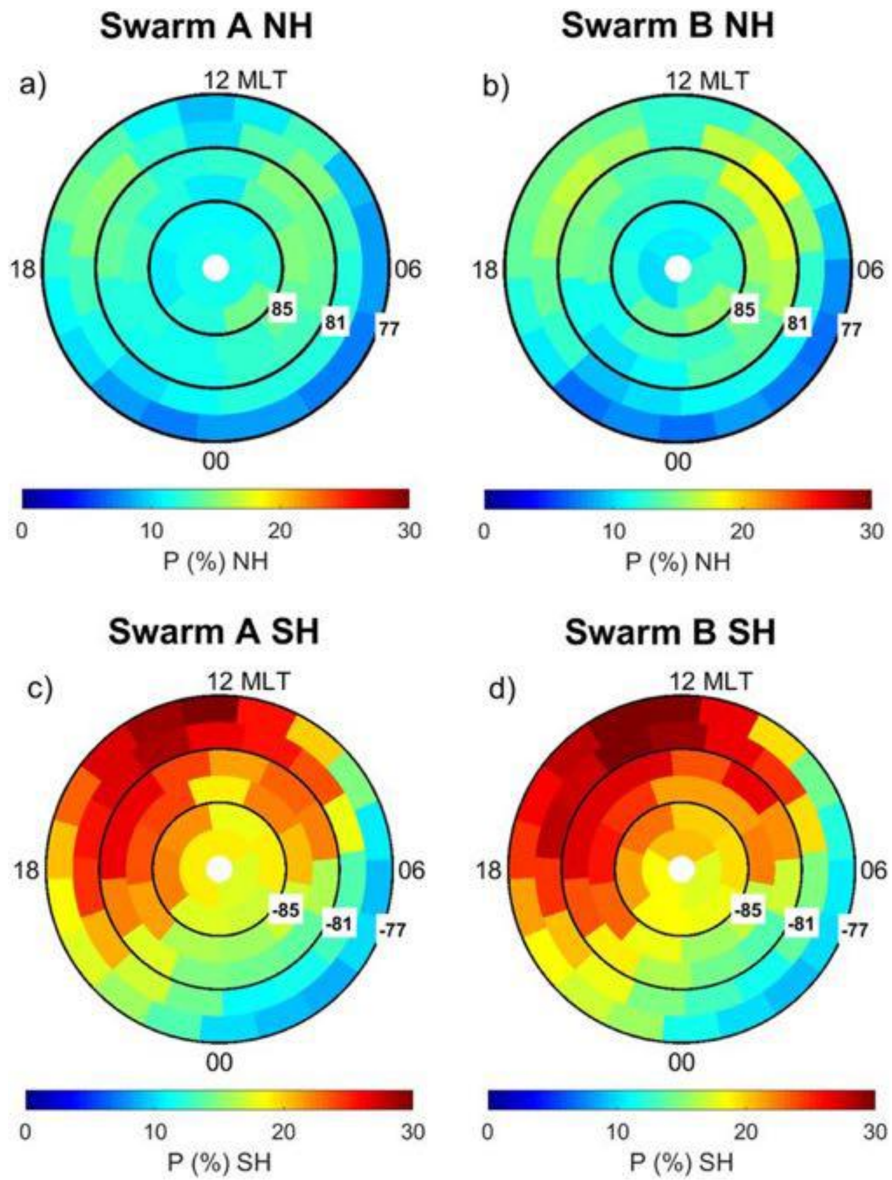
Polar Cap Products



- Detect edges by finding the average background density inside the patch proper

- And searching for when the foreground drops to within 30% of that level

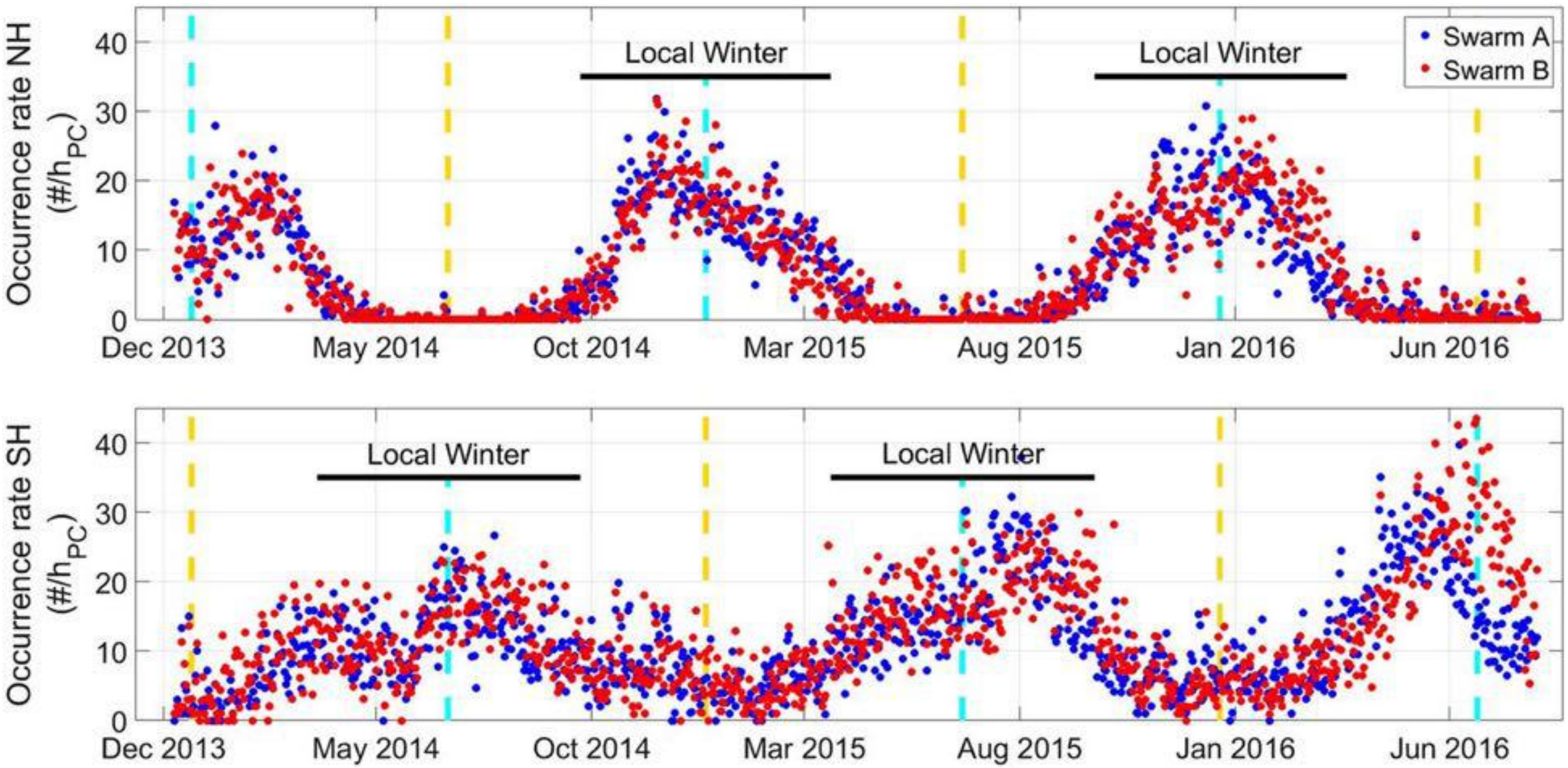
Polar cap patches - statistics



Time duration of patch observations (t_p) in each MLAT/MLT bin normalized by the time spent by the Swarm satellite (t_S) in the respective bin, i.e., $P \equiv t_p/t_S$. Results for (a and c) Swarm A and (b and d) Swarm B. Data for 9 Dec 2013 – 1 Aug 2016.

Spicher et al. JGR 122, 3837, 2016

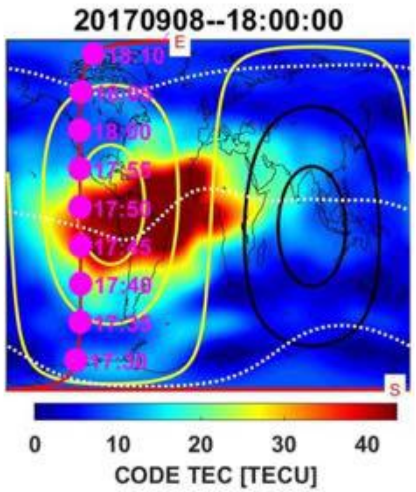
Polar cap patches - statistics

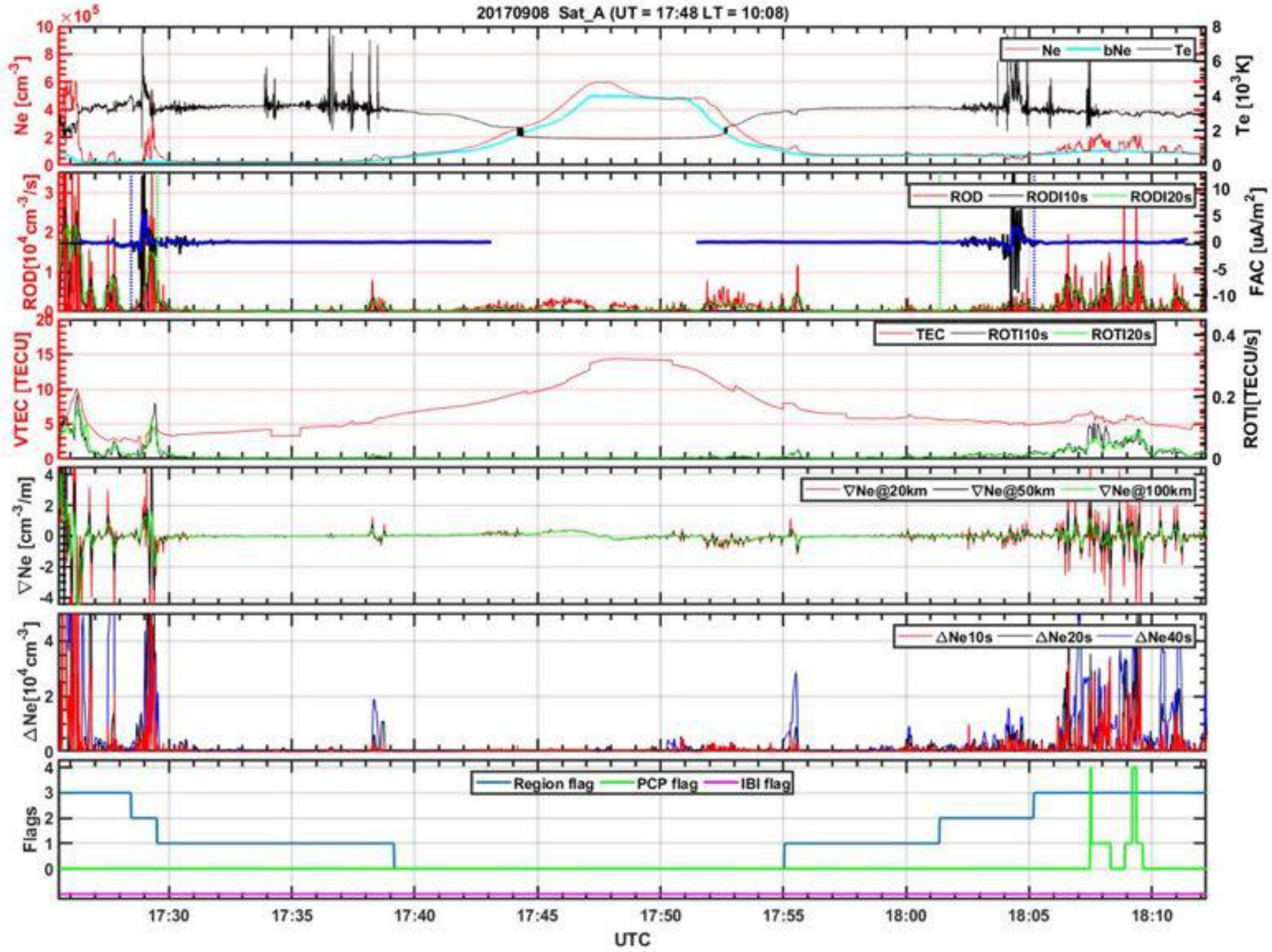


Patch occurrence rate (number of patches normalized by the number of hours, h_{PC}, spent by the satellite in the polar cap above |*MLAT*|=77°) observed by Swarm A (blue) and Swarm B (red). (top) The Northern Hemisphere (NH) and (bottom) the Southern Hemisphere (SH). The black horizontal lines highlight local wintertime taken between both equinoxes, and the vertical cyan and orange dashed lines mark local winter and summer solstices, respectively.

Spicher et al. JGR 122, 3837, 2016

IPIR – Ionospheric Plasma Irregularities by Swarm

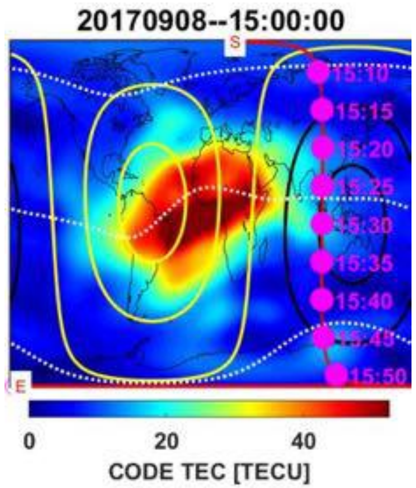


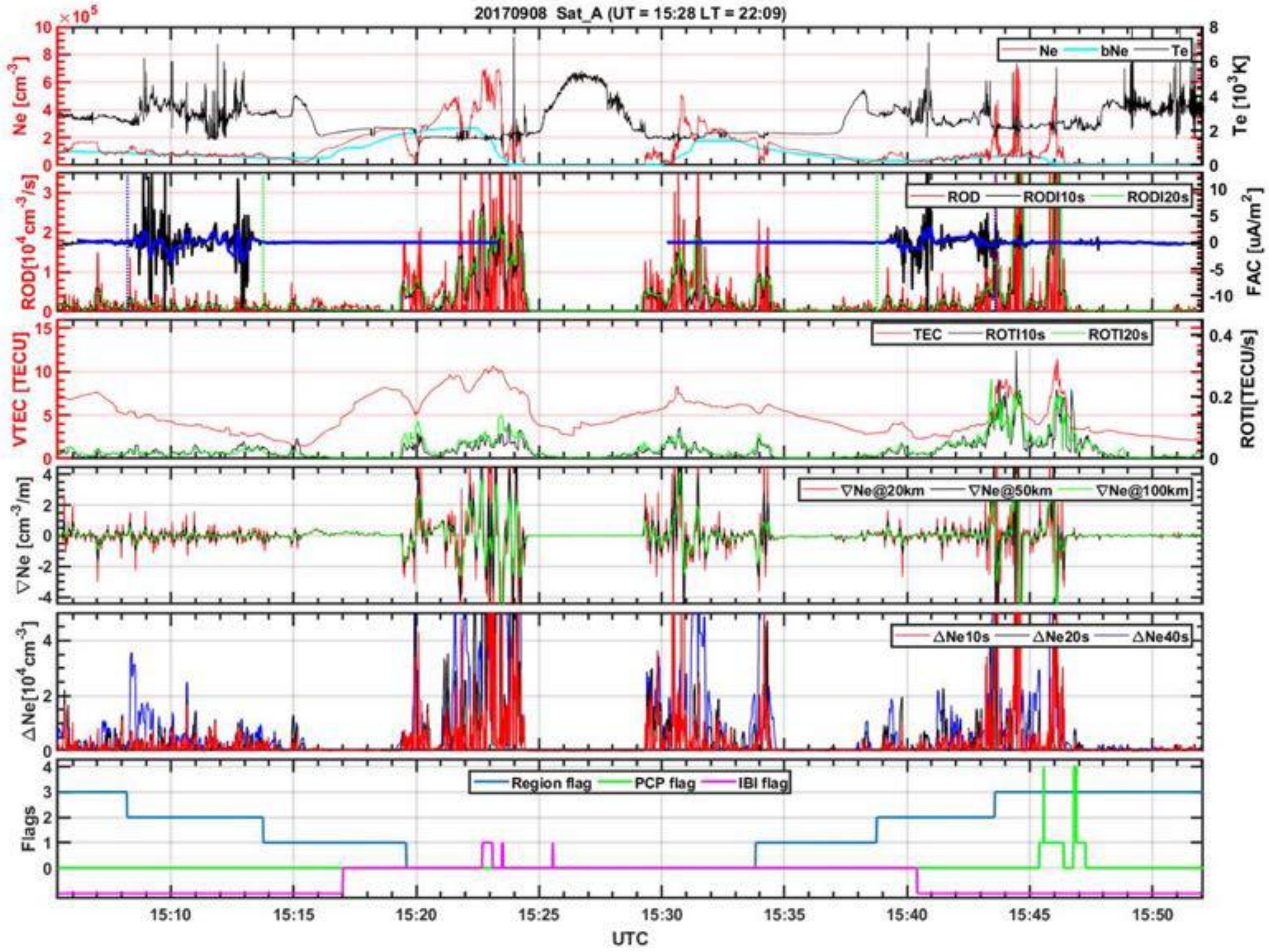


Jin et al., JGR 2022

An example of the parameters during one full orbit from the South to the North. The equatorial ionosphere show smooth variation in the early morning (10 LT), while the ionosphere at high latitudes shows irregularities.

IPIR – Ionospheric Plasma Irregularities by Swarm





Jin et al., JGR 2022

An example of the parameters during one full orbit from the North to the South. The equatorial ionosphere is characterized by plasma bubble (density depletion region) during premidnight morning (22 LT). The high-latitude ionosphere is characterized by polar cap patches and auroral blobs.

IPIR: ca. 30 entries, 1Hz data

Density

- Rate of change of Density (ROD),
- Rate of change of Density Index in 10 seconds (RODI10s),
- Rate of change of Density Index in 20 seconds (RODI20s),
- filtered *Ne* fluctuations in 10 seconds (Delta_Ne10s),
- filtered *Ne* fluctuations in 20 seconds (Delta_Ne20s),
- filtered *Ne* fluctuations in 40 seconds (Delta_Ne40s),
- *Ne* gradient in 100 km scale (Grad_Ne@100km),
- *Ne* gradient in 50 km scale (Grad_Ne@50km),
- *Ne* gradient in 20 km scale (Grad_Ne@20km),
- *Ne* gradient near the edge of a polar cap patch (Grad_Ne@PCP_edge).

TEC

- Rate of change of TEC (*ROT*),
- Rate of change of TEC index (*ROTI*).

IPIR index

++ IBI, PCP, foreground, background densities, IPIR index, etc.

ROD : time derivative of the electron density:

$$ROD(\mathrm{t}) = \frac{Ne(t+\Delta t) - Ne(t)}{\Delta t}$$

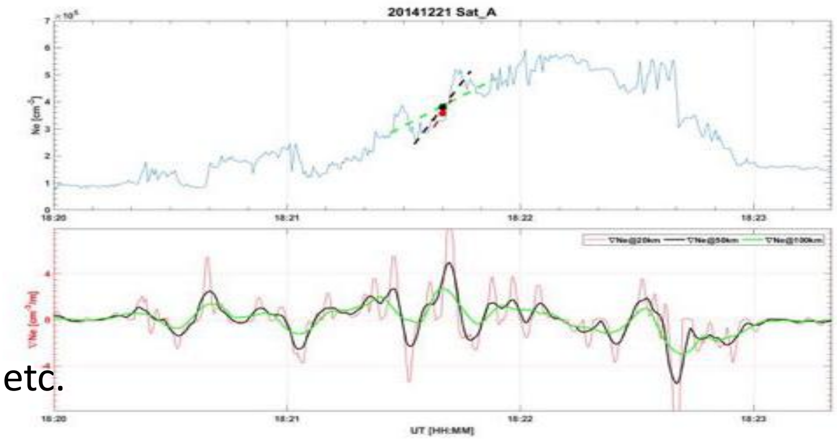
We use 2Hz Swarm data for accounting for small scale fluctuations, $\Delta t = 0.5\ seconds$.

RODI10s (RODI20s) is the STD of ROD in a running window of $\Delta t = 10$ (20) :

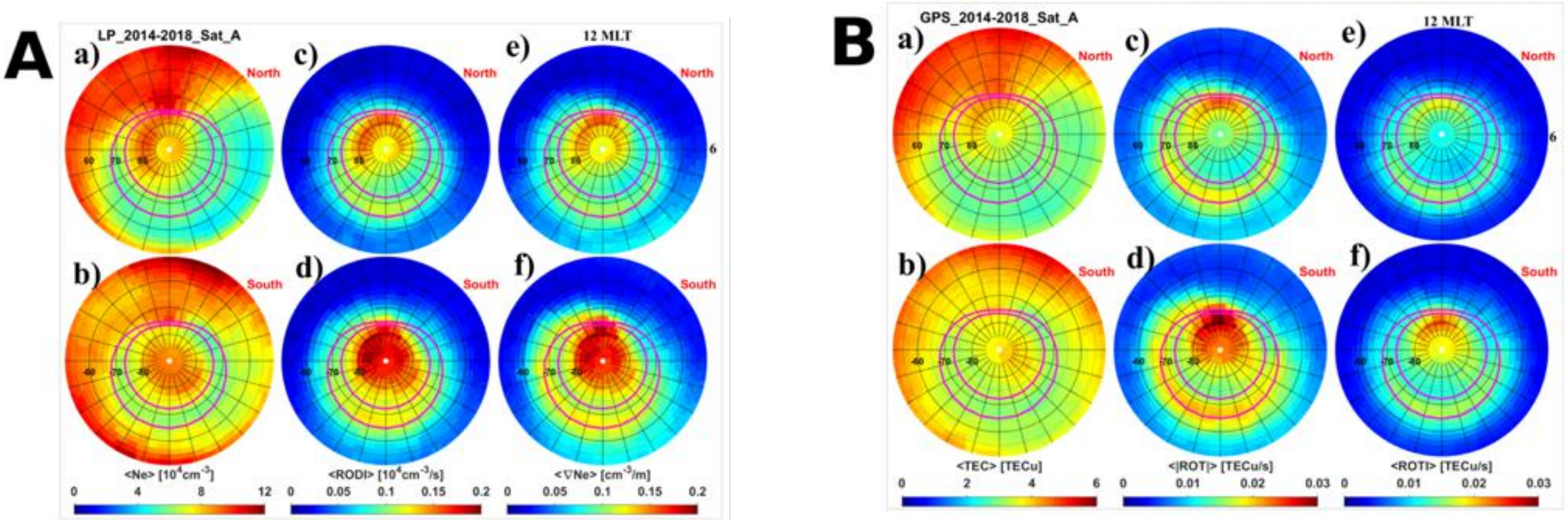
$$RODI(\mathrm{t}) = \sqrt{\frac{1}{N-1}\sum_{\mathrm{t}_i=t-\Delta t/2}^{\mathrm{t}_i=t+\Delta t/2} |ROD(\mathrm{t}_i) - \overline{ROD}|^2}$$

where $\overline{ROD}$ is the mean of $ROD(\mathrm{t}_i)$:

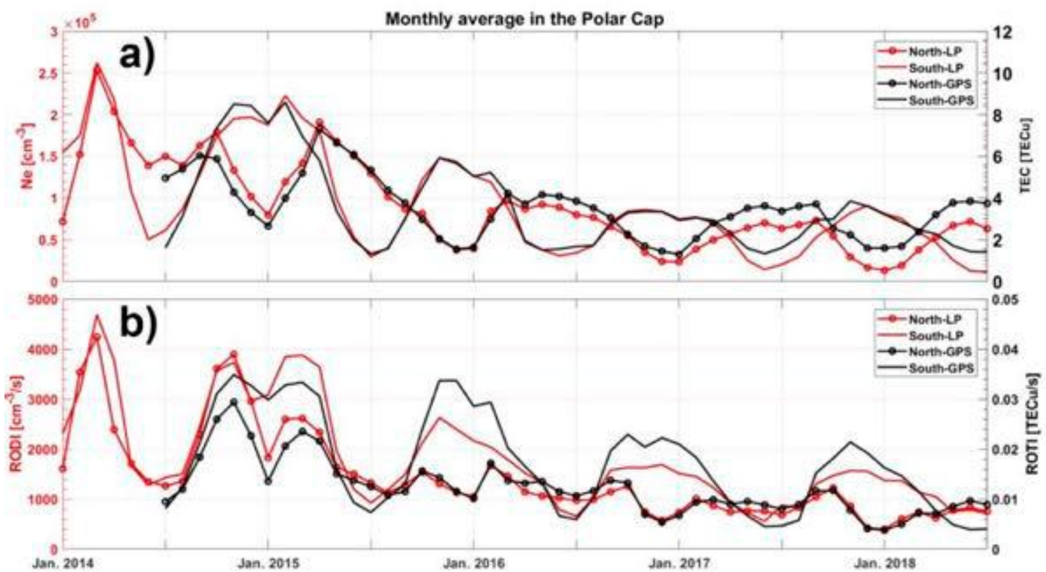
$$\overline{ROD} = \frac{1}{N}\sqrt{\sum_{\mathrm{t}_i=t-\Delta t/2}^{\mathrm{t}_i=t+\Delta t/2} ROD(\mathrm{t}_i)}$$



Climatology of plasma Irregularities



Climatology of plasma irregularities in MLAT-MLT coordinates using data from the LP (A) and GPS (B) from Swarm A. MLT noon is to the top and dawn is to the right.



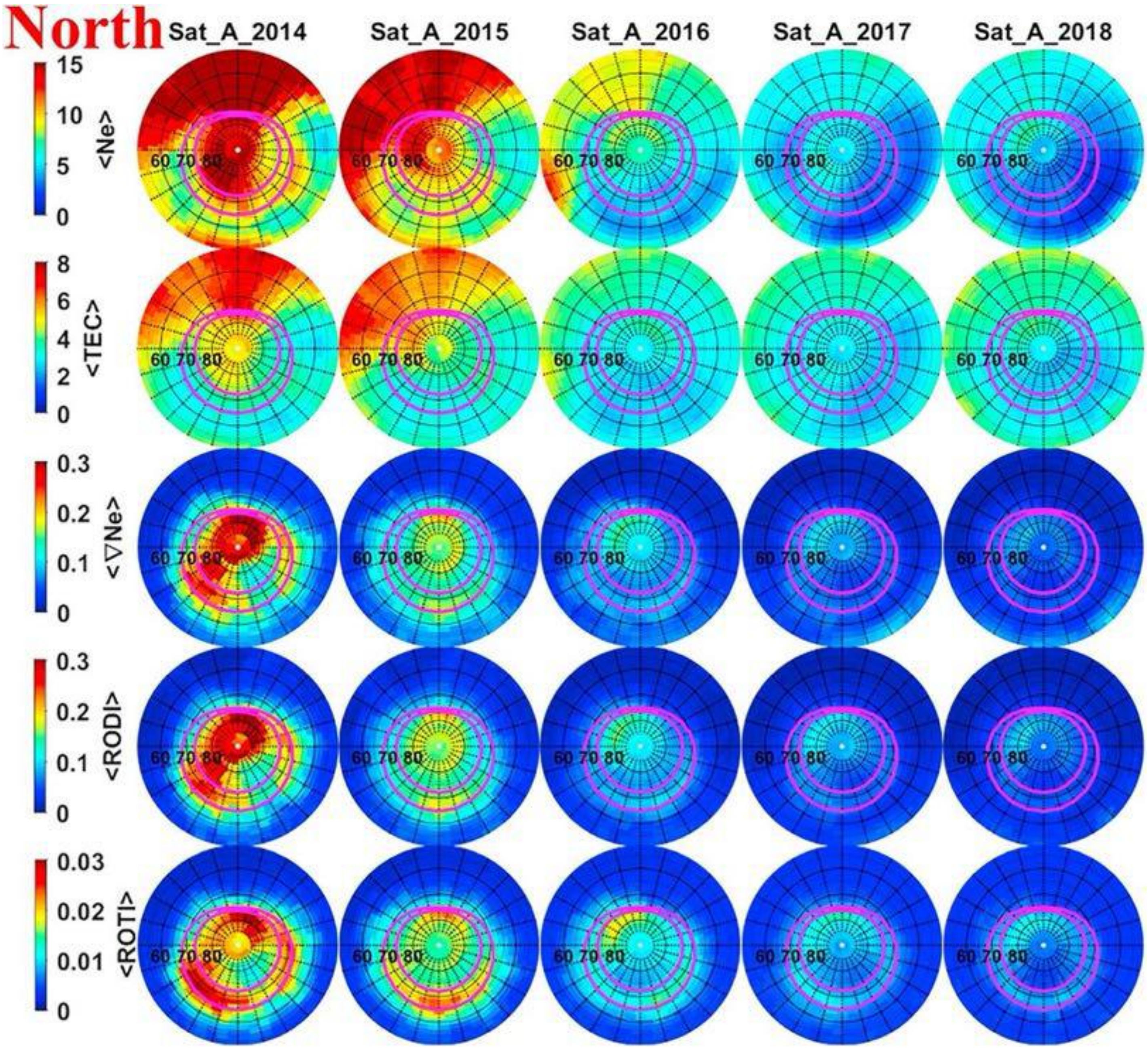
Seasonal variations of the ionospheric parameters from the LP (red, left axis) and GPS (black, right axis).

(a) Monthly averaged electron density and vertical TEC.

(b) (b) RODI and ROTI in the central polar cap (poleward of ±81° MLAT).

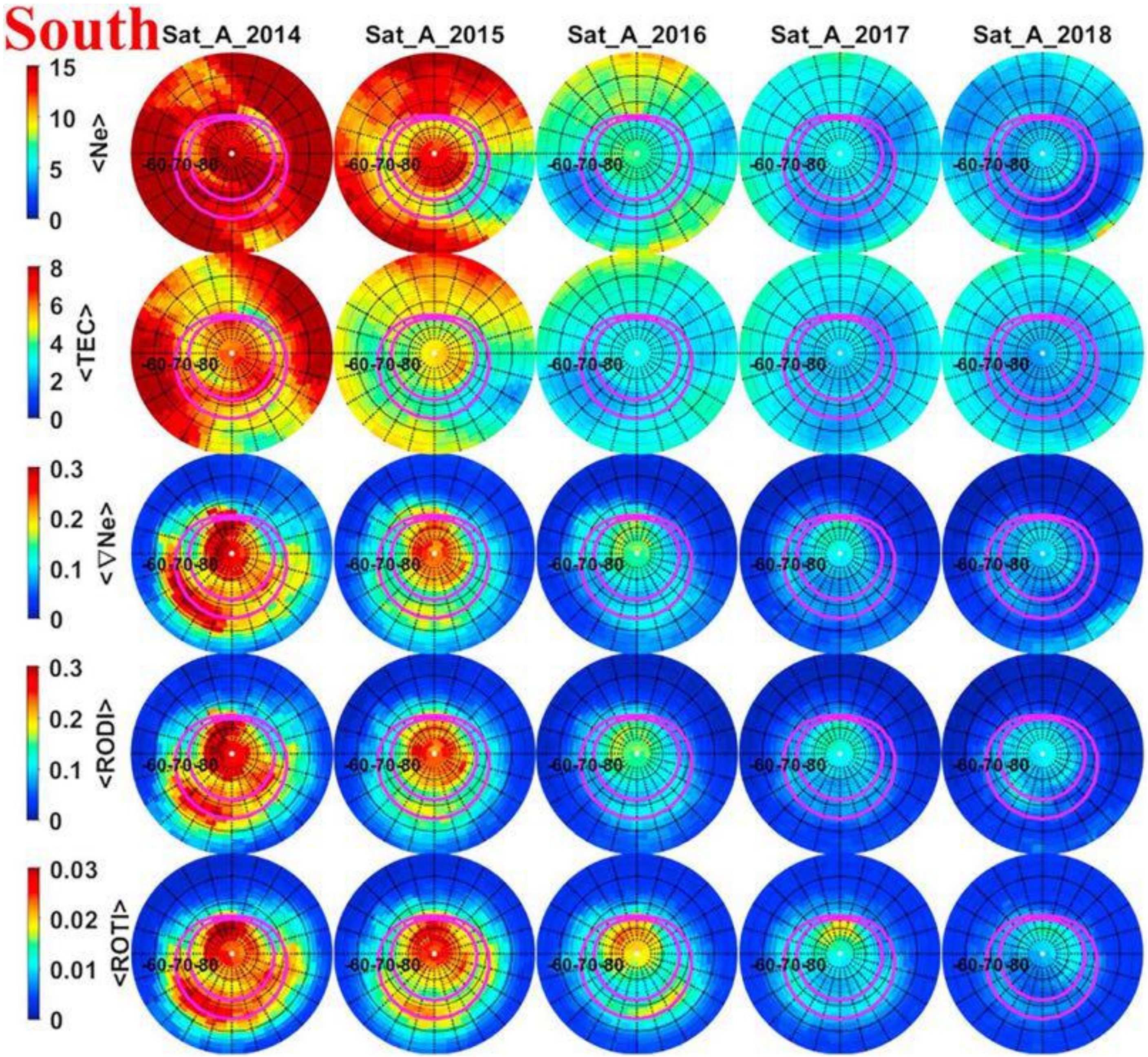
Jin et al., JGR 2019.

Climatology of plasma Irregularities



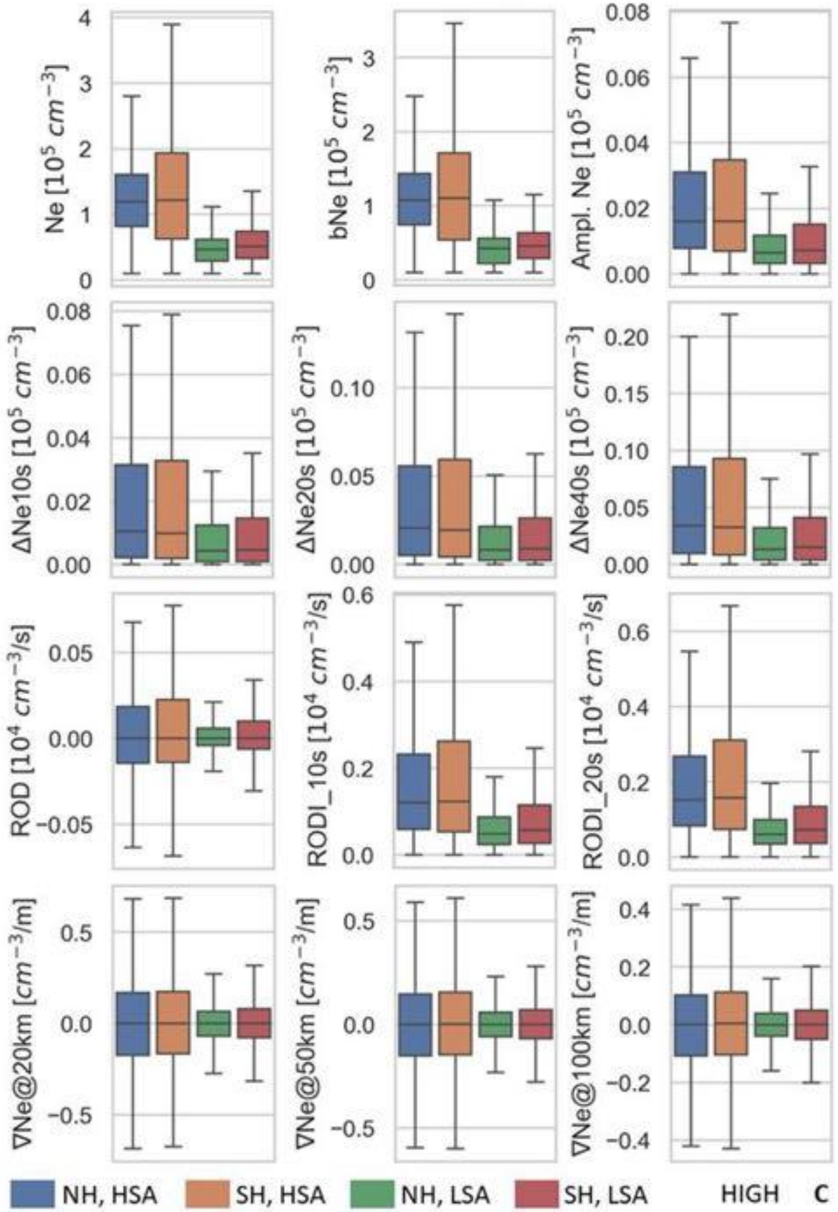
Jin et al., JGR 2019.

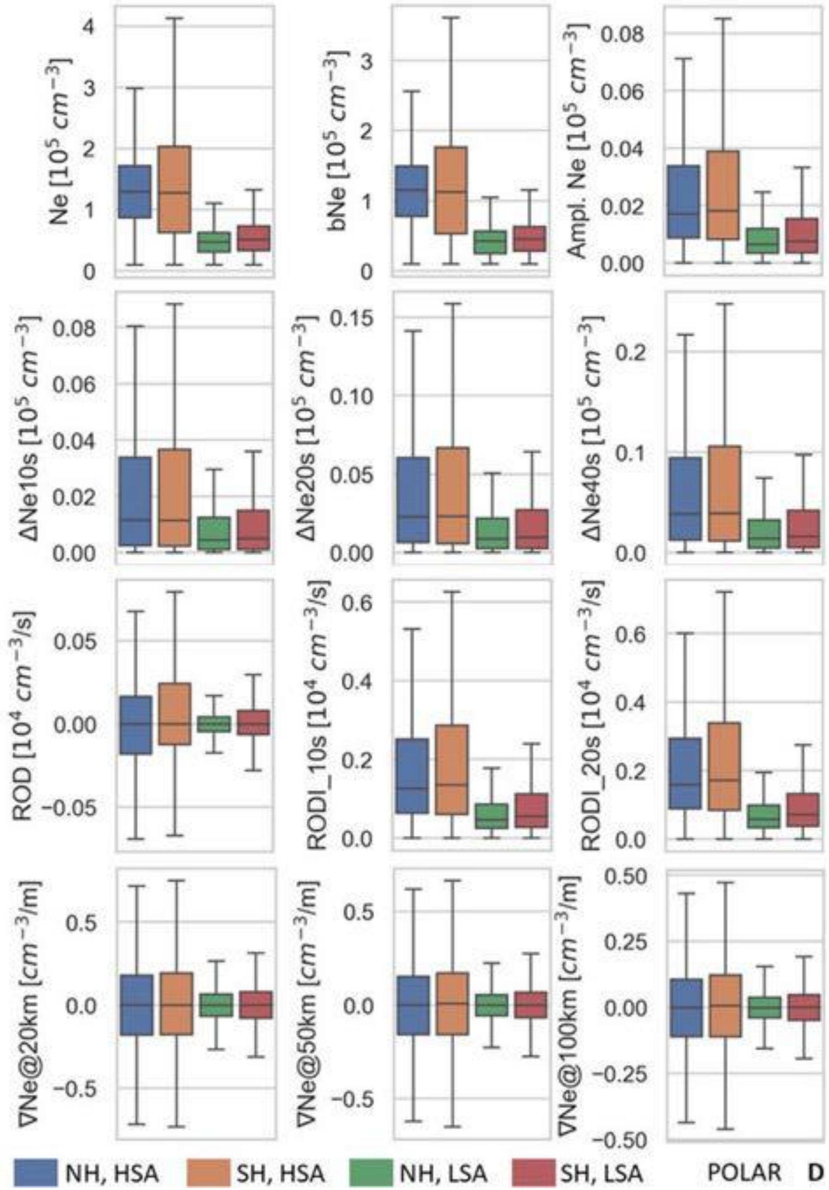
Climatology of plasma Irregularities



Jin et al., JGR 2019.

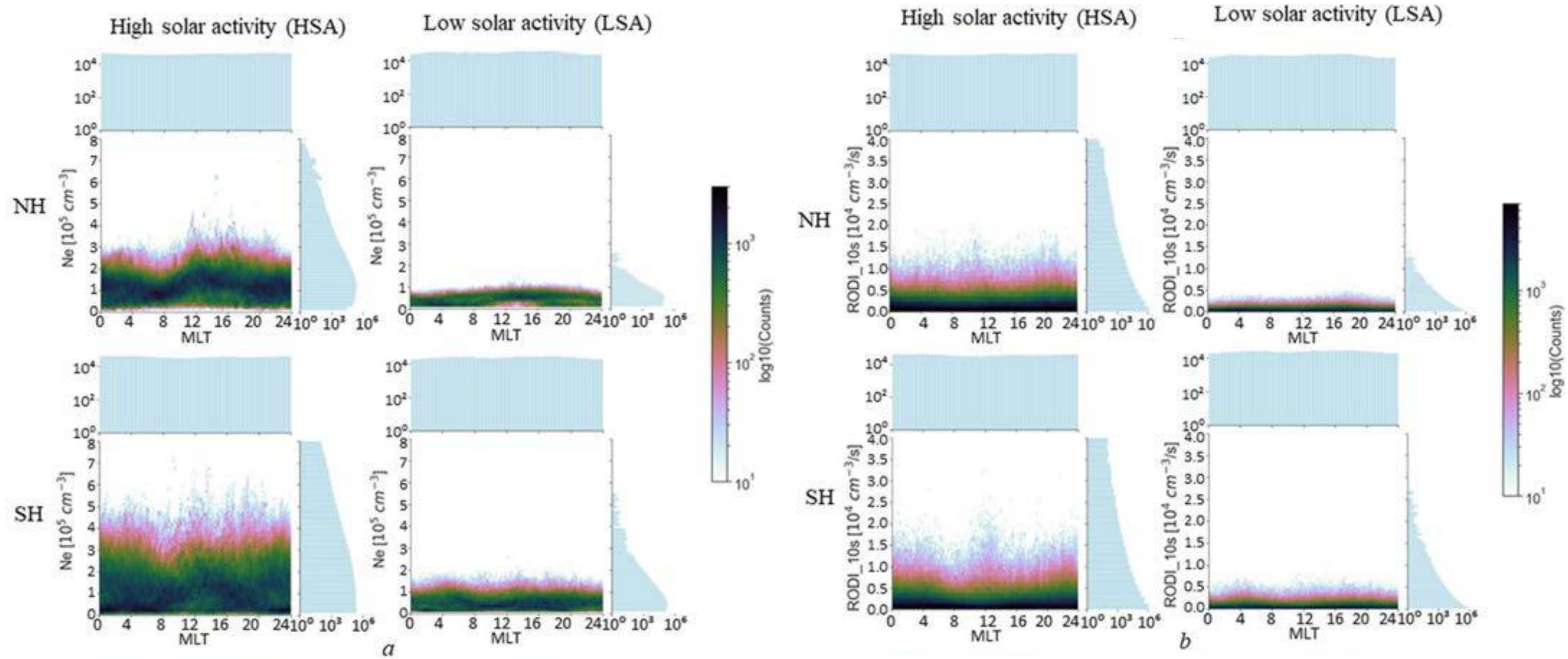
Climatology of plasma Irregularities





Kotova et al., SWSC 2022.

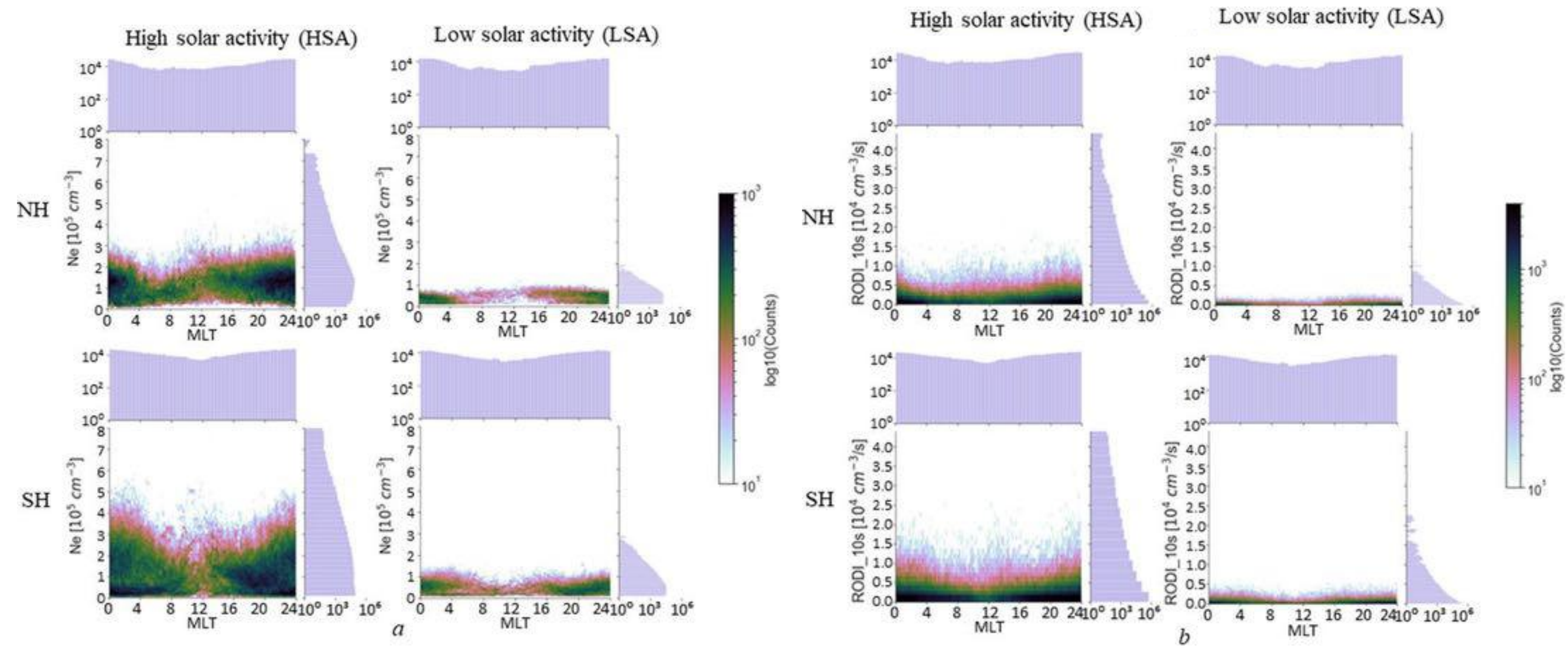
Climatology of plasma Irregularities



Auroral region / High latitudes

Kotova et al., SWSC 2022.

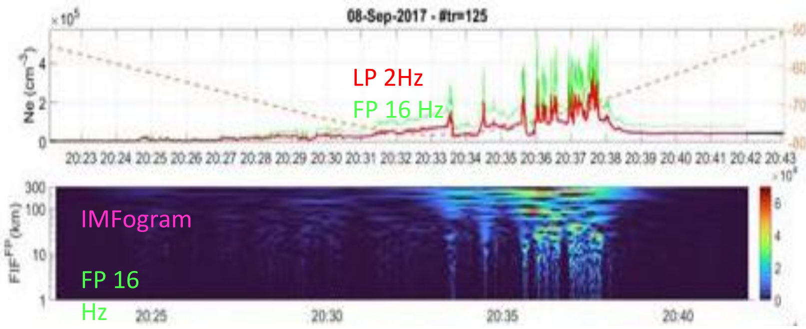
Climatology of plasma Irregularities



Polar cap

Kotova et al., SWSC 2022.

Creating models!



SWARM VIP
SWARM SPACE WEATHER
VARIABILITY OF IONOSPHERIC PLASMA

Example model: Polar model of |GradNe@100km|

$$|GradNe@100| = \left(\exp\left(\begin{array}{c}-1.9 + 5.3x10^{-3} \cdot F107_{81} + 9.1x10^{-3} \cdot |MLAT| + \\ + (\dots) + 1.3x10^{-3} \cdot SYM\_D\end{array}\right)\right)^3$$

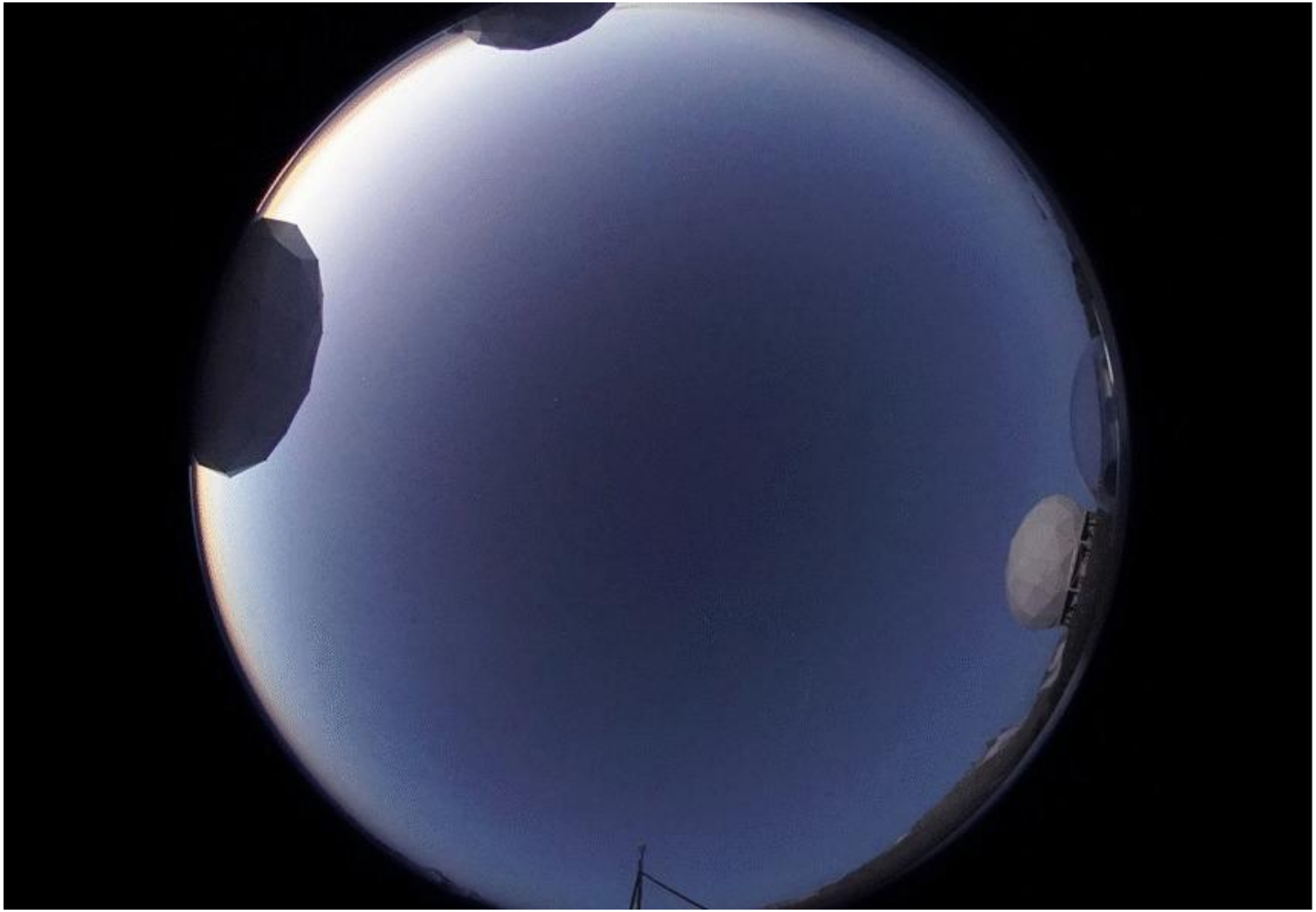
$F107_{81}$ 81 day average of the F10.7cm solar flux, centred on the day to be updated
|MLAT| Absolute value of magnetic latitude (in degrees)
SYM_D The longitudinally symmetric disturbances to the terrestrial magnetic field perpendicular to the dipole axis

Models created for Ne, |Grad_Ne@100km|, |Grad_Ne@50km|, |Grad_Ne@20km|, and the IPIR index in the polar, auroral, mid-latitude and equatorial regions.

UiO : University of Oslo
gmv
INGV
NOTTINGHAM TRENT UNIVERSITY
UNIVERSITY OF BIRMINGHAM
SERENE Space Environment & Radio Engineering

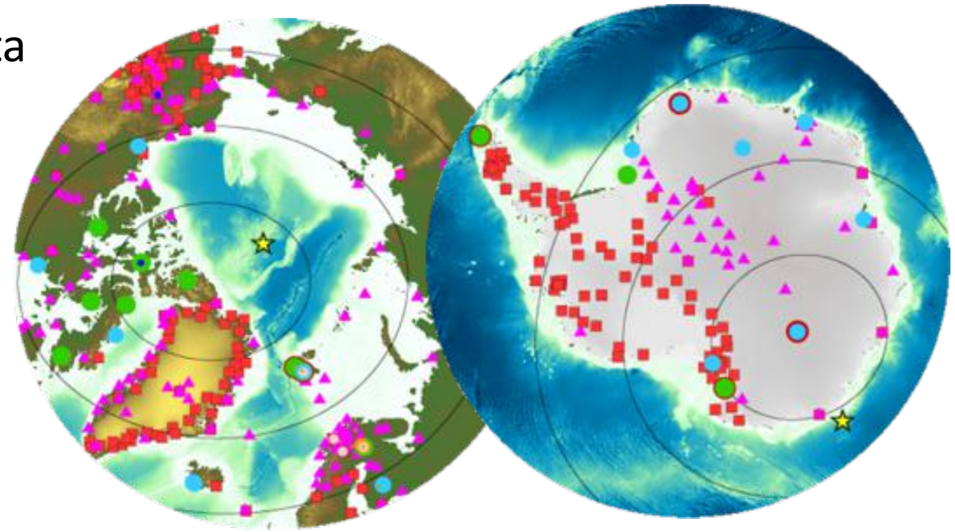
esa European Space Agency
Swarm + Ionosphere
Contract no: 4000130562/20/I-DT

Antarctic stations



Antarctic stations – AGATA initiative

International effort in sharing data and establishing complementary infrastructures in Antarctica.



The Antarctic Geospace and ATmosphere reseArch (AGATA) Programme Planning Group is **a coordinated, worldwide effort to monitor, investigate and better understand the physics of the polar atmosphere and the impact of the Sun-Earth interactions on the polar regions.**

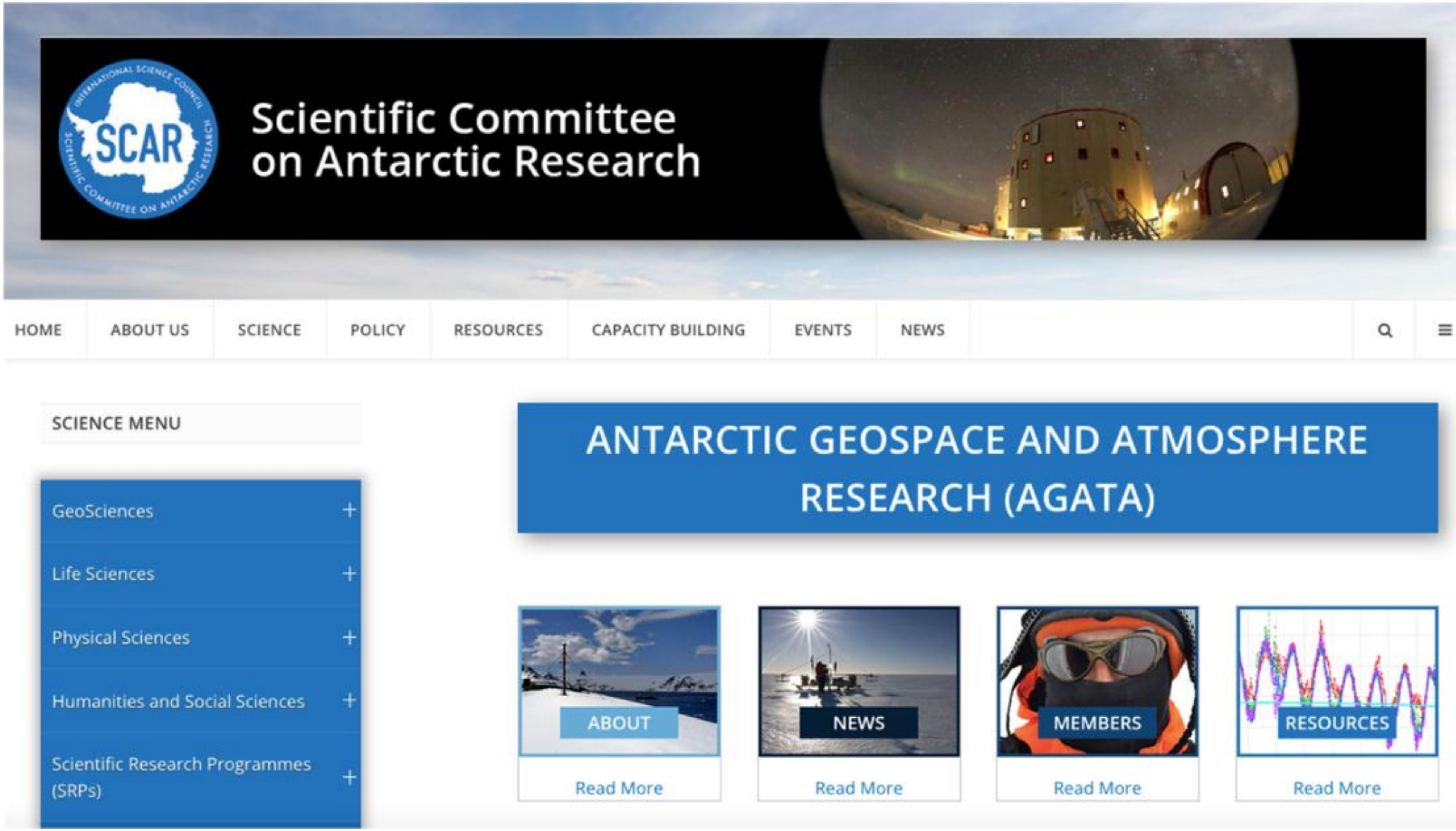
AGATA will take advantage of existing and planned instrumentation in Antarctica, but also in the Arctic and satellite-based observations, and it will aim for coordinated research efforts and data exchange.

This bi-polar perspective will allow the study of significant interhemispheric asymmetries in the atmospheric response observed in the polar region

Research infrastructures in polar regions.
- GNSS stations
- Scintillation receivers
- Magnetometers
- Ionosondes
- SuperDarn
- VLF receivers
- EISCAT radar
- HPLA radar
- All-sky Camera
- Geomagnetic pole
- --- Geomagnetic latitudes: N/S80°, 70° and 60°

Alfonsi et al., Surv. Geophys. 2022

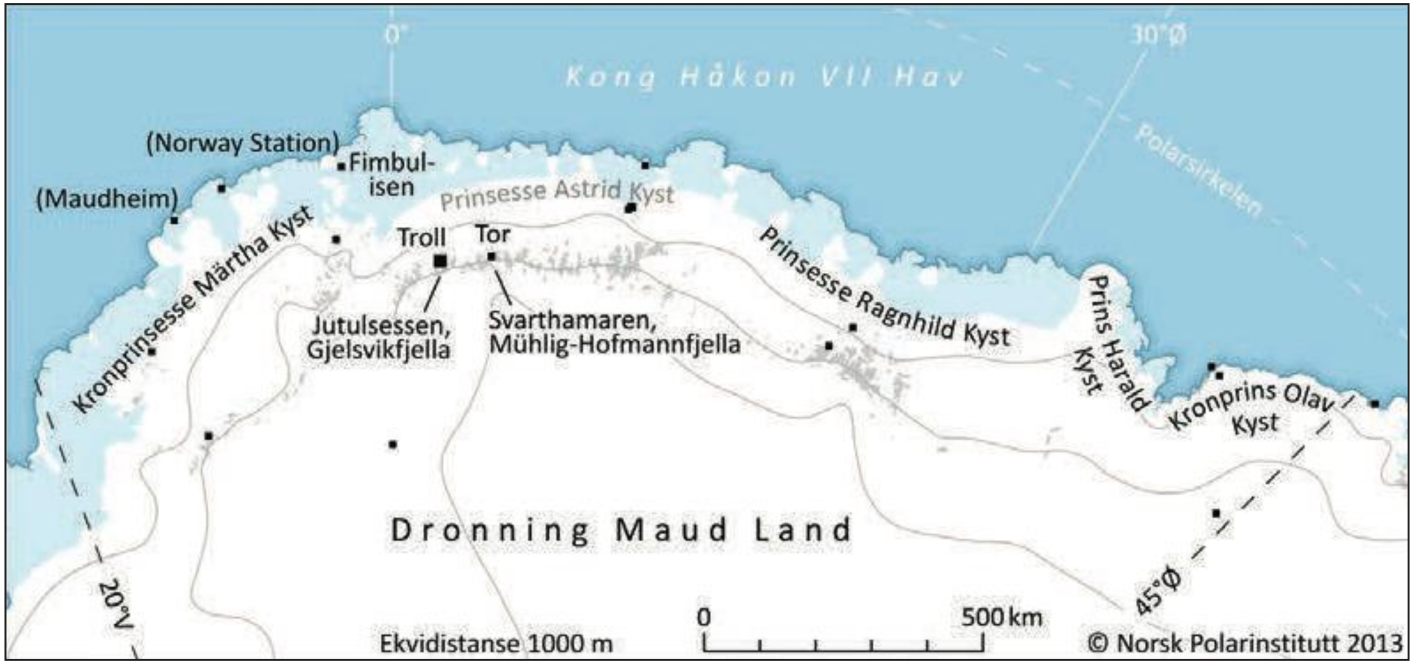
Antarctic stations – AGATA initiative



https://www.scar.org/science/agata/home/

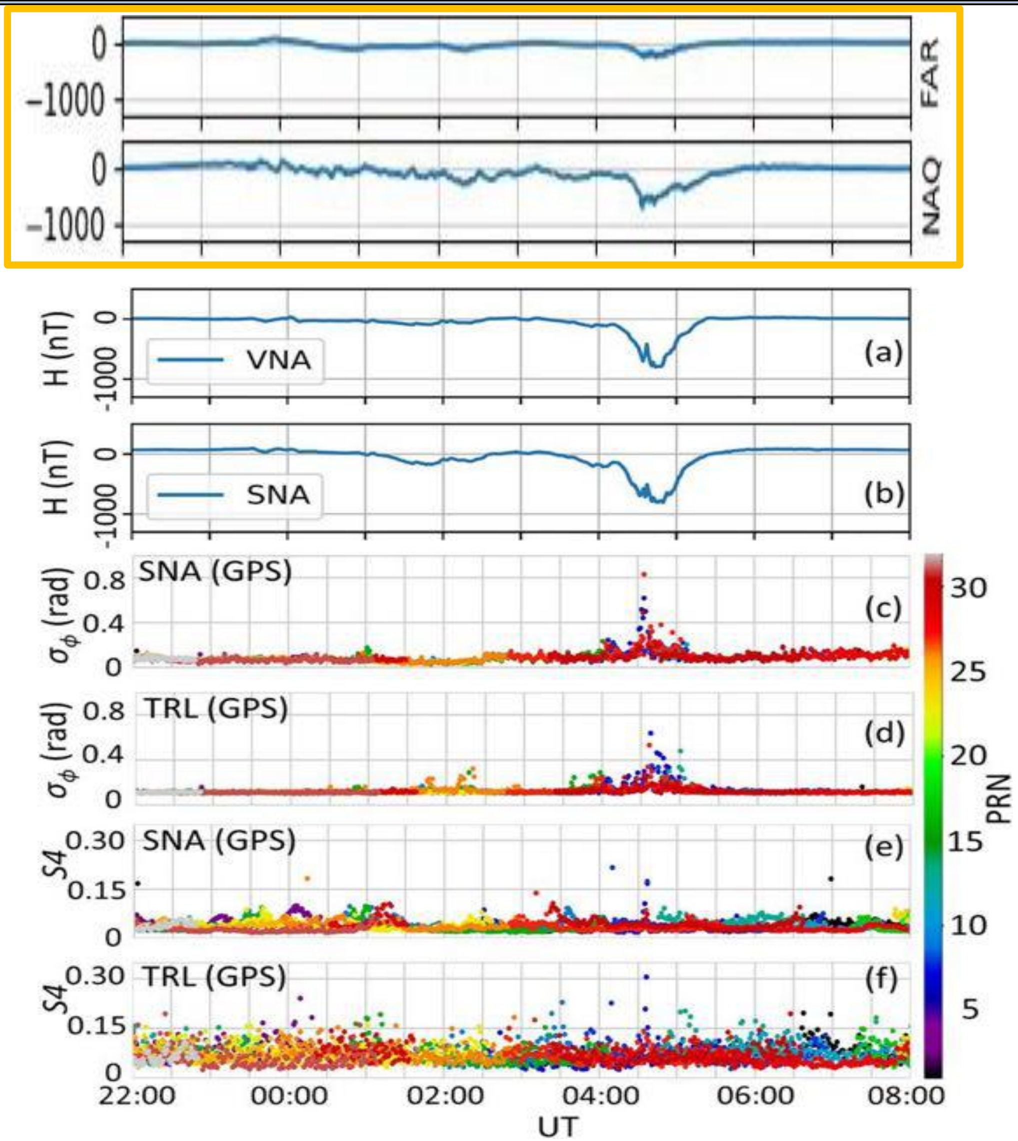
lucilla.alfonsi@ingv.it nicolas.bergeot@oma.be

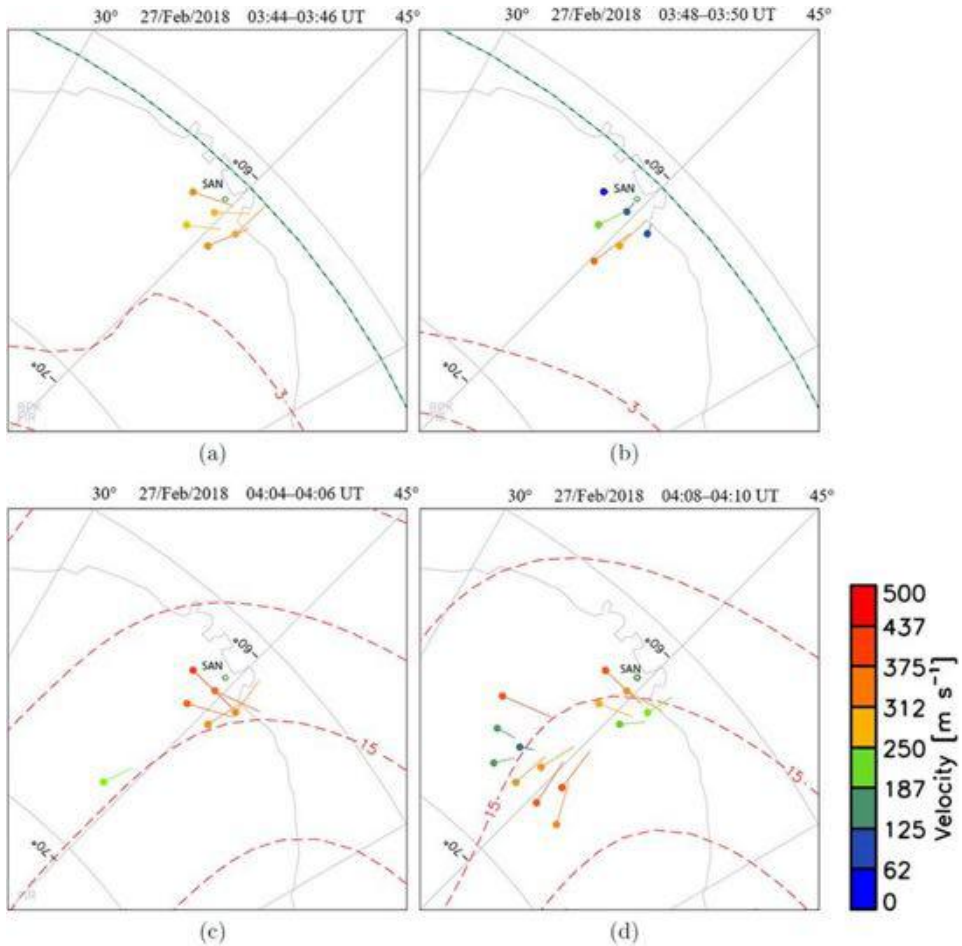
Antarctica: Troll Research Station in Dronning Maud Land



Troll Ionospheric Observatory: all sky imagers and GISTM receiver (as of 2022)

Case study: 26-27 februar 2018

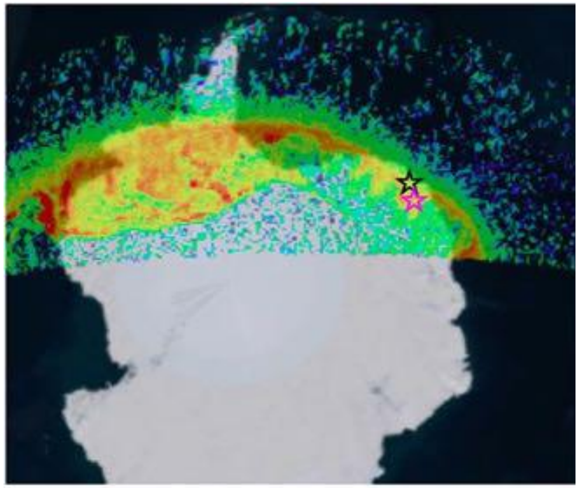




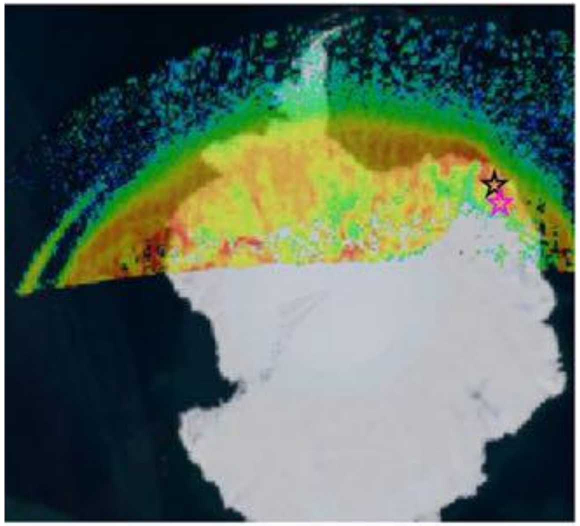
- Elevated scintillation indices are associated with flow shears at the edge of convection pattern during the substorm expansions phase.
- Similar behaviour in the NH conjugate point (scintillation data not shown).

Skjæveland et al. JGR 2021

Case study: 26-27 februar 2018

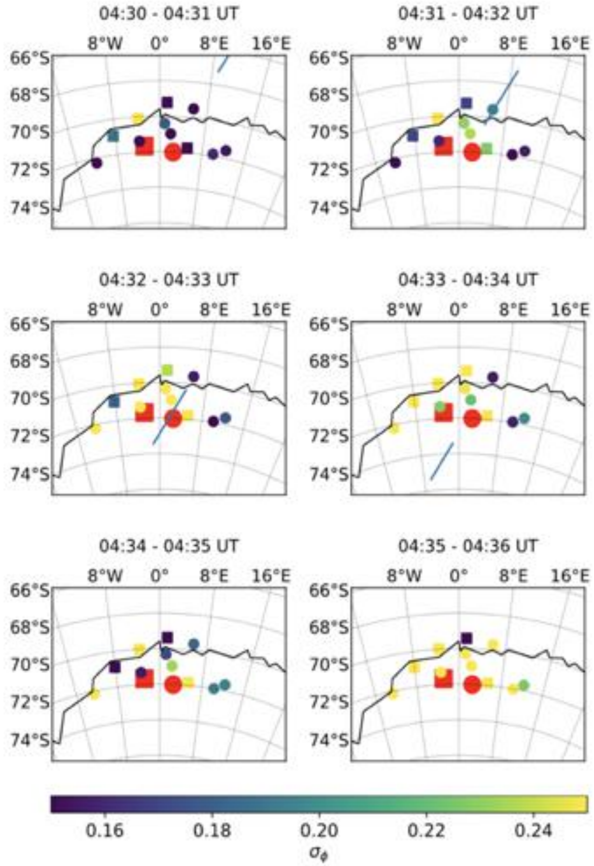


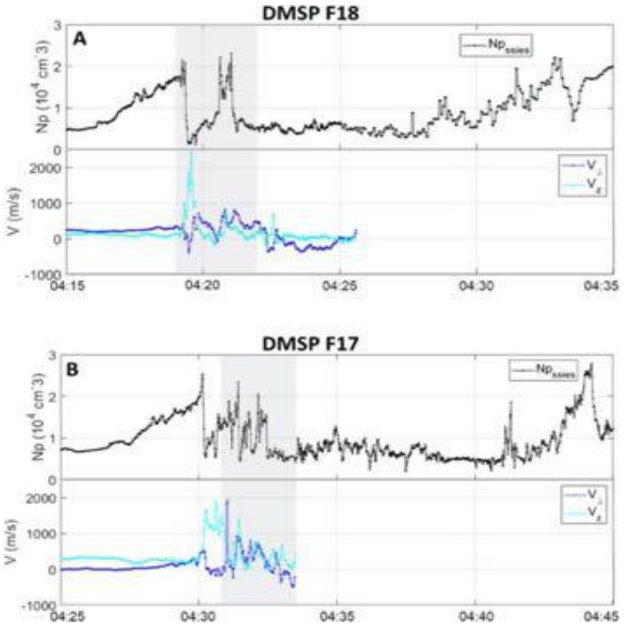
(a)



(b)

DMSP satellites confirm strong variations in plasma density and velocity at the edge of the expanding auroral oval.



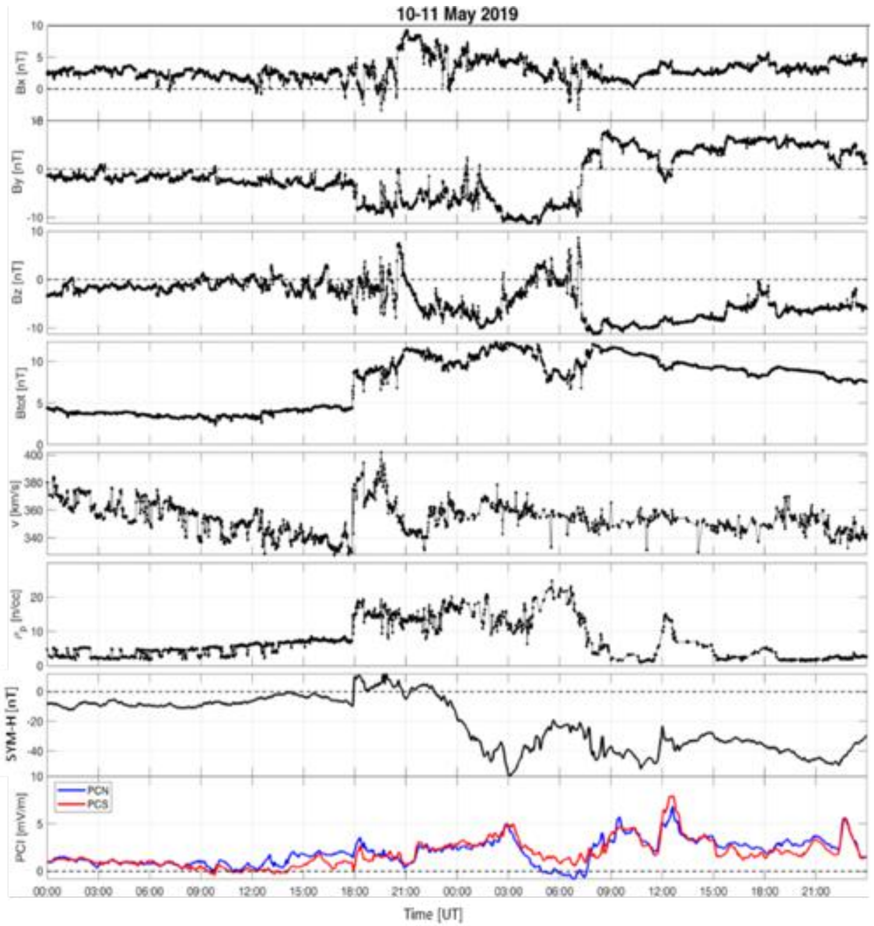


This is associated with highest levels of the phase scintillation indices.

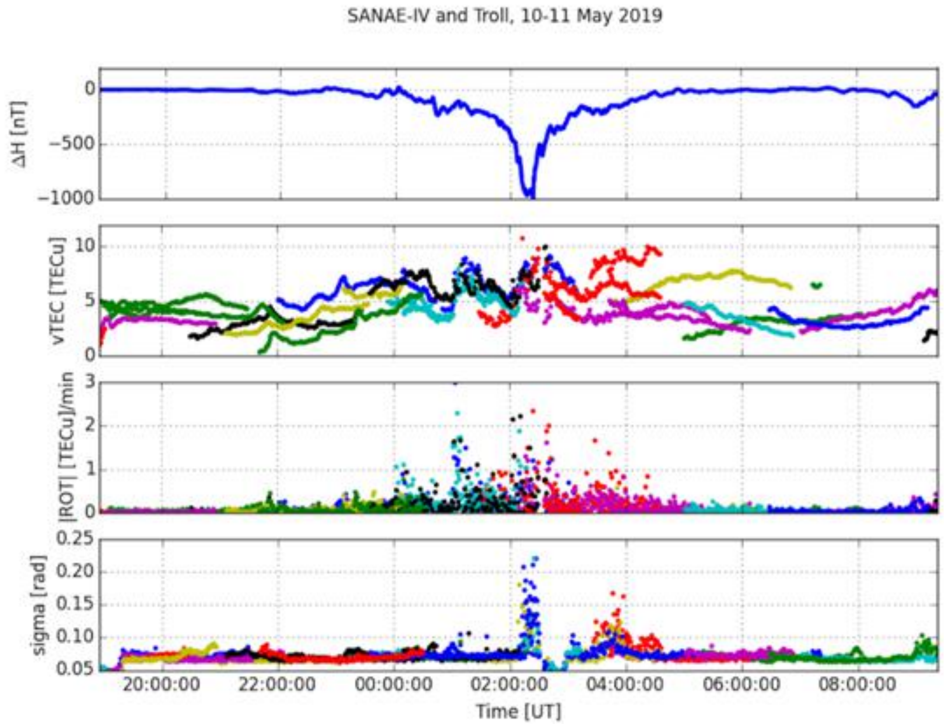
(center) Data from SANAE-IV (South African research station) and Troll (Norwegian research station).
(left/right) data from DMSP satellite.

Skjæveland et al. JGR 2021

Case study: 10-11 May 2019



Observations by satellites in L1 point and ground based magnetometers

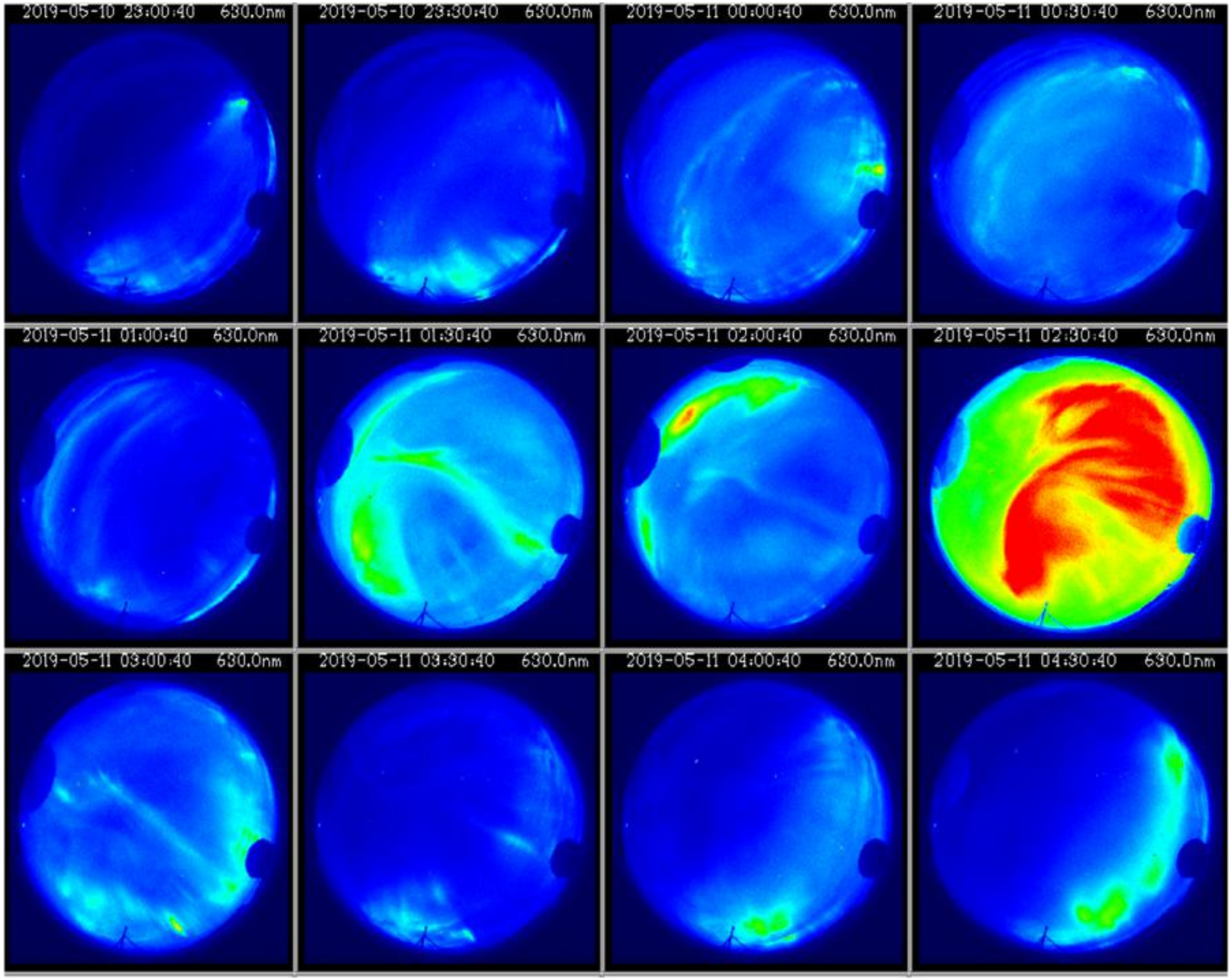


- Onset of the magnetic substorm associated with ionospheric structuring.

Alfonsi et al., Surv. Geophys. 2022

SANAE-IV and Troll

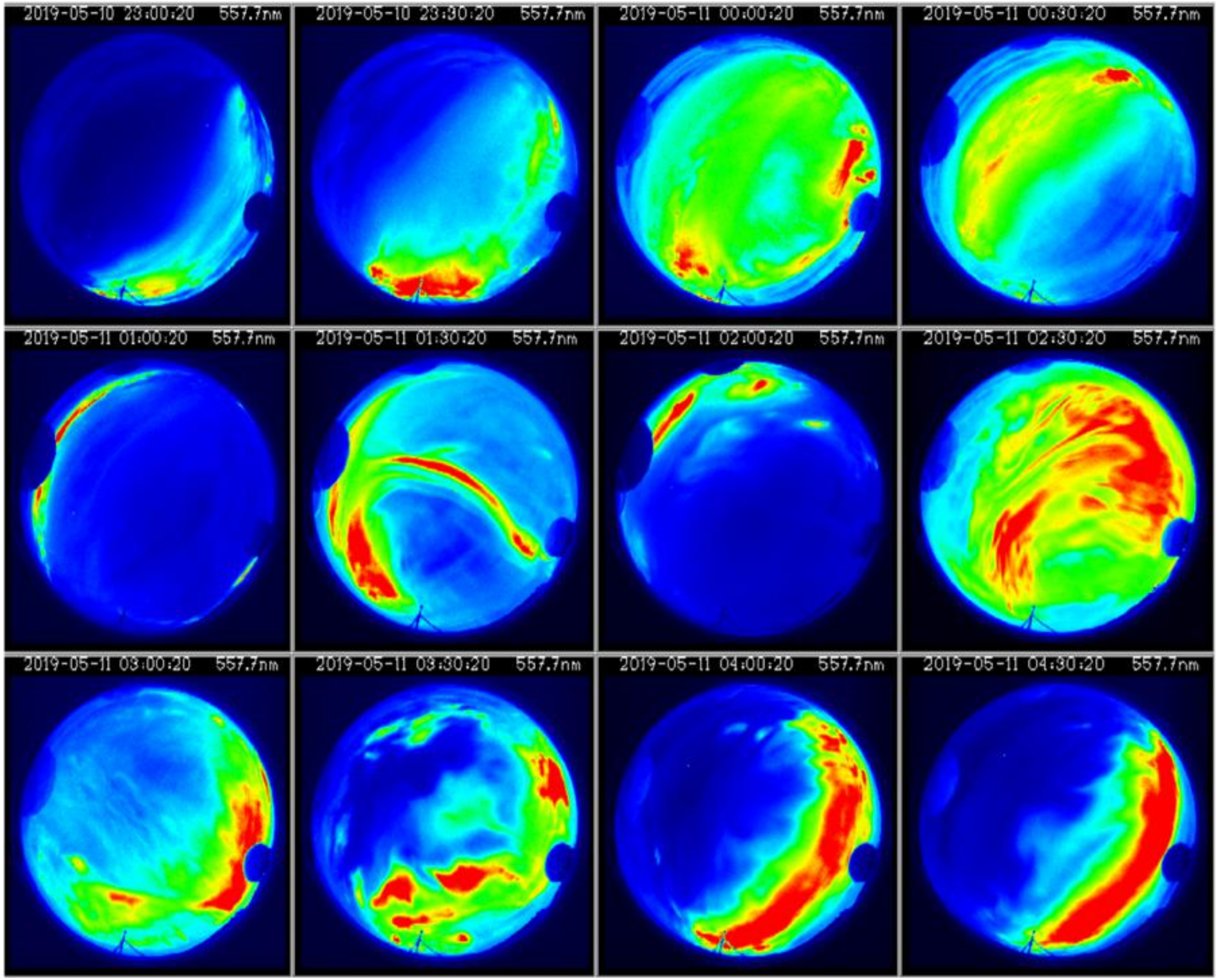
Case study: 10-11 May 2019



Troll

Alfonsi et al., Surv. Geophys. 2022

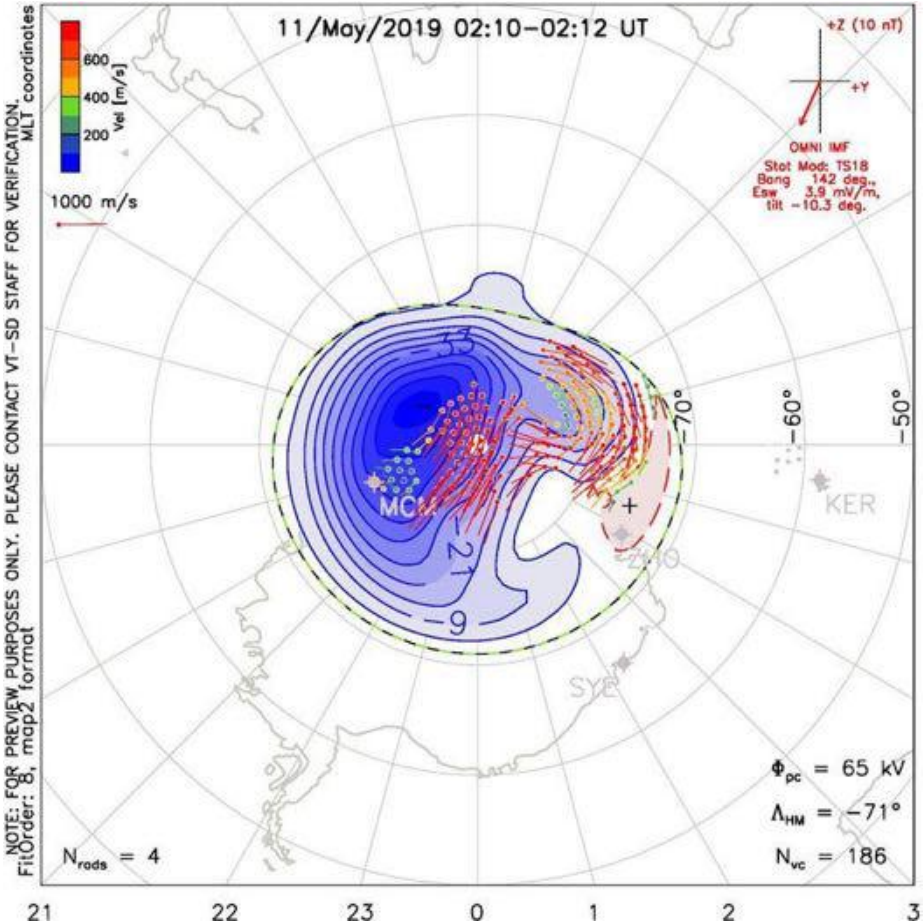
Case study: 10-11 May 2019

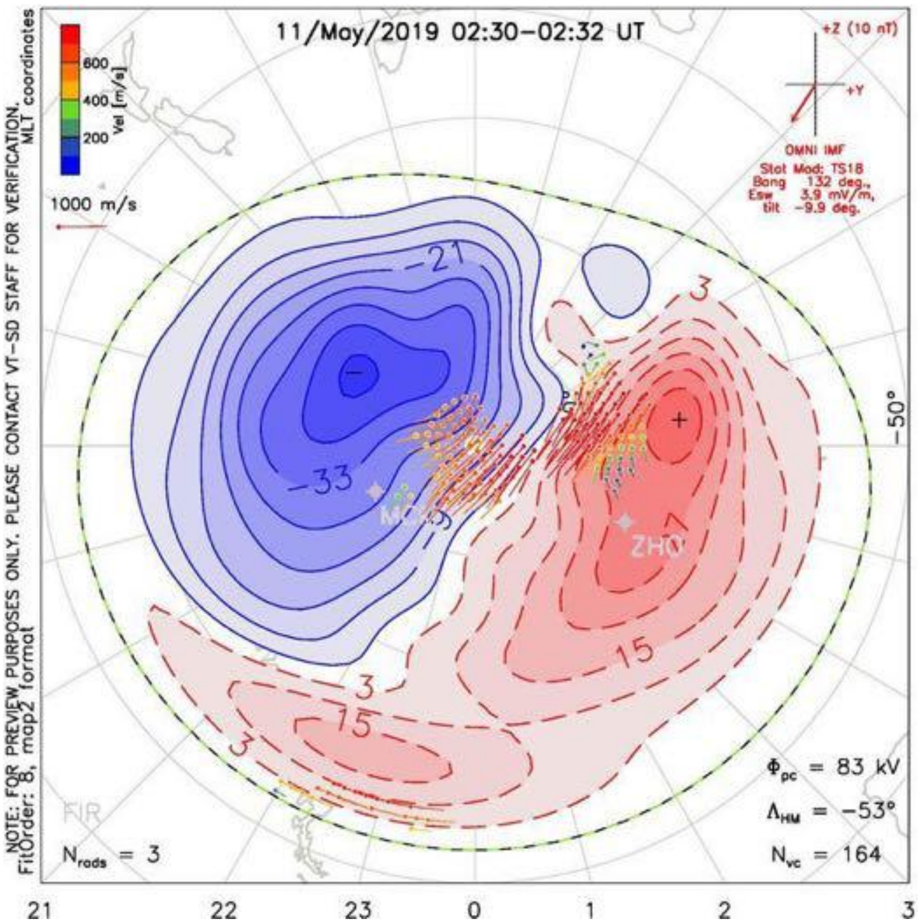


Troll

Alfonsi et al., Surv. Geophys. 2022

Case study: 10-11 May 2019

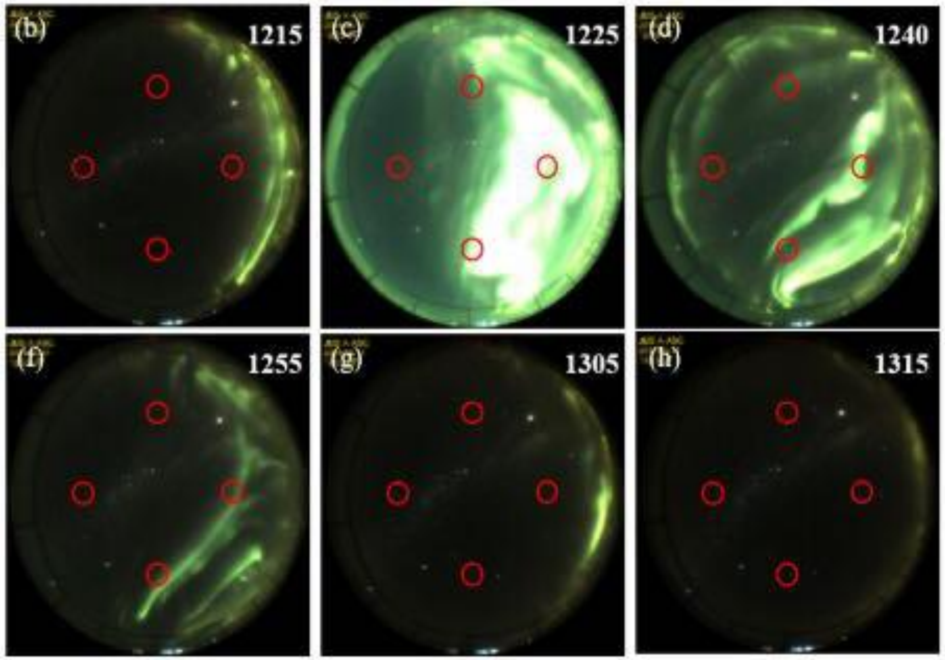


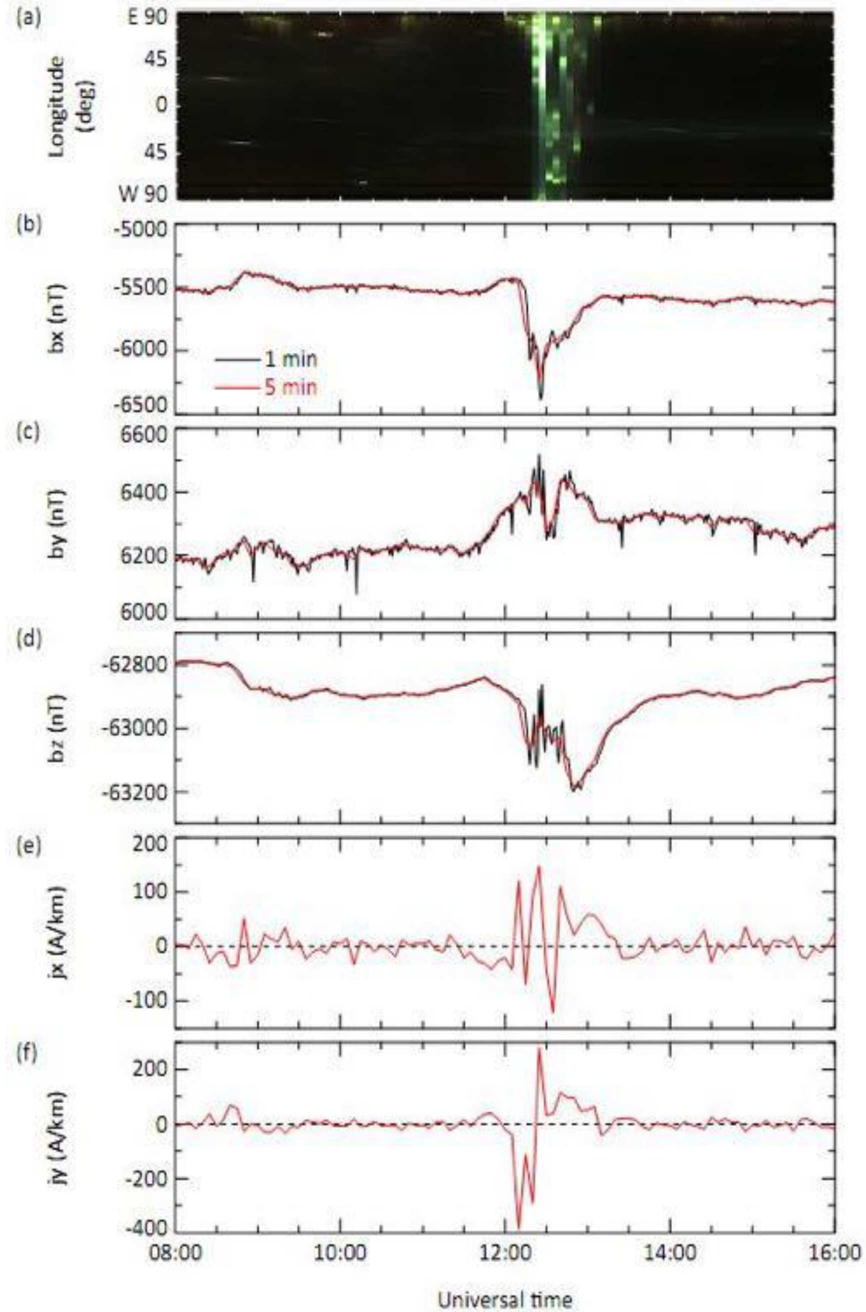


Alfonsi et al., Surv. Geophys. 2022

SuperDARN

Case study: 10-11 May 2019



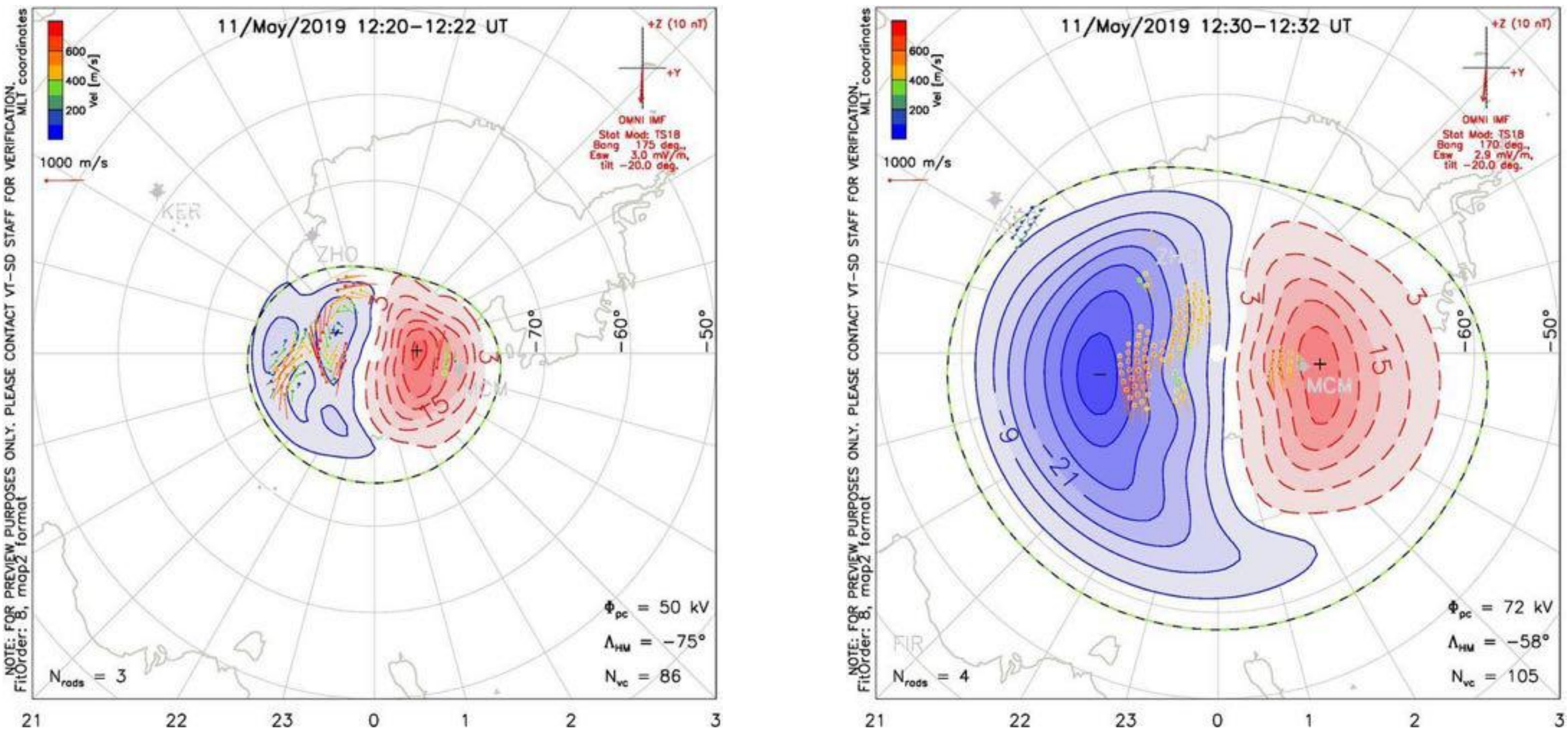


All sky imager and magnetic field data for the South Korean ***Jang Bogo Station***

- Substorm onset at 12:20 UTC.
- Strong auroral emissions and ionospheric currents.
- Additional measurements of neutral winds – study of auroral heating.

Alfonsi et al., Surv. Geophys. 2022

Case study: 10-11 May 2019



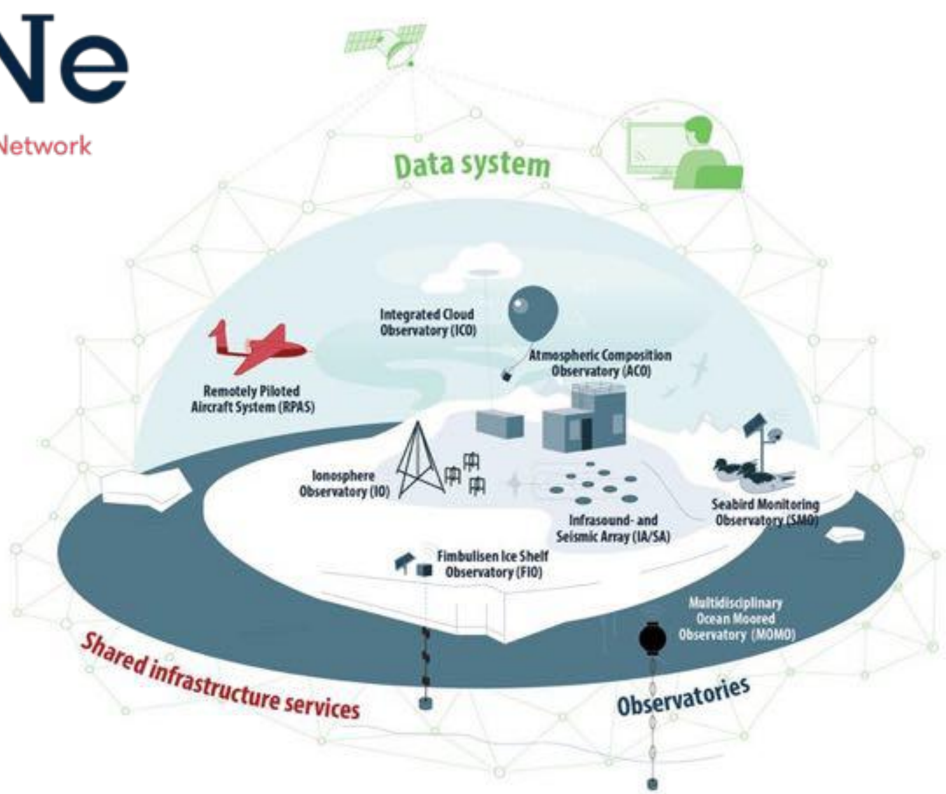
- Convection patters based on the radar network meaurments and model. Expansion during the onset and strong velocities..

Alfonsi et al., Surv. Geophys. 2022

SuperDARN

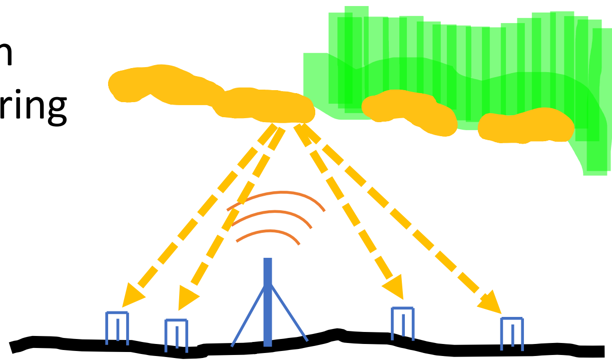
Troll Observing Network – TONe: 2022-2033

TONe
Troll Observing Network



Through the TONe project we will deploy an ionosonde to study the ionospheric structuring and its dynamics in great detail.

We also plan to install a magnetometer.



https://www.npolar.no/en/tone/

The Research Council of Norway

Norsk Polarinstitutt

NILU

UiO : University of Oslo

NORCE

NORSAR

University of Bergen

British Antarctic Survey
Natural Environment Research Council

Washington State University

University of Leeds

GISTM:

GNSS Ionospheric Scintillation and TEC Monitor (GPStation6)

Imager #1

KeoSentry Imager : spectral filter camera for monitoring spectral emissions (660.0 nm, 557.7 nm, 427.8 nm)

Imager #2

Automatic All Sky Camera *Sony* α*7ii*

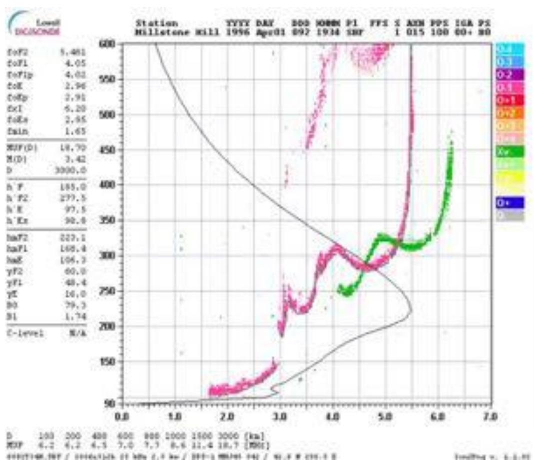
Monitoring cloud cover

Monitoring aurora in true color

Ionosonde

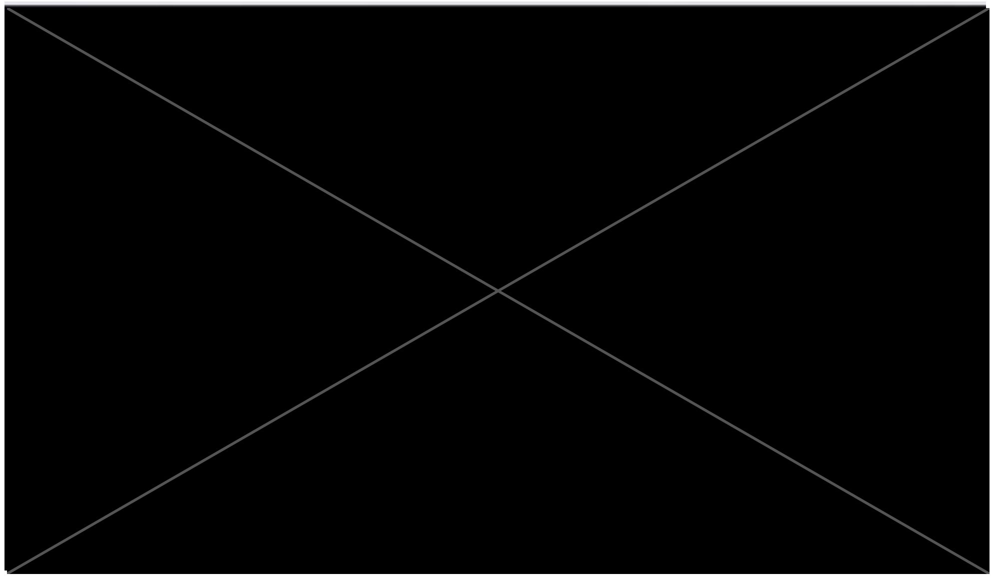
Digisonde / DPS4D

To operate from 2024/25



Opportunities for ECR…

- Data is there and there will be much more!
- There are new techniques for modeling and data processing
- Join our efforts!
- What happens now will «bring fruits» in 5 years.
- AGATA – it is a unique platform for collaborating within space science in polar regions; studying coupling between different layers of atmosphere: research stays abroad, joint projects, capacity building, networking, and mentoring.



https://www.scar.org/science/agata/home/

AGATA

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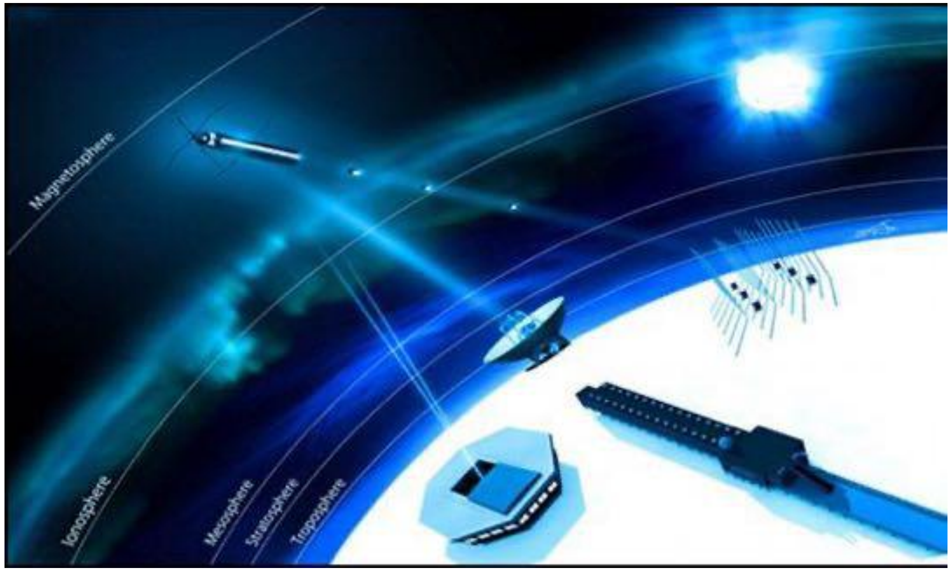
Polar ionosphere -> a roadmap for ionospheric plasma irregularities



4DSpace concept, credits: ASC

Roadmap towards understanding and modelling of irregularities:

- Ground based instruments
- LEO satellite and rocket data
- Extensive statistical studies
- Physics-based space weather data product and models

=> Creating models and forecasting of ionospheric conditions and scintillations in the polar regions.

The Research Council of Norway

esa
European Space Agency

erc
European Research Council
Established by the European Commission

DIKU
Norwegian Agency for International Cooperation and Quality Enhancement in Higher Education

European Union's Horizon 2020 research and innovation programme (ERC Consolidator Grant agreement No. 866357, POLAR-4DSpace

Norsk Romsenter
Norwegian Space Agency

SCAR
International Science Council
Scientific Committee on Antarctic Research

Thank you!