

Magnetometers by IRF observatory

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Per Danielsson (TOP)

Kiruna (KIR)

**Lycksele: SGU in
collaboration with
IRF (since 2007)**

only variometer (TOP)

KIR measurement area

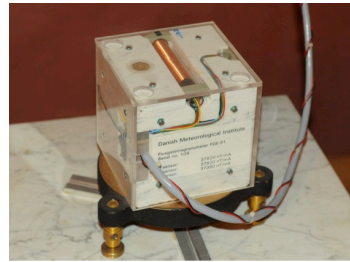


Kiruna magnetometers

(1) Vector field (every 1 sec):
Fluxgate variometer (Kiruna)

Primary

Secondary



(3) Total field (every 3-4 sec): Proton magnetometer = scalar value (Kiruna)

Primary + Secondary

To be upgraded to
1-sec resolution



(2) Absolute measurement (weekly): DI-flux magnetometer (Kiruna)

in operation

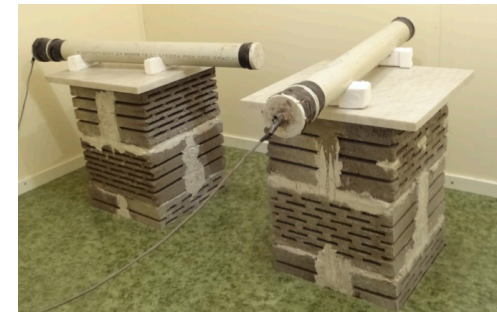
spare



(4) Higher frequency than 1 Hz: Pulsation magnetometer (Kiruna)

3 sensors (XYZ) in operation

1 spare



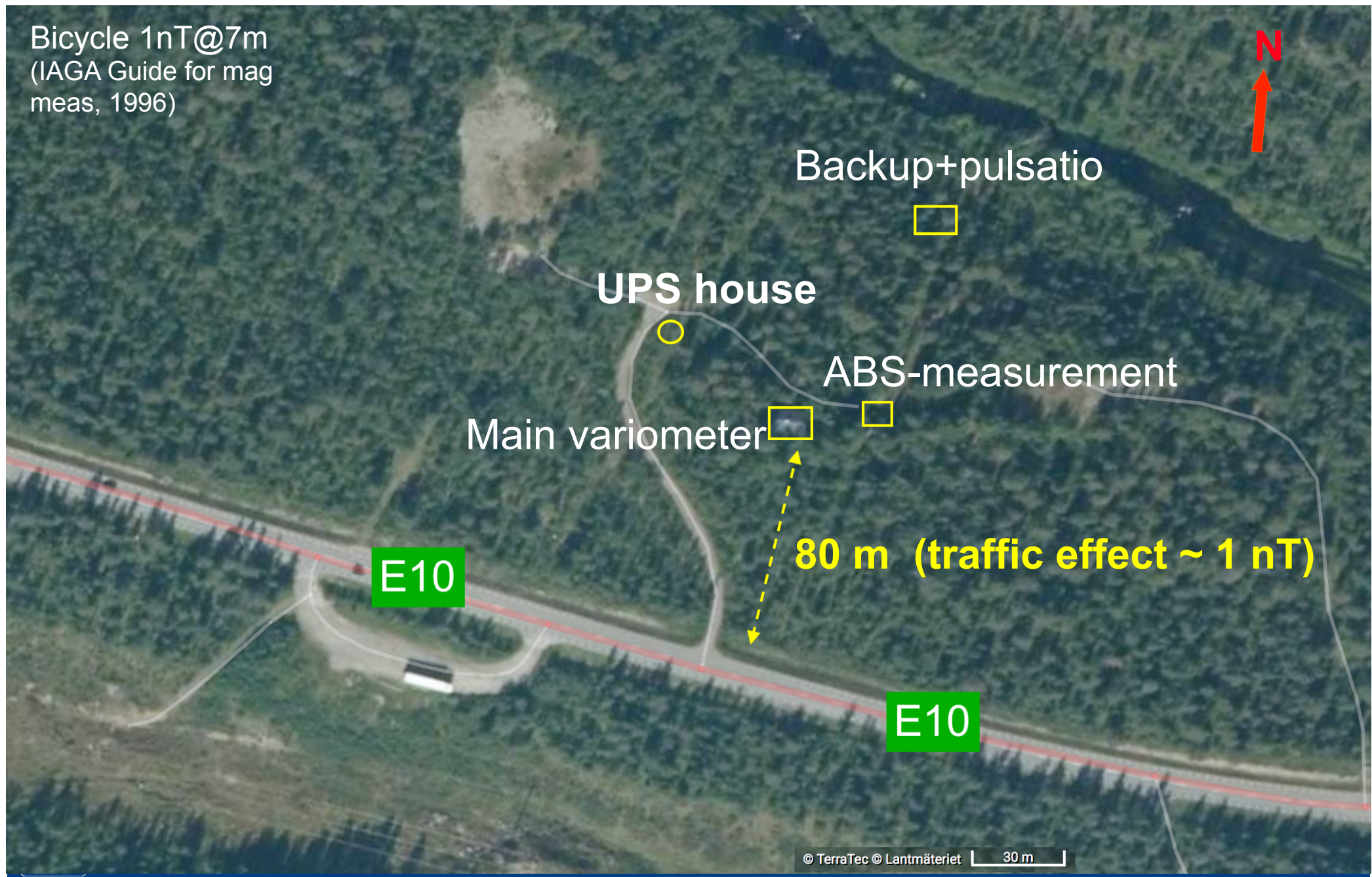
Specialty of Kiruna:

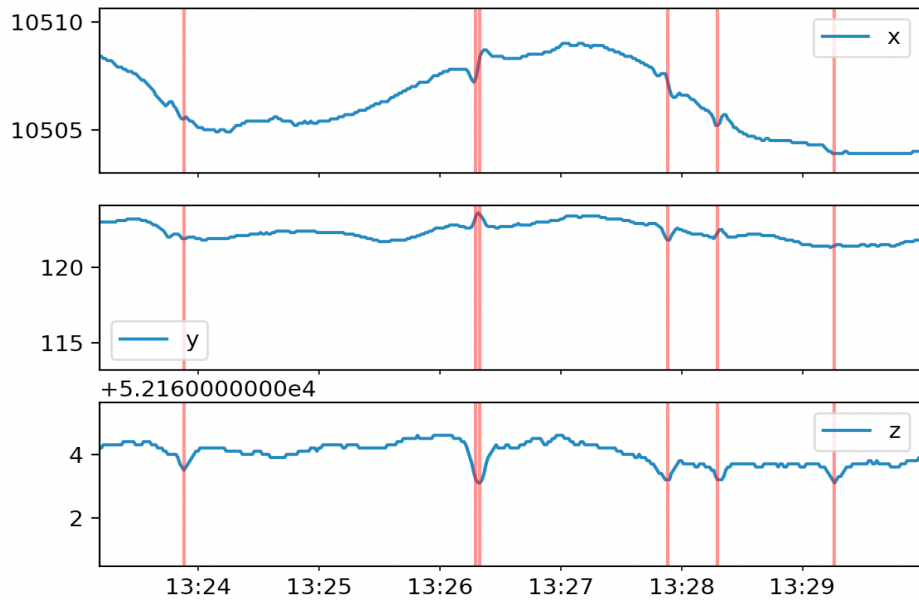
1) near the iron mining ($\Delta D \sim 10^\circ$)

2) can combine with other ionospheric measurements

- auroral image
- riometer
- ionosonde
- mm wave for O_2+O_3 (Zeeman effect)

magnetic observatory facilities (Kiruna)

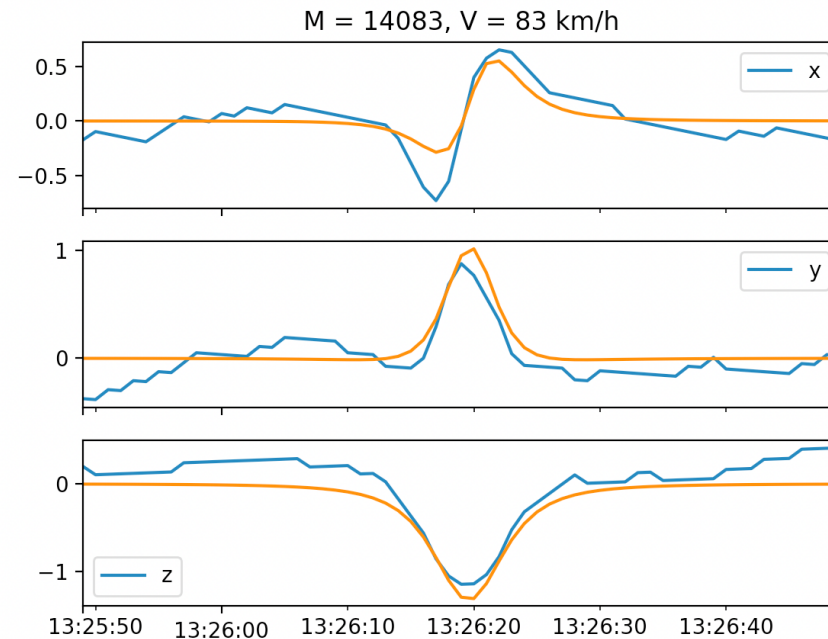
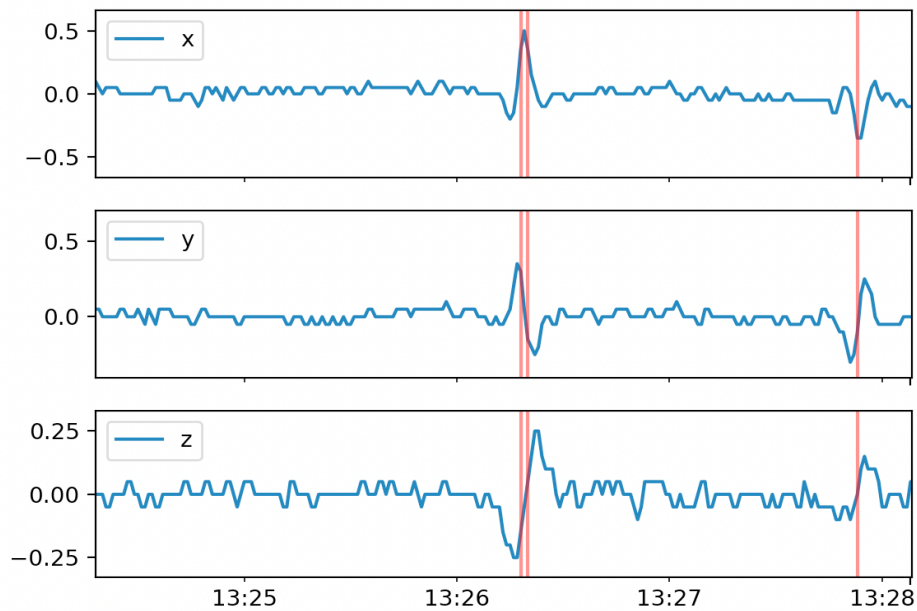




Highway (E10) effect

**Observed effect ~ only 1 nT
(at 80 m distance, 90 km/h)**

⇒ we do not remove such small spikes



Hässleholm (TOP) instrument

Variometer close to Tormestorp

<https://www.spaceweather.se/forecast/mag>

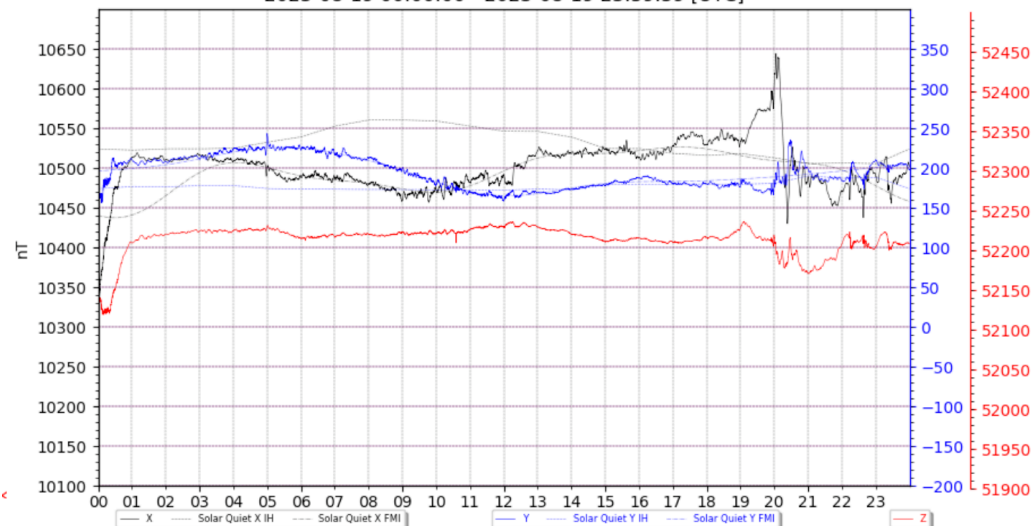
or <https://www2.irf.se/mag/>

- Site test with DTU: 2013
- Installation and first measurements: 2016
- Real-time since 2018
- Solar observations with DTU 20230502
- Broken spring 2023 => need for backup
- Having backup under discussion



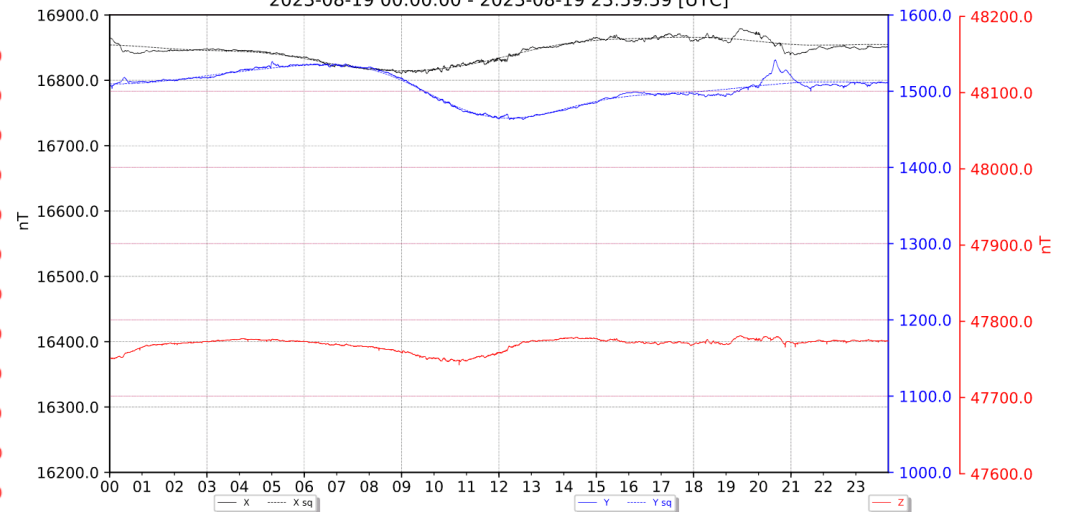
Kiruna (68°N)

Kiruna Suspended Magnetometer
2023-08-19 00:00:00 - 2023-08-19 23:59:59 [UTC]



Tormestorp (56°N)

Tormestorp magnetometer
2023-08-19 00:00:00 - 2023-08-19 23:59:59 [UTC]

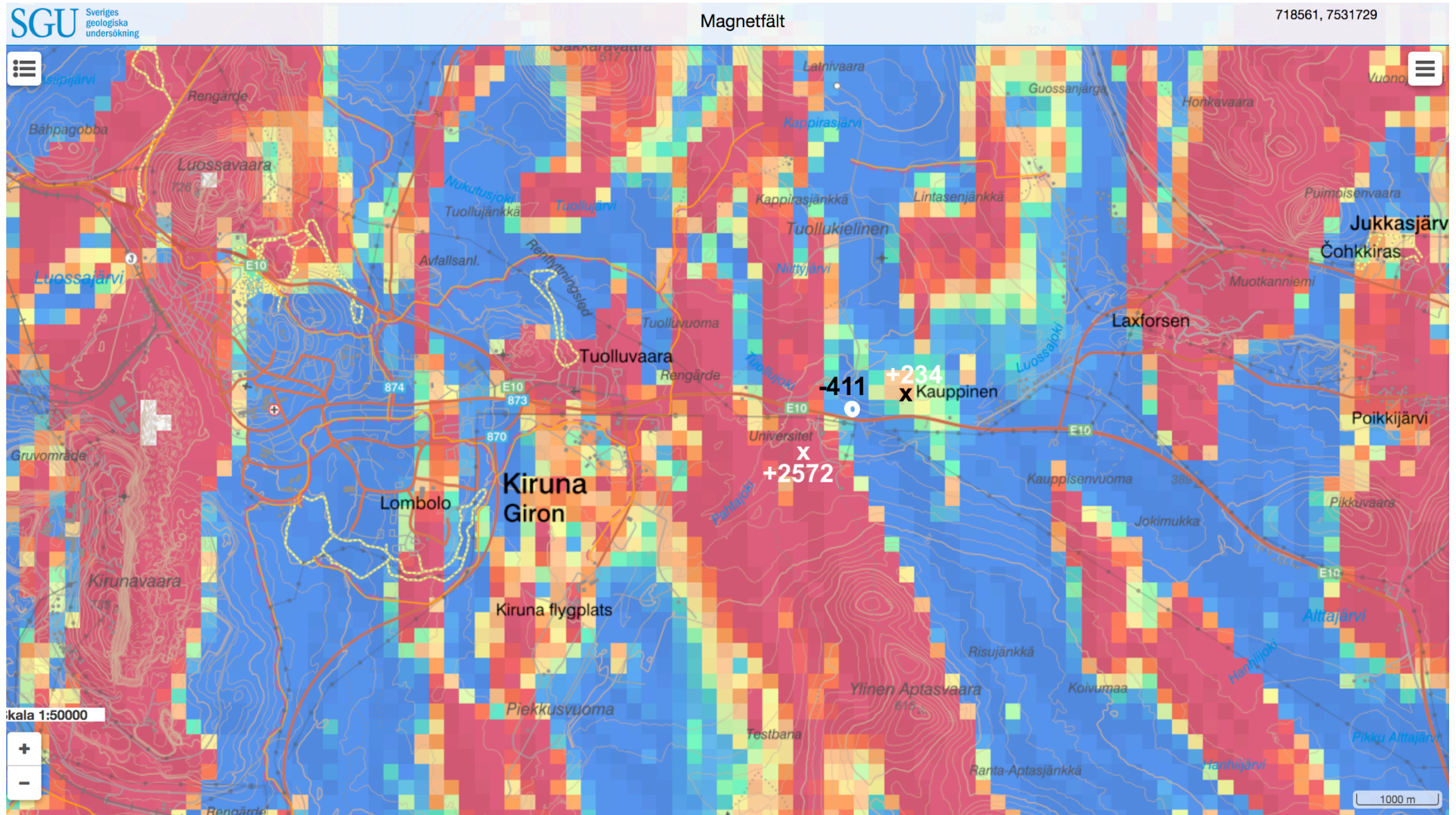


Recent developments

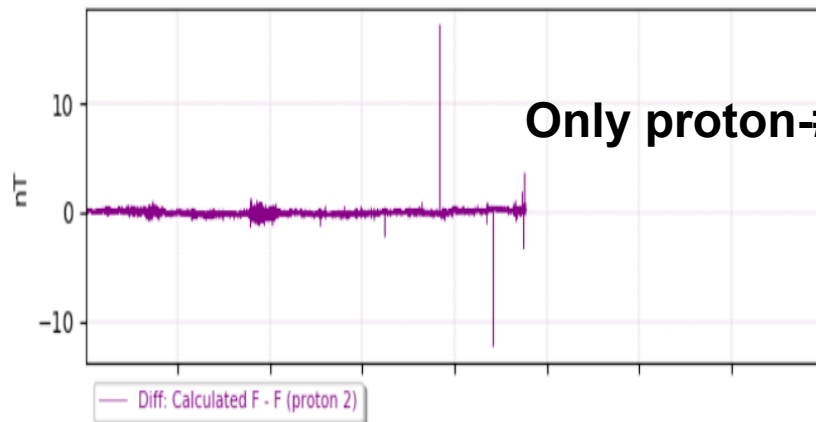
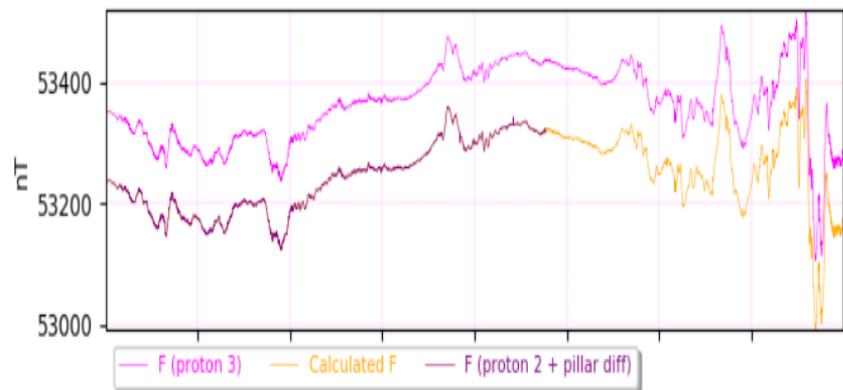
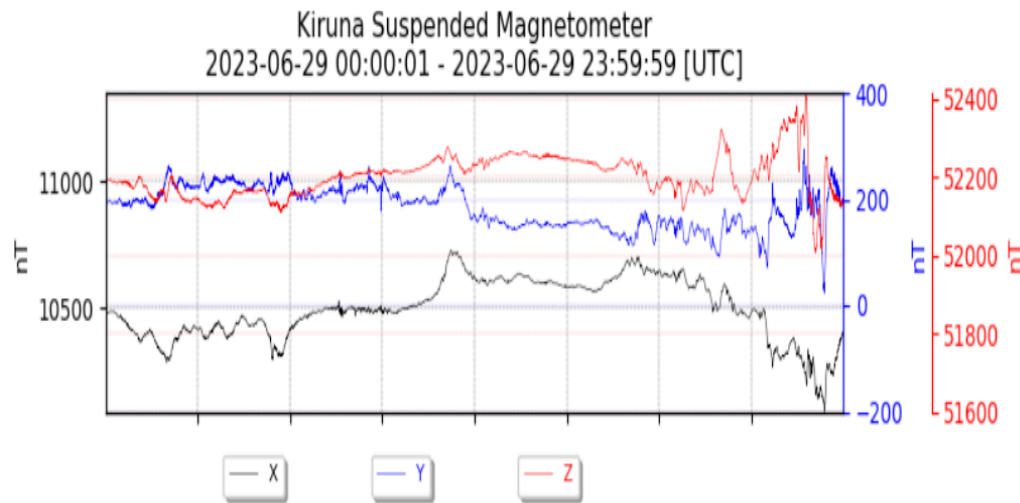
- Keep improving our data quality (hardware)
 - 2020: UPS house, true north, replace main variometer
 - 2023: **New 1 Hz portable scalar magnetometer is coming**
- Keep improving our data quality (software)
 - 2022: Start estimating magpy, scale factor (baseline Z)
 - 2023: Improved set of data 2021, 2022 are ready
- Local $|B|$ anomaly near KIR station
 - Retrieved past past measurements by SGU
 - **To be further examined (with new magnetometer)**
- **Thunderstorm** (2023-6-29: strongest? since 2014)
 - Damage on primary proton and data correcting system
 - Damage was within level of quick fix (same as 2022-7-1)
- **Possible fear**: E10 highway broadening (work starts 2027~)

[B] anomaly ~200 m resolution (by SGU)

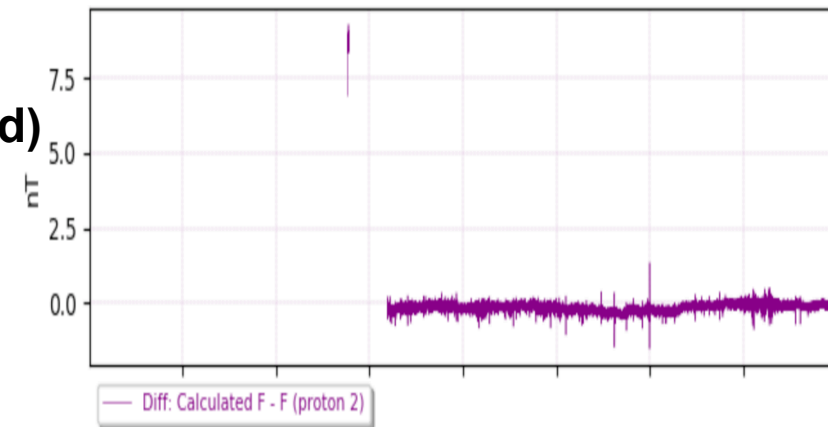
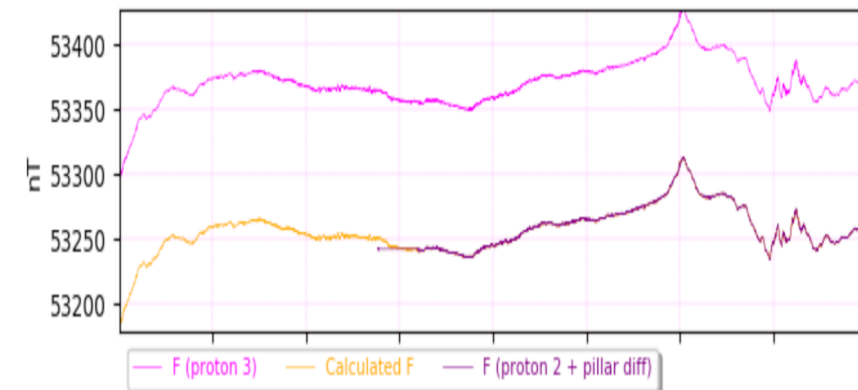
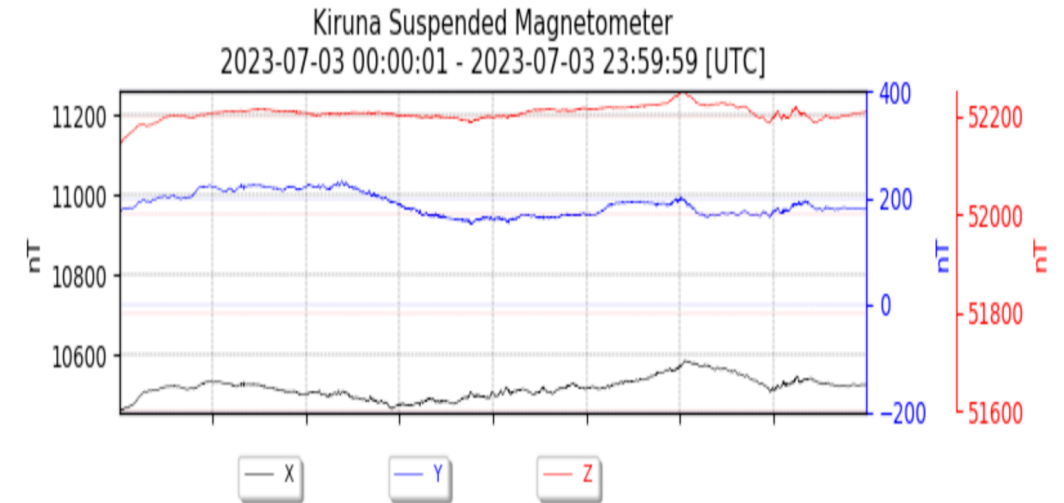
- KIR site sits at nearly one extreme (-440 nT).
- Deviation is nearly 3000 nT (out of $Z \sim 52000$ nT & $H \sim 10000$ nT)
- Old measurements with 30 km resolution show $\Delta D \sim 8^\circ$ around KIR
- **We plan more local measurement with portable scalar magnetometer coming soon**



Lightening 2023-6-29 (recover 2023-7-03)

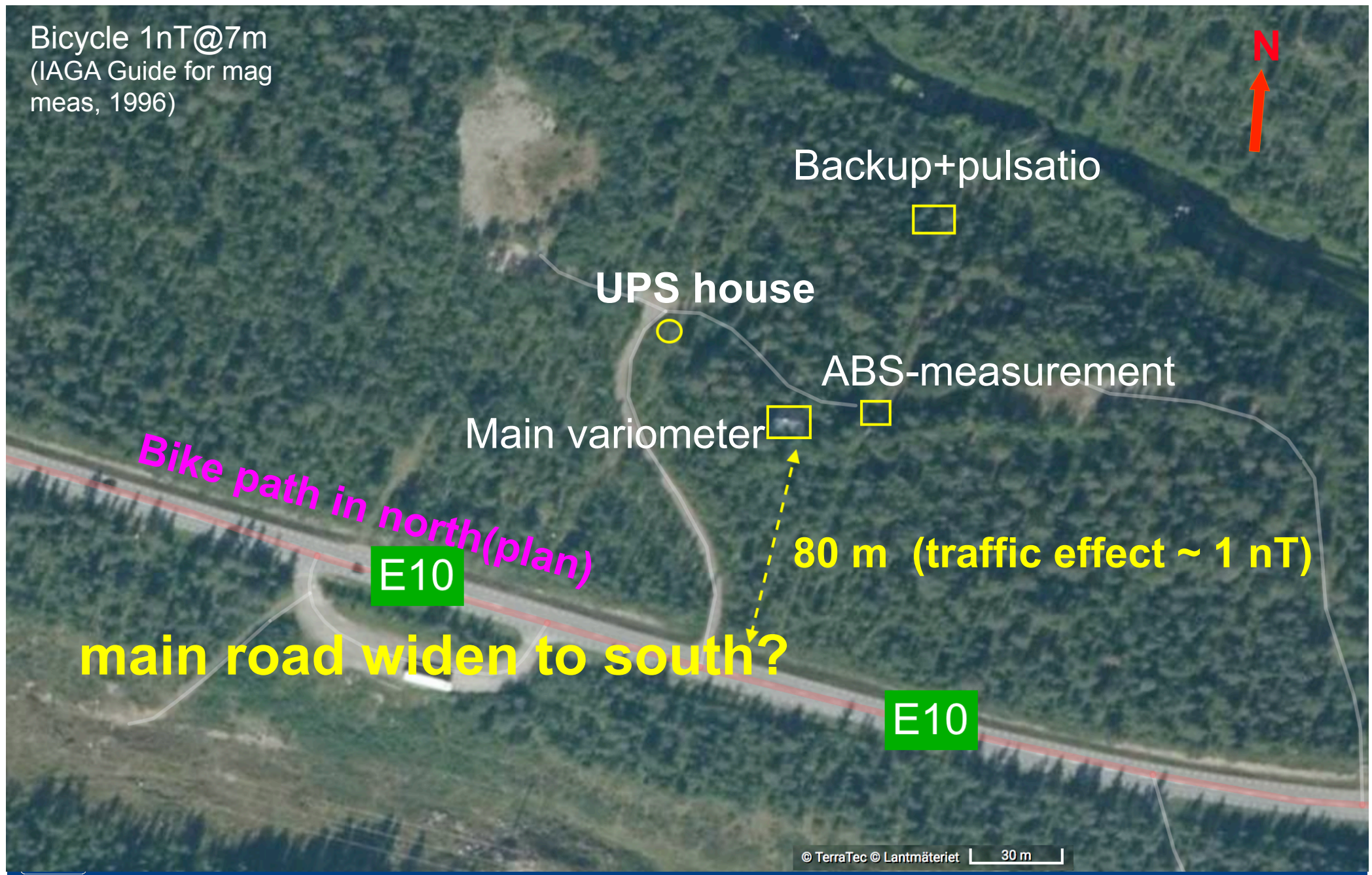


Only proton-#2 stopped



E10 will be widened ~ double (2+1 lane)

work to be started 2027



Recent developments (summary)

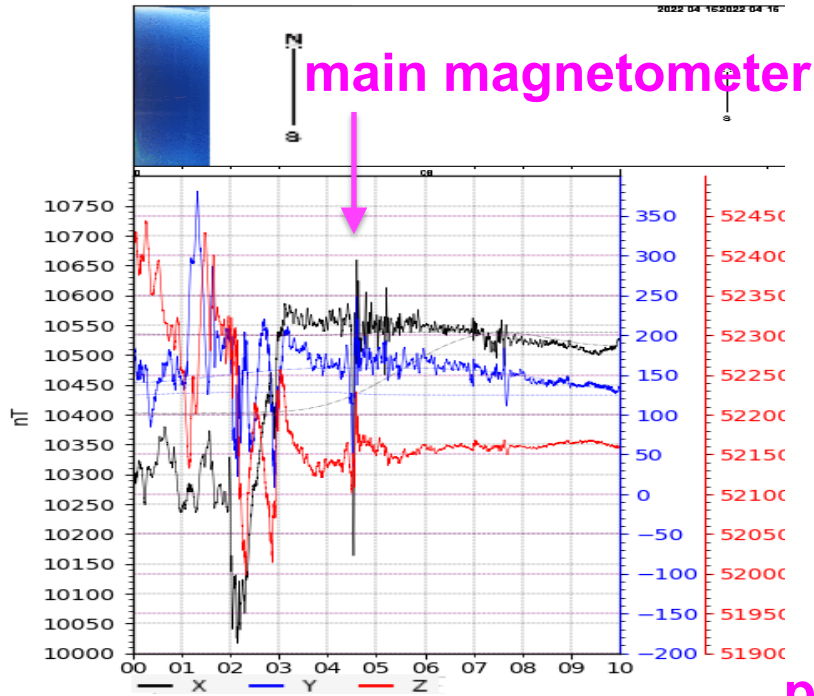
- Keep improving our data quality (hardware + software)
- |B| anomaly and D anomaly
- Thunderstorm (temporal damage on one of proton 2023-6-29)
- Possible fear: E10 highway broadening

Use of data

- **2022-4-15 event (large SC-like ΔB without SW shock)**
 - presented at EGU (April 2023)
- **Kiruna ASC Auroral index**
 - correlation to dB/dt is under way
- **2023-2-26 event (SC-driven shock aurora at 21 MLT)**
 - correlate magnetic signature to different aurora
- **Zeeman effect vs magnetic variation**
 - effect changes with time (relation to magnetic variation?)

2022-4-15 event

Kiruna Suspended Magnetometer
2022-04-15 00:00:00 - 2022-04-15 23:59:59 UTC1



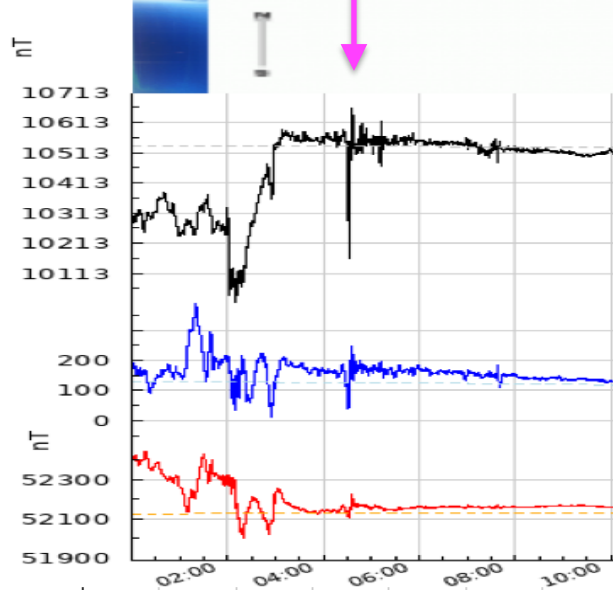
filtered quick data at Kiruna

UT	dX	dY	dZ	F
04:28:10	58.2	30.8	45.4	53136.0
04:30:13	0.7	1.2	22.2	53152.9
04:32:20	-342.2	36.4	63.2	53071.8
04:33:40	-1.0	101.5	21.3	53163.6
04:34:10	65.8	88.6	81.0	53236.7

$dX/dt = 50-60 \text{ nT}/10\text{s}$ around the peak

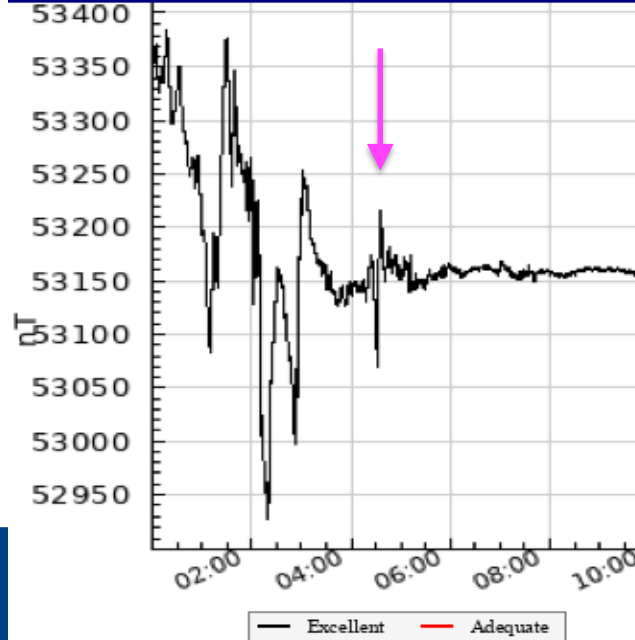
backup magnetometer

Raw Kiruna magnetogram 2022-04-15, UTC



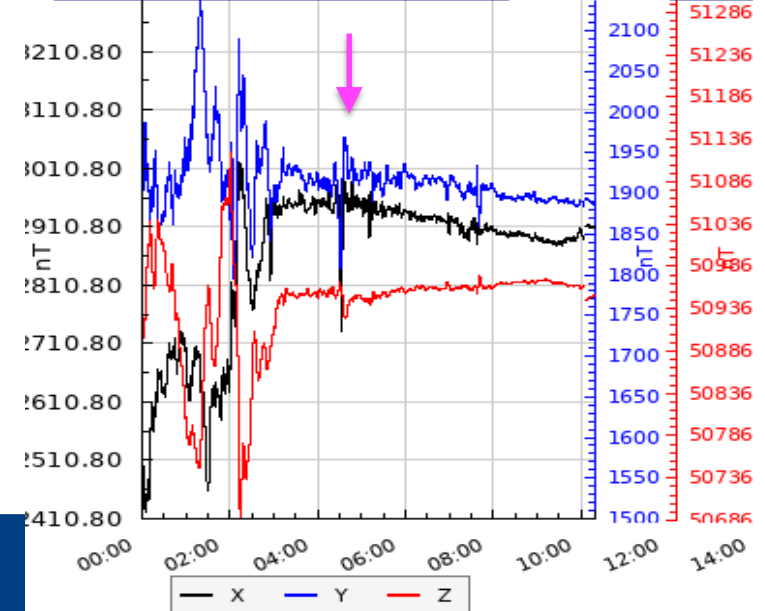
proton magnetometer

Kiruna proton magnetometer 2022-04-15, UTC



Lycksele

Lycksele SGU 1 magnetogram 2022-04-15 UTC

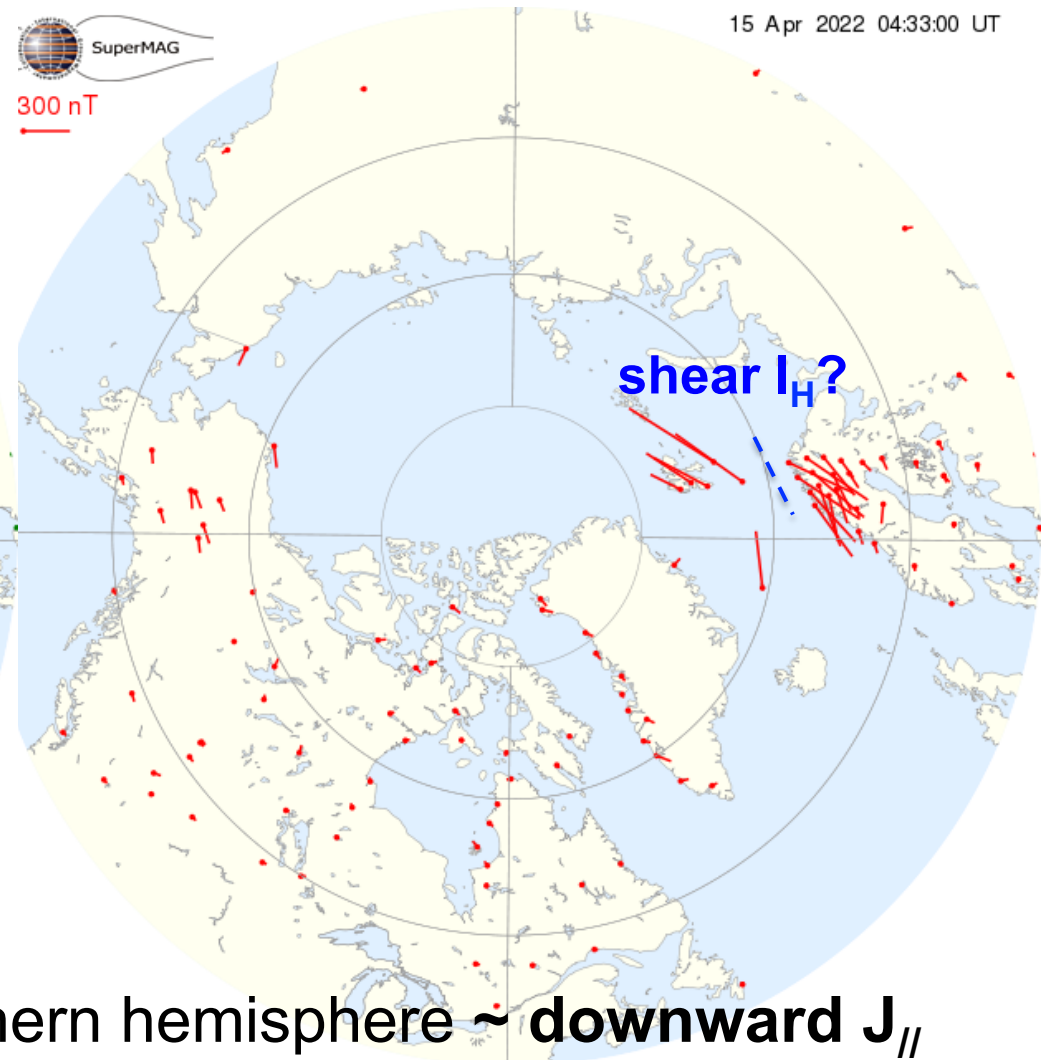
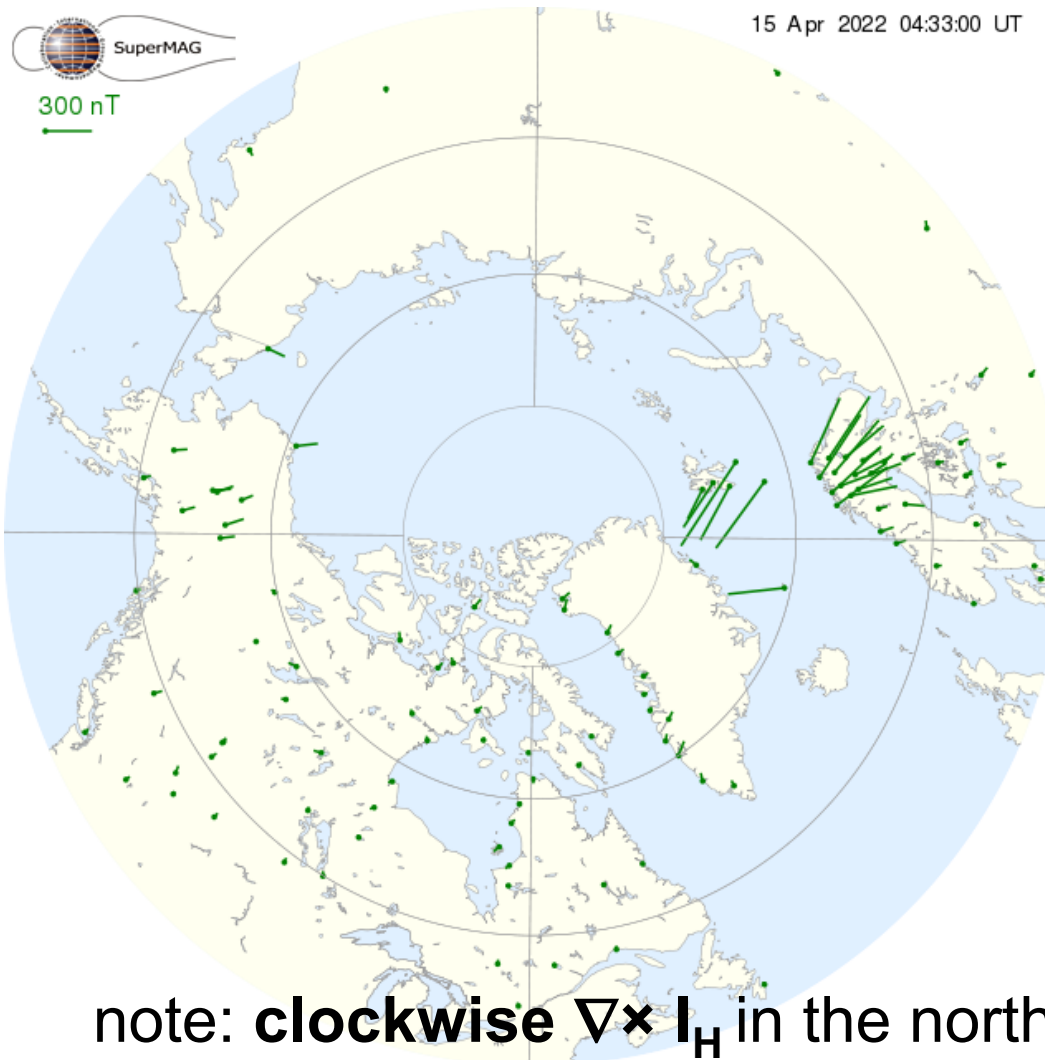


global perspective (2022-4-15 event)

SuperMAG plot @ 04:33 UT

ΔB

90° rotation of ΔB
~ ionospheric I_H



note: clockwise $\nabla \times I_H$ in the northern hemisphere ~ downward $J_{||}$

summary (2022-4-15 event)

- Large isolated ΔB spike (~ 400 nT in Kiruna), localized @ **dawn**
- $\nabla \times \mathbf{I}_H$ kernel is moving $\Rightarrow$ **downward $\mathbf{J}_{\parallel}$** moving toward night
- Riometer data is consistent with **downward $\mathbf{J}_{\parallel}$**
- At low latitudes, **SC-like compression** at wide longitude
- Unlikely SC, **no substorm/storm is followed** (rather ended)

- **But no shock** detection by any of L1 or MMS/Cluster.
- Stable northward $\mathbf{B}_z > +10$ nT (L1 and MMS), but big dip at Cluster ($\sim$ to near zero) during the density enhancement.

$\Rightarrow$ **Mysterious !**

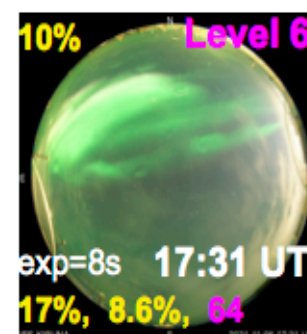
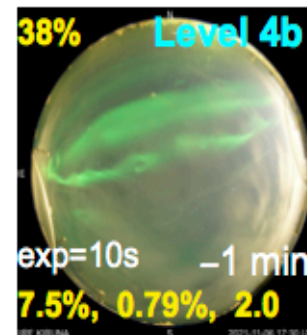
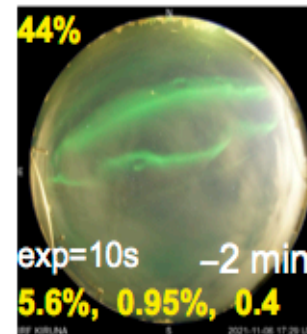
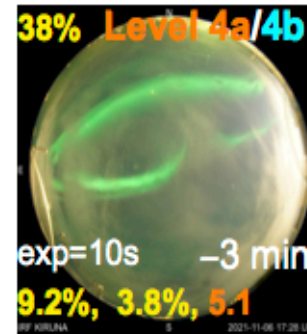
ASC auroral Index

- Just from ASC, Level 6 (brightening and breaking in the ASC), and Levels 4a+4b (possible precursor) are defined

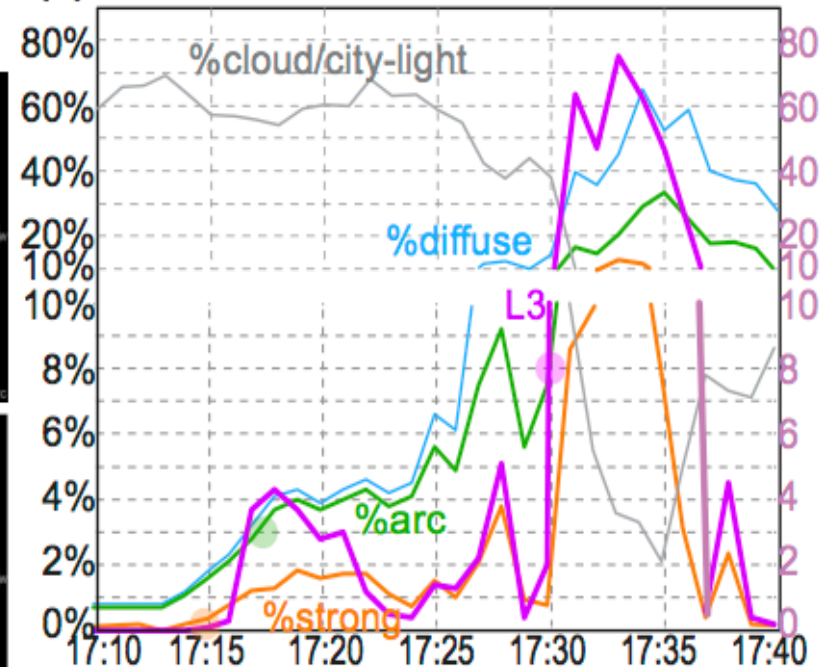
Additional Level using $|dB/dt|$

- Level 8: $|dB/dt| \geq 5 \text{ nT/s}$
- Level 7: Level 6 & $|dB/dt| > 2 \text{ nT/s}$
- Level 5: some ASC criteria + $|dB/dt| > 0.8 \text{ nT}$
- Level 4c: some ASC criteria + $|dB/dt| > 0.5 \text{ nT}$

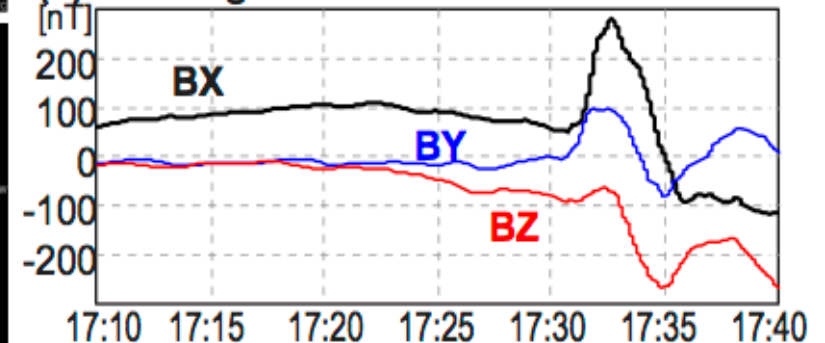
number/top = %cloud



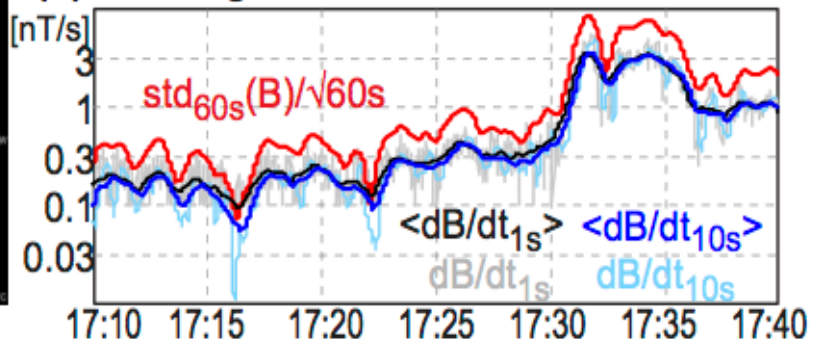
(b) ASC Index



(c) Geomagnetic field



(d) Geomagnetic fluctuation



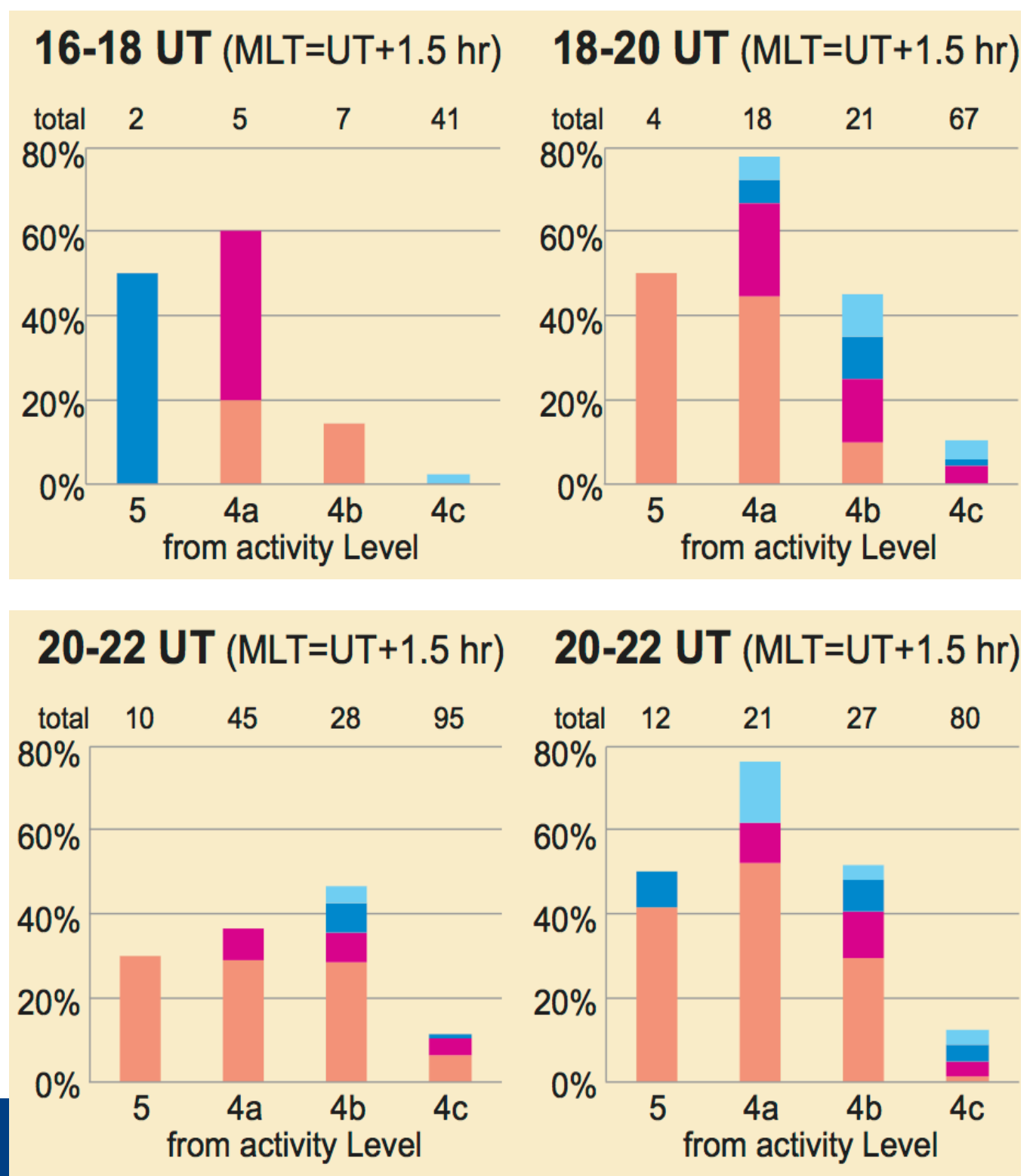
Probability of reaching Level 6

from first time of reaching the lower Level over-night

Note: Preliminary result with insufficient statistics due to limited (November 2021 – April 2022).

cf. Level 8 (> 5 nT/s)

Too little statistics (only 6 cases of Level 8), and only 3 cases had precursor (Level 5, Level 6, and Level 7).



Correlation between $|\text{dB}/\text{dt}|$ and ASC auroral index

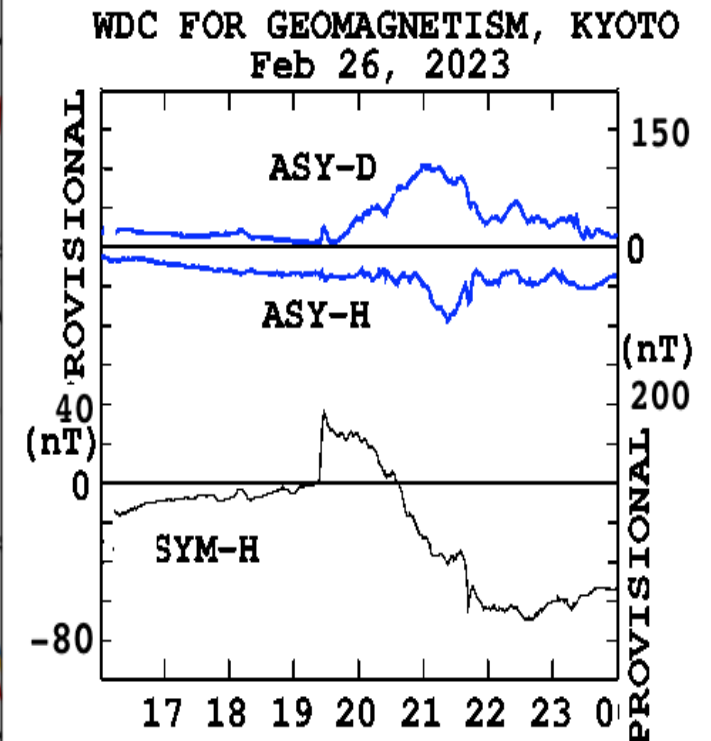
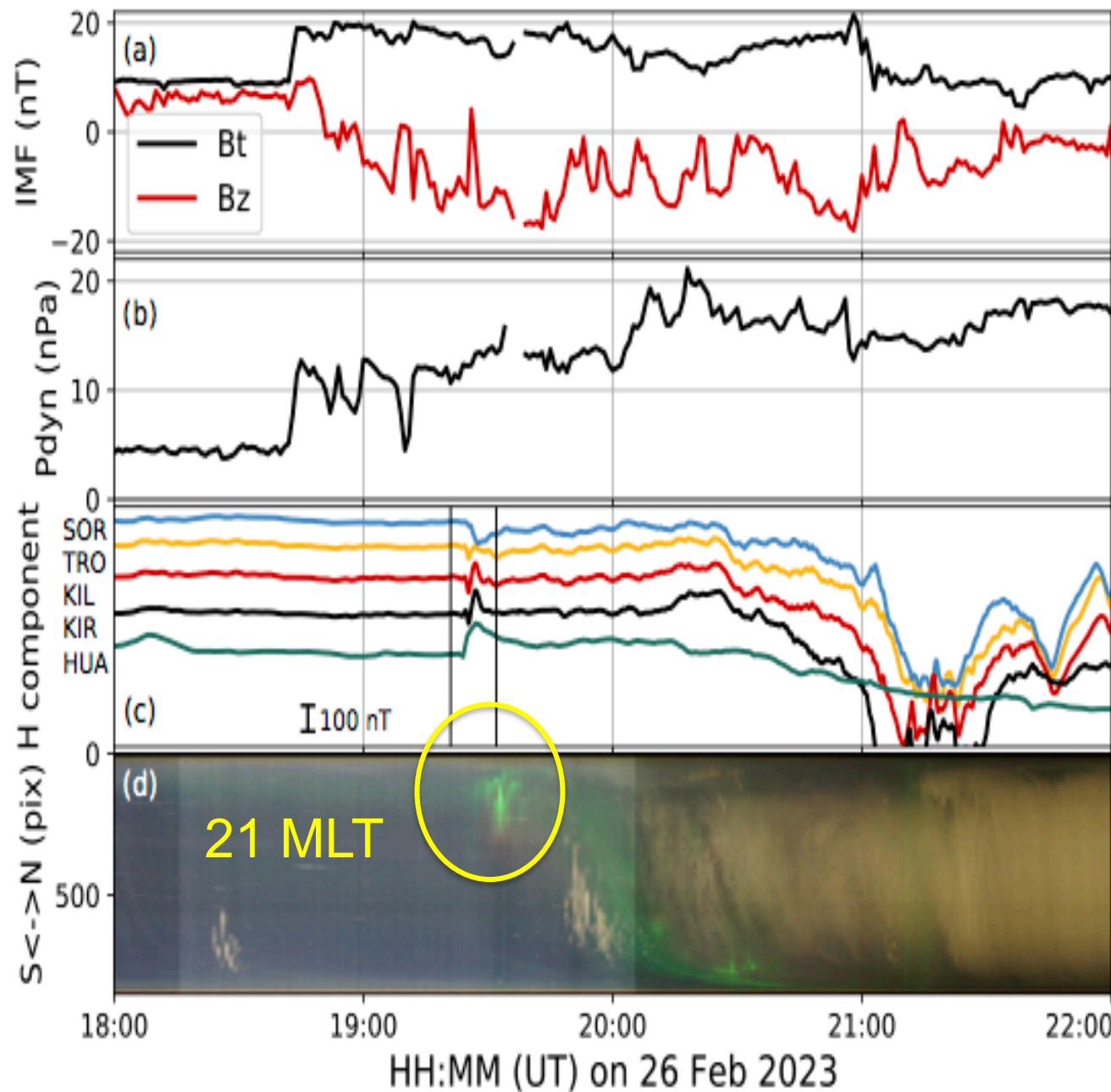
Note: Preliminary result with insufficient statistics due to limited (November 2021 – April 2022).

UT	16-18 UT	18-22 UT	20-22 UT	22-24 UT
$ \text{dB}/\text{dt} $ vs %arc	0.46	0.27	0.54	0.41
$ \text{dB}/\text{dt} $ vs %strong	0.40	0.20	0.26	0.36
$ \text{dB}/\text{dt} $ vs $L_3 = \text{aver}(L^3)$	0.39	0.22	0.26	0.36

$$\text{MLT} \approx \text{UT} + 1.5 \text{ hr}$$

- Correlation between the aurora activity (ASC auroral index) not very high, but still exists.
- Prediction of $\text{dB}/\text{dt} > 5 \text{ nT/s}$ (Level 8) is yet difficult, but Level 7 (Level 6 + $|\text{dB}/\text{dt}| > 2 \text{ nT/s}$) can be a possible candidate.
- We will examine more data in this direction (add 2022/2023 data and add 2023/2024 data).

shock aurora @ 21 MLT: 2023-2-26

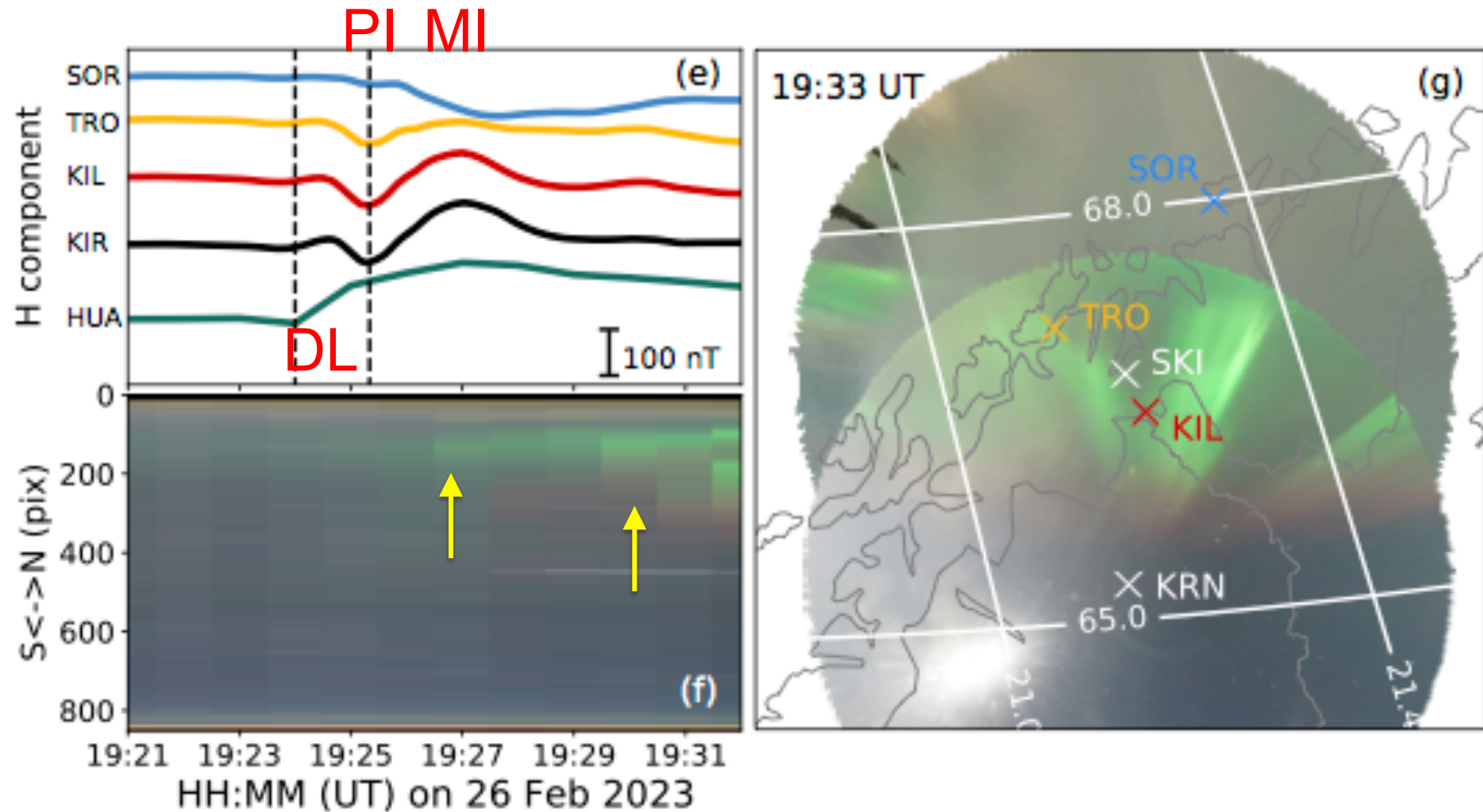


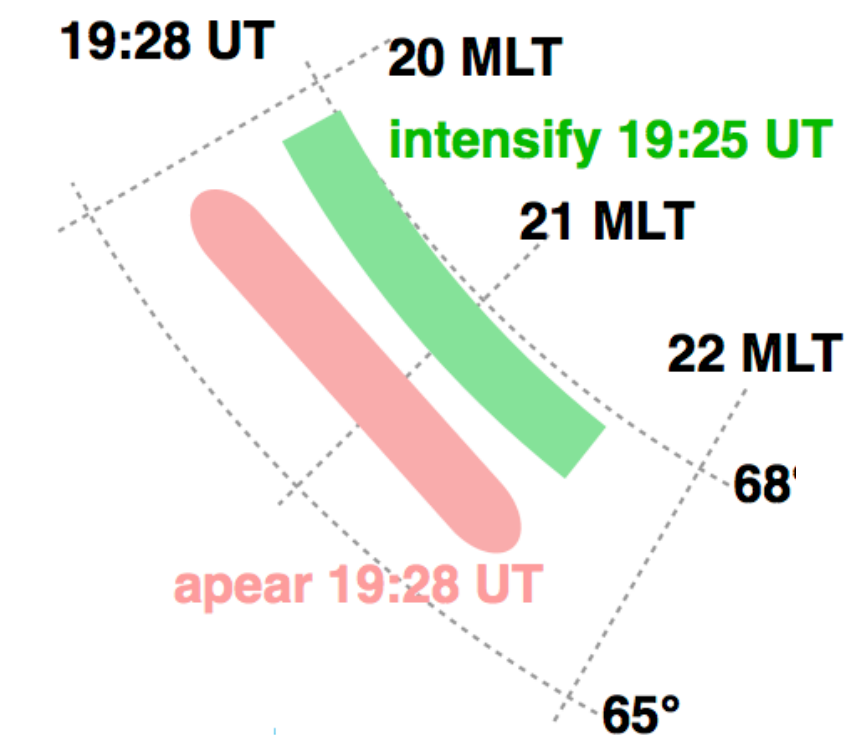
SYM-H ~ 0: no ring current effect remains

ASY-D ~ growth phase, but not substorm onset

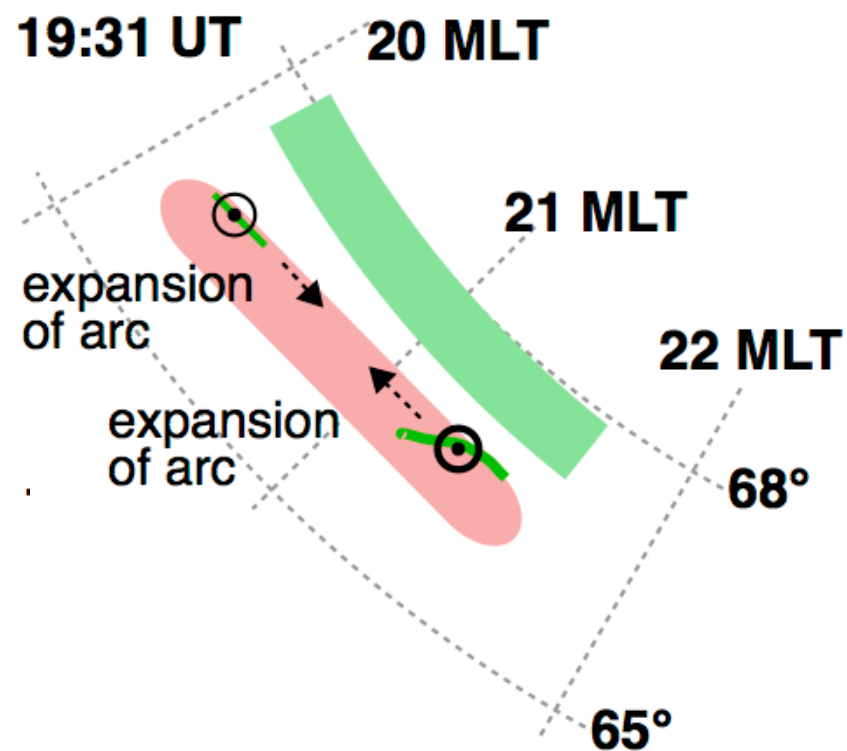
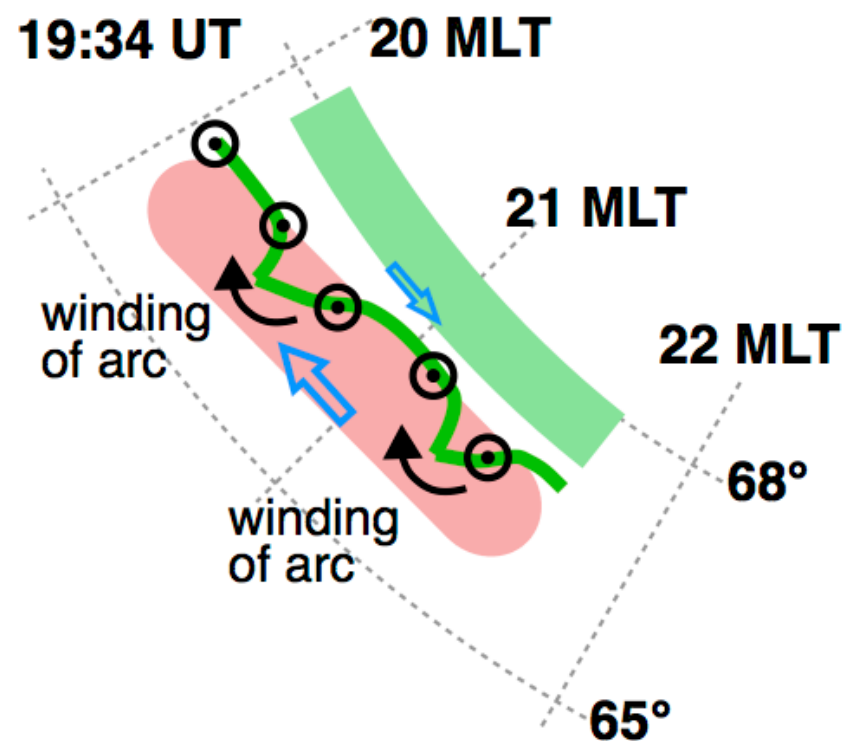
DL and DP (primary and main) after SC

reversal of $\Delta H \rightarrow$ conversing $J_p \rightarrow$ upward field-aligned current

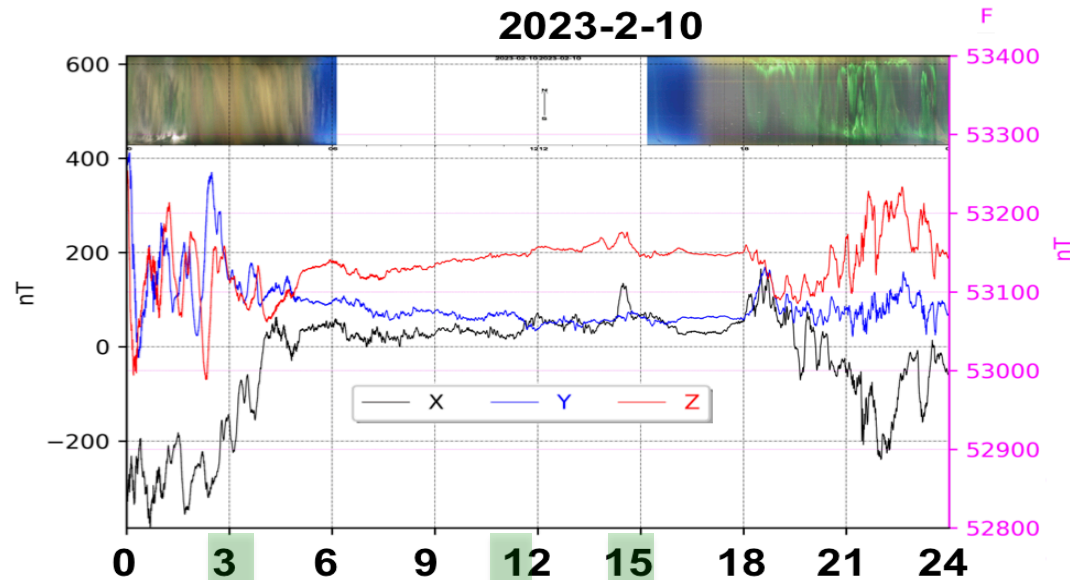




- pre-existing weak arc
- red aurora appeared 19:28 UT
- ~ new arc appeared 19:31 UT
- ← convection indicated from arc
- ⊙ field-aligned current

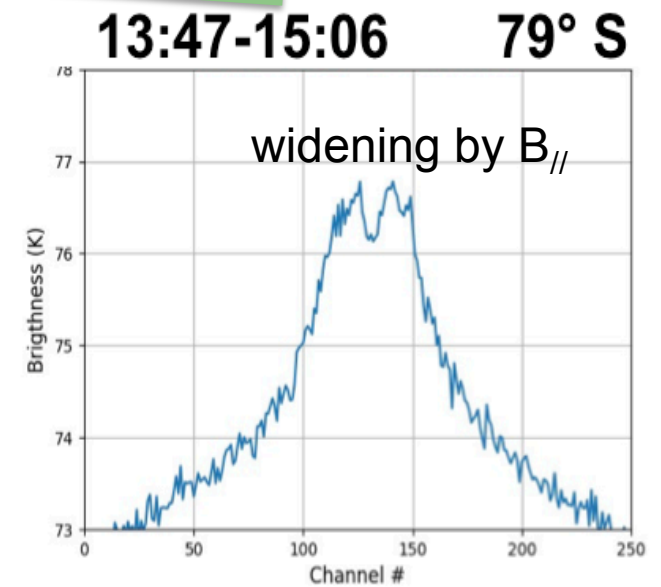
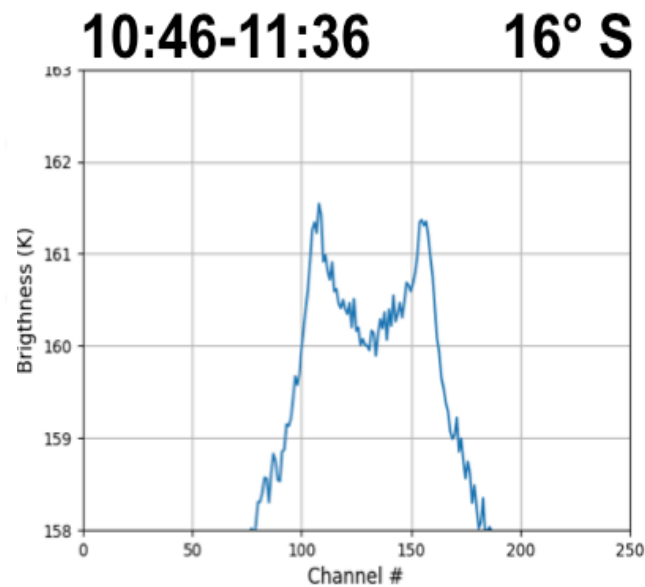
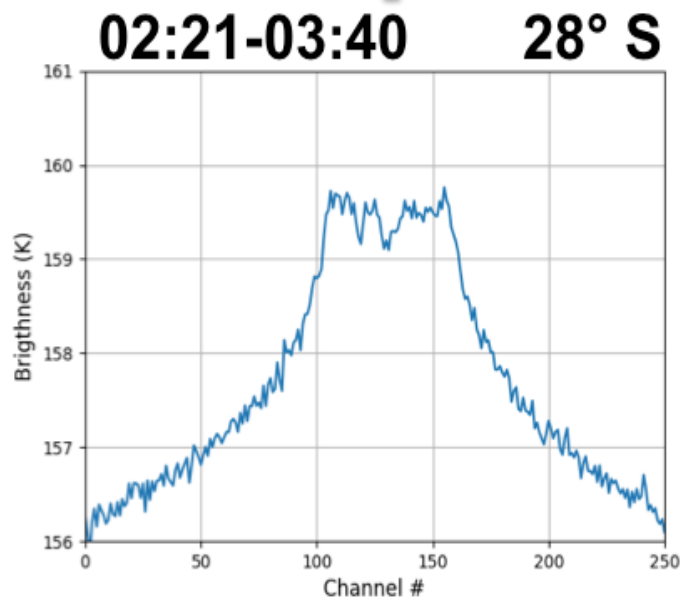


Zeeman effect seen in mm wave (O_2 & O_3)



for further information,
contact

uwe.raffalski@irf.se



End / questions?



Magnetometer quality

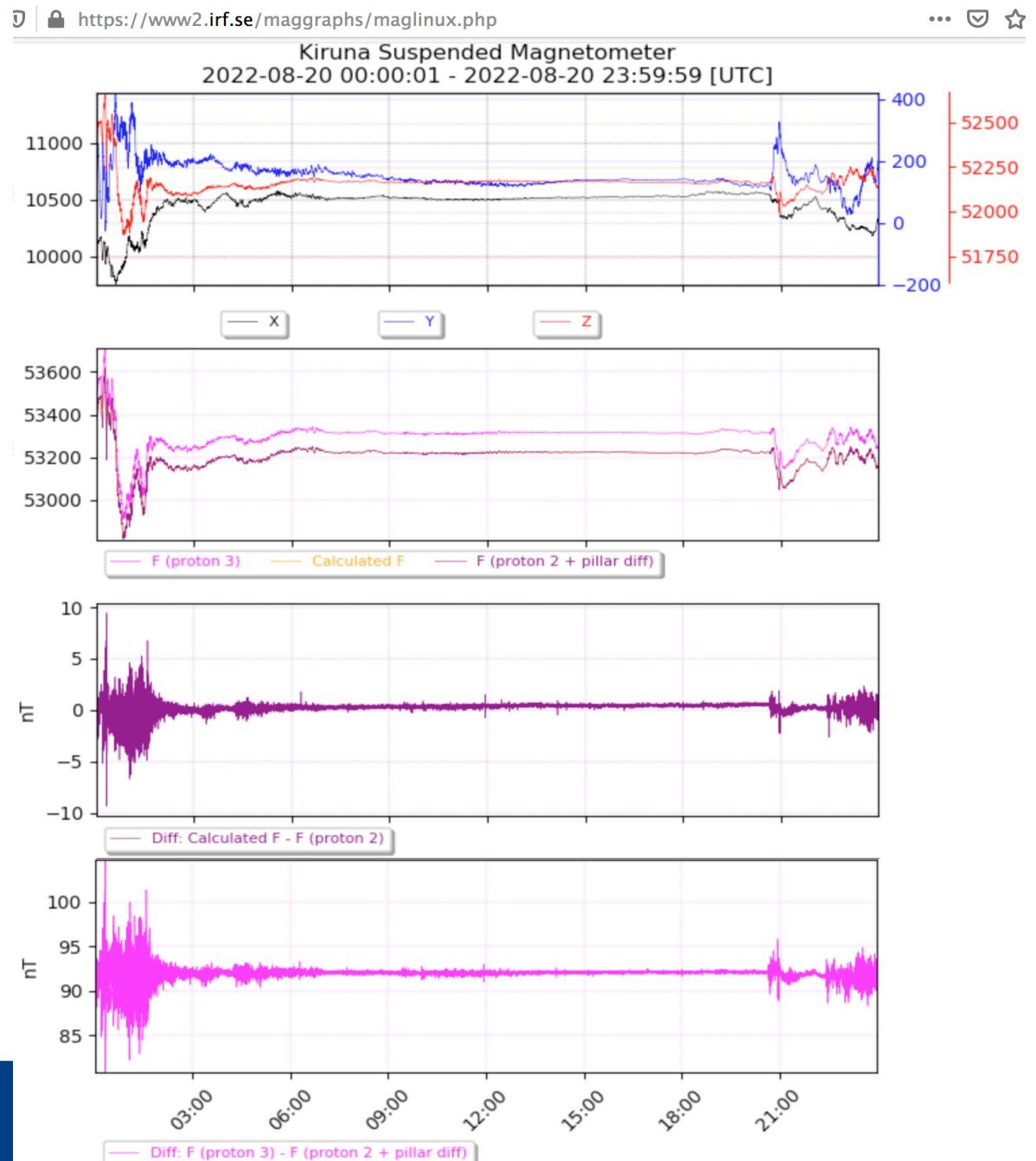
Scalar/vector difference may be due to time resolution difference, otherwise good agreement

Variometer

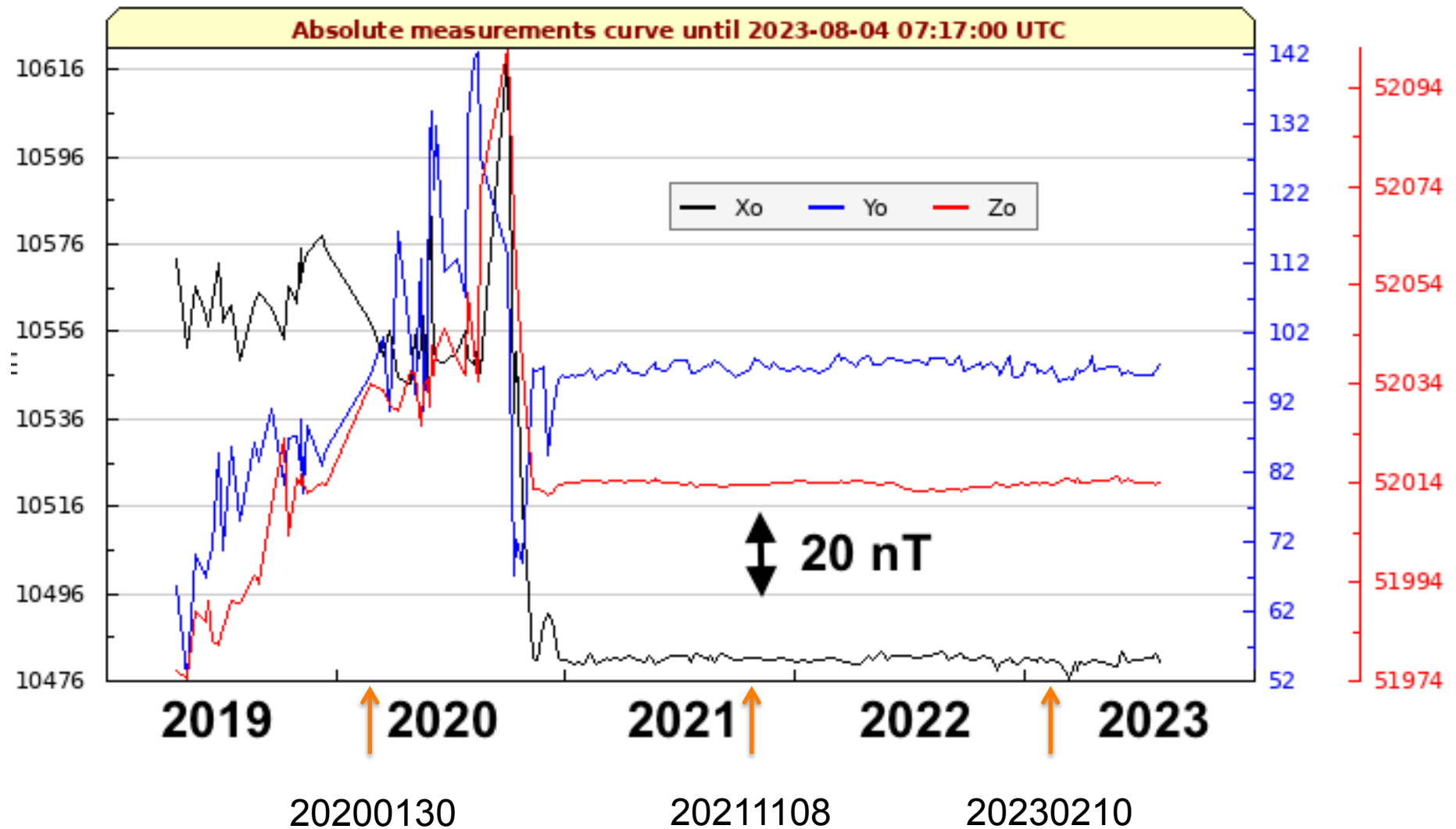
Proton (#2 & #3) & Variometer_F

Proton #2 – Variometer_F

Proton #3 – Proton #2

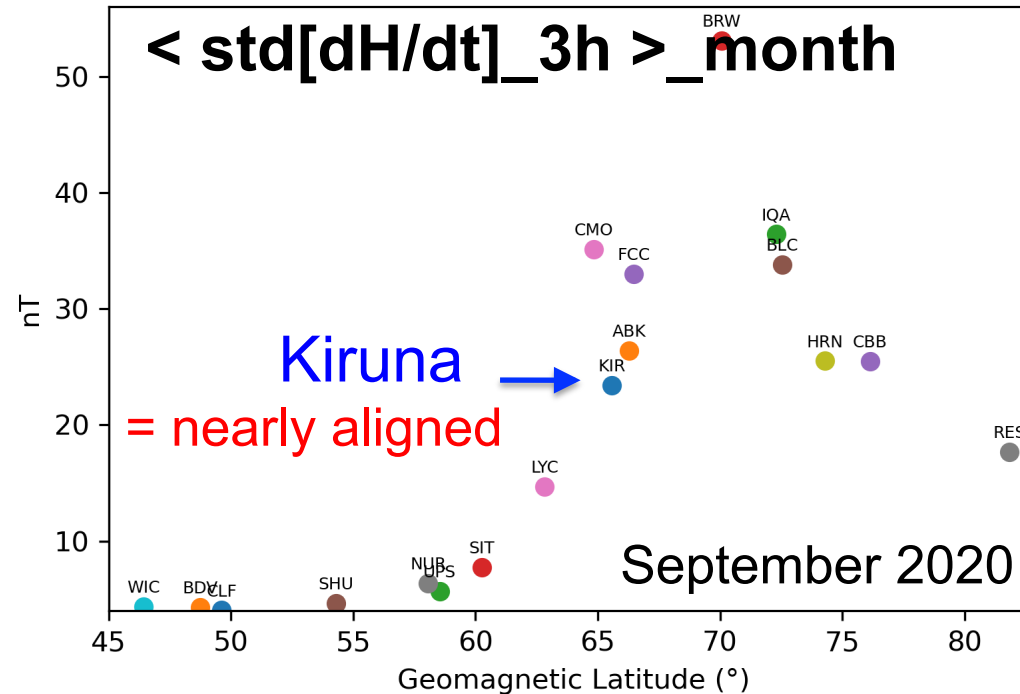
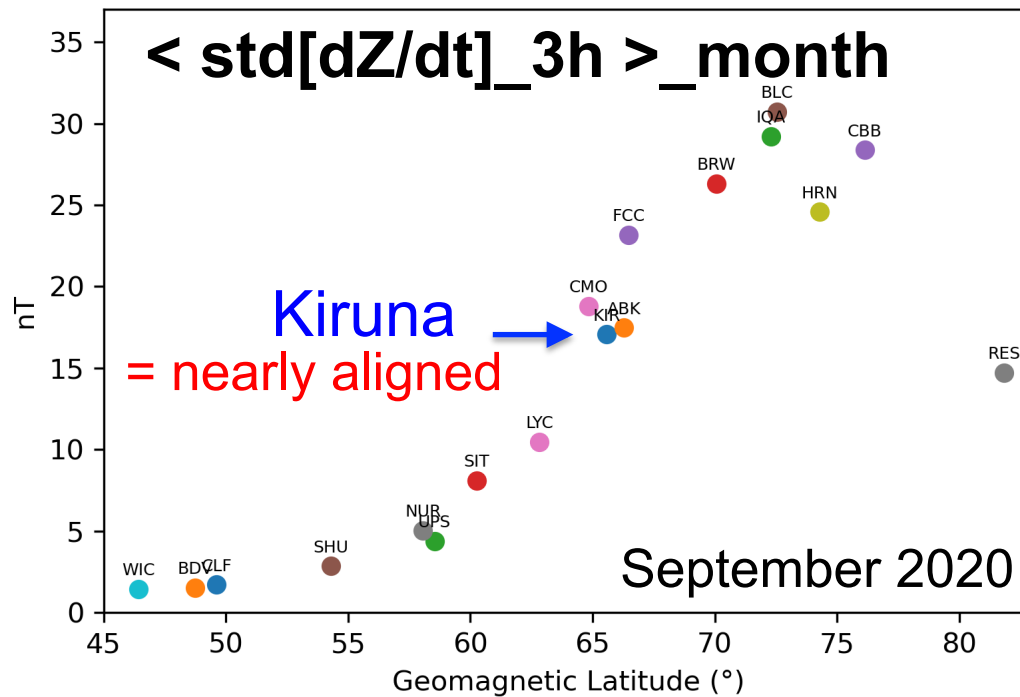


Absolute (baseline) measurement



Primary theodolite was in service ~ 2 weeks

Quality of 1-sec data

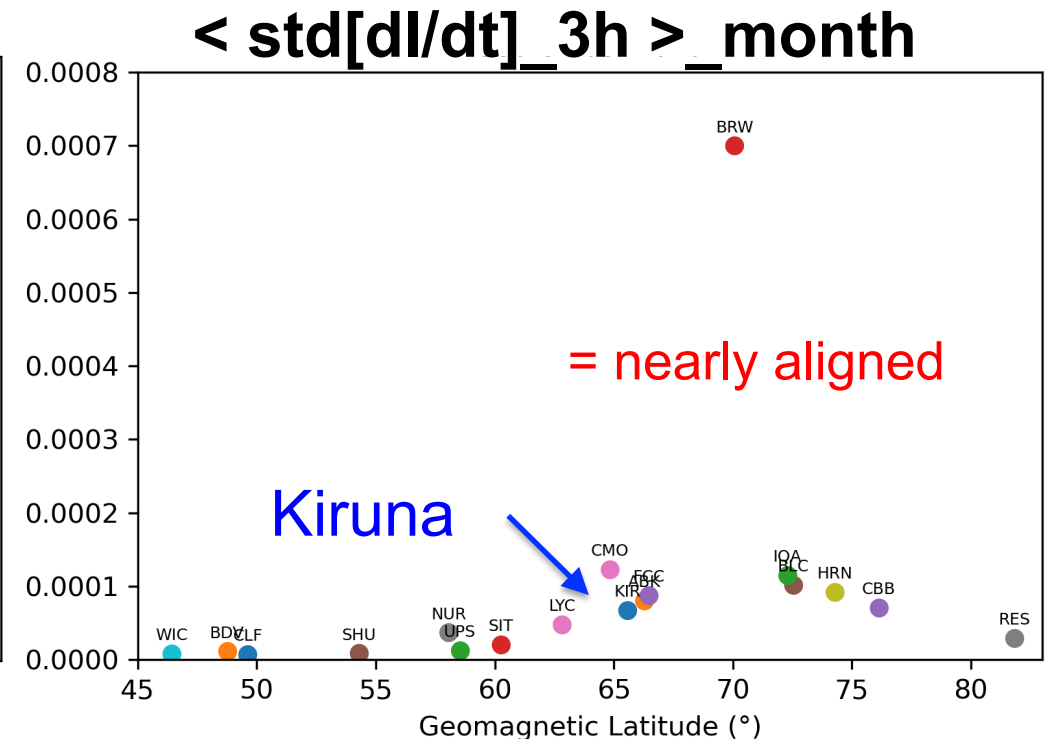


We calculate fluctuation of dB/dt

- a. 1-min average of |dB/dt|_1sec
- b. 3-hour standard deviation of |dB/dt|
- c. 1-month average of std(|dB/dt|)_3h

⇒ **Good fit with other stations**

The result is valid for both (DMI and DTU) magnetometers.



Mining effect?

Only if we make complicated analyses,
we can see mining effect

- 1-min average of $|dB/dt|_{1\text{sec}}$
- take Z/H ratio of this 1-min average
- 3-hour standard deviation of this ratio
- 1-month average of $\text{std}(\text{ratio})_{3h}$

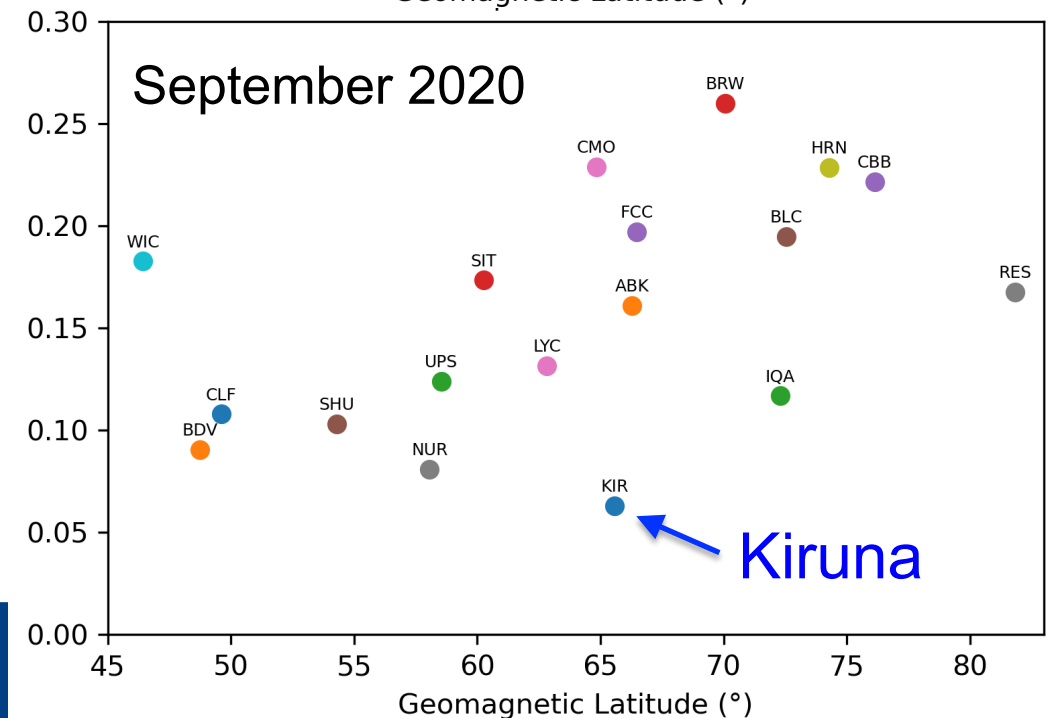
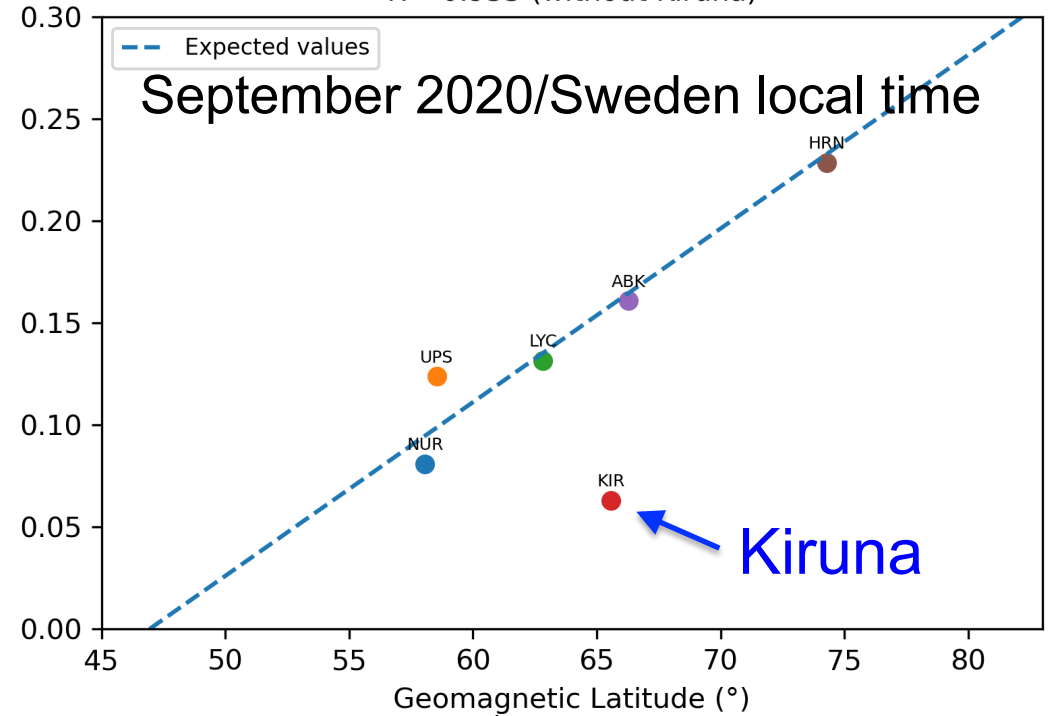
⇒ We finally see Kiruna anomaly

- dZ/dt is relatively small compared to dH/dt
- consistent with high conductivity.

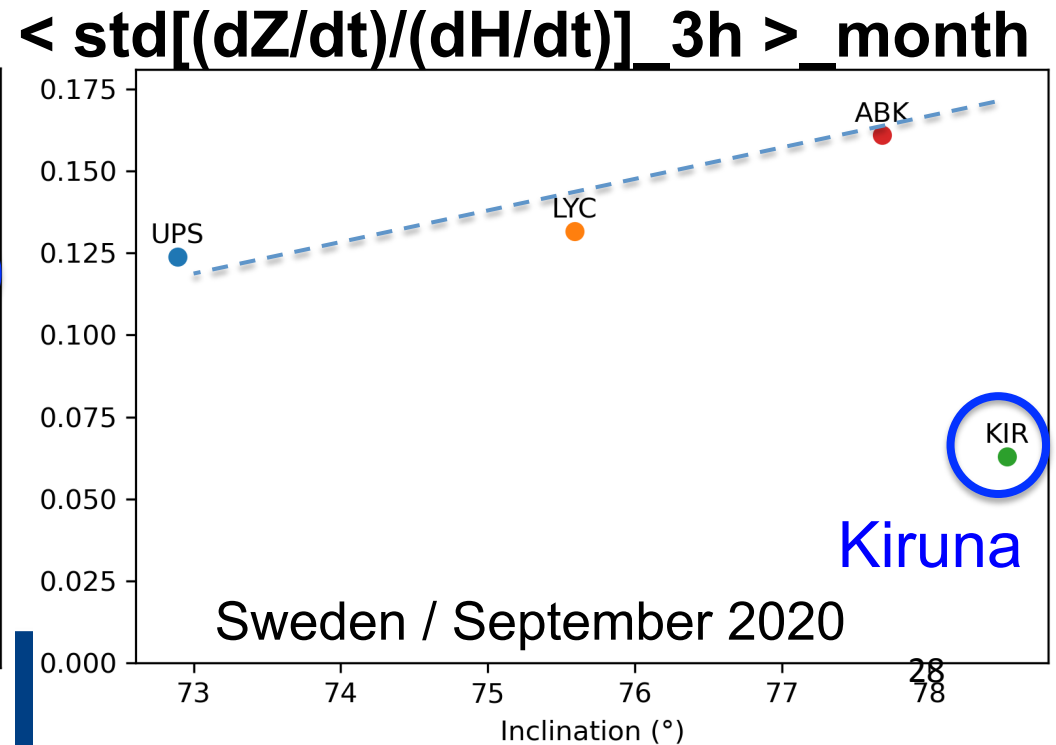
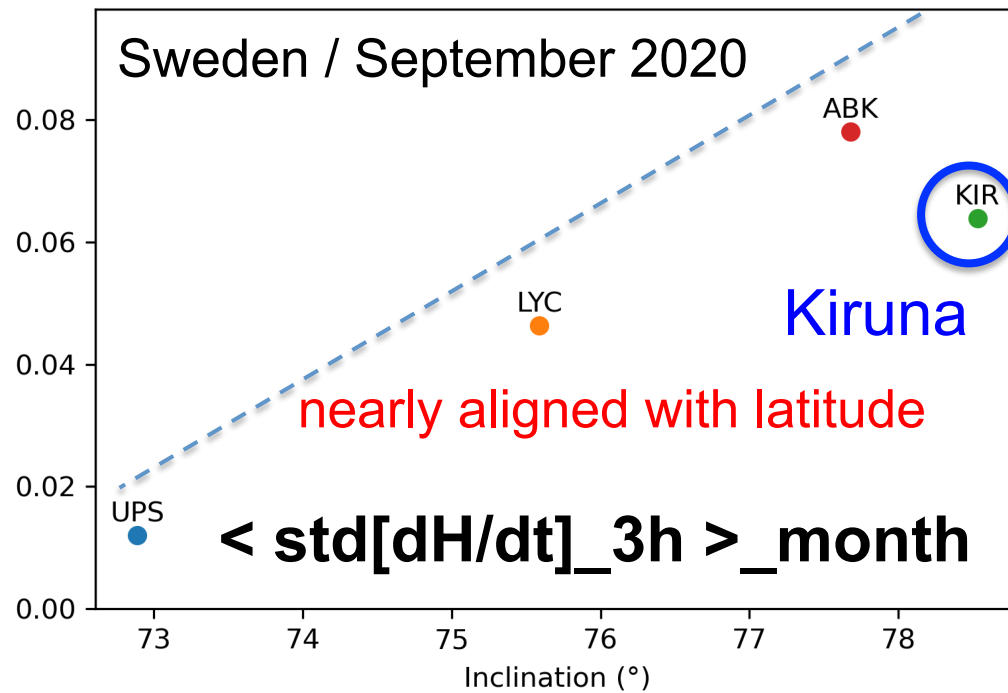
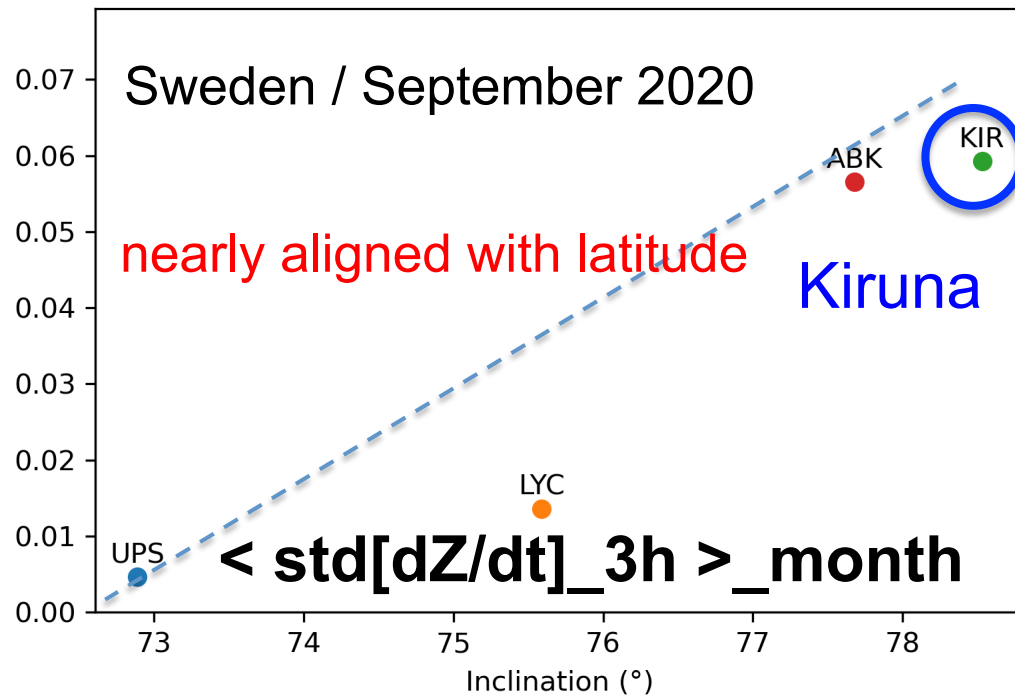
The result is again valid for both (DMI and DTU) magnetometers.

$\text{std}[|dZ/dt|/|dH/dt|]_{3h}$

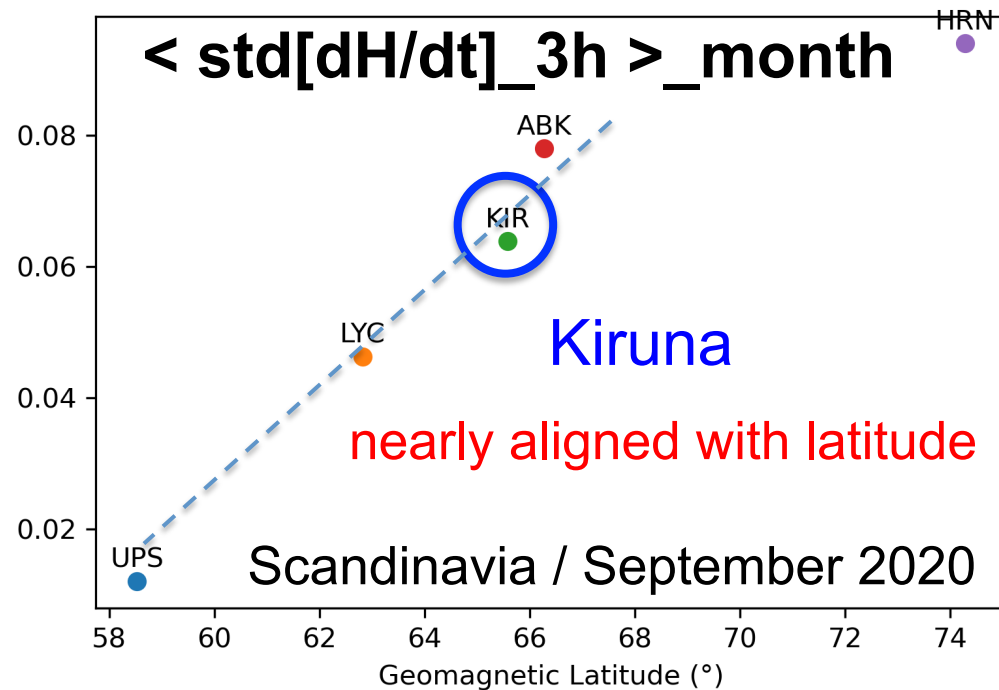
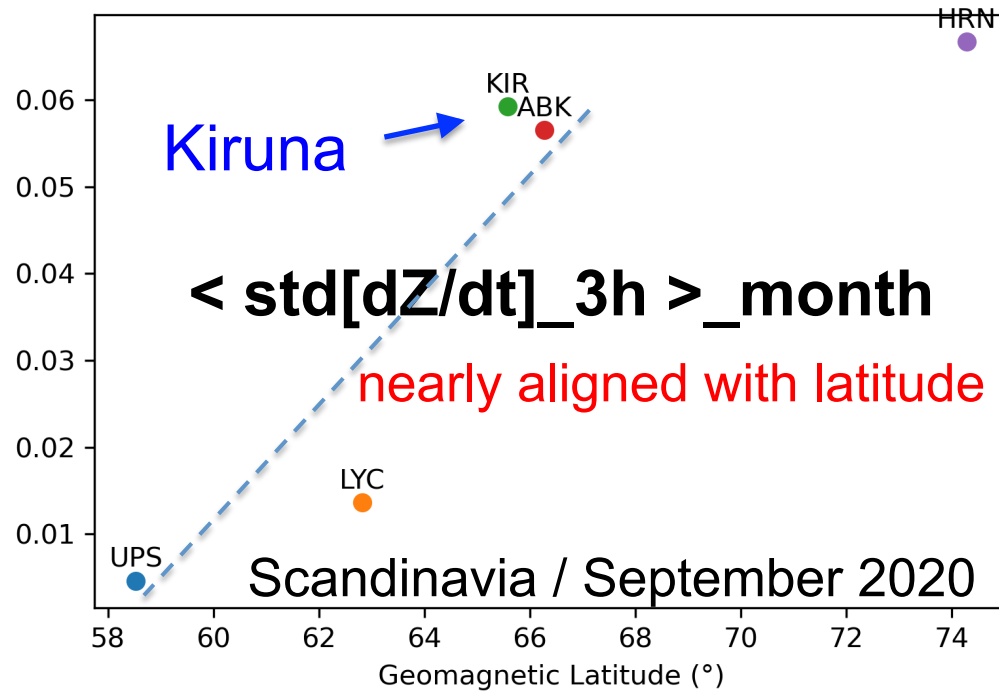
$R^2=0.933$ (without Kiruna)



Mining effect?



Mining effect?



< std[(dZ/dt)/(dH/dt)]_3h >_month

