Ionospheric ion response to the space weather event during 6-8 September 2017

A. Schillings[1,2], M. Yamauchi[1], H. Nilsson[1], T. Sergienko[1], C.-F. Enell[3], R. Slapak[3], P. Wintoft[1], M. Wik[1], M.G. Johnsen[4], I. Dandouras[5]

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4. Tromsø Geophysical Observatory (TGO), UiT the Arctic University of Norway, Tromsø, Norway,
5. IRAP, Université de Toulouse, CNRS, UPS, CNES, Toulouse, France

Outline

Paper I:

A. Schillings, H. Nilsson, R. Slapak, P. Wintoft, M. Yamauchi, M. Wik, I. Dandouras, and C. M. Carr

O^+ escape during the extreme space weather event of September 4–10, 2017, Submitted to Space Weather Special Issue, Apr. 2018

Paper II:

M. Yamauchi, T. Sergienko, C.-F. Enell, A. Schillings, R. Slapak, M. G. Johnsen, A. Tjulin, and H. Nilsson

Ionospheric ion response to the space weather event during 6-8 September 2017: EISCAT overview, Submitted to Space Weather Special Issue, May 2018

Advantages of September 2017 event

Cluster

- over cusp (only equinoxes)
- exactly at cusp when the 2nd ICME-shock arrived (multiple crossings of the cusp)

EISCAT/Norwegian magnetic chain

- near local noon when X9.3 flare occurred
- near local midnight when ICMEs arrived, first with IMF B_z northward, and next day with IMF B_z southward
- near local noon when only IMF changed from northward to < -15 nT
- many sudden southward turnings of IMF in the morning sector where the outflow flux is high

Paper I: O^+ escape during the extreme space weather event of September 4–10, 2017

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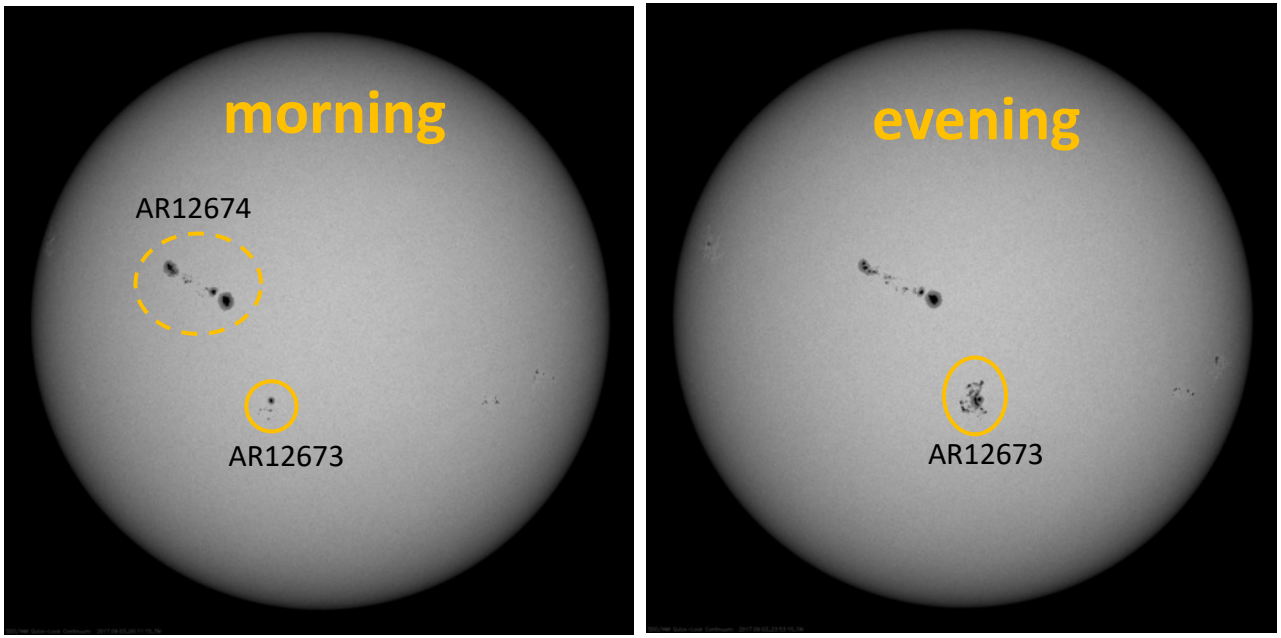
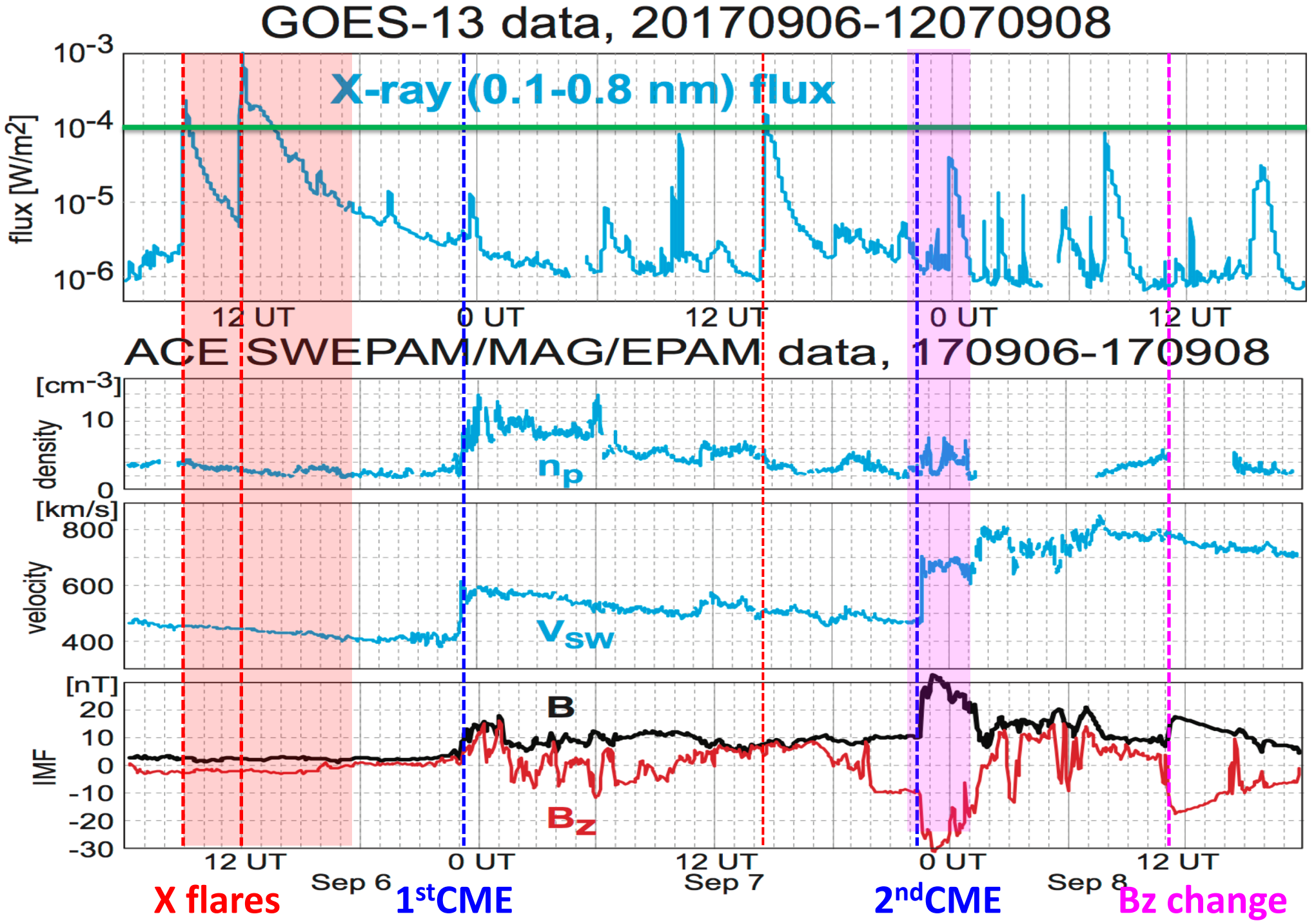
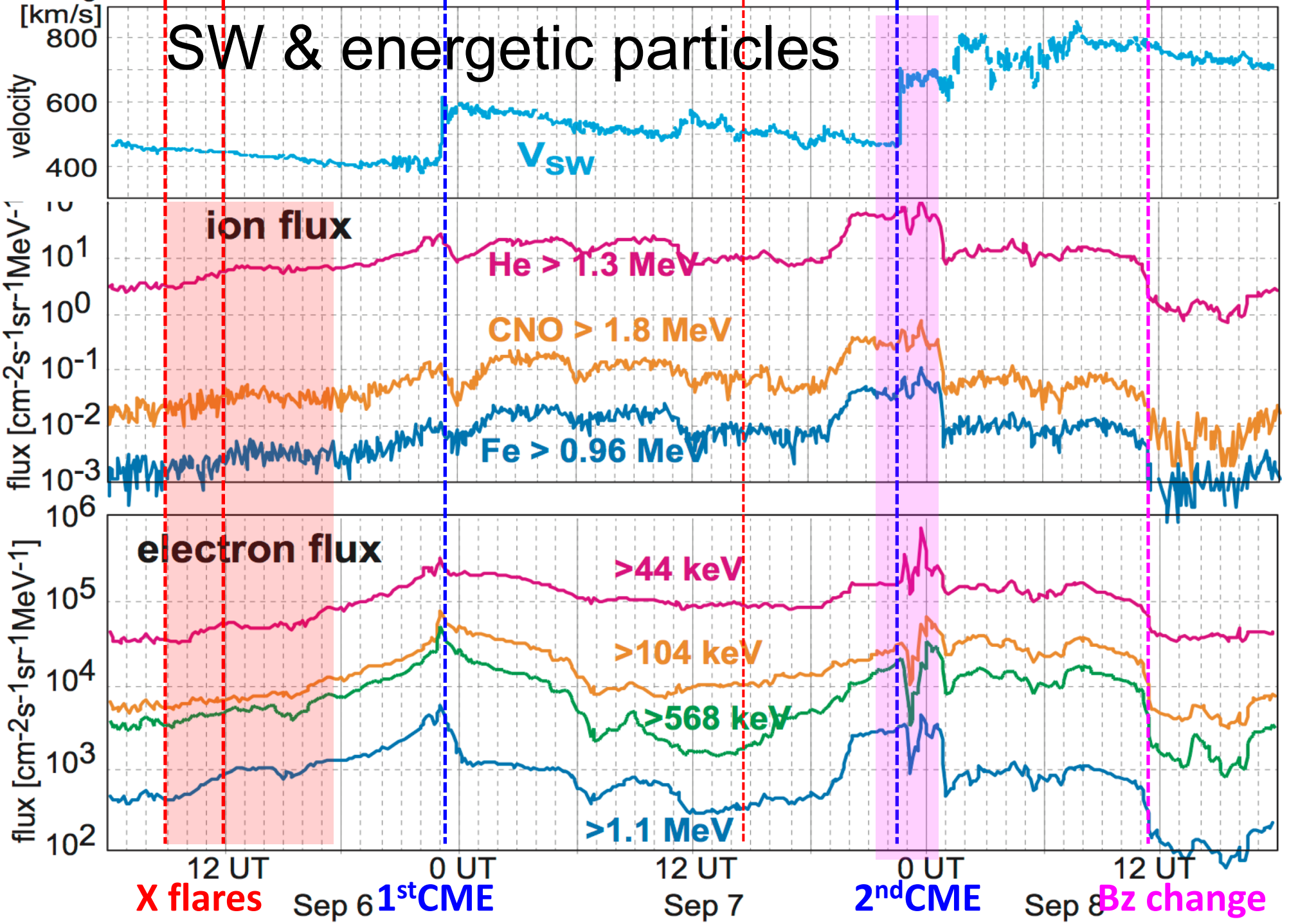
6. Imperial College, London, UK.

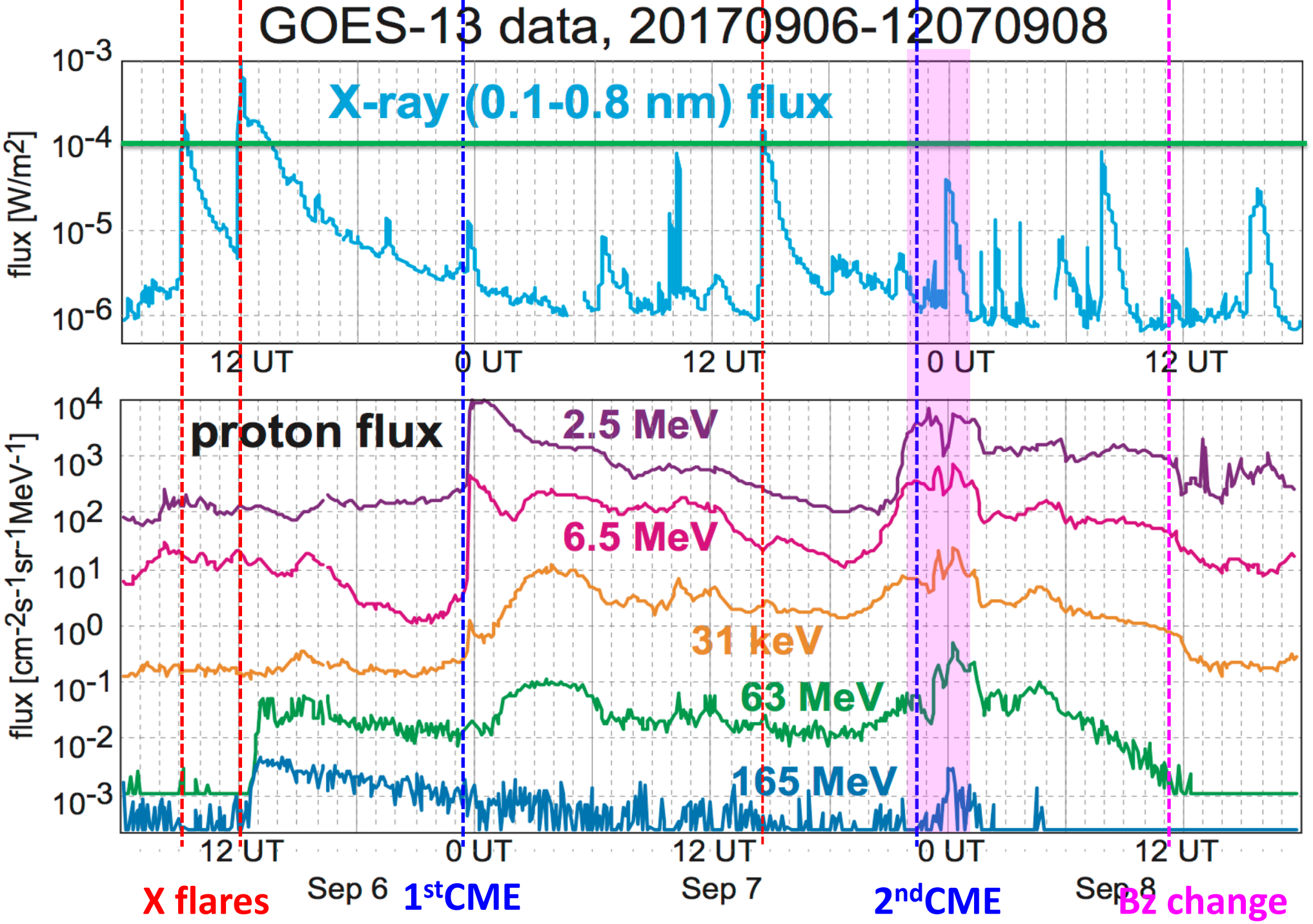
Solar and solar wind parameters

- Observations by Solar Dynamic Observatory (SDO)
- Active region **AR12673** increased significantly from morning to evening of Sep 3, 2017



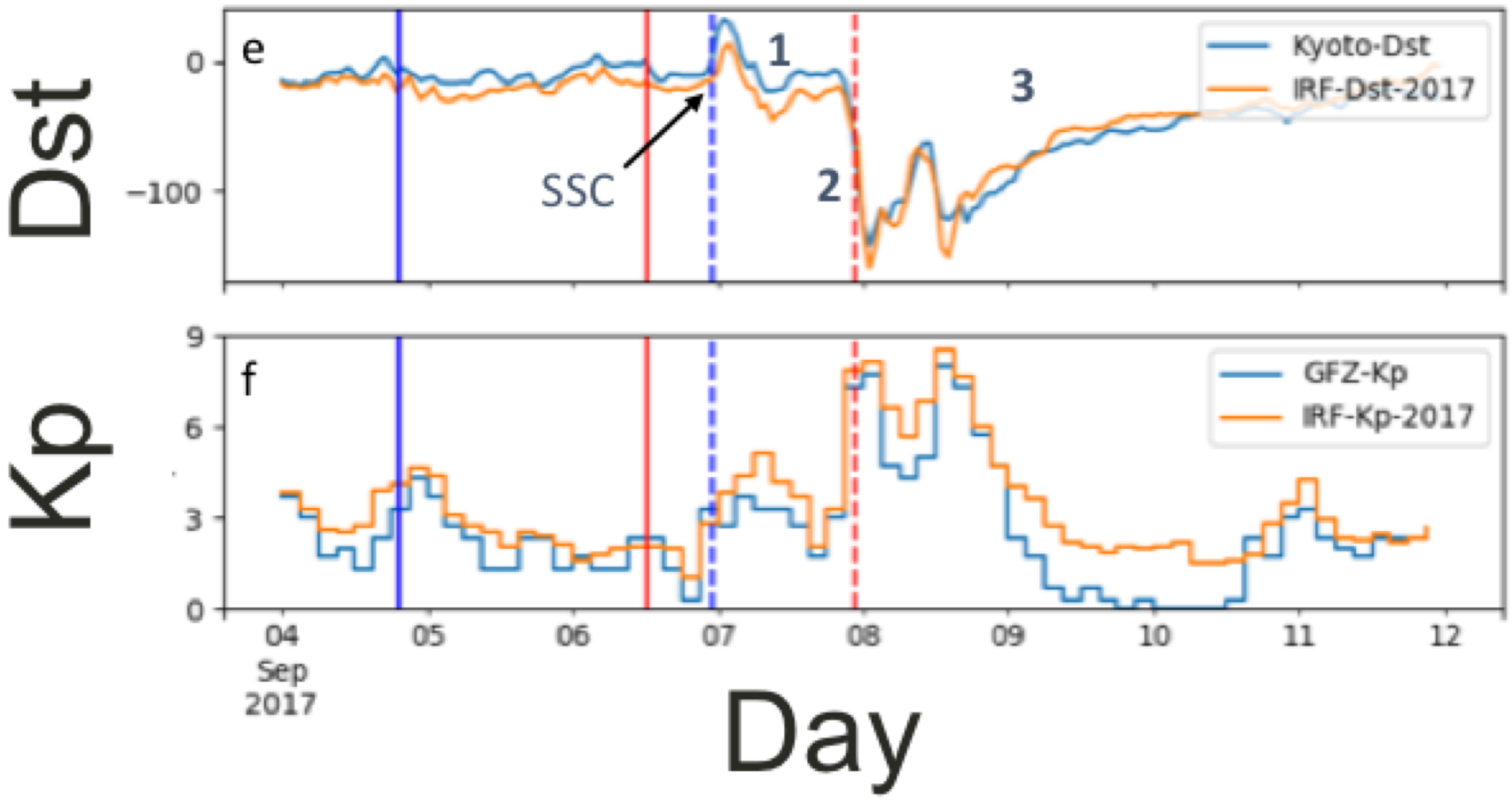

GOES-13 data, 20170906-12070908
X-ray (0.1-0.8 nm) flux
flux [W/m2]
10-3
10-4
10-5
10-6
12 UT
0 UT
12 UT
0 UT
12 UT
ACE SWEPAM/MAG/EPAM data, 170906-170908
[cm-3]
density
10
0
np
[km/s]
velocity
800
600
400
vsw
[nT]
IMF
20
10
0
-10
-20
-30
B
Bz
12 UT
0 UT
12 UT
0 UT
12 UT
Sep 6
Sep 7
Sep 8
X flares
1stCME
2ndCME
Bz change

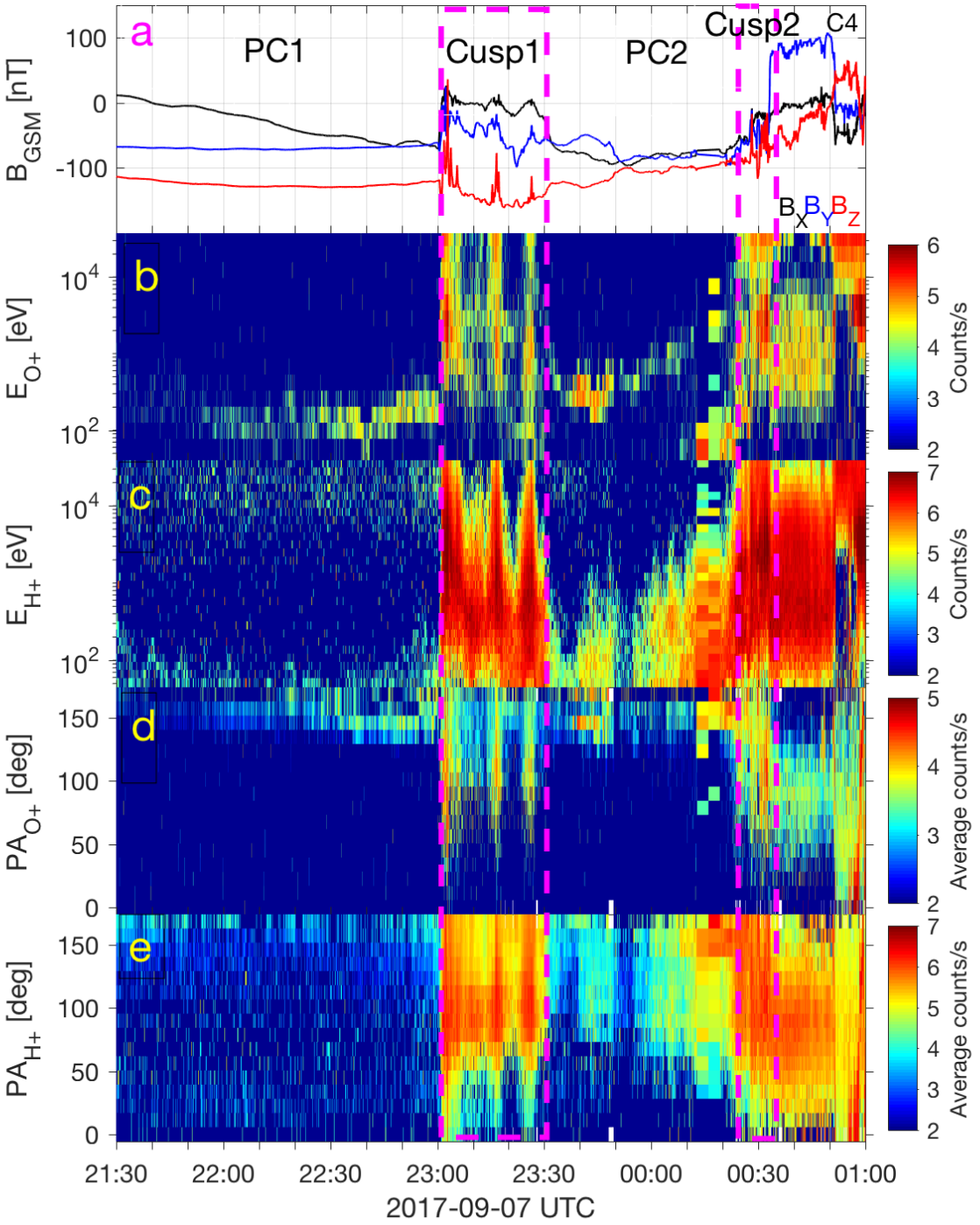

SW & energetic particles
[km/s]
800
600
400
velocity
V_{SW}
ion flux
flux [cm^{-2}s^{-1}sr^{-1}MeV^{-1}]
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
He > 1.3 MeV
CNO > 1.8 MeV
Fe > 0.96 MeV
electron flux
flux [cm^{-2}s^{-1}sr^{-1}MeV^{-1}]
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
>44 keV
>104 keV
>568 keV
>1.1 MeV
12 UT
0 UT
12 UT
0 UT
12 UT
Sep 6
Sep 7
Sep 8
X flares
1st CME
2nd CME
Bz change


GOES-13 data, 20170906-12070908
X-ray (0.1-0.8 nm) flux
flux [W/m2]
10-3
10-4
10-5
10-6
12 UT
0 UT
12 UT
0 UT
12 UT
proton flux
2.5 MeV
6.5 MeV
31 keV
63 MeV
165 MeV
flux [cm-2s-1sr-1MeV-1]
10-3
10-2
10-1
100
101
102
103
104
12 UT
0 UT
12 UT
0 UT
12 UT
Sep 6
Sep 7
Sep 8
X flares
1stCME
2ndCME
Bz change

Magnetic indices

Kp=8+ Dst = -142 nT



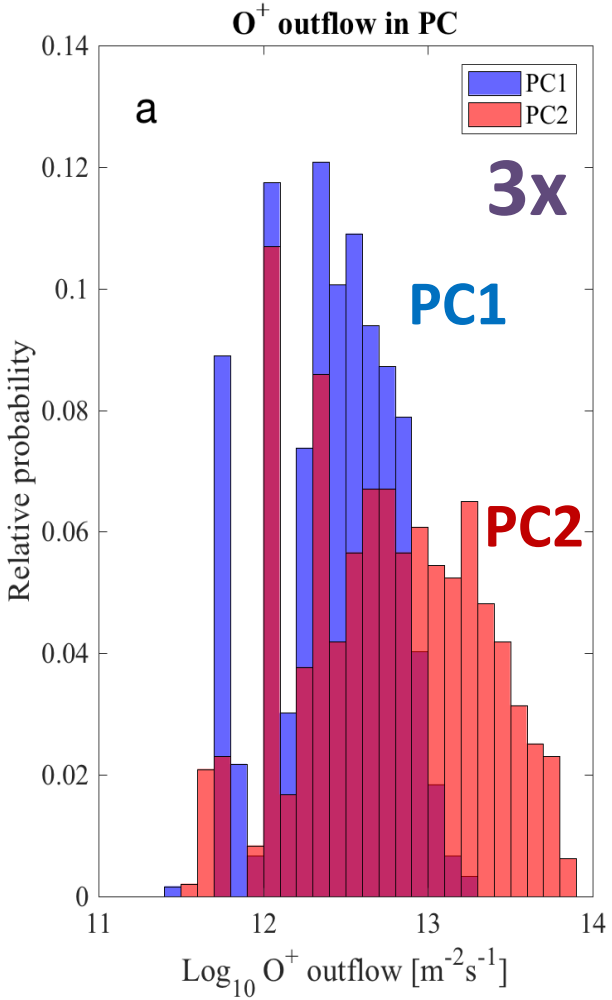


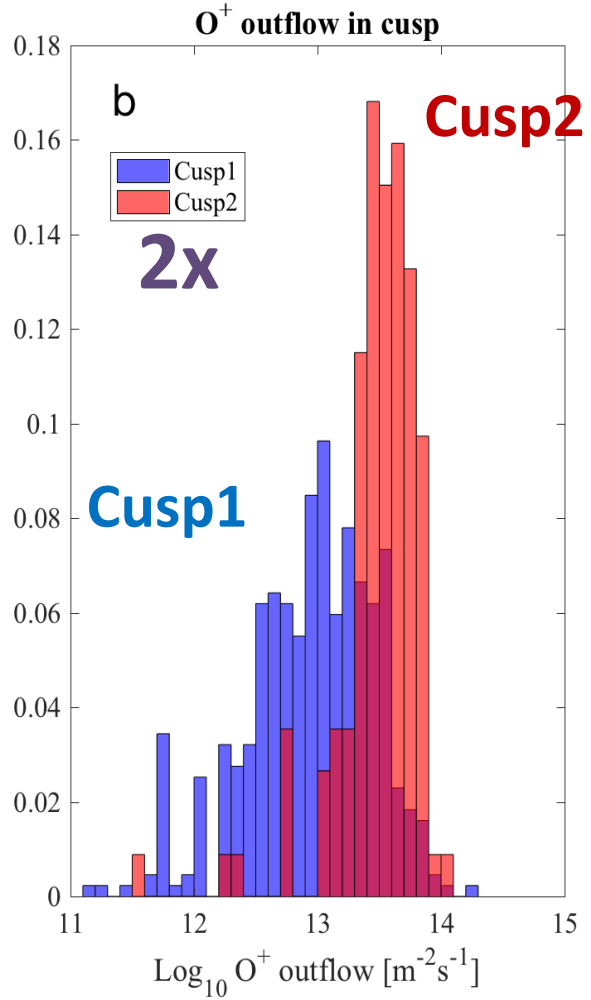
Cluster observations

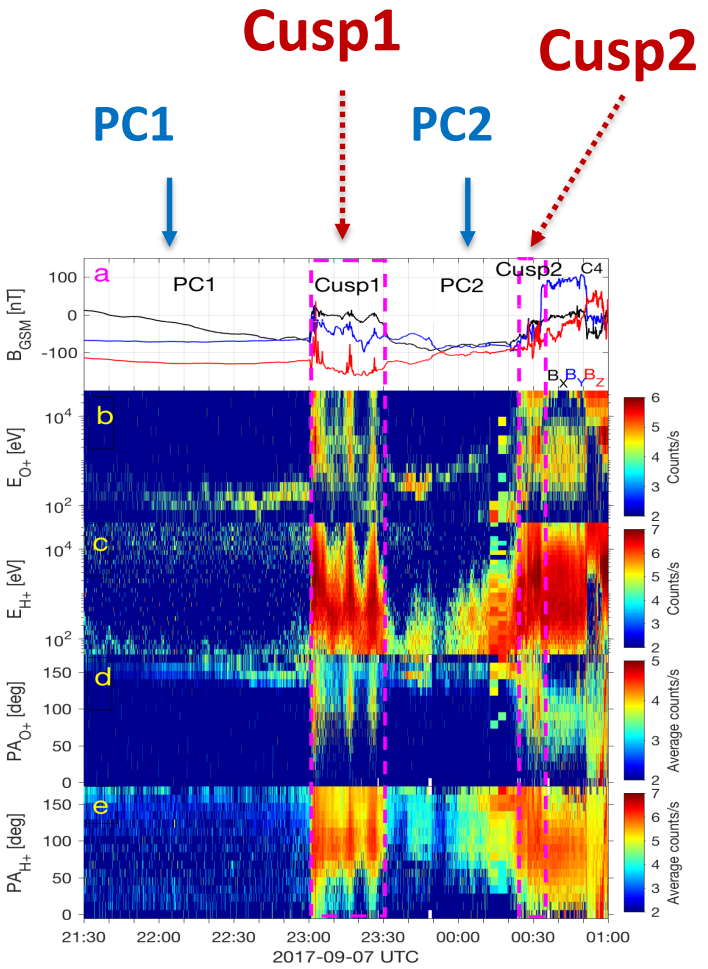
- Multiple crossings of the northern polar cap and cusp during the main phase
- Moving of the cusp corresponds to the 2nd ICME-shock arrival

Cluster observations

07 - 08 Sep 2017 21:30 – 01:00 UT

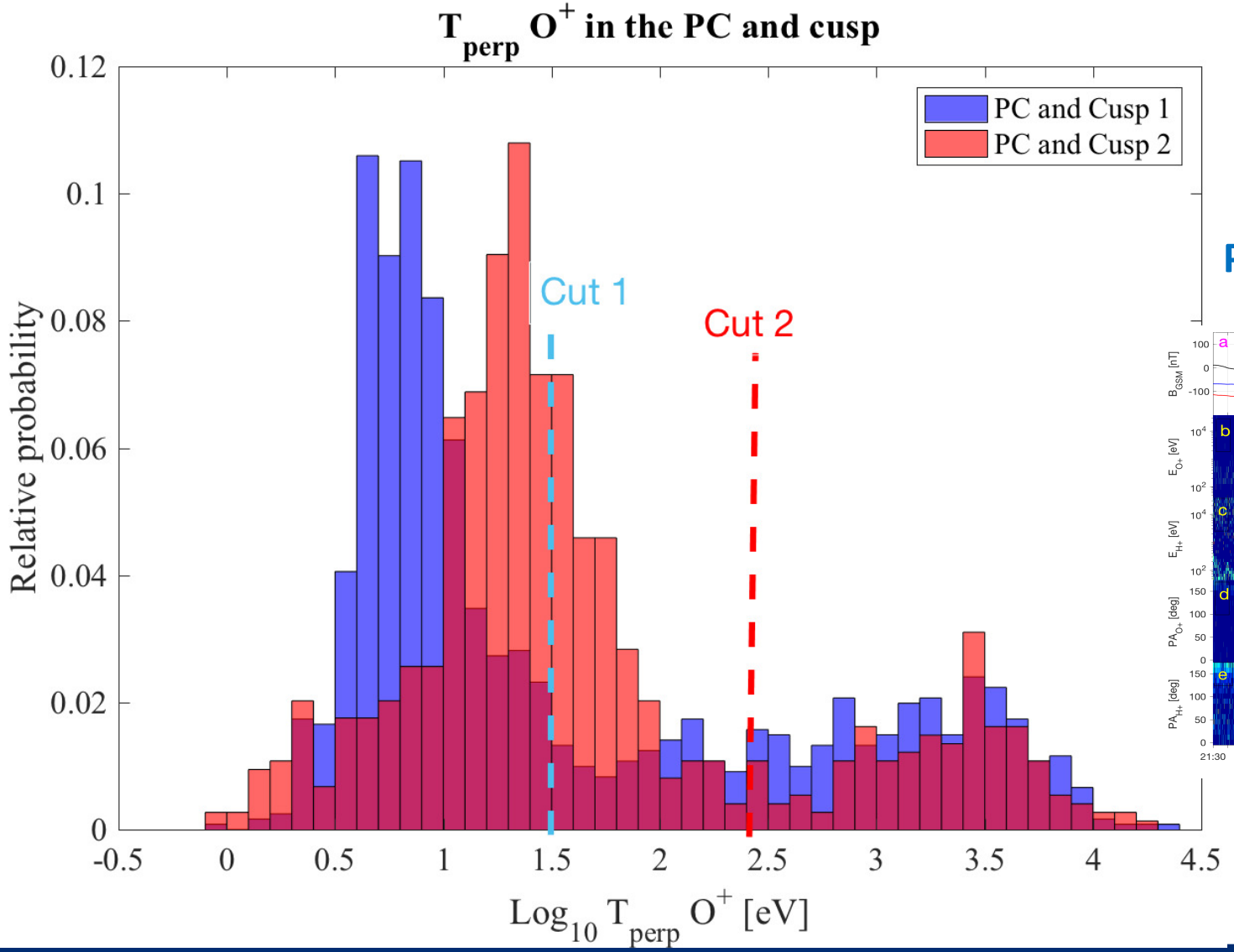


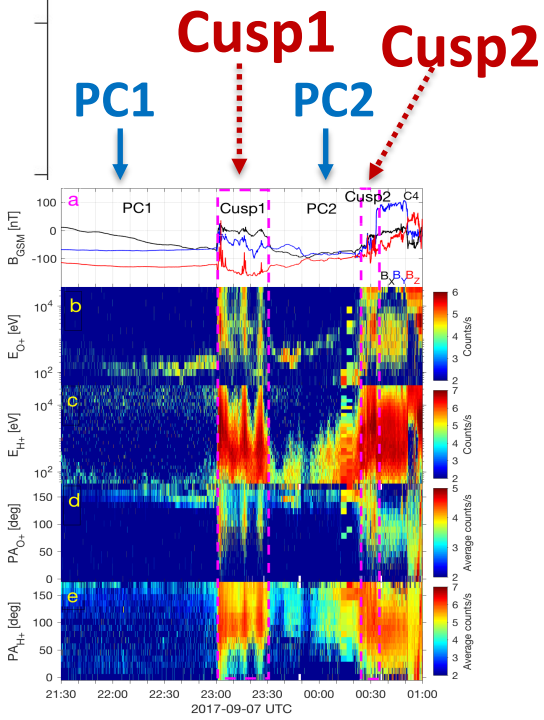




Cluster observations

07 - 08 Sep 2017 21:30 – 01:00 UT





12

Conclusions Paper I

1. Factor 2 and 3 increase in the polar cap and cusp respectively
2. These ions will eventually escape into interplanetary space.
3. Fast magnetosphere's response to the 2nd ICME (~ 40 minutes).
4. The upper limit of the ionospheric O^+ outflow is 6.3 x 10^{13} and 7.9 x 10^{13} $m^{-2}s^{-1}$ in the polar cap and cusp respectively.

Paper II: Ionospheric ion response to the space weather event during 6-8 September 2017: **EISCAT overview**

M. Yamauchi[1], T. Sergienko[1], C.-F. Enell[2], A. Schillings[1,2], R. Slapak[2], M. G. Johnsen[4], A. Tjulin[2], and H. Nilsson[1]

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4. Tromsø Geophysical Observatory (TGO), Tromsø, Norway

Scandinavia was at right location

X9.3 flare at near local noon (increase ionization rate)

- EISCAT can see most direct effect in Ne, Te, Ti, Vi
- IMAGE magnetometer chain can see Sq current

ICME/SEP-like event arrivals at midnight in consecutive days (substorm?)

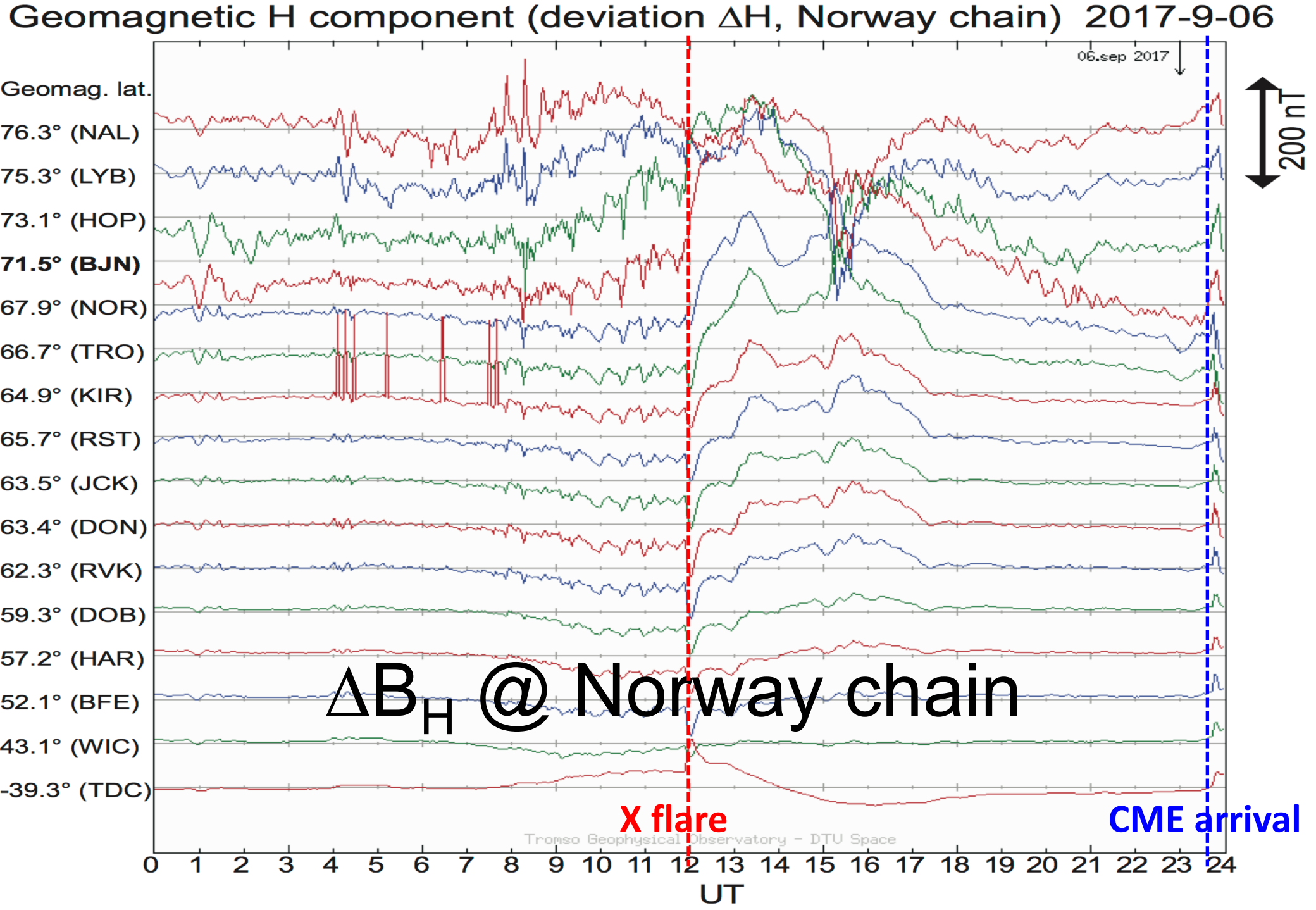
- EISCAT/IMAGE chain can monitor nightside activity
- EISCAT/IMAGE chain can separate effects of northward IMF (on 6 Sep) and southward IMF (on 7 Sep)
- SEP-like event = gradual, but ICME/GOES proton event is sudden.

IMF turning to strongly southward IMF at near local noon (cusp change)

- EISCAT can monitor direct consequence in Vi by the shift of cusp (monitored by Ne and Te).

Event list #1

day 2017	arrival UT	event	IMF Bz
6 Sep.	~09:00	**X2.2 flare**	< 0 nT
6 Sep.	~11:55	**X9.3 flare**	< 0 nT
6 Sep.	~18 UT	**X-ray < M-class**	~0 nT (B ~ 3 nT)
6 Sep.	~20 UT ~22 UT	SEP-like enhancement Its sharp increase	0 nT (B ~ 3 nT)
6 Sep.	~23:50	**ICME**	> 5 nT (change from near zero)
7 Sep.	~02:25 – 10:45	many Bz changes to < - 5 nT and < 0	< -5 nT
7 Sep.	~14:30	**(X1.3 flare)**	positive
7 Sep.	~20:45	Bz change to < 0	< -8 nT
7 Sep.	~23:10	**ICME**	< -25 nT (enhanced from -9 nT)
8 Sep.	~02:35 – 07:10	many Bz changes betwenn < - and > 0	positive
8 Sep.	~11:20	Bz change to < 0	< -5 nT (later -17 nT)



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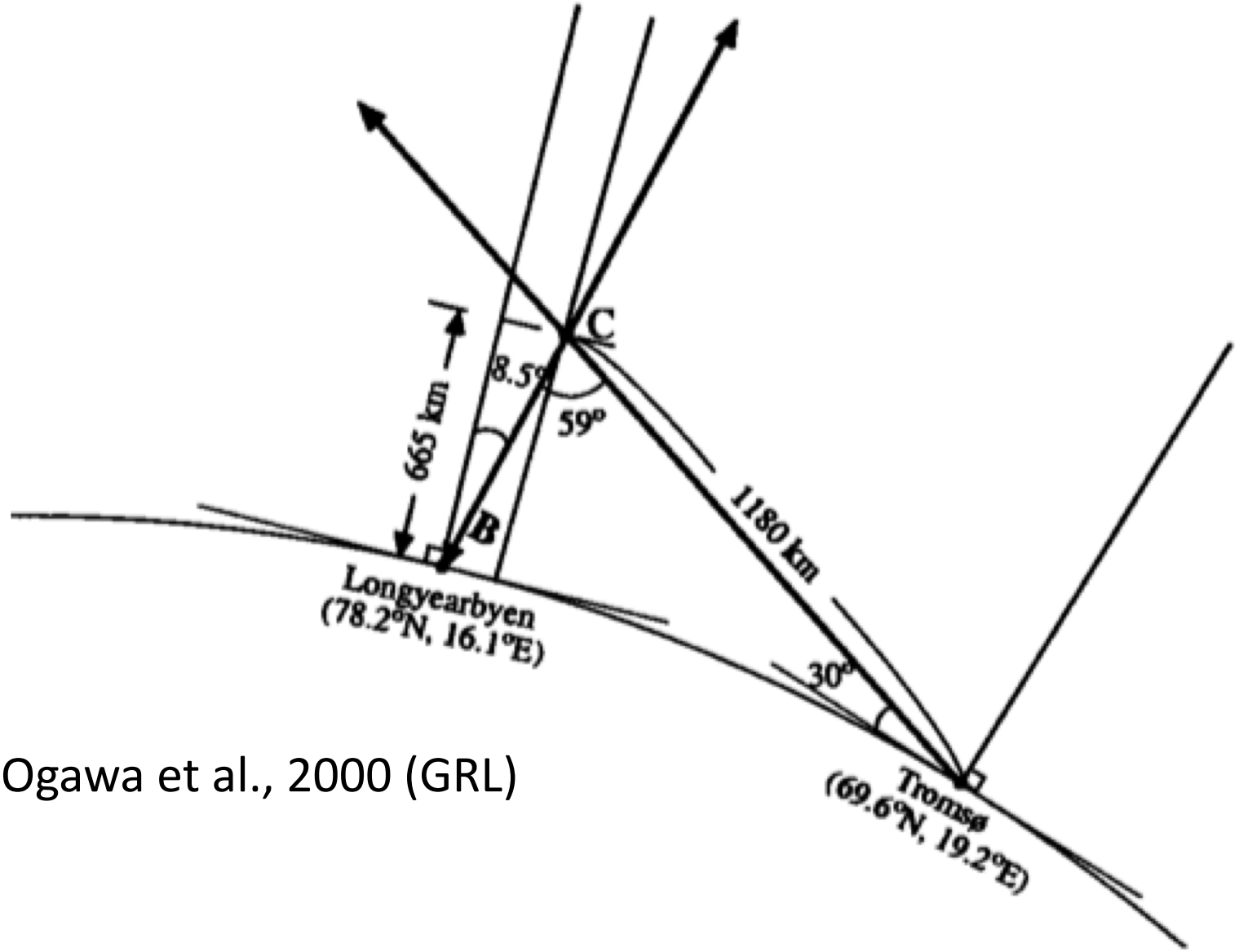
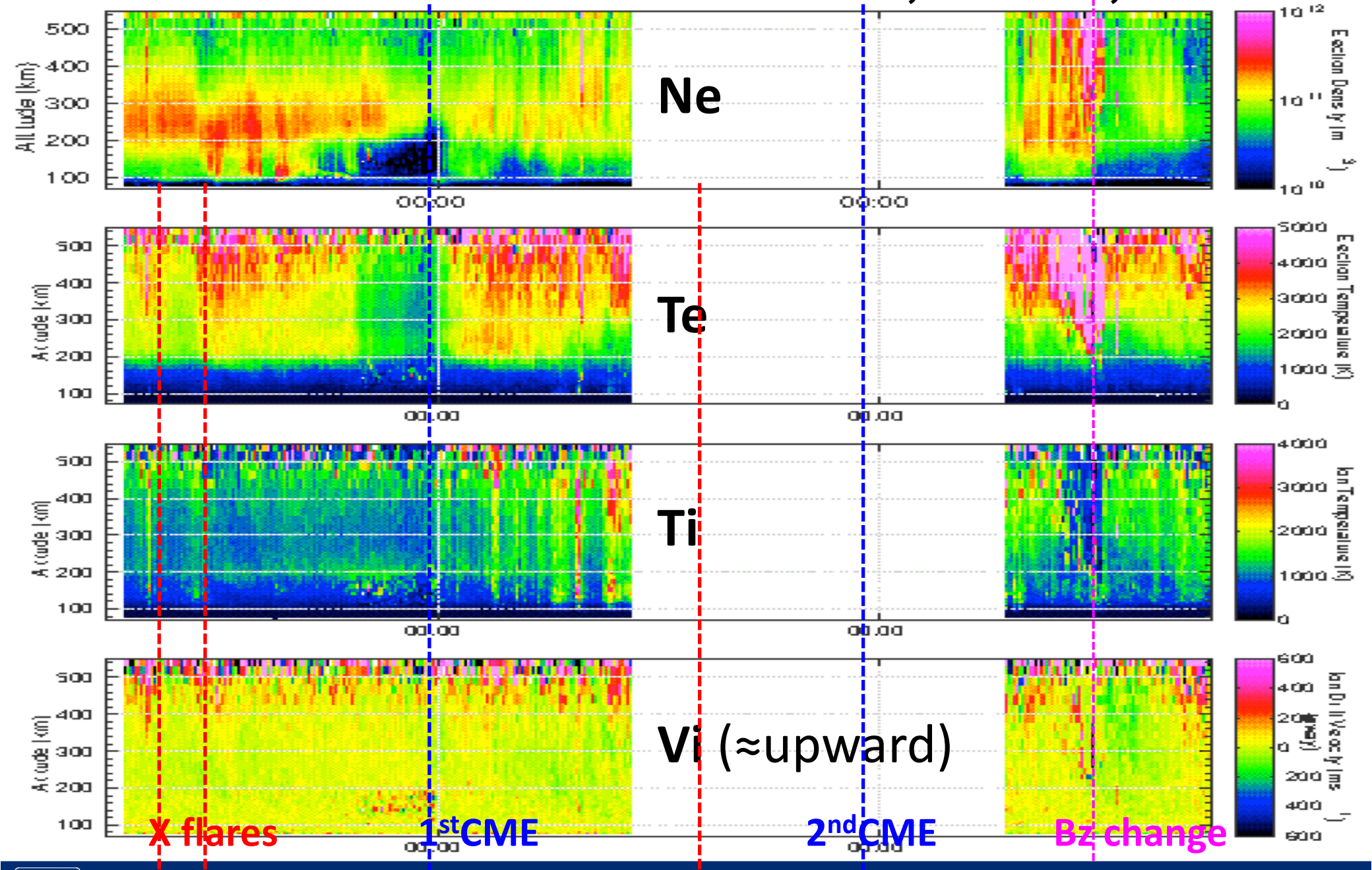
Kiruna, Sweden

EISCAT geometry

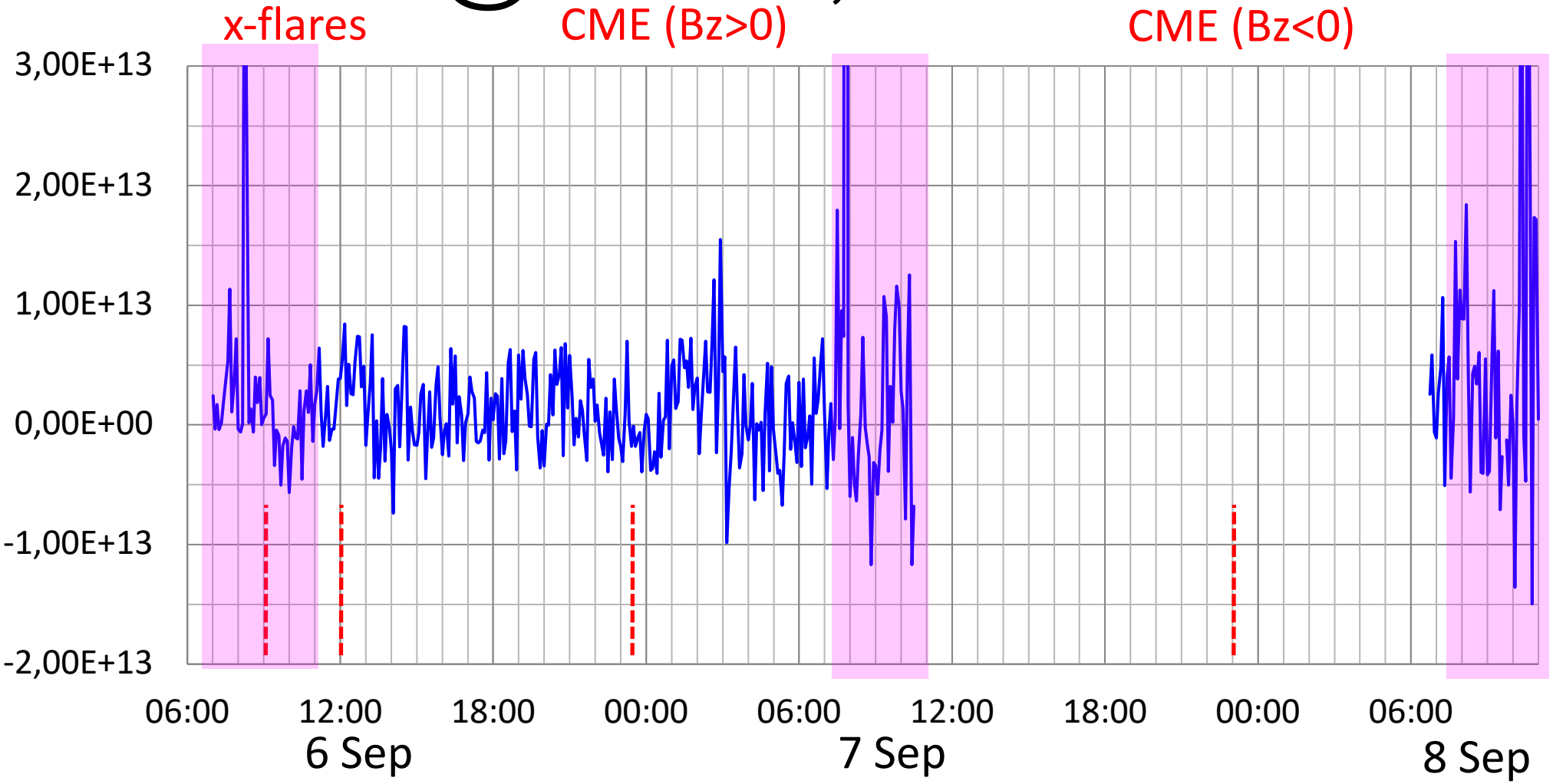


Ogawa et al., 2000 (GRL)

Svalbard 42m: 2018-9-6, 6 UT; +60h

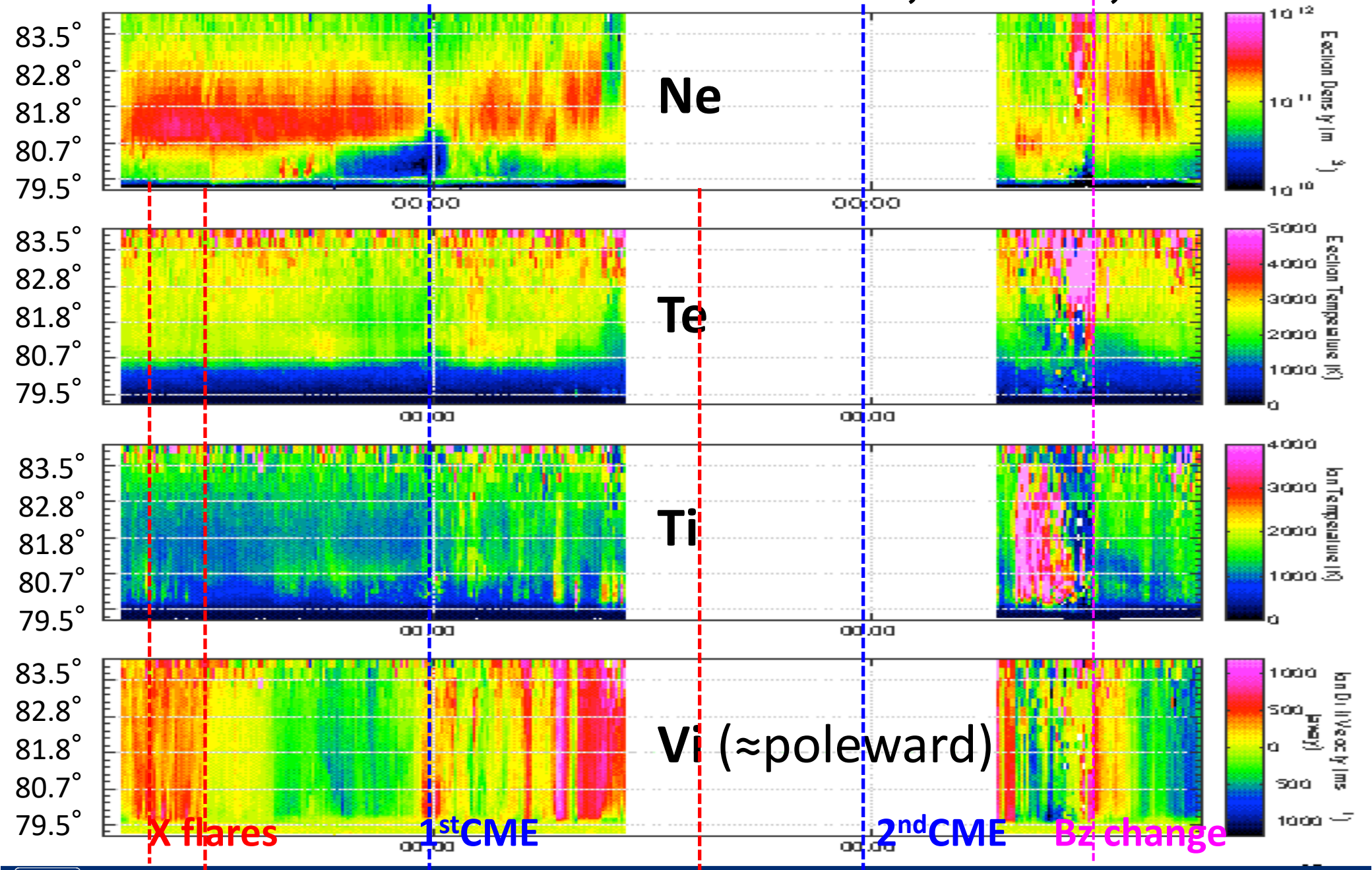


nv@400 km, overview

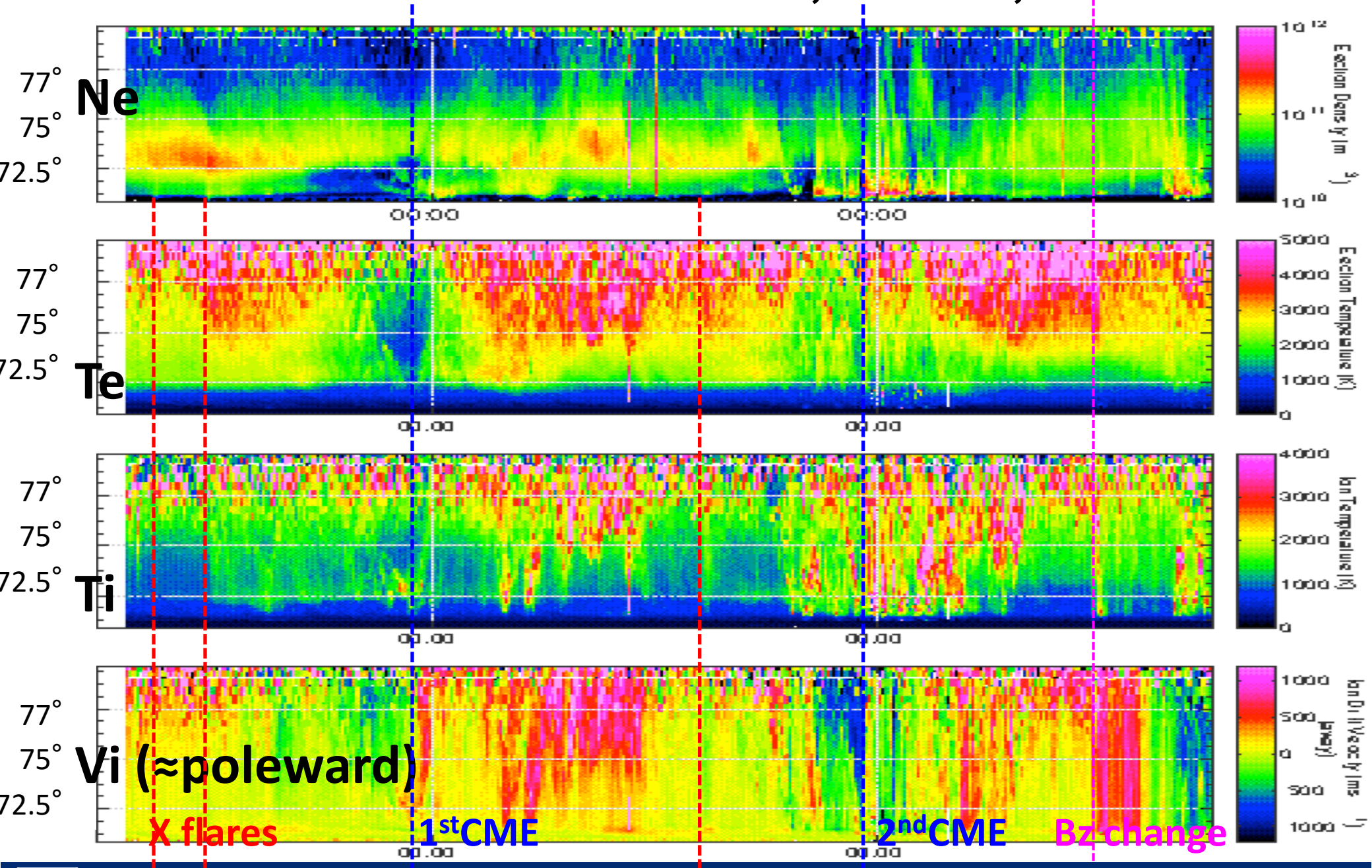


- **No outstanding change directly after X flare**
- **Effect of ICME is difficult to see because it is midnight sector**
- **Yet, upflow flux reached $10^{13}s^{-1}m^{-2}$ more often($8^{th} > 7^{th} > 6^{th}$) = increase**

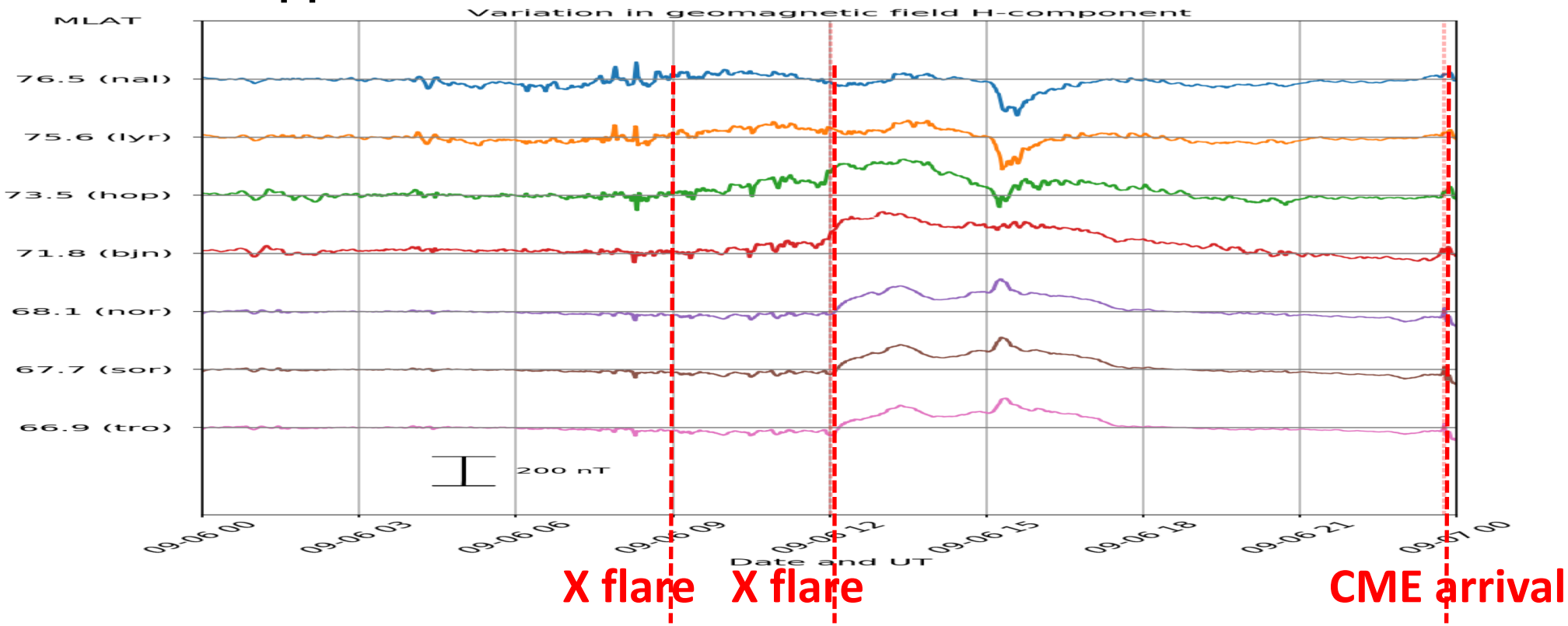
Svalbard 32m: 2018-9-6, 6 UT; +60h



Tromsø : 2018-9-6, 6 UT; +60h



ΔB_H @ Norway chain, 2017-9-6

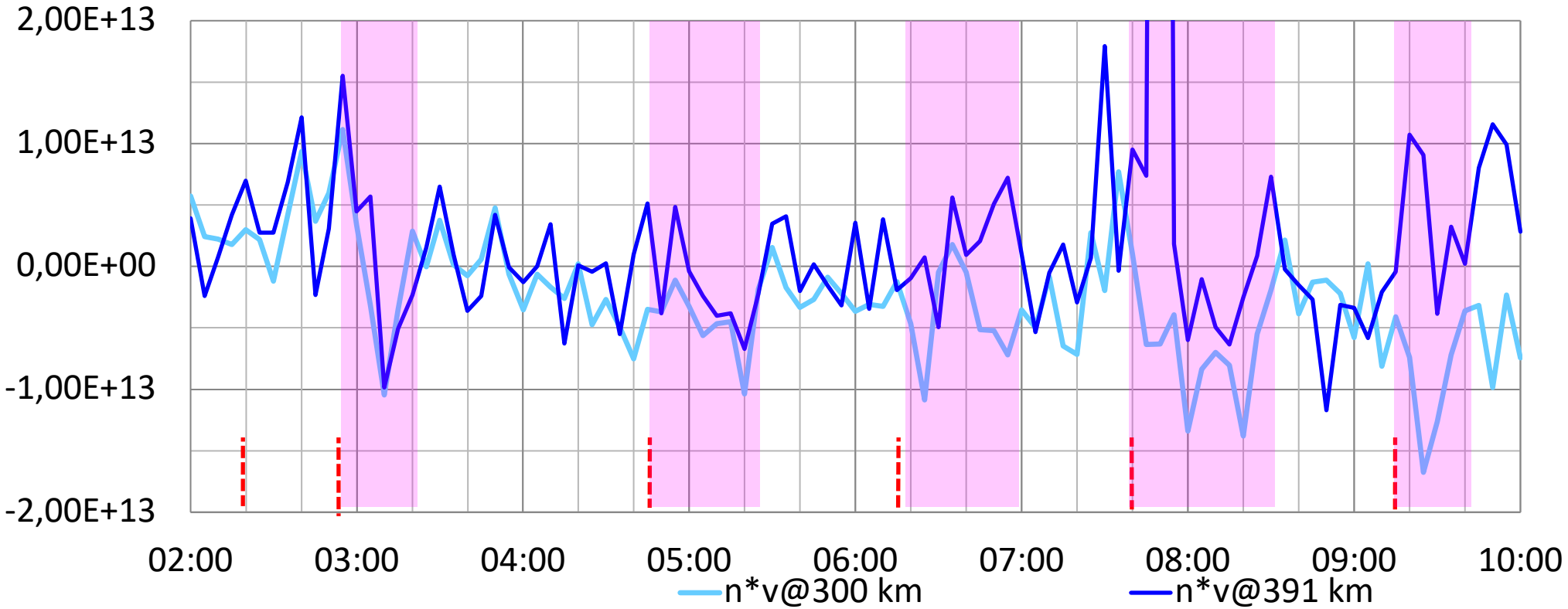


- **Density (Ne) spike @<200 km, at the time of X flare**
- **Temperature increase after X flare (pre-condition for outflow)**
- **Sq current drastically increase after X flare (enough Joule heating)**
- **Auroral-like activity before CME without ΔB_H (IMF was weak, Bz>0)**
  $\Rightarrow$ only SEP-like event can trigger such activity
- **CME triggered strong Sunward convection at mitnight to morning**

Event list #2

day 2017	arrival UT	event	IMF Bz
7 Sep.	~02:25	Bz change	< -5 nT
7 Sep.	~03:00	Bz change	< -5 nT
7 Sep.	~04:50	Bz change	< -5 nT
7 Sep.	~06:20	Bz change	< -5 nT
7 Sep.	~07:40	Bz change	< -5 nT
7 Sep.	~09:15	Bz change	< -5 nT
7 Sep.	~10:45	Bz change	positive
8 Sep.	~02:35	Bz change	positive
8 Sep.	~03:30	Bz change	< -5 nT
8 Sep.	~04:10	Bz change	positive (> 10 nT)
8 Sep.	~06:00	Bz change	< -5 nT
8 Sep.	~07:10	Bz change	positive

nv@400 km, 2017-9-7



---------- Quick turning to Bz<-5 nT

- **Downward ion flow @ 300 km when IMF turning to Bz < -5 nT**
- **Upward ion flow @ 400 km when IMF turning to Bz < -5nT ???**

  ⇒ **Need more timing analyses**

2017-9-8

- **Cusp moved southward of radar, reducing upflow**

⇒ Svalvard radar should see this "out of cusp" effect in upflow statistics

Discussion

- **Effect of ICME or SEP-like event?**

- EISCAT see strong sunward convection at midnight
- Morning upflow hours later increased = consistent with Cluster
- However, cause is not clear between ICME and SEP-like event

- **Does IMF Bz<0 really increase outflow if substorm effect is removed?**

- Outflow flux for Bz<0 is only twice for Bz>0
- But outflow flux depend on Kp exponentially

⇒ Bz>0 might favor outflow if only dayside effect is considered.

Summary of EISCAT observation

- **Effect of X-flares**
- No outstanding increase of upflow directly after X-flare
- Density (Ne) spike @<200 km, at the time of X-flare
- Temperature and Sq current increased directly after X-flare

  $\Rightarrow$ **pre-condition for outflow rather than direct increase of outflow**

- **Effect of ICME or SEP-like event?**
- Consistent with Cluster observation of increase of outflow dayside
- However, we cannot distinguish if this is due to ICME or SEP-like event
- substorm-like motion of auroral arc before ICME $\Rightarrow$ SEP is the cause?

- **Sudden turning to IMF Bz<0**
- It is not clear if southward IMF triggers more outflow in morning
- Outflow region becomes outside EISCAT field-if-view for southward IMF

  $\Rightarrow$ Bz>0 might favor outflow if only dayside effect is considered.

Thank you