Multi-Point Geostationary Observations of Major 2024 Space Weather Events : Data from GK2A, Himawari-9, GOES-16 and -18

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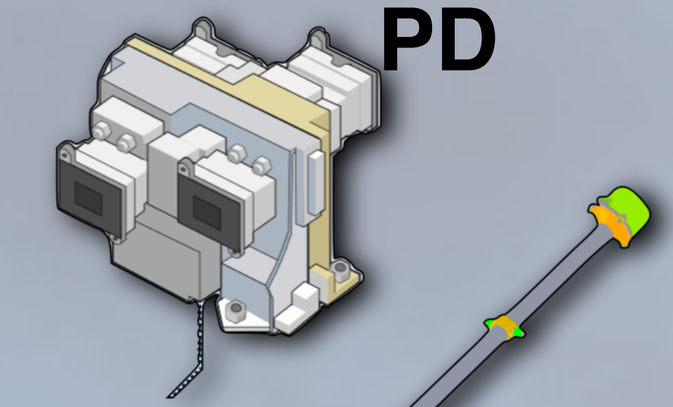
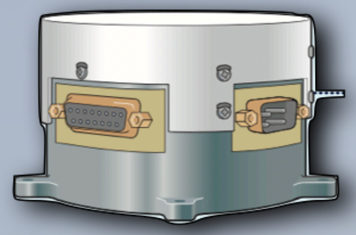
2025-03-17

Korean Space Weather Monitor on GK2A: KSEM

KSEM





Sensor	Parameter	Specification
PD	Energy range	e: 100 keV - 3.8 p: 77 keV - 6 MeV
	Energy resolution	$\Delta E/E \leq 0.2\%$
	View direction	6 directions
MG	Accuracy	≤ 1 nT
	Boom length	1 m
CM	Range	±3 pA/cm^2
	Accuracy	≤ 0.01 pA/cm^2

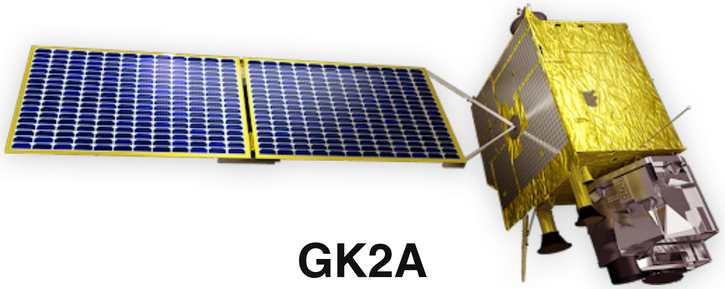
GK2A

GK2A provides multiple continuous measurements of space weather over the eastern hemisphere

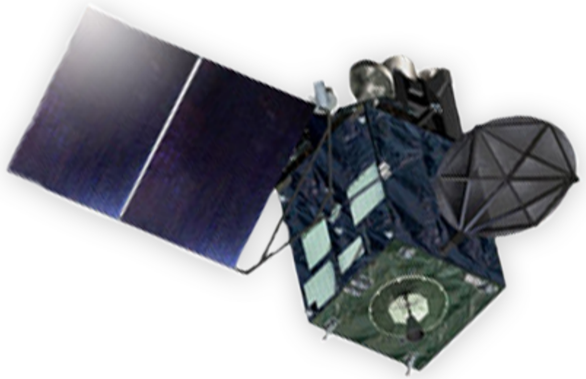
Multi-Point Simultaneous Observations in Space Weather Events

Importance of Multi-Point Simultaneous Observations and Comparative Studies in Space Weather Events

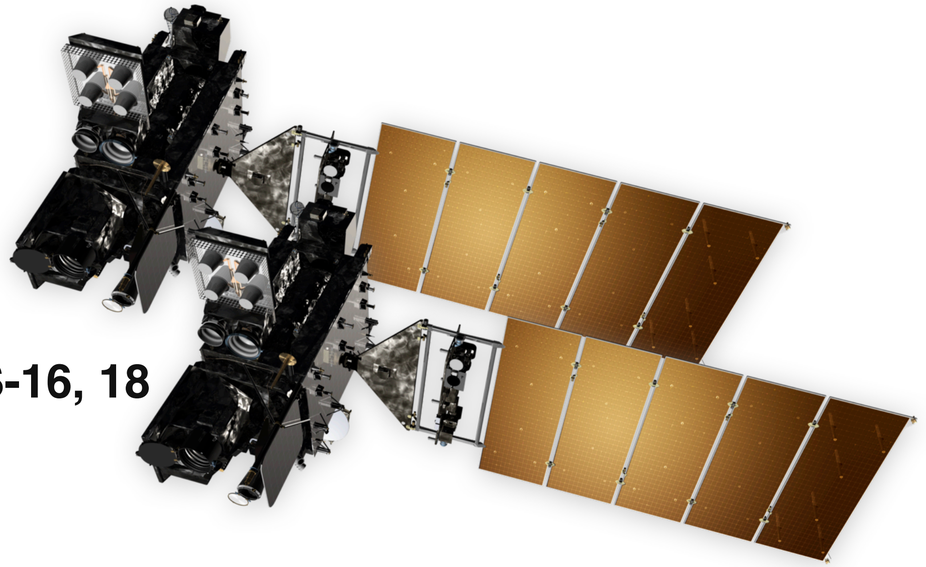
- The Earth's magnetosphere is continuously influenced by the solar wind with sudden magnetospheric disturbances.
- During extreme space weather events, the magnetopause undergoes compression and restructuring, causing GEO satellites to transition between the magnetosphere and interplanetary space
- GK2A, Himawari-9, GOES-16, and GOES-18 provide simultaneous multi-point observations from different locations, allowing for a comprehensive analysis of global magnetospheric dynamics.
- In this time, we utilizes multi-point simultaneous observations from major space weather events in May and October 2024 to compare and analyze effects of magnetopause compression on magnetic field and electron flux measurements.



GK2A

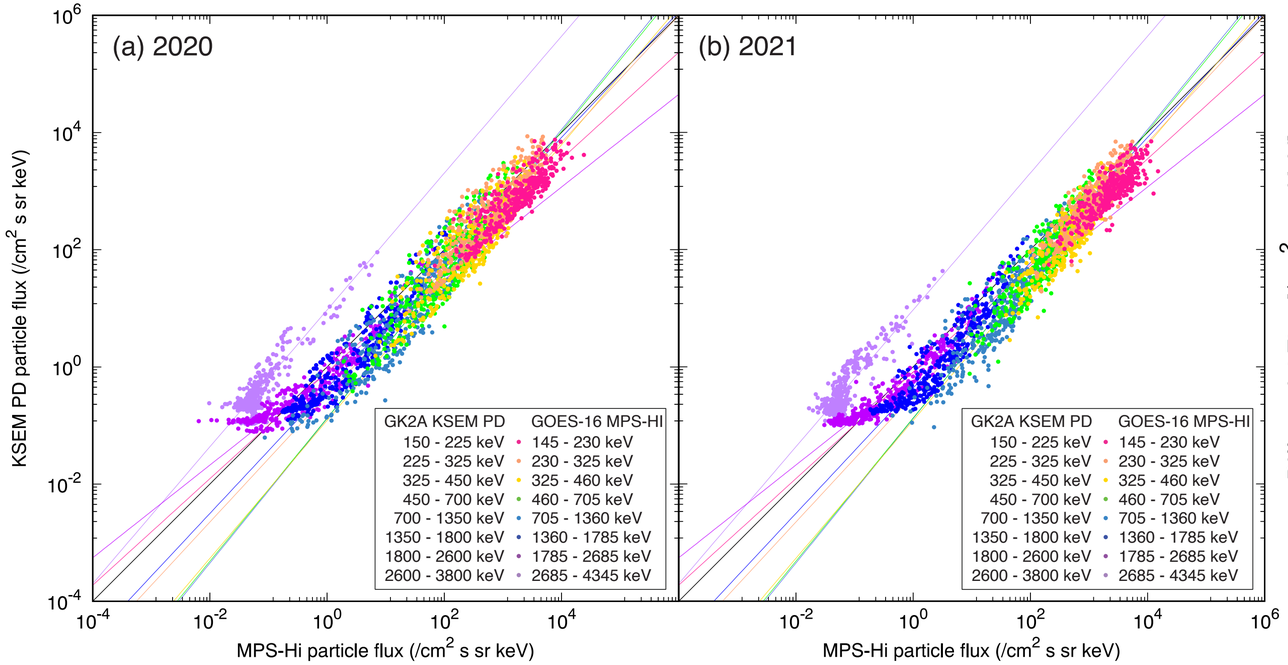


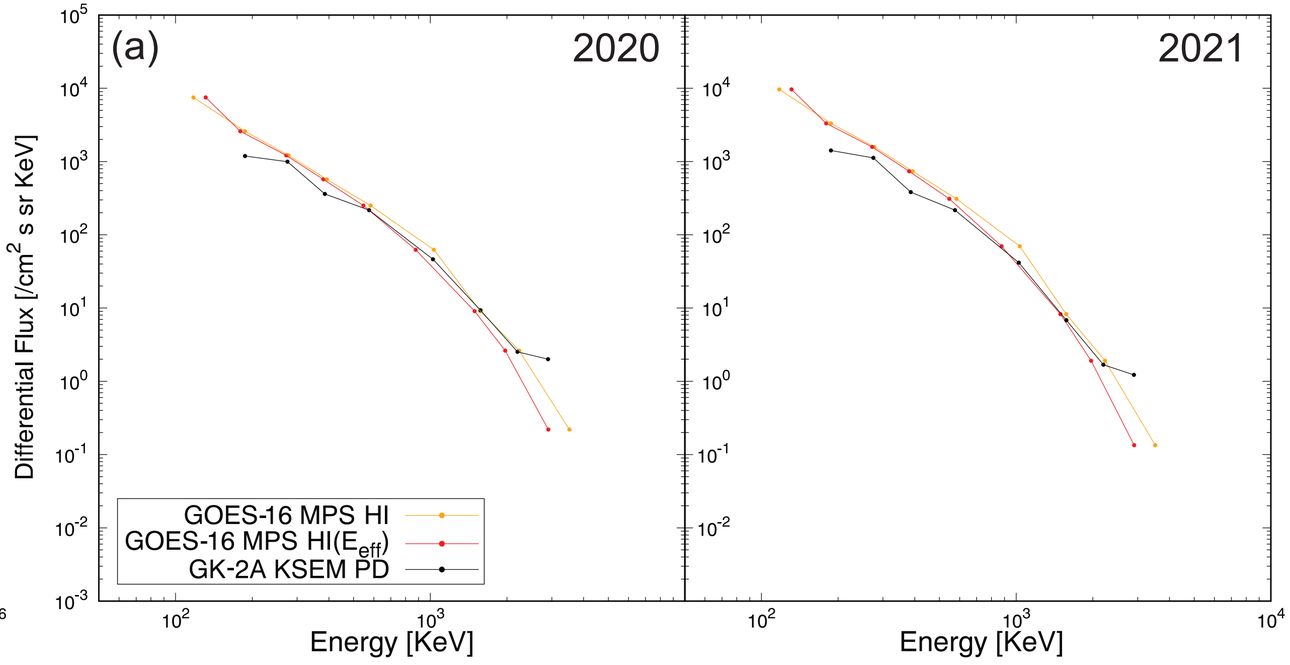
Himawari-9



GOES-16, 18

Electron flux correlations between GK2A and GOES-16 (Day-averaged)

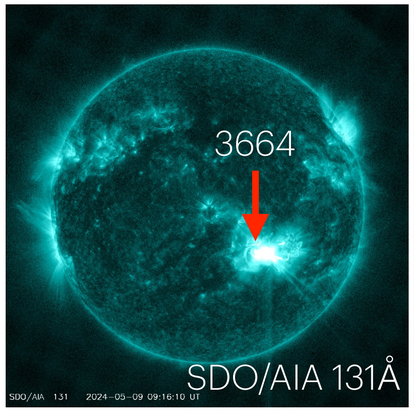


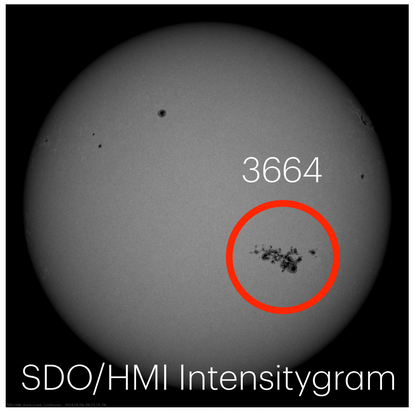


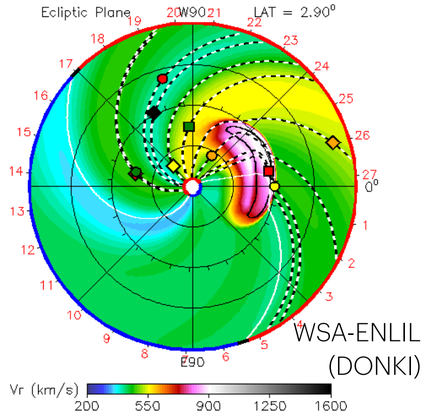
Channel No.	α		β		R	
	2020	2021	2020	2021	2020	2021
2	0.914	0.909	-0.085	-0.089	0.882	0.844
3	1.019	1.080	-0.246	-0.488	0.886	0.868
4	1.078	1.176	-0.567	-0.915	0.880	0.875
5	1.147	1.222	-0.610	-0.874	0.907	0.891
6	1.123	1.233	-0.607	-0.884	0.925	0.904
7	0.998	1.069	-0.249	-0.363	0.940	0.940
8	0.750	0.791	-0.074	-0.095	0.932	0.951
9	1.121	1.168	0.889	0.971	0.911	0.902

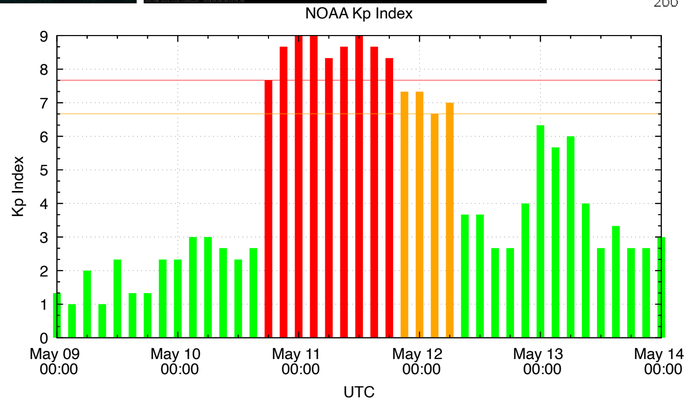
- The comparisons were made using the conjunction condition of dL* < 0.1 between two satellites
- Scatter plots of daily-averaged electron particle flux from both detectors show a reasonable correlation for most channels except for Channel 9.
- Energy based spectral distributions show good agreement between KSEM PD and MPS-HI with similar power law distributions, except for Channel 9
- Correlation coefficients obtained from $\log[\mathrm{Flux}_{\mathrm{KSEM\ PD}}]=\alpha\log[\mathrm{Flux}_{\mathrm{MPS\text{-}HI}}]+\beta$.
- The Pearson's R-values are ~0.85 or greater, indicating a strong correlation between the two detectors' data.

2 Major Space Weather Events in 2024: May and October



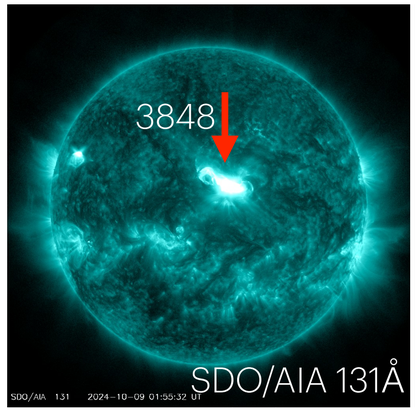


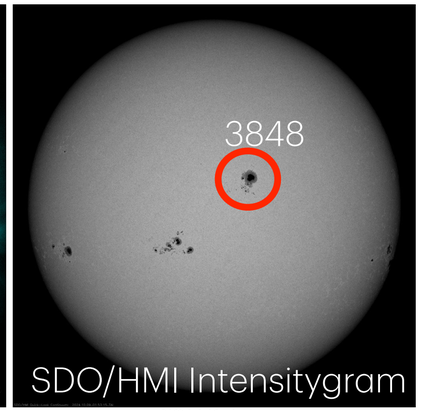


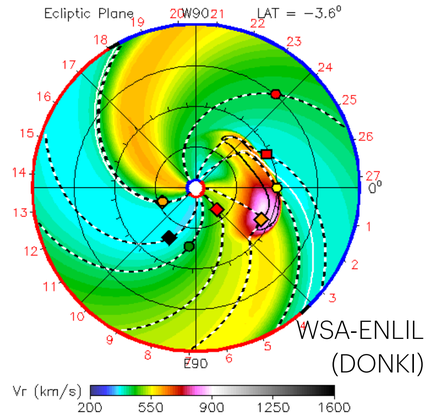


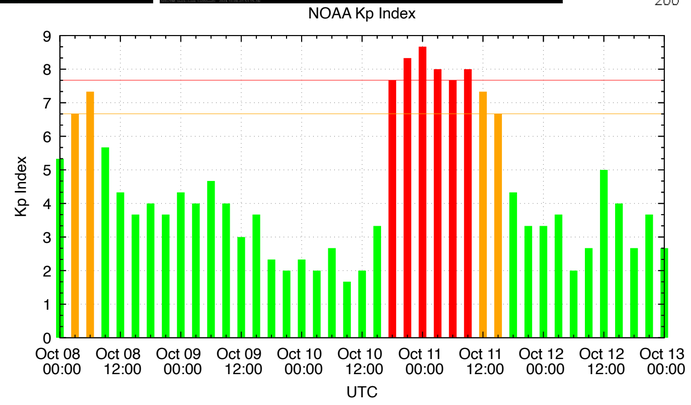
May 9-12, 2024

- AR 3664 exhibited extreme activity, producing multiple X-class solar flares and Earthward CMEs.
- More than 6 CMEs merged into a single structure before reaching Earth.
- The noon-side magnetopause contracted to 4.66 RE (based on the Lin model, 10-minute averaged data).
- The Kp index peaked at 9, and the Dst index dropped to -412 nT.
- The largest geomagnetic storm since the 2003 Halloween event.





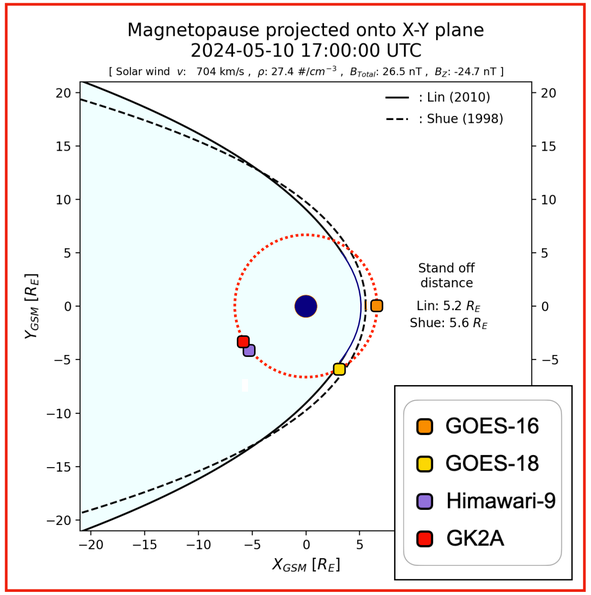


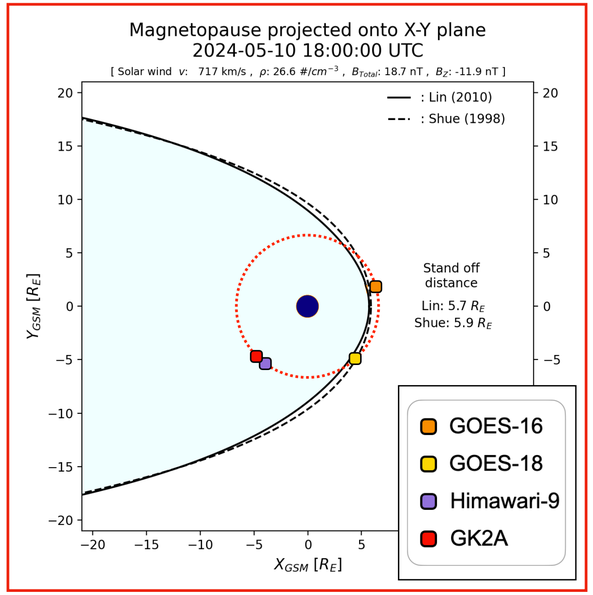


October 9-11, 2024

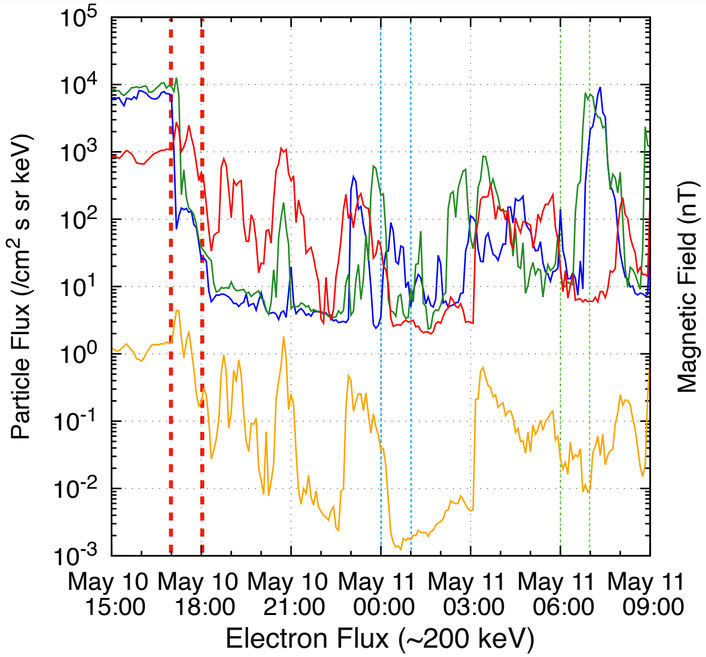
- AR 3848 became highly active, producing multiple X-class solar flares and Earth-directed CMEs.
- Geomagnetic disturbances persisted due to the combined effects of high-speed solar wind and successive CME impacts.
- The dayside magnetopause contracted to 5.05 RE (based on the Lin model, 10-minute averaged data).
- The Kp index reached 9-, and the Dst index dropped to -341 nT.

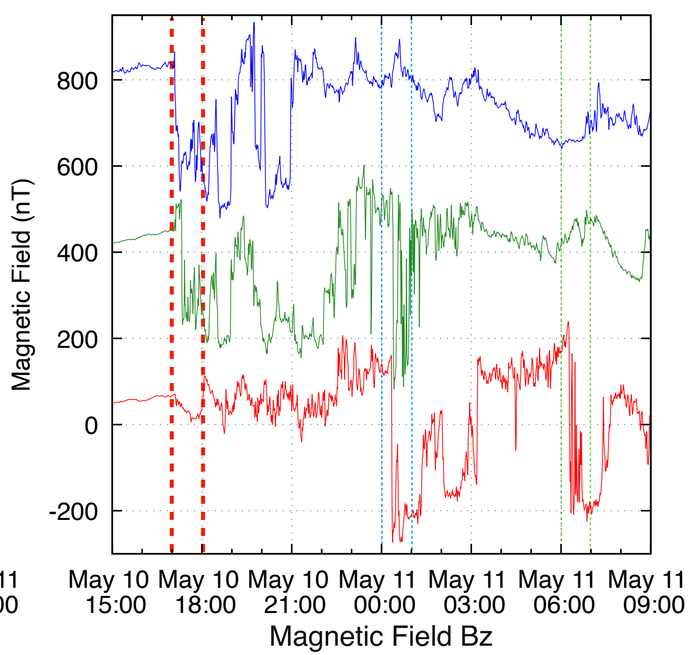
May 2024 Case 1 (2024-05-10 17:00 - 18:00)





Solid line: Lin Model, Dashed line: Shue





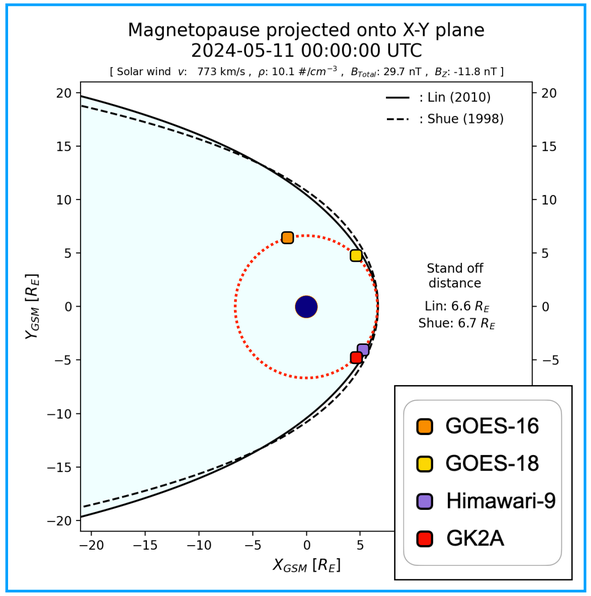
GOES-16 (Near Noon), GOES-18 (Morning)

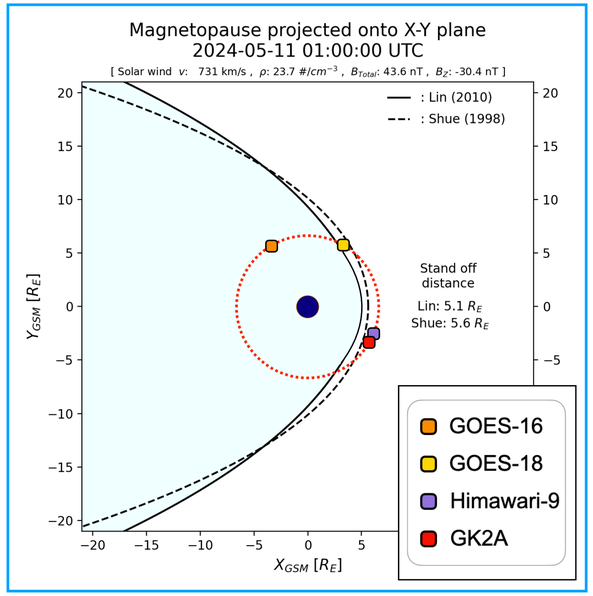
- **Exposure to Interplanetary Space**: GOES-16 was exposed before GOES-18.
- **Electron Flux Changes**: GOES-16, being closer to the noon sector, showed a rapid decrease, while GOES-18 exhibited a slower decline.
- **Magnetic Field Changes**: Sudden and strong Bz reversal (w/ a shorter SSC duration for GOES-16).
  - **SSC Onset Time**:
    - **GOES-16**: 2024-05-10 17:05
    - **GOES-18**: 2024-05-10 17:08 (or 17:06?)

GK2A, Himawari-9 (Night)

- **Exposure to Interplanetary Space**: Not exposed.
- **Electron Flux Changes**: Gradual and slight decrease.
- **Magnetic Field Changes**: GK2A's Bz decreased but did not reverse direction.
  - **SSC Onset Time**: ?

May 2024 Case 2 (2024-05-11 00:00 - 01:00)





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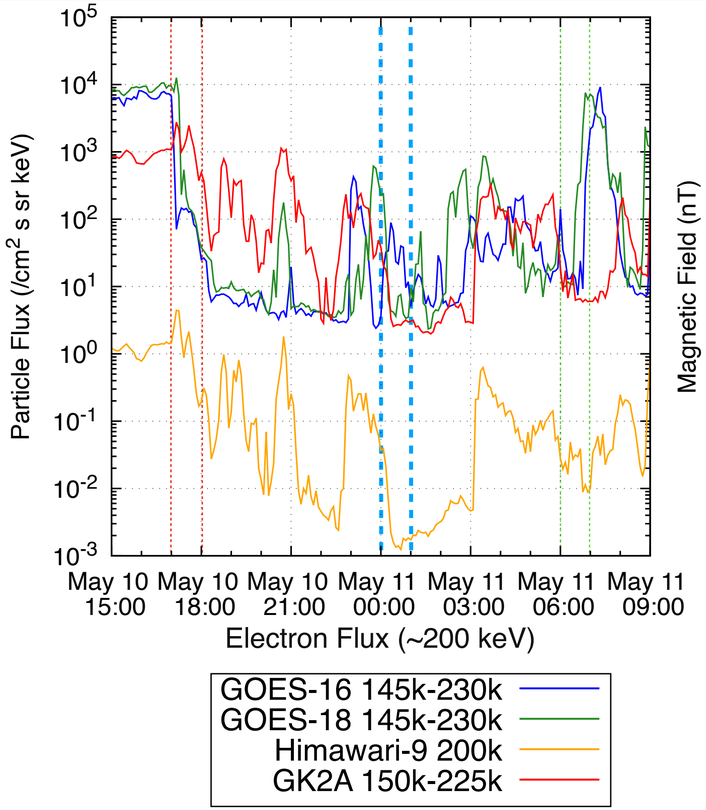
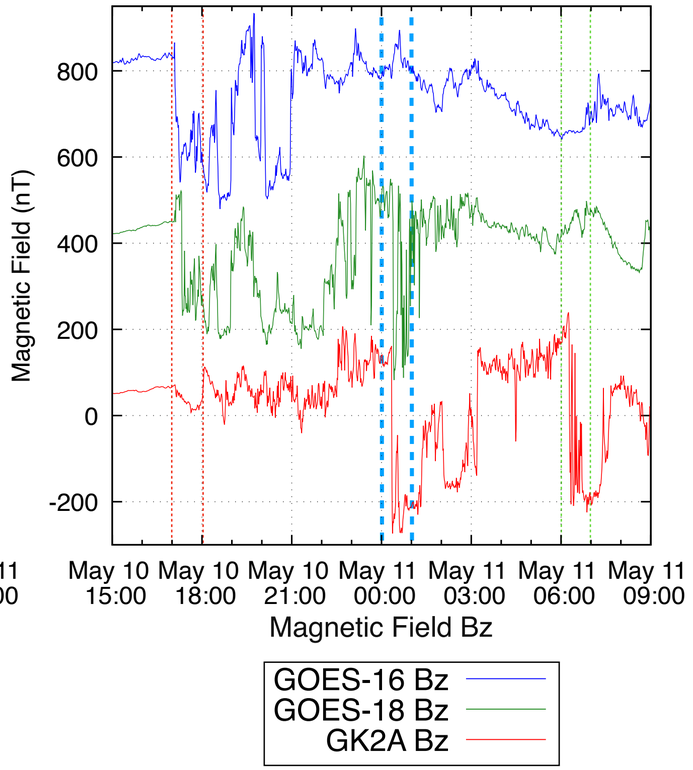




GOES-16 (Night)

- **Exposure to Interplanetary Space**: Not exposed.
- **Electron Flux Changes**: No significant decrease.
- **Magnetic Field Changes**: No clear decrease or reversal in Bz.

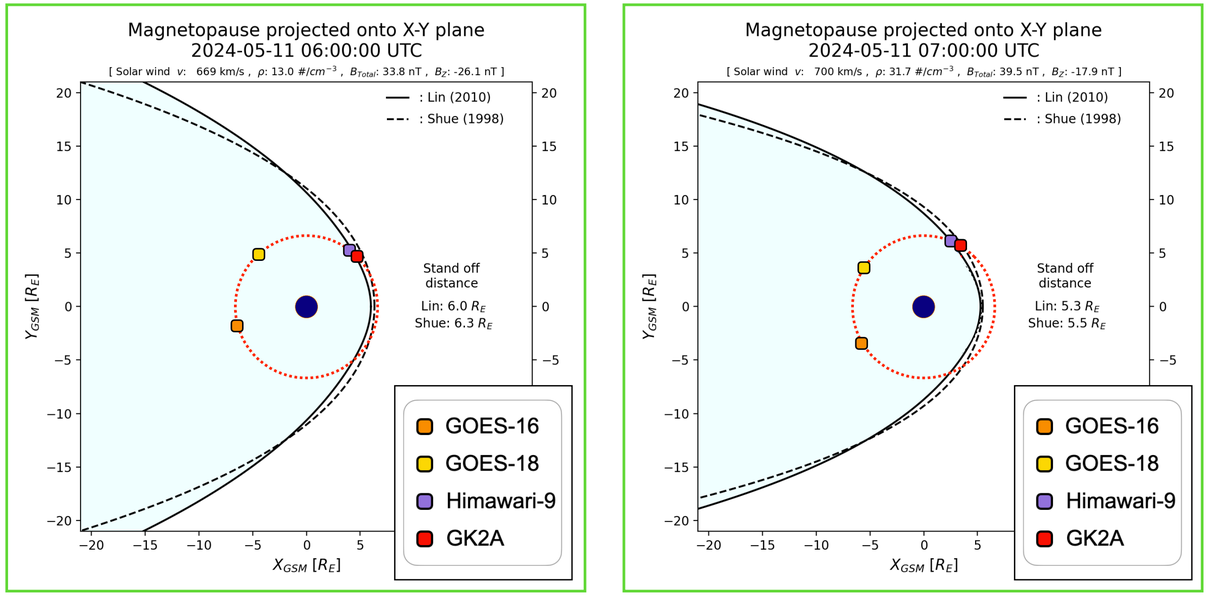
GOES-18 (Early Afternoon)

- **Exposure to Interplanetary Space**: Exposed.
- **Electron Flux Changes**: Sharp decrease.
- **Magnetic Field Changes**: Bz showed repeated reversals, indicating instability → Possibly located near the magnetopause boundary?
  - **SSC Onset Time**: 2024-05-11 00:16

GK2A, Himawari-9 (Morning)

- **Exposure to Interplanetary Space**: Exposed.
- **Electron Flux Changes**: Gradual decrease (likely due to prior multiple exposures).
- **Magnetic Field Changes**: GK2A recorded a sharp Bz decrease and reversal.
  - **SSC Onset Time**: ?

May 2024 Case 3 (2024-05-11 06:00 - 07:00)



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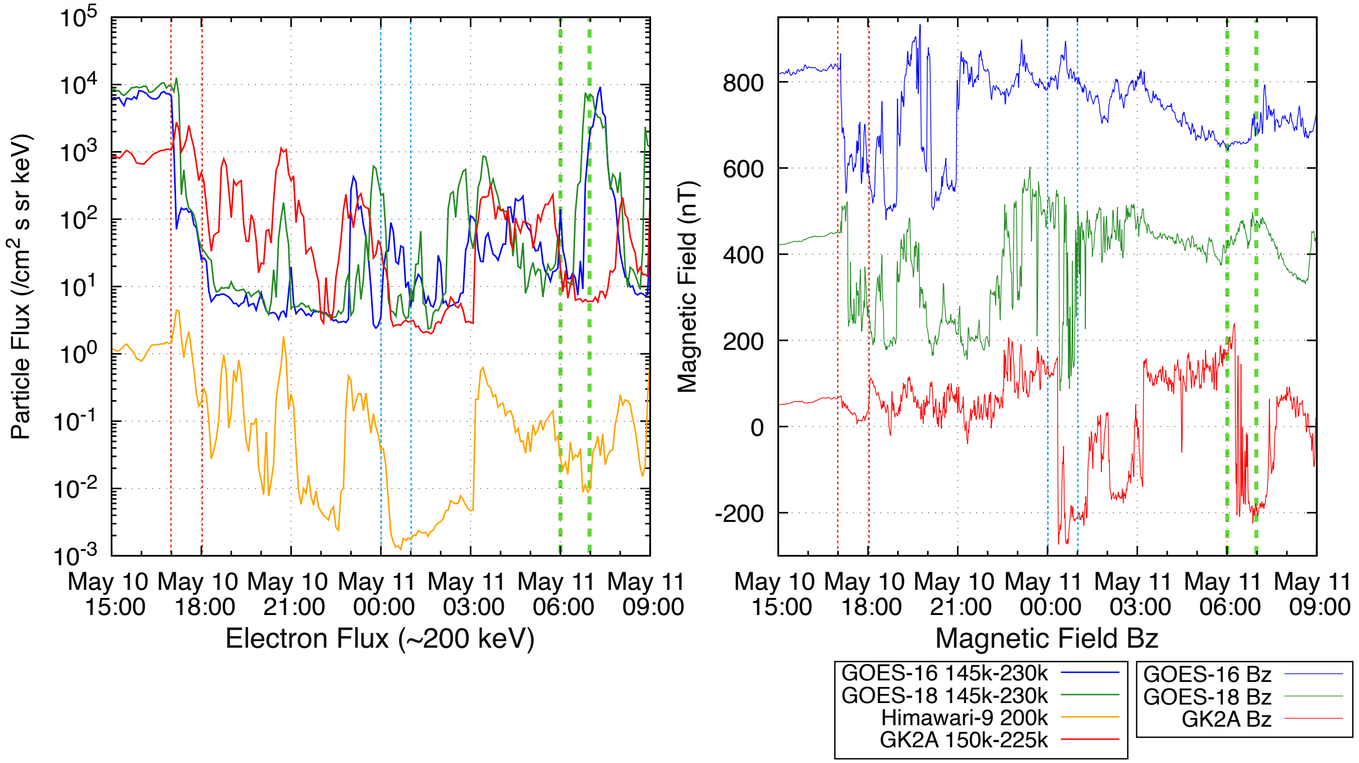


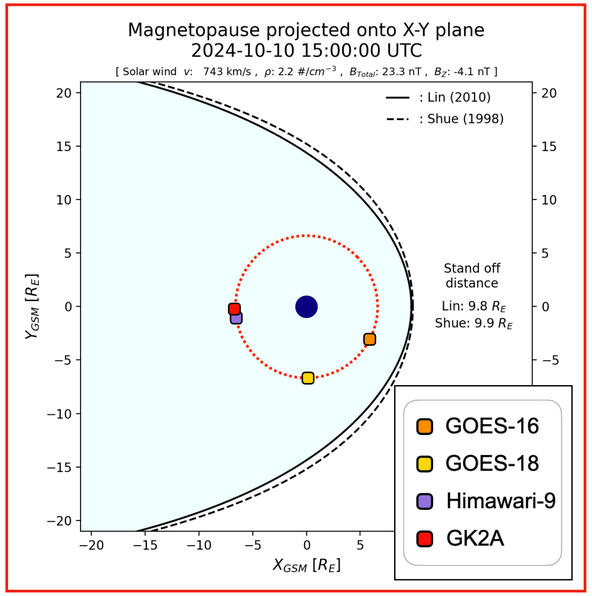
GOES-16, GOES-18 (Night)

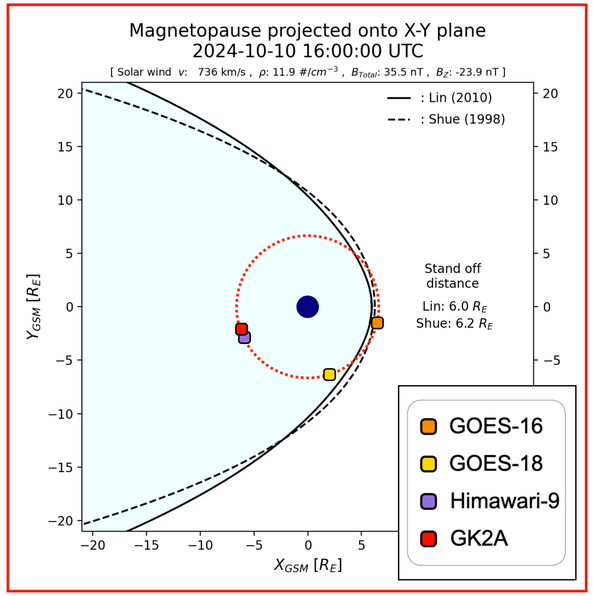
- **Exposure to Interplanetary Space**: Not exposed.
- **Electron Flux Changes**: No significant additional decrease, as most flux had already been lost.
- **Magnetic Field Changes**: No noticeable changes.

GK2A, Himawari-9 (Early Afternoon)

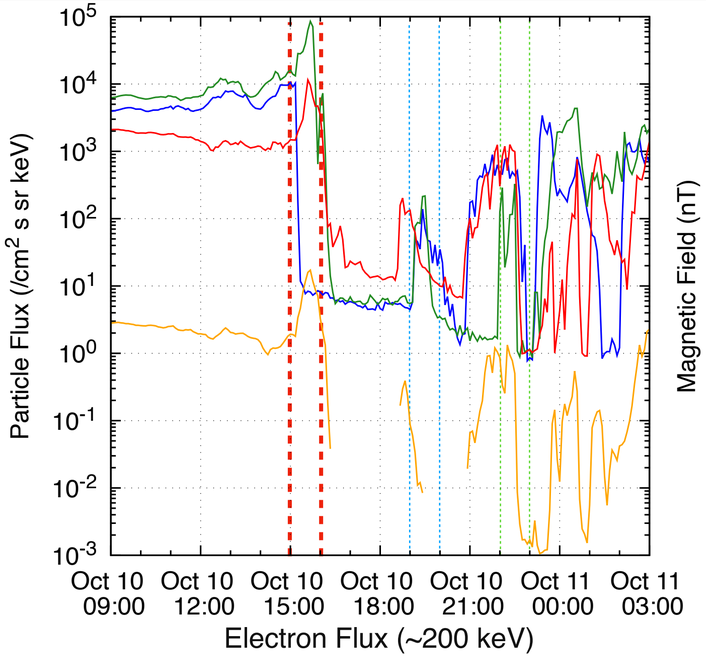
- **Exposure to Interplanetary Space**: Exposed.
- **Electron Flux Changes**: No significant additional decrease, as flux had already been largely depleted.
- **Magnetic Field Changes**: GK2A recorded a sharp Bz decrease and reversal.
  - **SSC Onset Time**: 2024-05-11 06:10
  - Shortly after the decrease, Bz fluctuated significantly → Possibly indicating that the magnetopause boundary remained near GK2A.

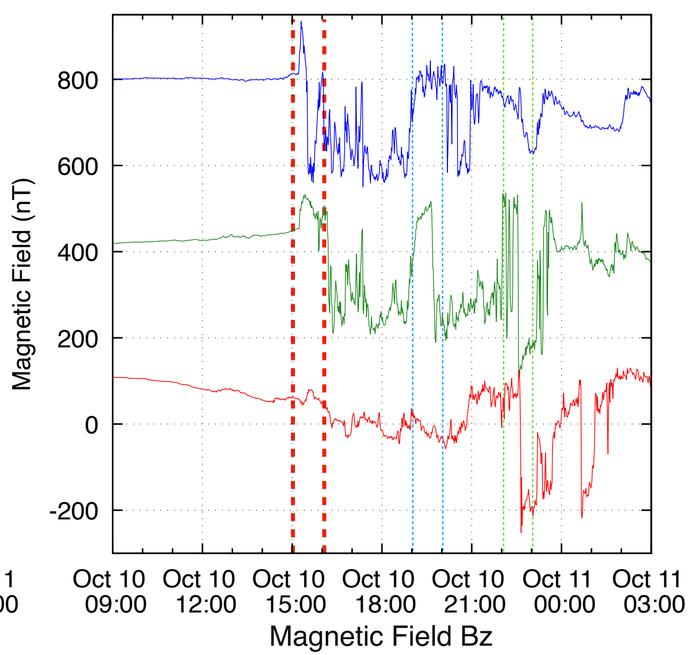
October 2024 Case 1 (2024-10-10 15:00 - 16:00)





Solid line: Lin Model, Dashed line: Shue





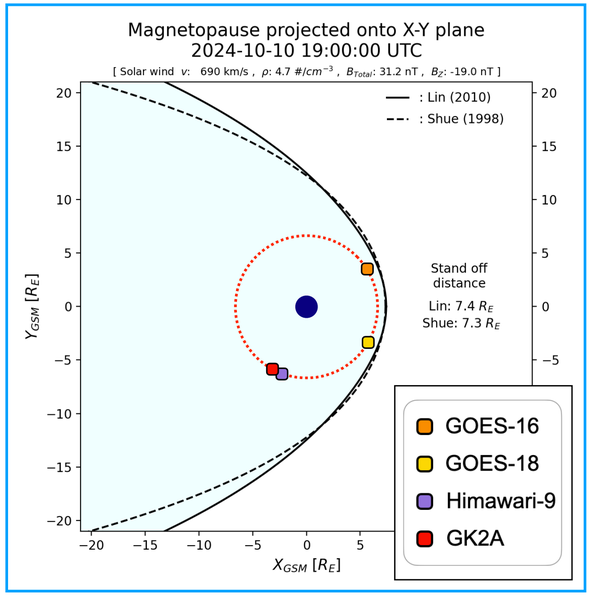
GOES-16 (Near Noon), GOES-18 (Morning)

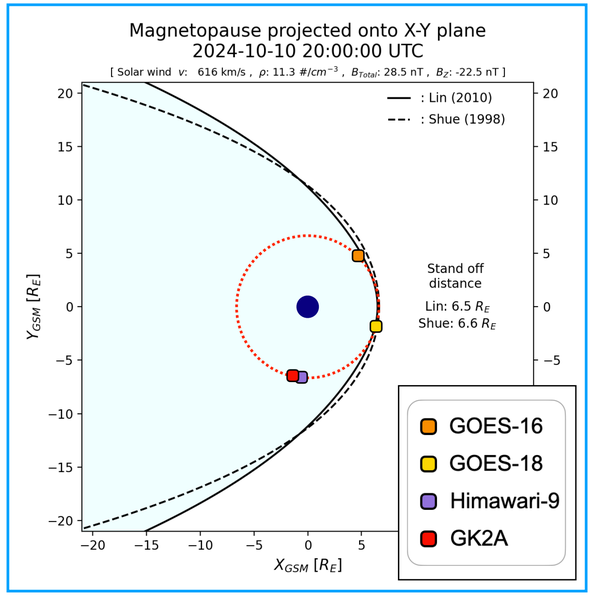
- **Exposure to Interplanetary Space**: GOES-16 was exposed before GOES-18.
- **Electron Flux Changes**: GOES-16, being closer to the noon, showed a rapid decrease, while GOES-18 exhibited a relatively slower decline.
- **Magnetic Field Changes**: Sudden and strong Bz reversal (w/ a shorter SSC duration for GOES-16).
  - **SSC Onset Time**:
    - **GOES-16**: 2024-10-10 15:14
    - **GOES-18**: 2024-10-10 15:15

GK2A, Himawari-9 (Night)

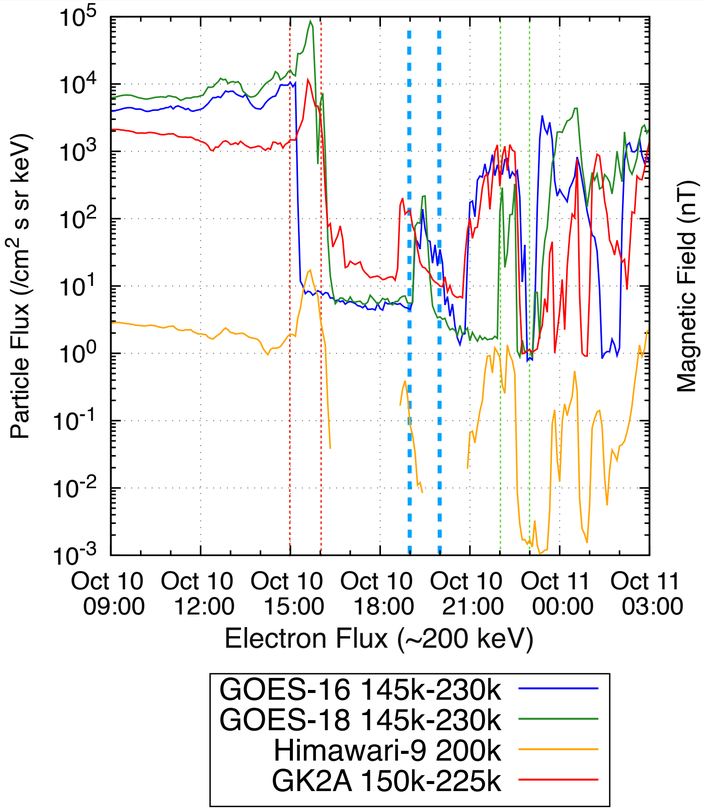
- **Exposure to Interplanetary Space**: Not exposed.
- **Electron Flux Changes**: Temporary rapid increase after magnetopause contraction → Possible temporary trapping of electrons in the tail?
- **Magnetic Field Changes**: GK2A's Bz was already low but decreased slightly without reversal.
  - **SSC Onset Time**: ?

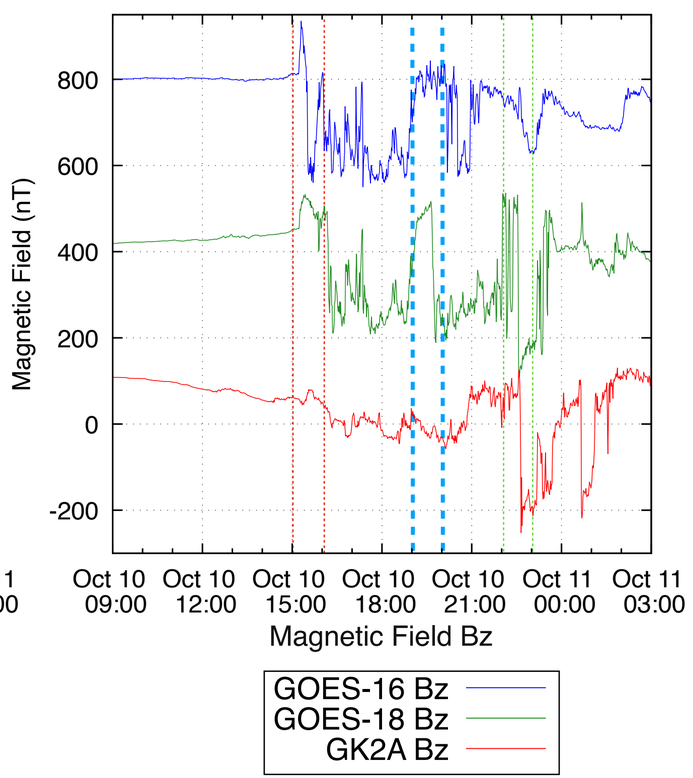
October 2024 Case 2 (2024-10-10 19:00 - 20:00)





Solid line: Lin Model, Dashed line: Shue





GOES-16 (Early Afternoon)

- **Exposure to Interplanetary Space**: Briefly exposed or not exposed.
- **Electron Flux Changes**: Gradual decrease.
- **Magnetic Field Changes**: Slight Bz decrease, weak or no reversal.

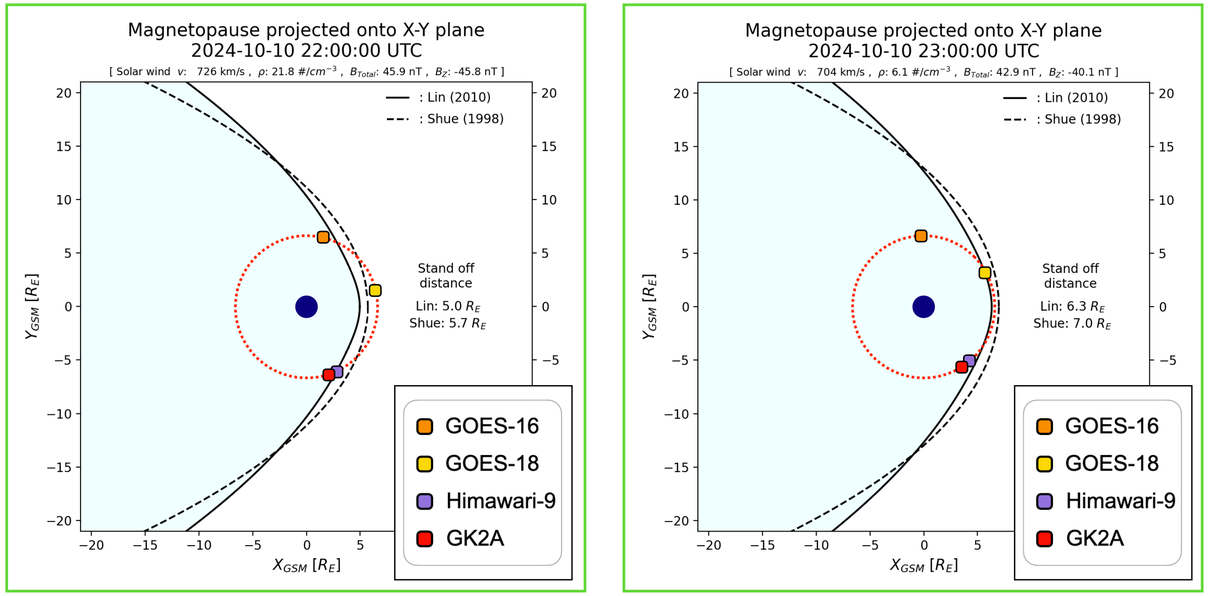
GOES-18 (Near Noon)

- **Exposure to Interplanetary Space**: Exposed.
- **Electron Flux Changes**: Sharp decrease.
- **Magnetic Field Changes**: Bz decreased and reversed.
  - **SSC Onset Time**: 2024-10-10 19:37

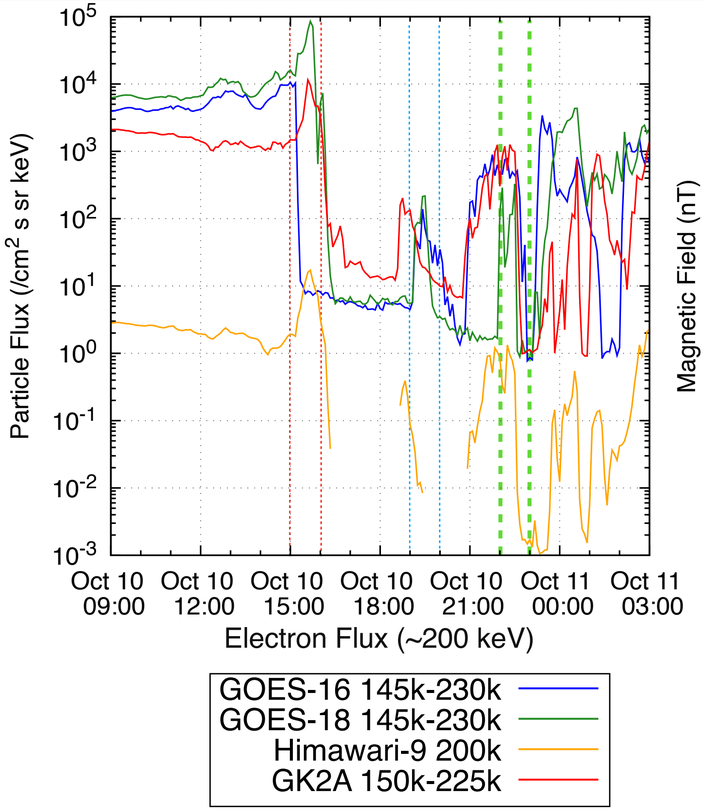
GK2A, Himawari-9 (Dawn)

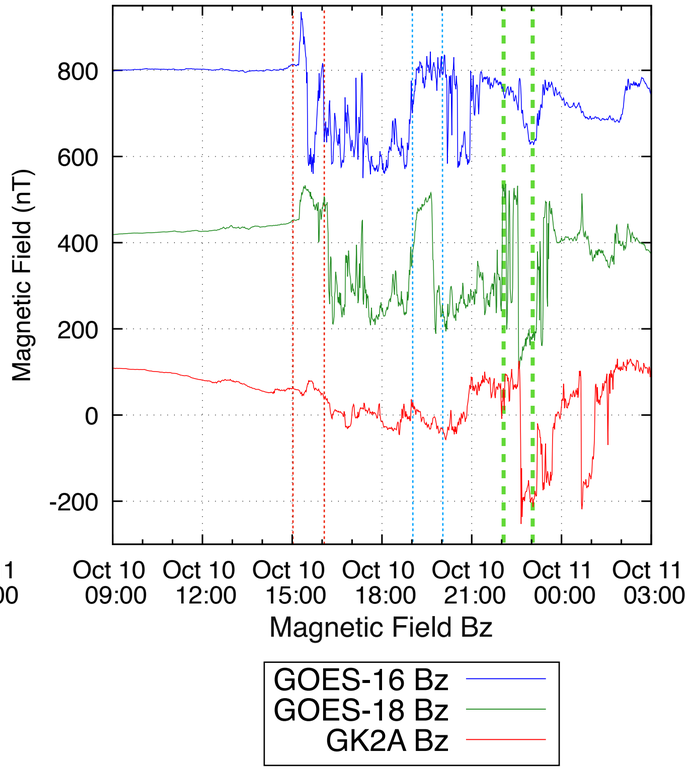
- **Exposure to Interplanetary Space**: Not exposed.
- **Electron Flux Changes**: Gradual and minor decrease.
- **Magnetic Field Changes**: GK2A's Bz decreased slightly but did not reverse.
  - **SSC Onset Time**: ?

October 2024 Case 3 (2024-10-10 22:00 - 23:00)



Solid line: Lin Model, Dashed line: Shue





GOES-16 (Evening)

- **Exposure to Interplanetary Space**: Briefly exposed.
- **Electron Flux Changes**: Sharp decrease.
- **Magnetic Field Changes**: Bz decreased and temporarily reversed.
  - **SSC Onset Time**: 2024-10-10 22:34
  -

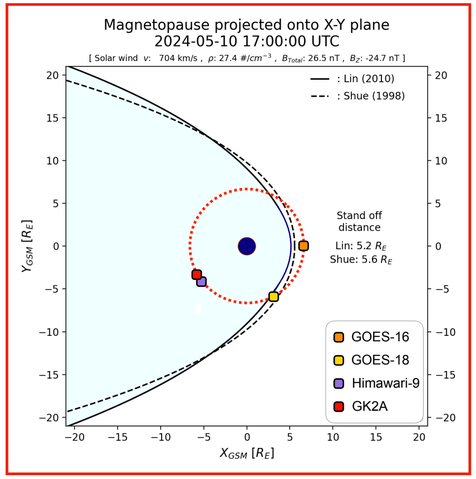
GOES-18 (Near Noon)

- **Exposure to Interplanetary Space**: Exposed.
- **Electron Flux Changes**: Sharp decrease.
- **Magnetic Field Changes**: Bz decreased and reversed.
  - **SSC Onset Time**: 2024-10-10 22:31

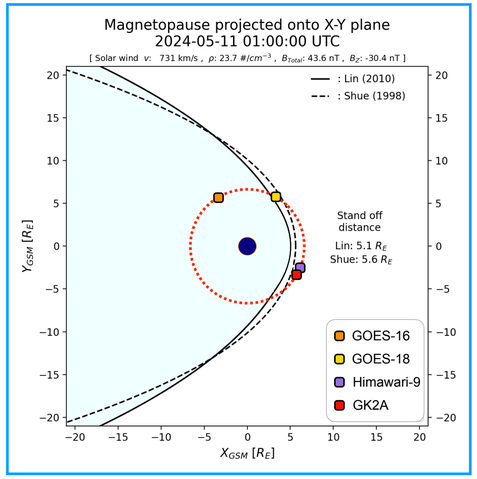
GK2A, Himawari-9 (Morning)

- **Exposure to Interplanetary Space**: Exposed.
- **Electron Flux Changes**: Sharp decrease.
- **Magnetic Field Changes**: GK2A's Bz decreased sharply and reversed.
  - **SSC Onset Time**: 2024-10-10 22:33

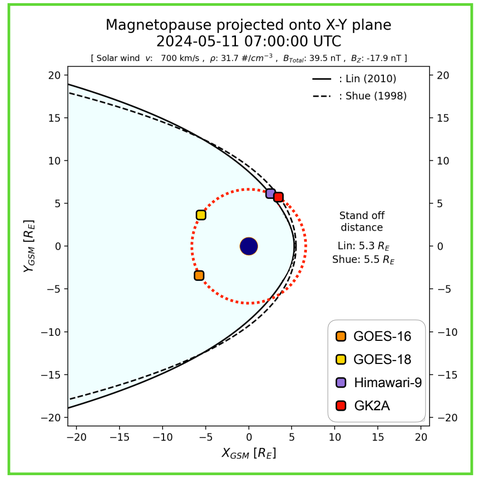
Overview of Observed May Cases



May Case 1



May Case 2



May Case 3

May Case 1: GOES-16 and GOES-18 (day) were exposed to interplanetary space, showing sharp electron flux drops and Bz reversals, while GK2A and Himawari-9 (night) recorded gradual flux decreases without direct exposure.

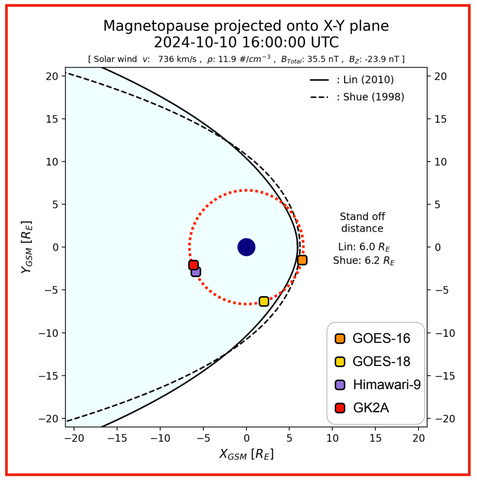
May Case 2: GOES-18 (evening) showed unstable Bz, suggesting the magnetopause boundary remained near the satellite, while GK2A and Himawari-9 (day), moving toward noon, experienced moderate flux decreases and Bz reversals.

May Case 3: GOES-16 and GOES-18 (night) showed minimal changes, while GK2A and Himawari-9 (evening) recorded strong Bz reversals and electron flux losses.

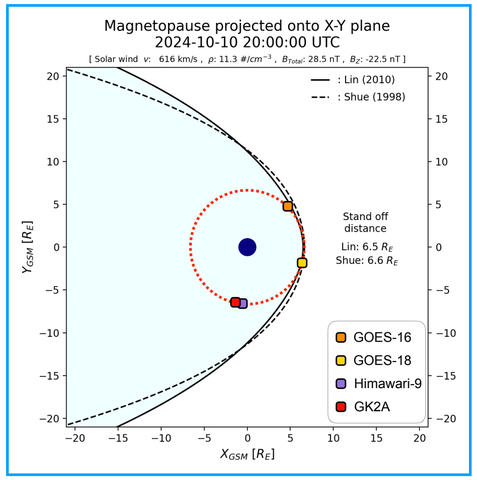
May 2024

Date & Time	Satellite	Exposure to Interplanetary Space	Electron Flux Changes	Magnetic Field Changes	SSC Onset Time
2024-05-10 17:00 - 18:00	**GOES-16** (Near Noon)	Exposed before GOES-18	Sharp decrease	Bz decreased and reversed	2024-05-10 17:05
	GOES-18 (Morning)	Exposed after GOES-16	Gradual decrease	Bz decreased and reversed	2024-05-10 17:08
	GK2A, Himawari-9 (Night)	Not exposed	Gradual decrease	Bz slightly decreased, no reversal	?
2024-05-11 00:00 - 01:00	**GOES-16** (Night)	Not exposed	No significant change	No significant change	?
	GOES-18 (Early Afternoon)	Exposed	Sharp decrease	Bz reversed and unstable	2024-05-11 00:16
	GK2A, Himawari-9 (Morning)	Exposed	Gradual decrease	Bz decreased and reversed	?
2024-05-11 06:00 - 07:00	**GOES-16** (Night)	Not exposed	No significant change	No significant change	?
	GOES-18 (Night)	Not exposed	No significant change	No significant change	?
	GK2A, Himawari-9 (Evening)	Exposed	Sharp decrease	Bz decreased and reversed	2024-05-11 06:10

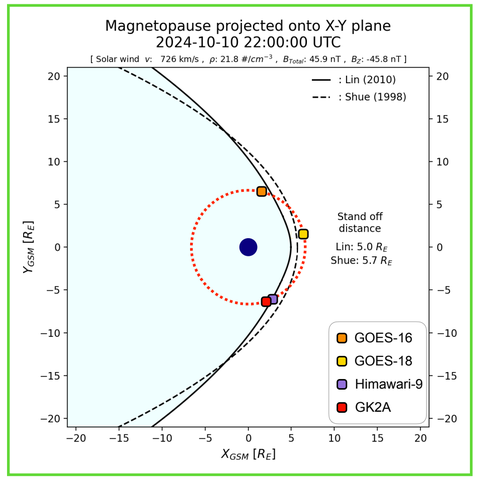
Overview of Observed OctoberCases



October Case 1



October Case 2



October Case 3

October Case 1: GOES-16 and GOES-18 (noon) were exposed, showing sharp flux drops and Bz reversals, while GK2A and Himawari-9 (night) briefly saw flux increases, possibly from temporary particle trapping.

October Case 2: GOES-18 (noon) was exposed, showing flux drops and Bz reversals, while GOES-16 (afternoon) had weaker responses. GK2A and Himawari-9 (dawn) saw gradual flux decreases, indicating a weaker impact.

October Case 3: GOES-18 (noon) was exposed, showing strong flux drops and Bz reversals, while GOES-16 (evening) had brief exposure. GK2A and Himawari-9 (morning) saw electron flux losses and strong Bz changes, reflecting magnetospheric evolution.

October 2024

Date & Time	Satellite	Exposure to Interplanetary Space	Electron Flux Changes	Magnetic Field Changes	SSC Onset Time
2024-10-10 15:00 - 16:00	**GOES-16** (Near Noon)	Exposed before GOES-18	Sharp decrease	Bz decreased and reversed	2024-10-10 15:14
	GOES-18 (Morning)	Exposed after GOES-16	Gradual decrease	Bz decreased and reversed	2024-10-10 15:15
	GK2A, Himawari-9 (Night)	Not exposed	Temporary increase	Bz decreased, no reversal	?
2024-10-10 19:00 - 20:00	**GOES-16** (Early Afternoon)	Briefly exposed or not exposed	Gradual decrease	Bz decrease, weak or no reversal	?
	GOES-18 (Near Noon)	Exposed	Sharp decrease	Bz decreased and reversed	2024-10-10 19:37
	GK2A, Himawari-9 (Dawn)	Not exposed	Gradual and minor decrease	Bz decreased, no reversal	?
2024-10-10 22:00 - 23:00	**GOES-16** (Evening)	Briefly exposed	Sharp decrease	Bz decreased and temporarily reversed	2024-10-10 22:34
	GOES-18 (Near Noon)	Exposed	Sharp decrease	Bz decreased and reversed	2024-10-10 22:31
	GK2A, Himawari-9 (Morning)	Exposed	Sharp decrease	Bz decreased and reversed	2024-10-10 22:33

Summary

Multi-Point Observations in Geostationary Orbit for Space Weather Research

- Using GK2A, Himawari-9, GOES-16 and -18, we analyzed major space weather events from May and October 2024.
- During magnetopause compression, satellites in the dayside were exposed to interplanetary space, showing sharp electron flux drops and Bz reversals.
- Satellites in the nightside were not exposed but showed gradual changes in Bz and electron fluxes due to magnetospheric deformation.
- This shows the value of multi-point observations in providing a more comprehensive view of magnetospheric responses in space weather events.

- *To maximize the effectiveness of multi-point observations, continuous cross-calibration and validation of space weather data are essential.*
- *Well-calibrated data enhances the synergy of multi-point observations, improves space weather modeling, increases satellite operation stability, and strengthens forecasting capabilities.*

Thank you

Korea Meteorological Administration (KMA)
National Meteorological Satellite Center (NMSC)