The relation between magnetospheric state parameters and the occurrence of plasma depletion events in the night-time mid-latitude F-region

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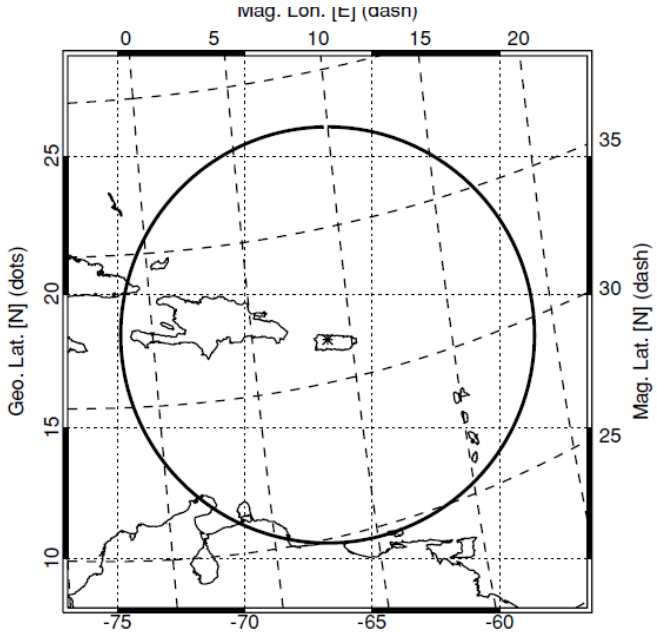
Introduction

Penn State All-Sky Imager



Arecibo Observatory

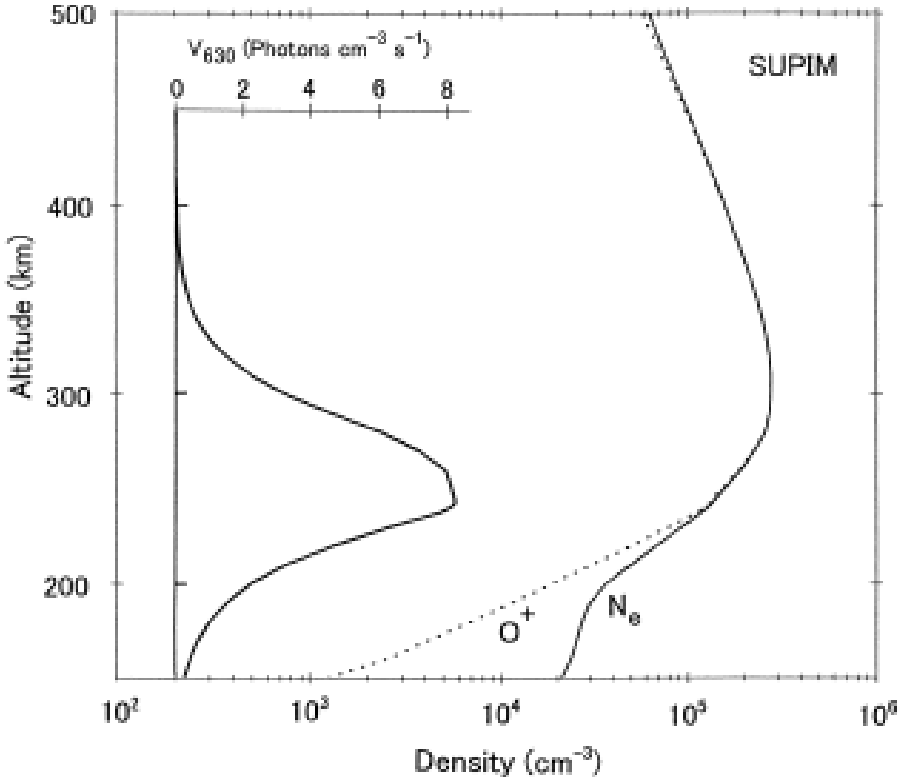
Airglow (630 nm)

$$O^+ + O_2 \rightarrow O_2^+ + O$$

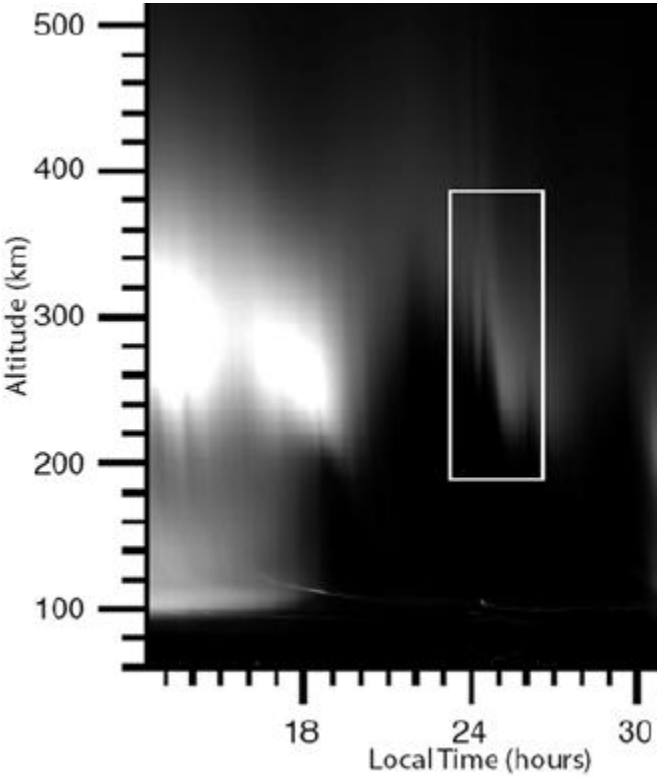
Charge Exchange

$$O_2^+ + e^- \rightarrow O^* + O$$

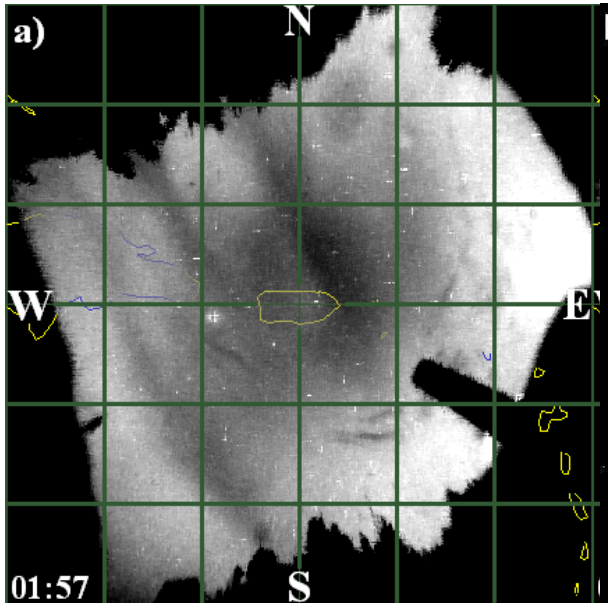
Dissociative Recombination



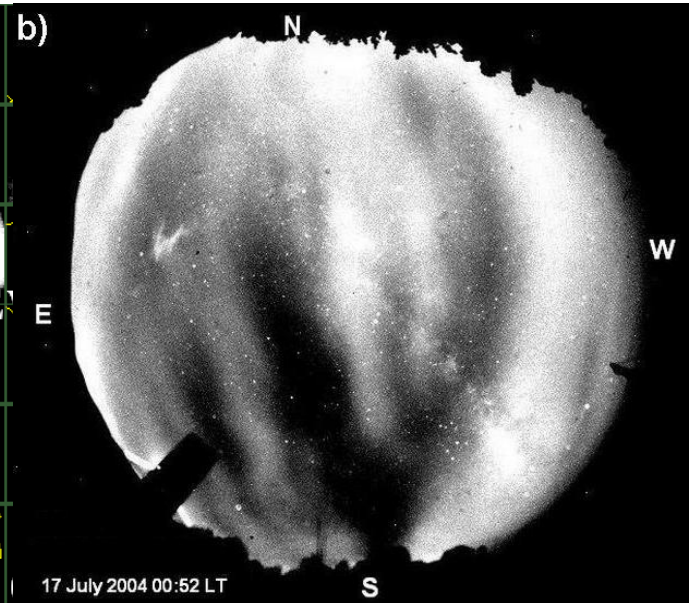
Introduction



MSTIDs



Plumes



Structure	Parallel bands	Single plume
Appearance	Extending from north	From south
Alignment	Northwest-southeast	North-south
Propagation	Toward southwest	Westward
Wavelength & period	100-300 km, ~1 hr	Not periodic
Theory	Perkins Instability [1, 2]	Rayleigh-Taylor [3]
Occurs when Kp is	Low	High

Method

- F-region events from the Penn State All-sky Imager were categorized according to type (MSTID or plume), depletion intensity (weak, moderate, intense), and start/end times.

- The imager results were then analyzed according to solar wind and geomagnetic conditions between 2003 and 2008.

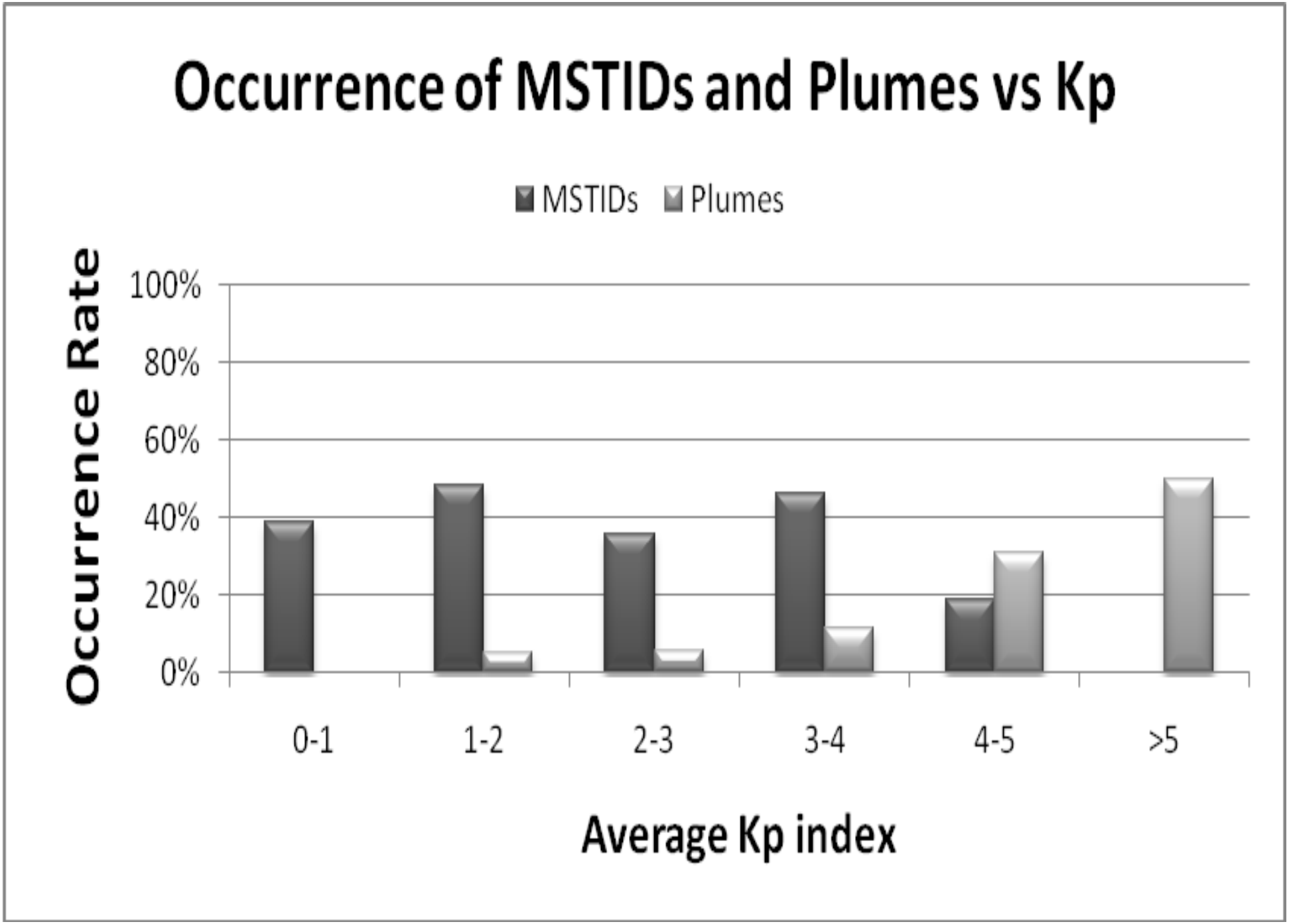
- Magnetospheric state parameters used in this study (Kp, Dst, AE, SW B, SW Bz, SW E, SW V, SW P) were obtained from the NASA Magnetospheric State Query System (MSQS).

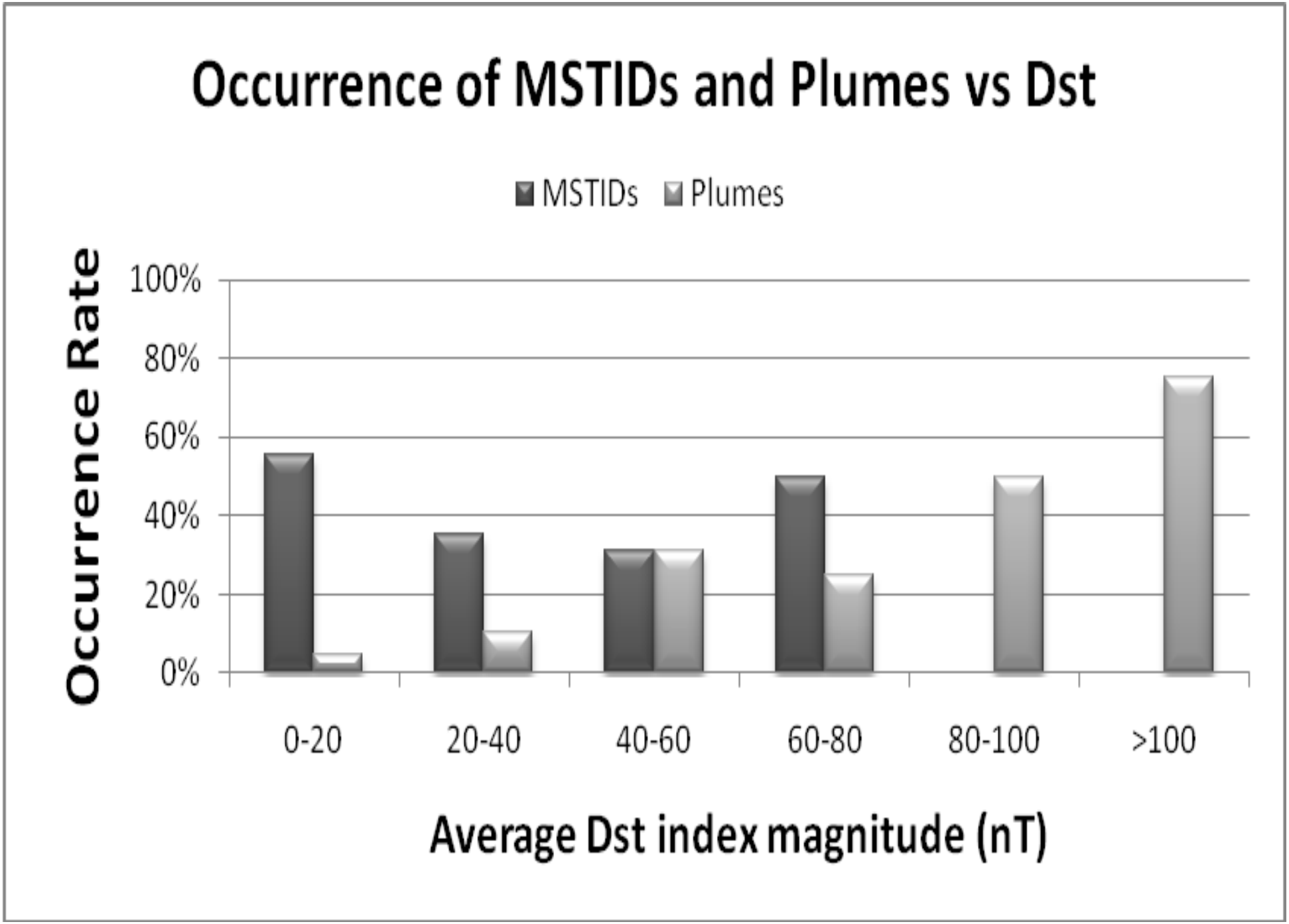
- Each parameter is first averaged over the time duration of each event observed with the all-sky imager and then over all such MSTID or plume events.

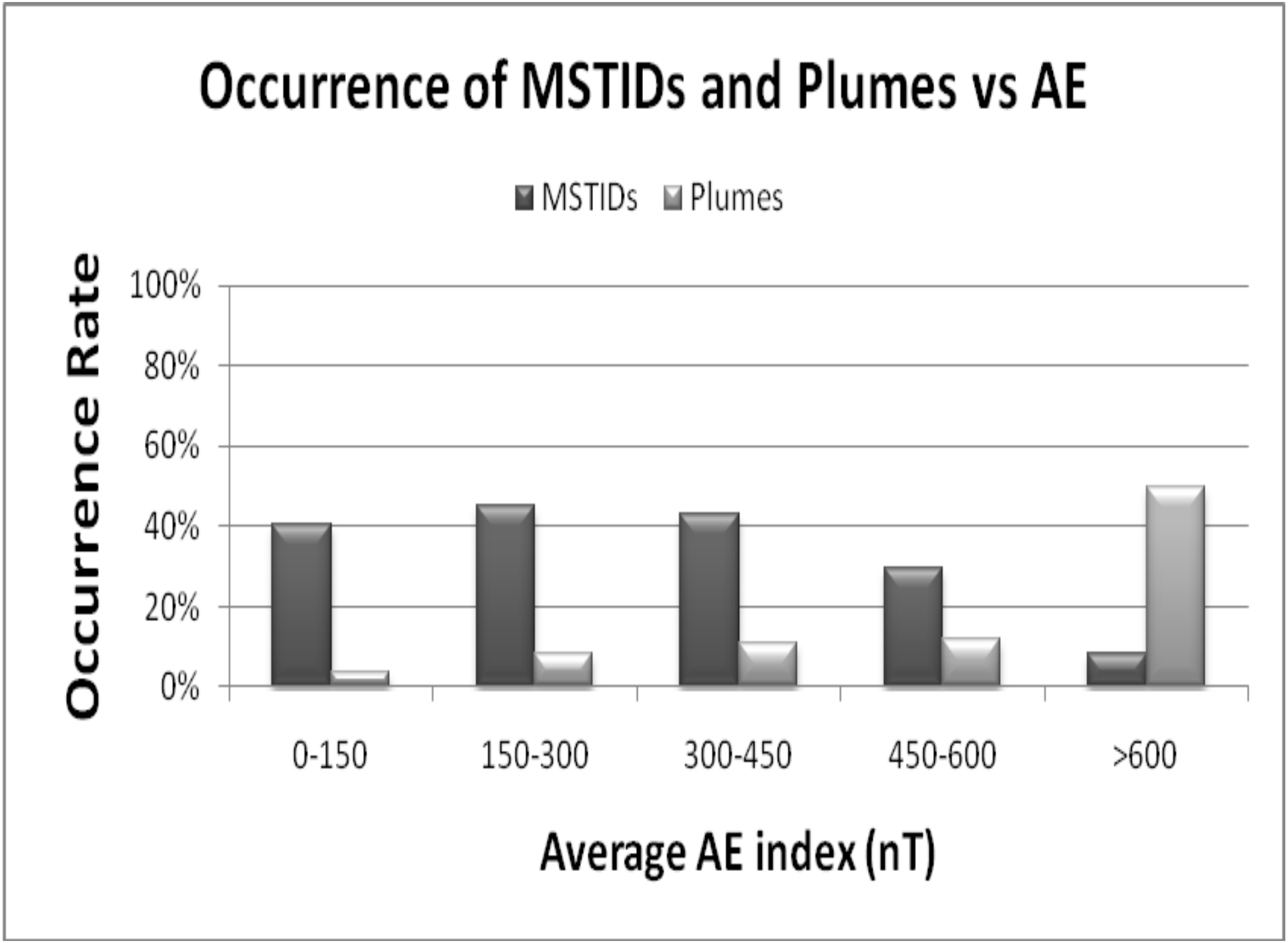
Results

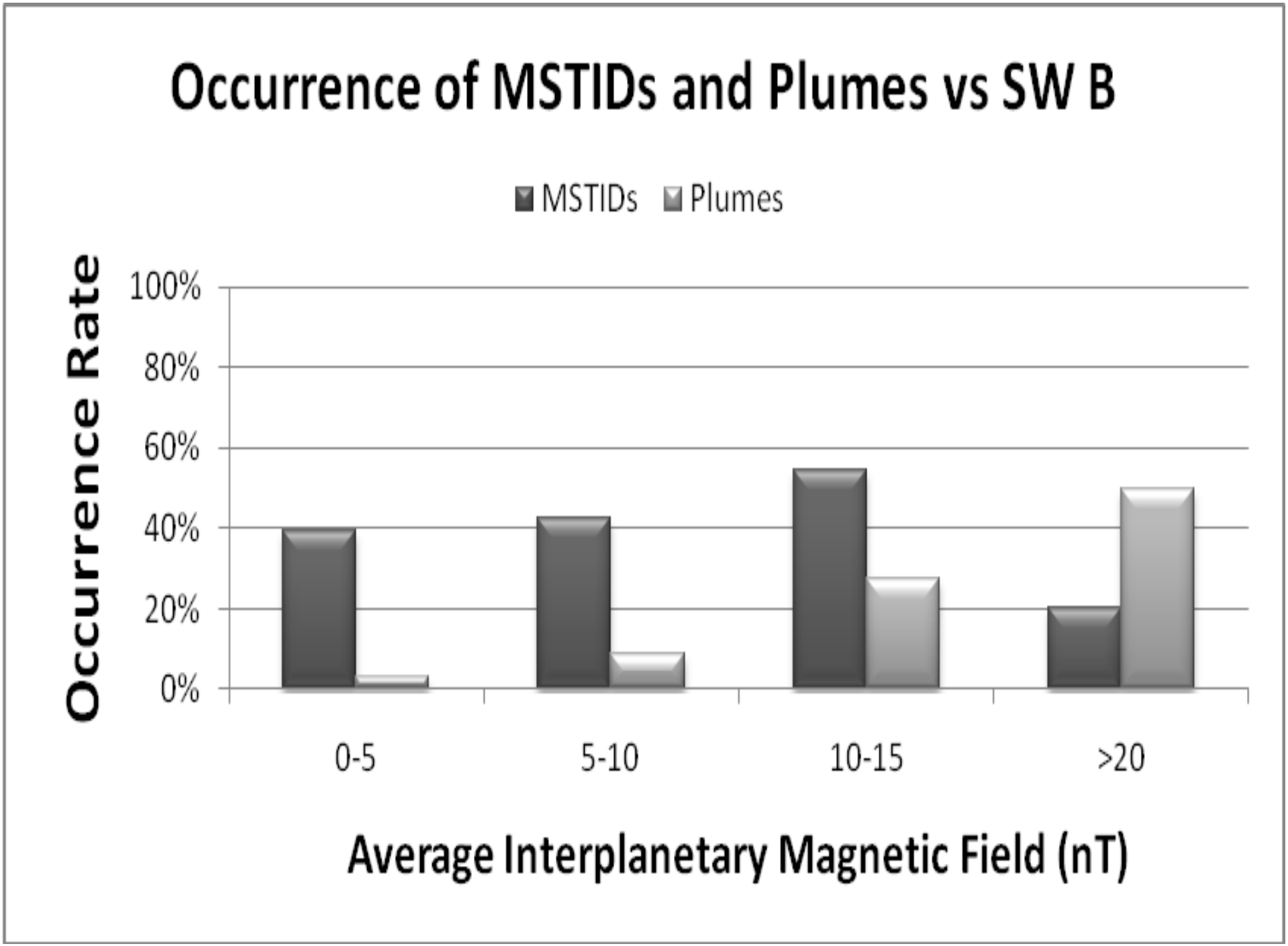
Type	Plume			MSTID			
Intensity	**high**	**total**	**moderate**	**moderate**	**total**	**high**	
# of events	11	23	12	88	125	37	
Parameter							**Units**
Kp	4.79	3.84	2.97	1.84	1.81	1.75	
AE	654	415	203	182	171	144	nT
Dst	-86	-58	-30	-15	-13	-8	nT
SW V	542	520	506	451	452	458	km/s
SW E	3.9	1.9	0.5	-0.1	-0.2	-0.5	mV/m
SW B	15.1	10.6	5.9	5.2	5.3	5.6	nT
SW Bz	-5.9	-2.8	-0.8	0.2	0.4	0.9	nT
SW P	4.10	3.15	2.28	1.97	1.94	1.87	nPa
SW N	6.26	5.46	4.72	5.36	5.11	4.54	cm^{-3}
SW T	128	127	126	120	123	131	10^3 K

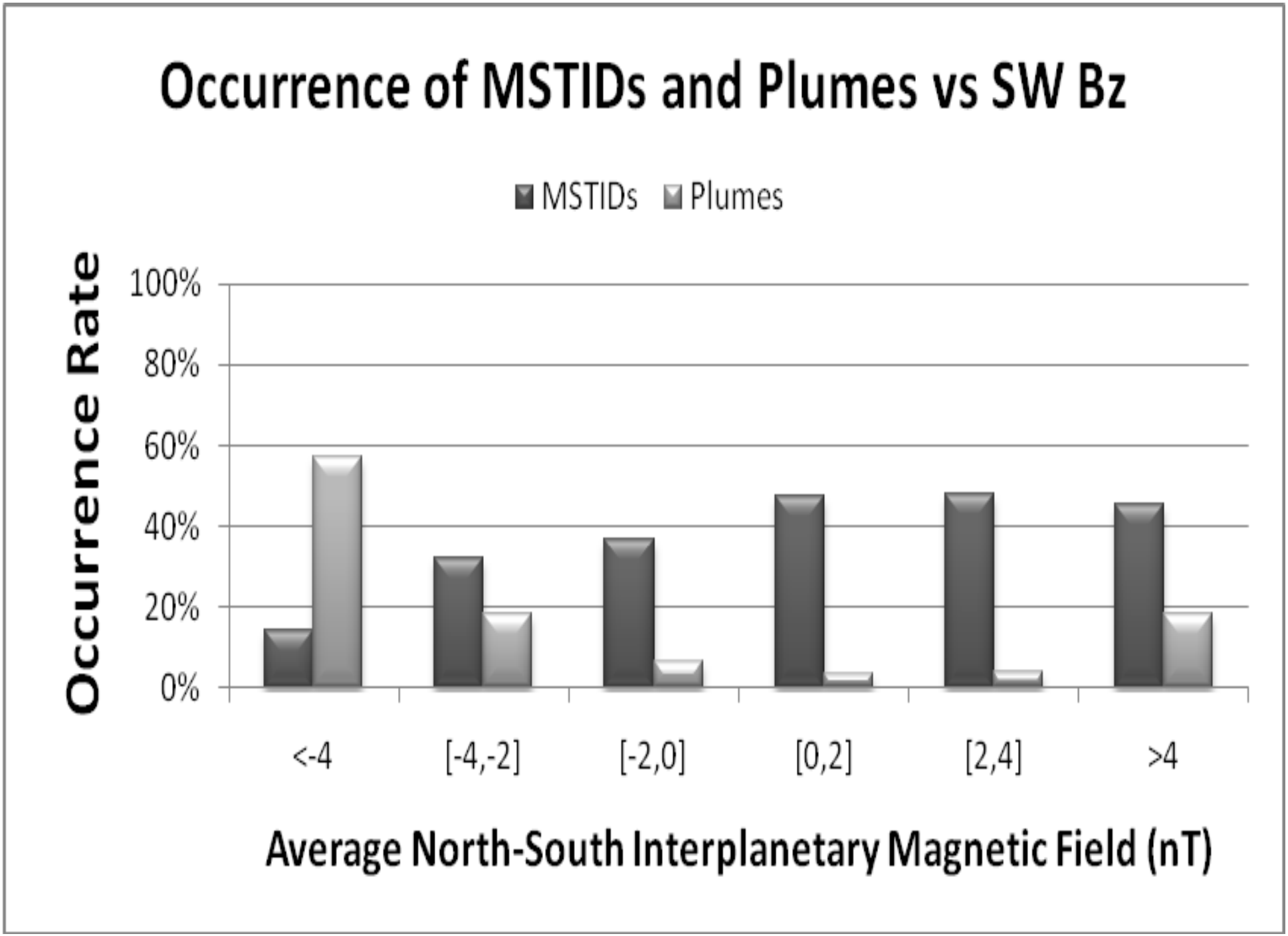
- The results suggest a relation between the geomagnetic state parameters and the occurrence of plumes and MSTIDs.

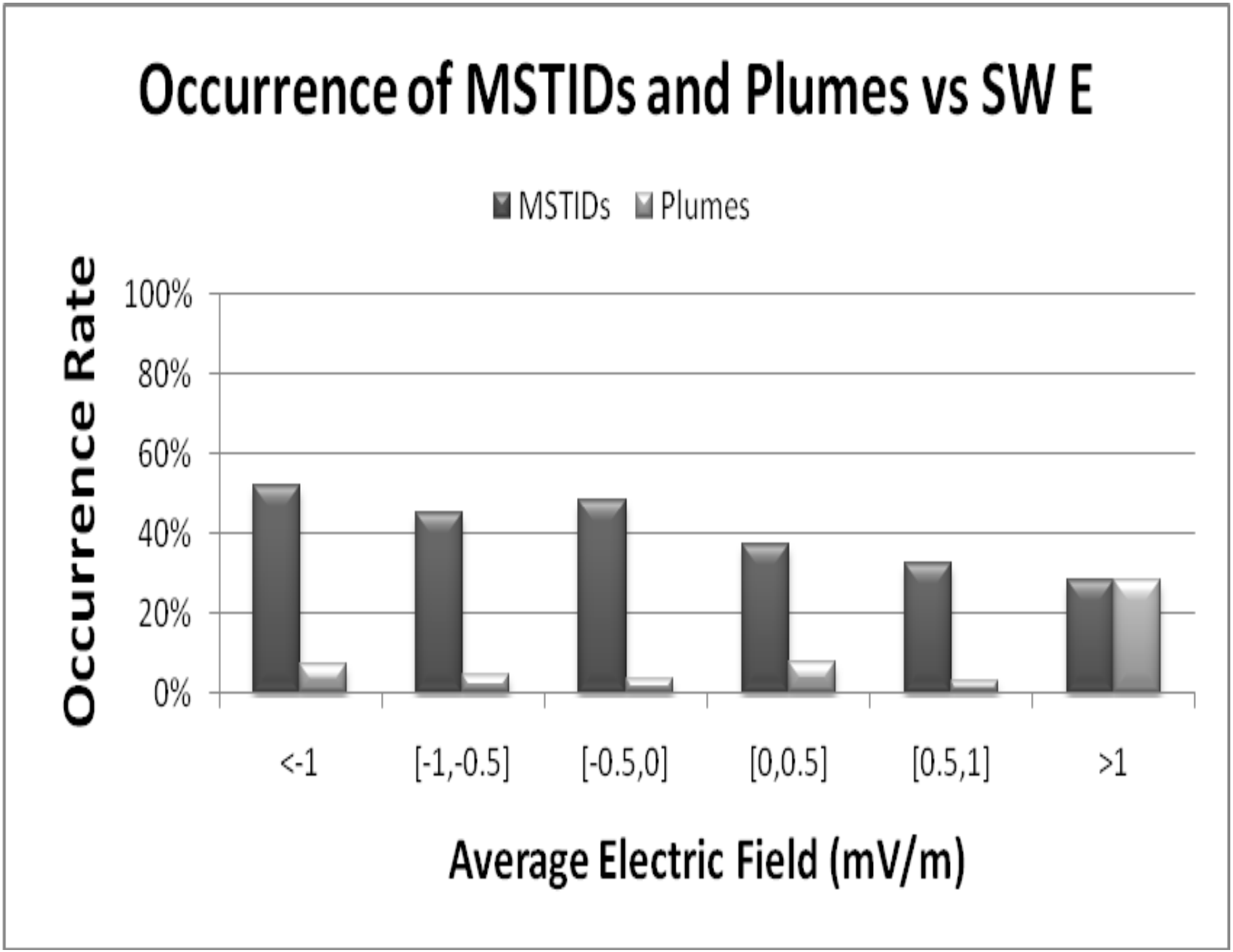

Occurrence of MSTIDs and Plumes vs Kp
MSTIDs
Plumes
Occurrence Rate
100%
80%
60%
40%
20%
0%
0-1
1-2
2-3
3-4
4-5
>5
Average Kp index

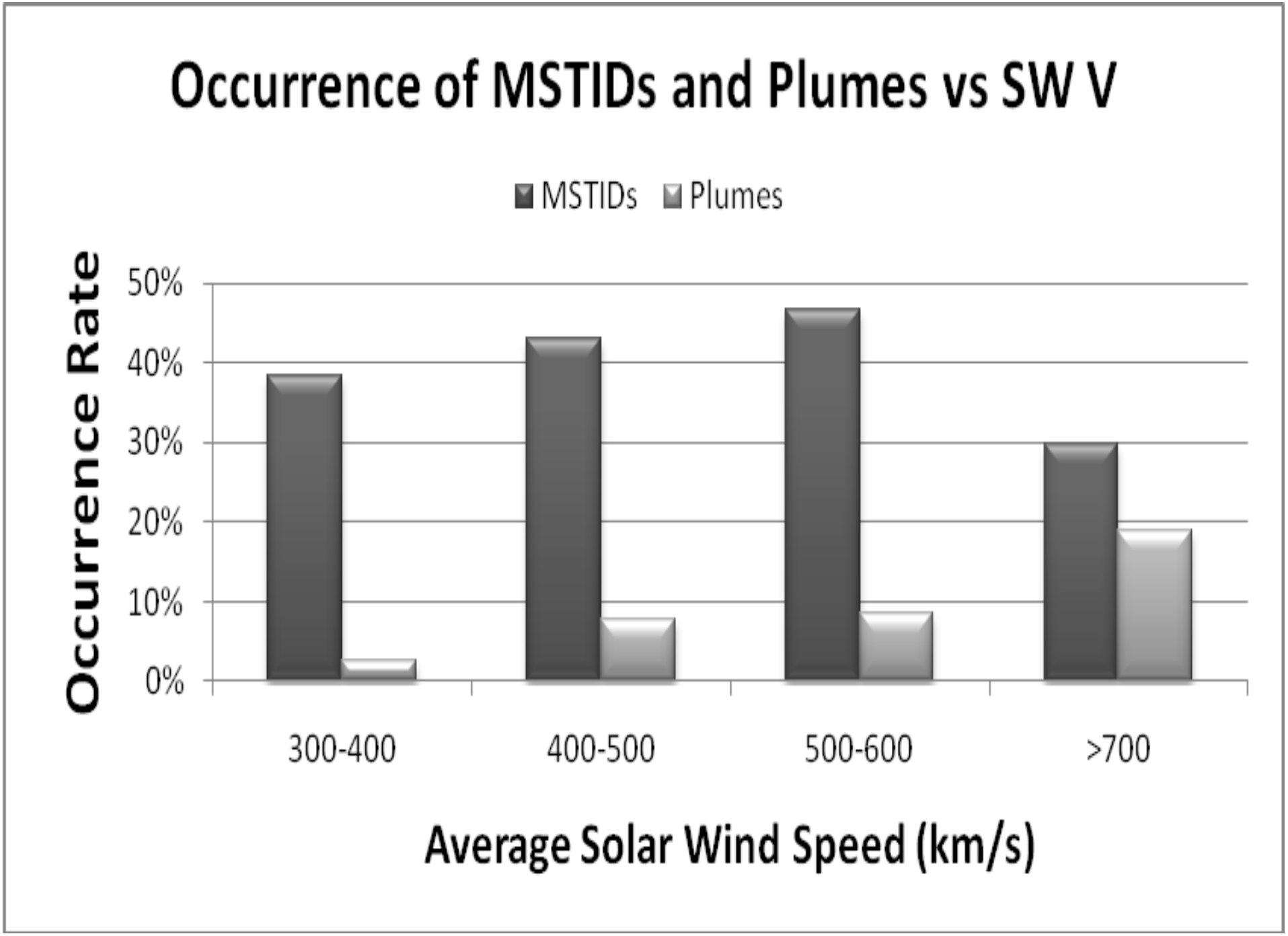

Occurrence of MSTIDs and Plumes vs Dst
MSTIDs
Plumes
Occurrence Rate
100%
80%
60%
40%
20%
0%
0-20
20-40
40-60
60-80
80-100
>100
Average Dst index magnitude (nT)

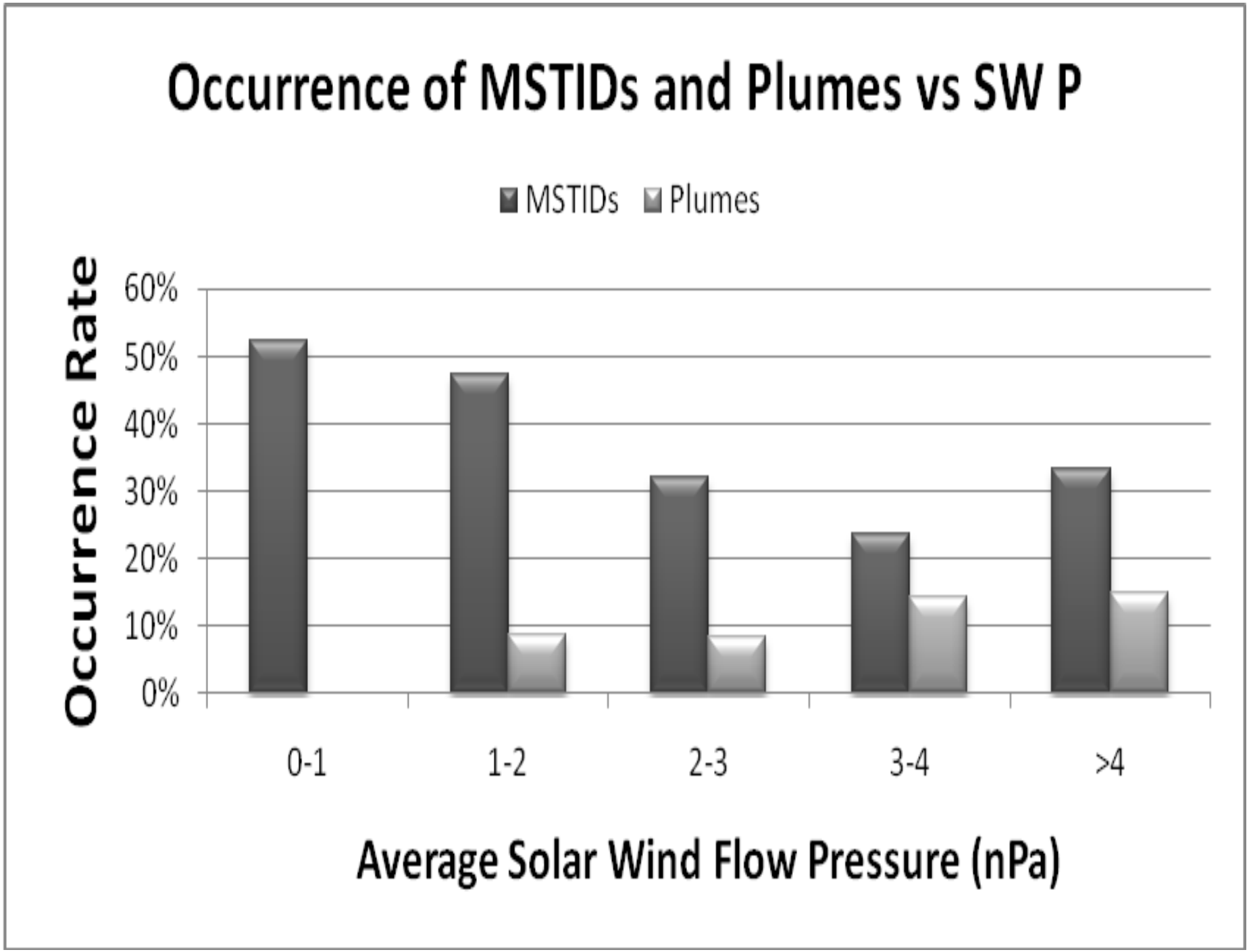

Occurrence of MSTIDs and Plumes vs AE
MSTIDs
Plumes
Occurrence Rate
100%
80%
60%
40%
20%
0%
0-150
150-300
300-450
450-600
>600
Average AE index (nT)

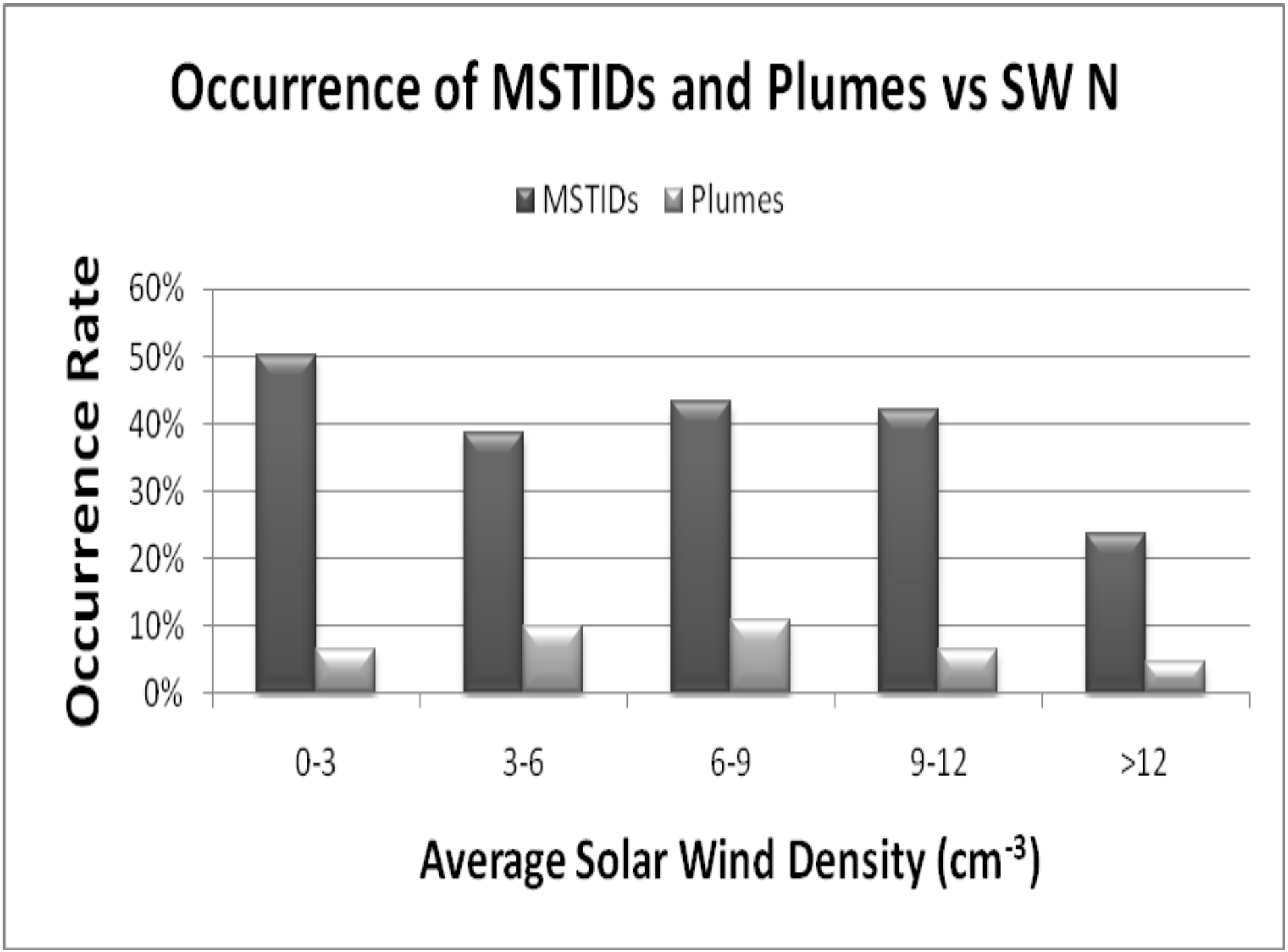

Occurrence of MSTIDs and Plumes vs SW B
MSTIDs
Plumes
Occurrence Rate
100%
80%
60%
40%
20%
0%
0-5
5-10
10-15
>20
Average Interplanetary Magnetic Field (nT)

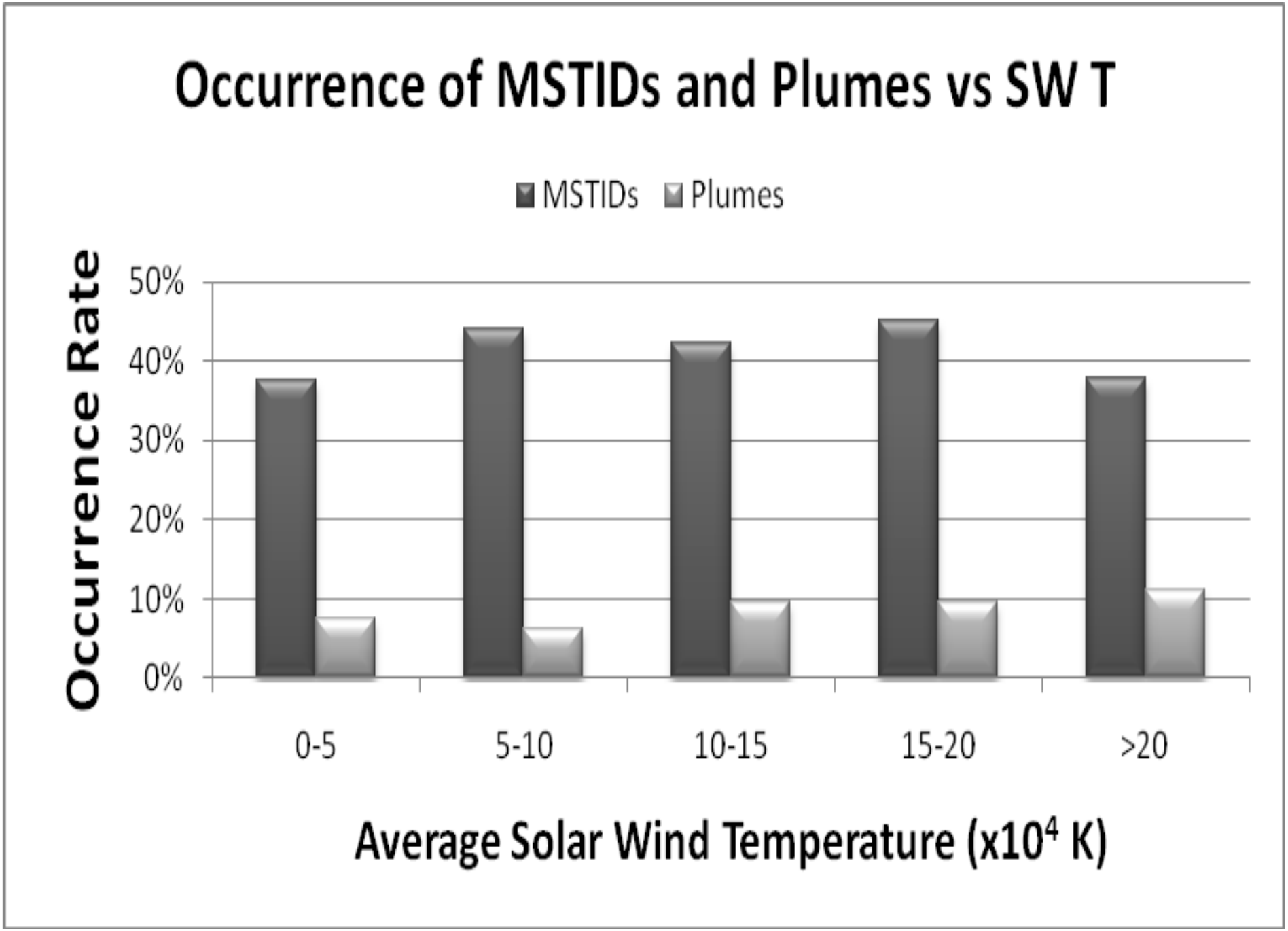

Occurrence of MSTIDs and Plumes vs SW Bz
MSTIDs
Plumes
Occurrence Rate
100%
80%
60%
40%
20%
0%
<-4
[-4,-2]
[-2,0]
[0,2]
[2,4]
>4
Average North-South Interplanetary Magnetic Field (nT)


Occurrence of MSTIDs and Plumes vs SW E
MSTIDs
Plumes
Occurrence Rate
100%
80%
60%
40%
20%
0%
<-1
[-1,-0.5]
[-0.5,0]
[0,0.5]
[0.5,1]
>1
Average Electric Field (mV/m)


Occurrence of MSTIDs and Plumes vs SW V
MSTIDs
Plumes
Occurrence Rate
50%
40%
30%
20%
10%
0%
300-400
400-500
500-600
>700
Average Solar Wind Speed (km/s)


Occurrence of MSTIDs and Plumes vs SW P
MSTIDs
Plumes
Occurrence Rate
60%
50%
40%
30%
20%
10%
0%
0-1
1-2
2-3
3-4
>4
Average Solar Wind Flow Pressure (nPa)


Occurrence of MSTIDs and Plumes vs SW N
MSTIDs
Plumes
Occurrence Rate
60%
50%
40%
30%
20%
10%
0%
0-3
3-6
6-9
9-12
>12
Average Solar Wind Density (cm-3)


Occurrence of MSTIDs and Plumes vs SW T
MSTIDs
Plumes
Occurrence Rate
50%
40%
30%
20%
10%
0%
0-5
5-10
10-15
15-20
>20
Average Solar Wind Temperature (x10^4 K)

Conclusions

- Although individual midlatitude plumes tend to occur during geomagnetic storms, they might also occur during quiet times.

- On the other hand, MSTIDs hardly occur during storms.

- In general, plumes and MSTIDs tend to occur at high and low Kp, Dst (magnitude), solar wind speed, pressure, magnetic and electric field (magnitude), respectively.

- In addition to the occurrence rate, the intensity of MSTIDs and plumes are also affected by the magnetospheric state.

- So, based on the magnetospheric parameters, it might be possible to tell whether an ambiguous depletion event (e.g., in the all-sky or satellite data) is likely a plume or MSTID.

Conclusions

- So, even if these F-region irregularities are seeded at lower altitudes (e.g., by GWs), their occurrences are clearly affected by the condition of the magnetosphere and solar wind.

- Recent studies suggest a connection between ionospheric waves and the solar wind oscillations [4, 5].

- Are various properties of MSTIDs or plumes affected by the magnetospheric state?

- Since parameters measure different parts of the magnetosphere, time delays might reveal the sequence of events from solar wind to ionosphere.

References

[1] Perkins, F. W., Spread F and ionospheric currents, *J. Geophys. Res.*, 78, 218-226, 1973.

[2] Zhou, Q.-N., J. D. Mathews, C. A. Miller, and I. Seker, The evolution of nighttime mid-latitude mesoscale F-region structures: A case study utilizing numerical solution of the Perkins instability equations, *Planetary and Space Science*, **54**, 710-718, 2006.

[3] Makela, J. J., A review of imaging low-latitude ionospheric irregularity processes, *J. Atmos. Solar-Terr. Phys.*, 68, 1441-1458, 2006.

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[5] Livneh, D. J., I. Seker, F. T. Djuth, and J. D. Mathews, Omnipresent vertically coherent fluctuations in the ionosphere with a possible worldwide-midlatitude extent, *J. Geophys. Res.*, doi:10.1029/2008JA013999, 2009.

Acknowledgements

This research was supported by an appointment to the NASA Postdoctoral Program at the Goddard Space Flight Center, administered by Oak Ridge Associated Universities through a contract with NASA.

The relation between gravity waves in the E-region and plasma depletion bands in the F-region observed with an all-sky imager at Arecibo Observatory

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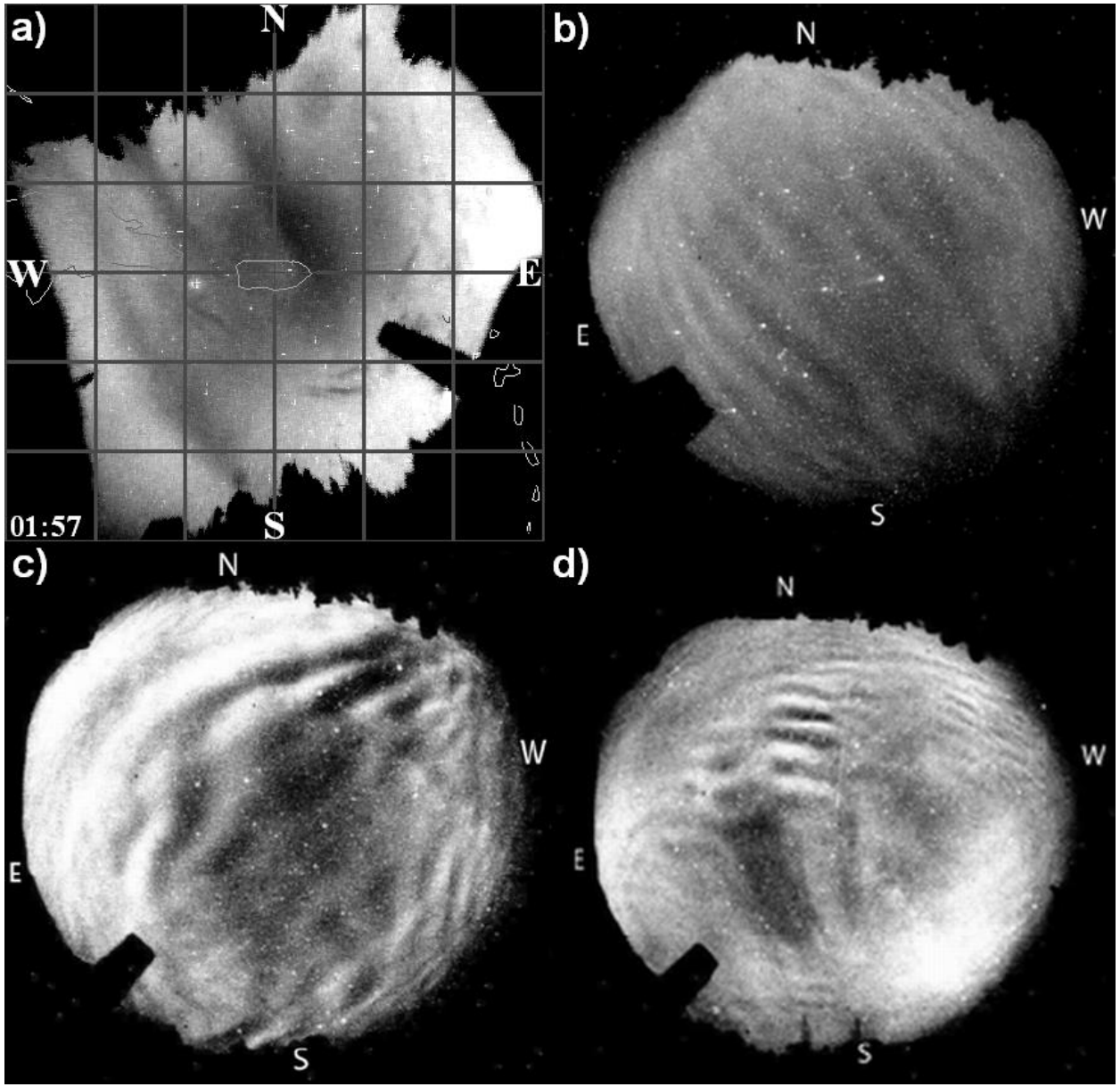
Introduction

	MSTIDs	Gravity Waves
Structure	Parallel bands	Waves, Ripples
Region	F-region	Mesosphere
Alignment	Northwest-southeast	Any direction
Propagation	Toward southwest	Any direction
Wavelength & period	~200 km, ~1 hr	~20 km, ~10 min
Theory	Perkins Instability	Gravity Wave Theory
Occurs when Kp is	Low	Any Kp
Airglow λ	**630 nm**	**557.7 nm**
Airglow height	200-300 km	90-105 km
Airglow chemistry	$O^+ + O_2 \rightarrow O_2^+ + O$ Charge Exchange $O_2^+ + e^- \rightarrow O^* + O$ Dissociative Recombination	$O + O + M \rightarrow O_2^* + M$ $O_2^* + O \rightarrow O_2 + O^*$ $O^* \rightarrow O + h\nu$

Introduction

MSTIDs



Regular GW

Turbulent GW

Ripple GW

Method

Number of nights	MSTIDs	No MSTIDs
GWs	A	C
No GWs	B	D

T = A+B+C+D = total number of nights
M = A+B = MSTID occurrences
W = A+C = GW occurrences
A = both MSTID and GW
B = only MSTID, no GW
C = only GW, no MSTID
D = neither MSTID nor GW

Occurrence Rates	MSTIDs	GWs
Dependent	$Rm_d = A/W$	$Rw_d = A/M$
Independent	$Rm_i = M/T$	$Rw_i = W/T$

$$\mathbf{C_{MW}} = Rm_d/Rm_i = Rw_d/Rw_i = AT/MW$$

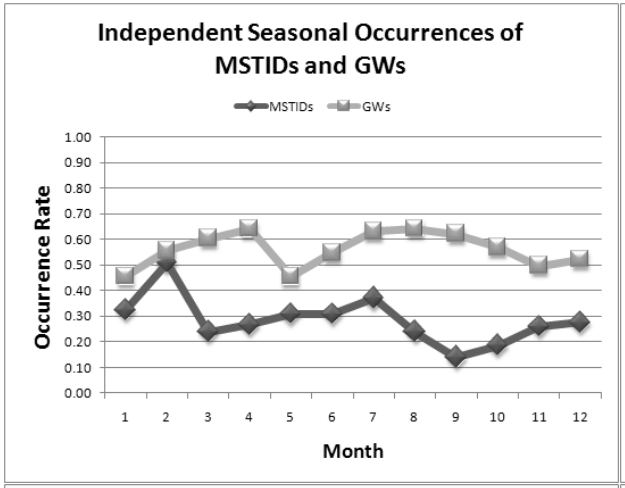
$C_{MW} > 1$ => positive correlation
$C_{MW} < 1$ => negative correlation
$C_{MW} \sim 1$ => no correlation

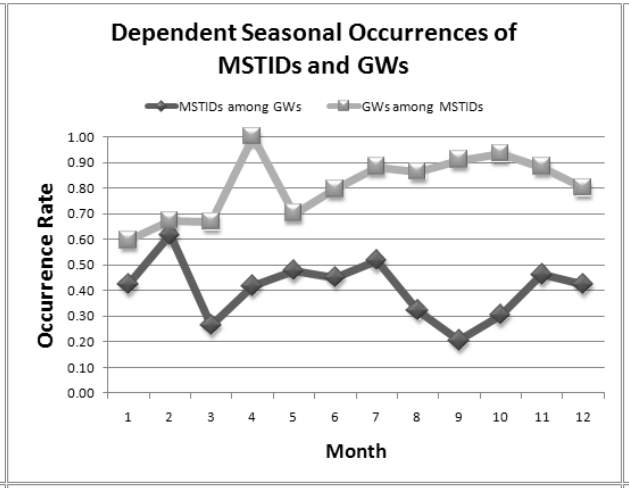
Results

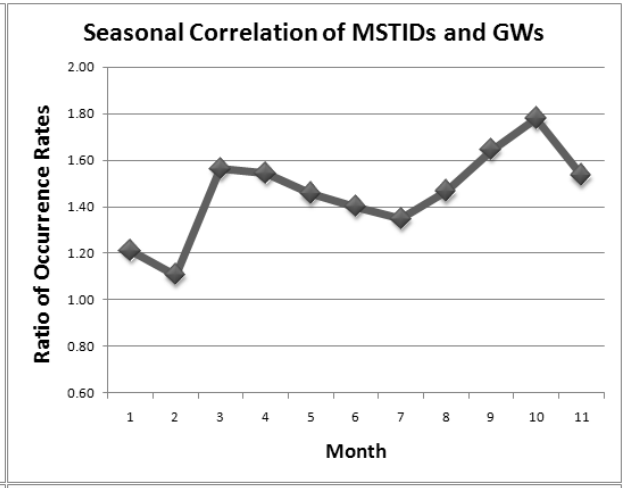
Number of Nights	MSTIDs	No MSTIDs	
GWs	283	403	686
No GWs	80	480	
	363		Total=1246

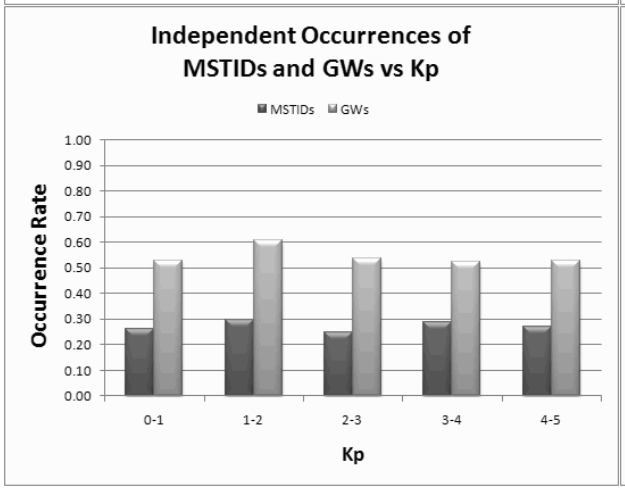
Occurrence Rates	MSTIDs	GWs
Dependent	$Rm_d = 41\%$	$Rw_d = 78\%$
Independent	$Rm_i = 29\%$	$Rw_i = 55\%$

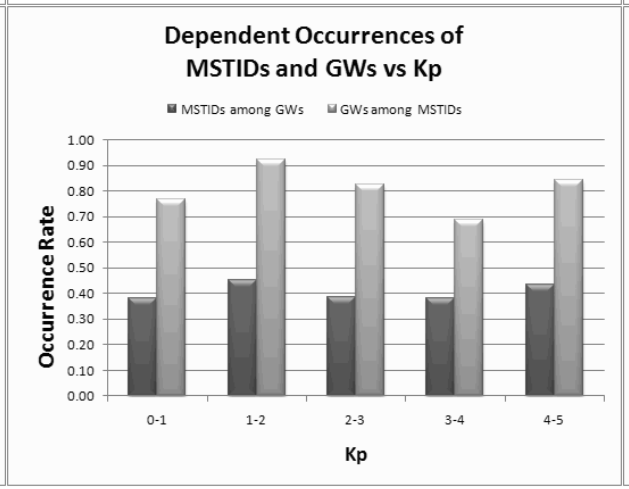
$$C_{MW} = 1.42 = Rm_d/Rm_i = Rw_d/Rw_i$$

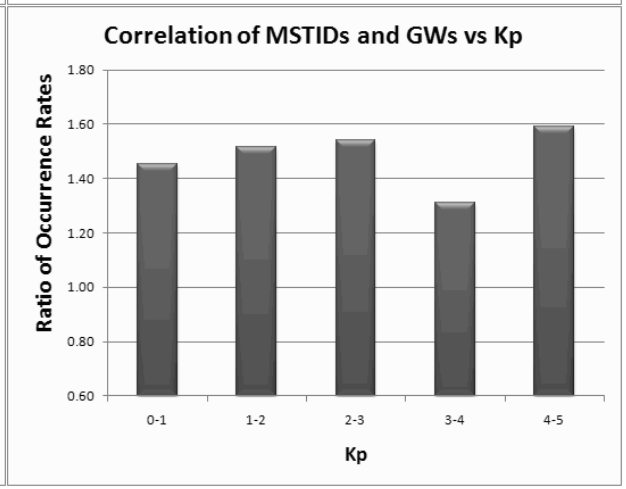




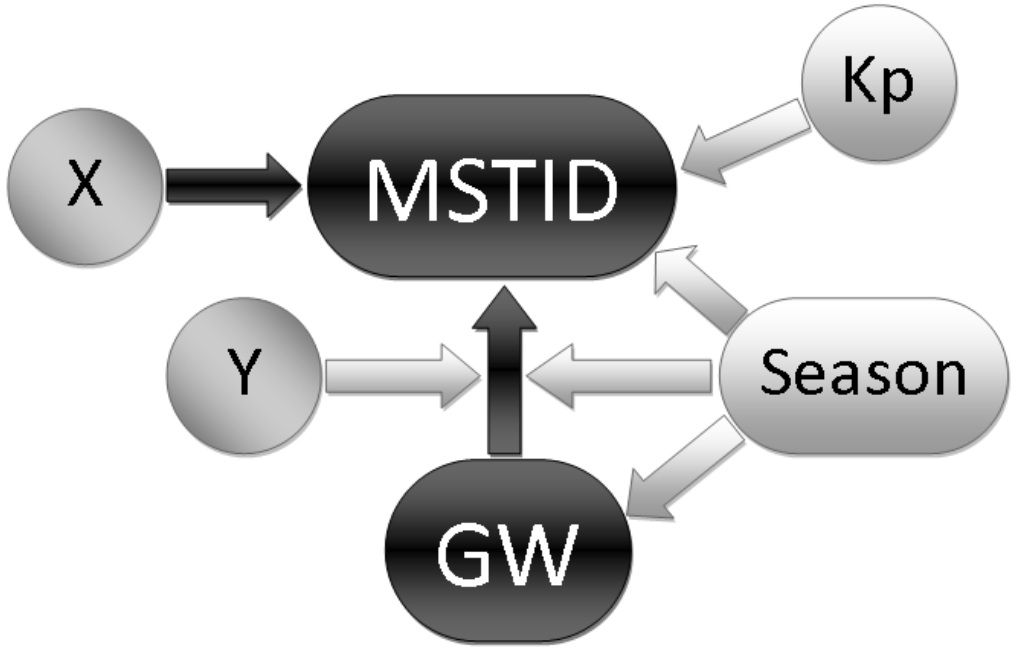








Discussion



X ➔ auroral GWs, tides, and oscillations in solar wind/magnetosphere

Y ➔ intensity, wavelength, orientation of GWs, neutral winds, E-field.

Discussion

Physical Mechanism

➔ GWs with $\lambda_Z > 200$ km can propagate up to the F-region.

- The neutral GWs are generated in the troposphere by local sources.
- These neutral GWs then propagate vertically up to the local mesosphere.
- GWs then transfer their energy to the E-region plasma via ion-neutral collisions causing perturbations in the plasma which appear as GWs in the airglow images.
- This modulated E-region plasma electrodynamically couples to the F-region plasma causing seed perturbations in the F-region.
- These perturbations then obey mid-latitude F-region electrodynamics (such as the Perkins Instability) and form plasma irregularities (such as MSTIDs).