# Risk of false alarms in ICMEs, IMF and solar wind predictive capabilities of the major geomagnetic and ionospheric storms


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# Introduction

Numerous studies of geo-effectiveness of the solar and interplanetary parameters testify on their limited predictive capabilities.

For example, results by *Alves et al. [JGR, 111, A07S05, 2006]* show that 33% of Corotating interaction regions (CIRs) are followed by moderate / intense magnetic activity (Dst <-50 nT), i.e., approximately one third of the CIR events observed near Earth are geo-effective while 67% of observed CIRs could be a source of the false alarms in Dst storm predictions.

The present study is focused on estimates of efficiency of the ICME's, IMF and the solar wind SW impact on the evolution of the geomagnetic storm and ionospheric TEC storm with its positive phase (Vp) and negative phase (Vn).

# Introduction (cont.)

The ionospheric activity is analyzed with daily-hourly V(TEC) index maps produced from Global Ionospheric Maps, GIM-TEC, for 1999-2015.

The geomagnetic storms affecting the ionosphere are determined with relevant thresholds of AE, aa, ap, ap(τ) and Dst indices. The *ap(τ)* is the mean weighted value of *ap* index *[Wrenn, JGR, 92, 10125,1987]*:

$ap(\tau) = (1 - \tau)(ap_0 + ap_{-1}\tau + ap_{-2}\tau^2 + \ldots)$, T = 11h or $\tau = \exp(-3/T) \approx 0.76$

The ICME list of 409 events [*Richardson and Cane, Solar Phys., 264, 189-237, 2010*] during 1999-2015 is associated with 3 categories of geomagnetic activity: (1) intense storms; (2) moderate disturbance; (3) quiet state.

Risk of the false alarms in using the ICME, IMF, SW and SSC parameters for the geomagnetic and ionospheric storm predictions is evaluated.

# Metrics of the ionosphere storms

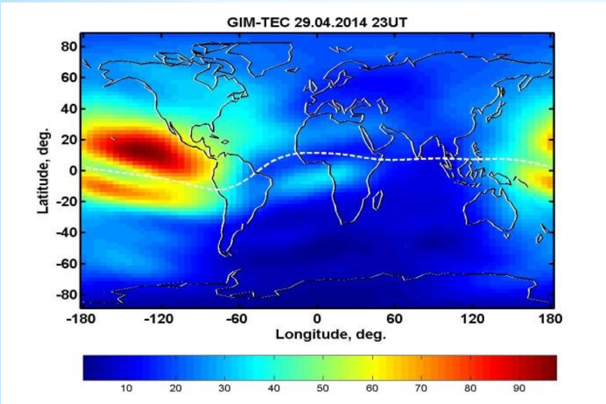
- The source JPL Global Ionosphere Maps GIM-TEC for 1999-2015 in IONEX format (-87.5:2.5:87.5°N in latitude, -180:5:180°E in longitude) are analyzed.
- Using sliding-window statistical analysis, moving daily-hourly TEC median $\mu$ for -15 preceding days with estimated variance bounds is obtained at GIM-TEC cell
- $\sigma$ - root-mean square TEC deviation for particular UT hour at the map cell regarding quiet reference median $\mu$
- The ionospheric disturbance

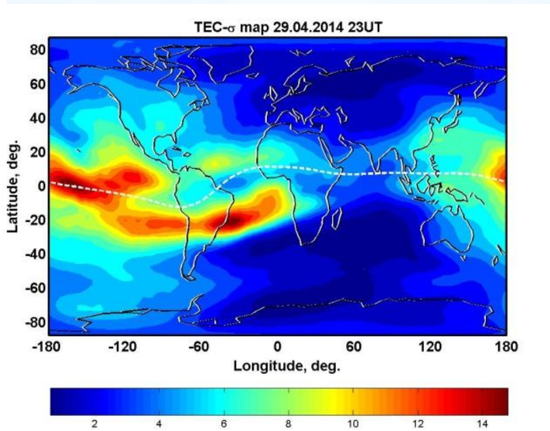
$$V(TEC) = \Delta TEC/\sigma, \quad \Delta TEC = TEC - TEC_\mu$$

- TEC enhancement/diminution is defined by the positive/negative V index.
- TEC storm occurs when an instant TEC is outside of $\mu \pm 1\sigma$
- Relative occurrence density (%) of clouds of positive TEC storm, Vp, at $TEC > \mu+1\sigma$ and large-scale troughs of ionization , Vn, at $TEC < \mu-1\sigma$ are represented by the number of cells with TEC enhancement (m1) /diminution (m2) normalized by the total number of cells (m3) on a map:

$$Vp = m1/m3 \times 100\%, \quad Vn = m2/m3 \times 100\%$$

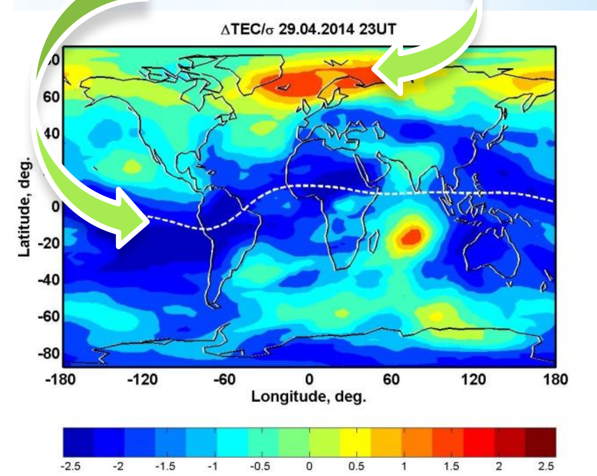
# Global maps of GIM-TEC, TECσ, and V(TEC) storm on 29.04.2014 23:00 UT after ICME/SSC

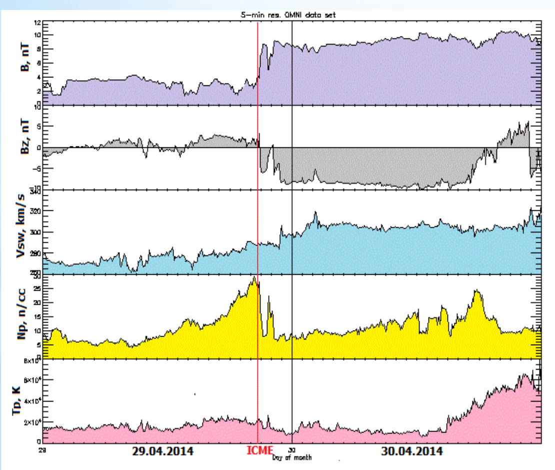


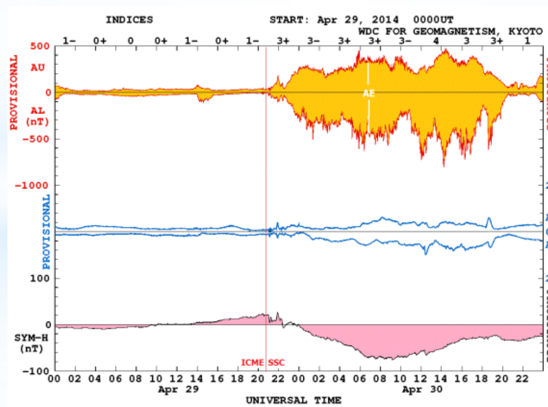

Trough

Cloud



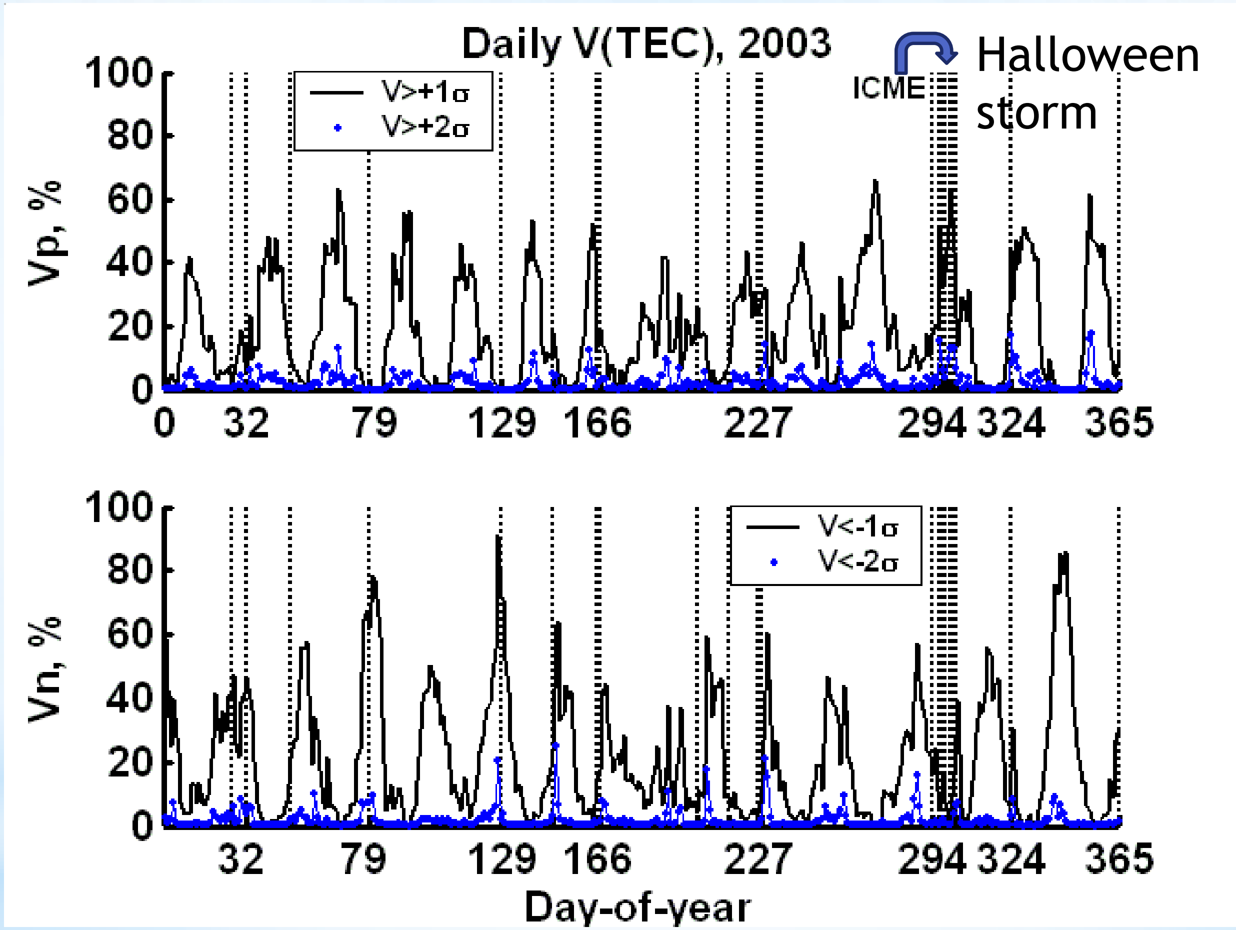

OMNI IMF and SW indices




Geomagnetic indices

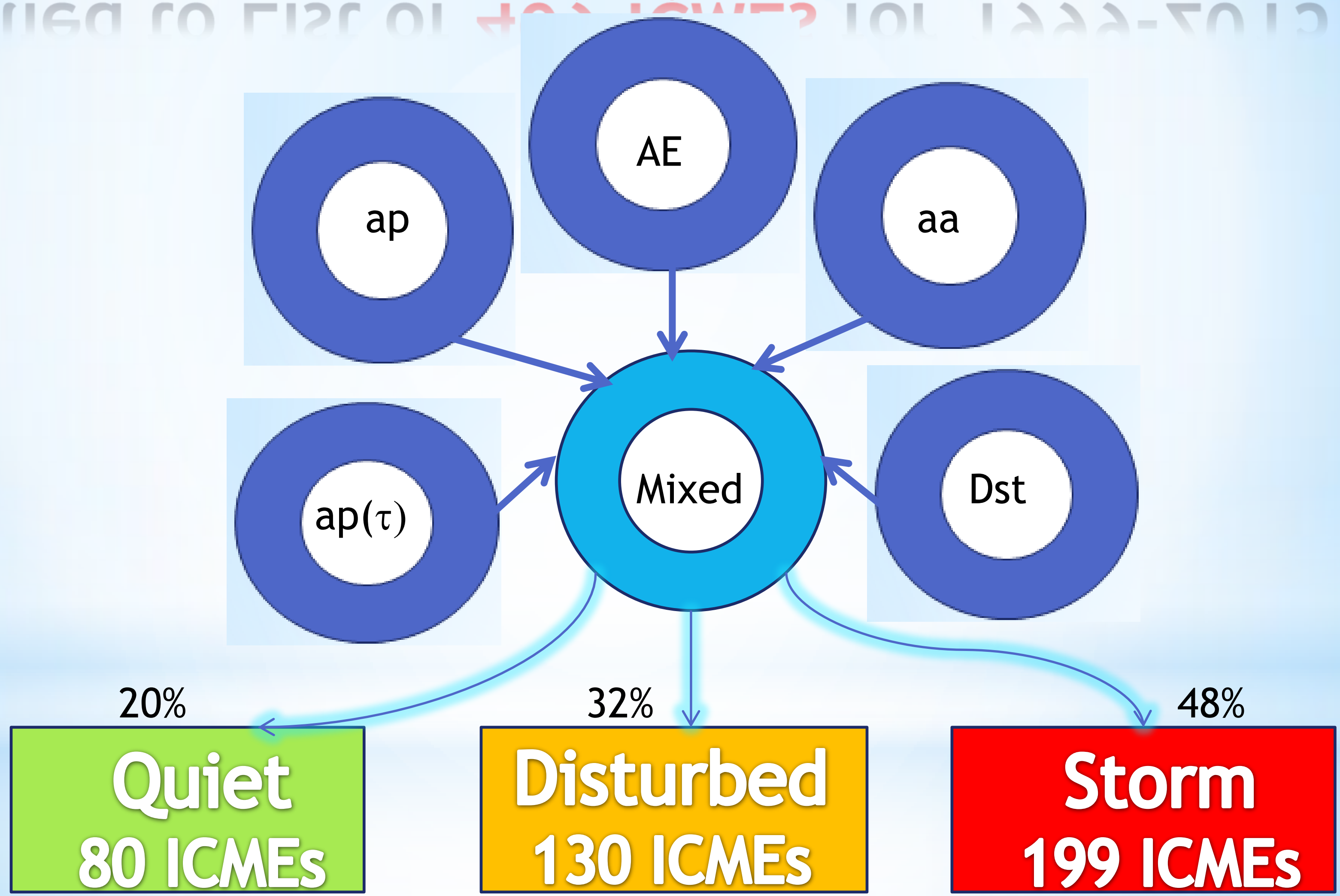
ICME/SSC on
04/29/2014 20:00:00 UTC
[*The ISEST Event List*]
[*ICMEs List 1996-2016*]
[*SSC.dat*]

# Daily Vp, Vn indices during 2003



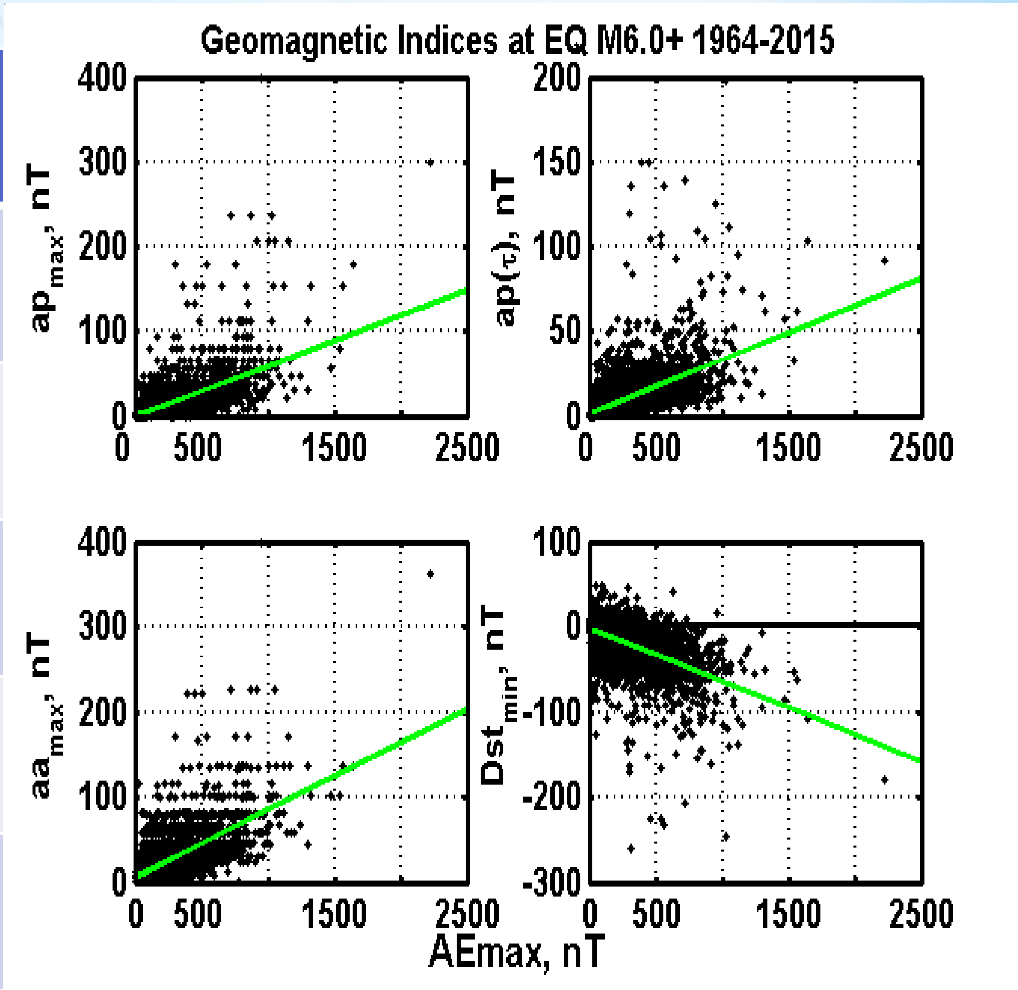

ICME days - grid on, including Halloween storm 29-30 October, 2003.

# Combined criteria of geomagnetic activity applied to List of 409 ICMEs for 1999-2015



# Thresholds for three categories of geomagnetic activity

| Index, nT | Storm | Disturb | Quiet |
|---|---|---|---|
| AE-max | 1000+ | 500:999 | <500 |
| aa-max | 90+ | 45:89 | <45 |
| ap-max | 60+ | 30:59 | <30 |
| ap(τ)-max | 28+ | 14:27.9 | <14 |
| Dst-min | ≤-100 | -99:-50 | >-50 |

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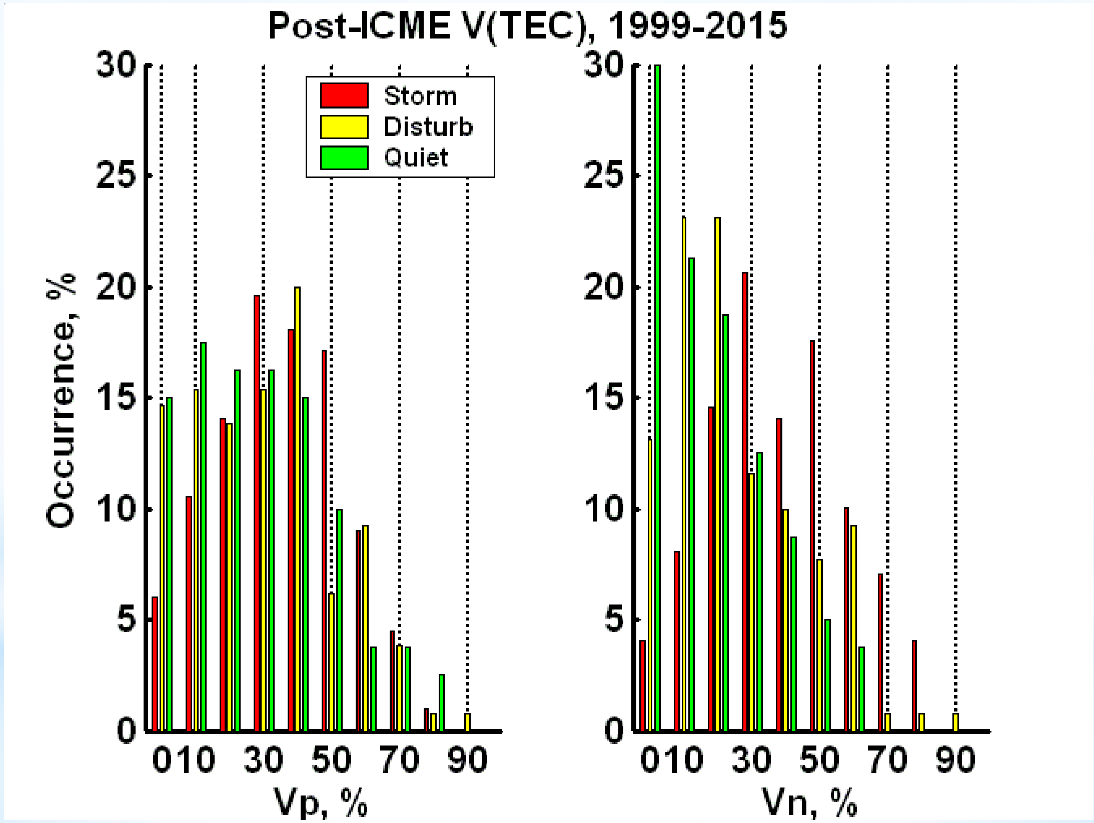
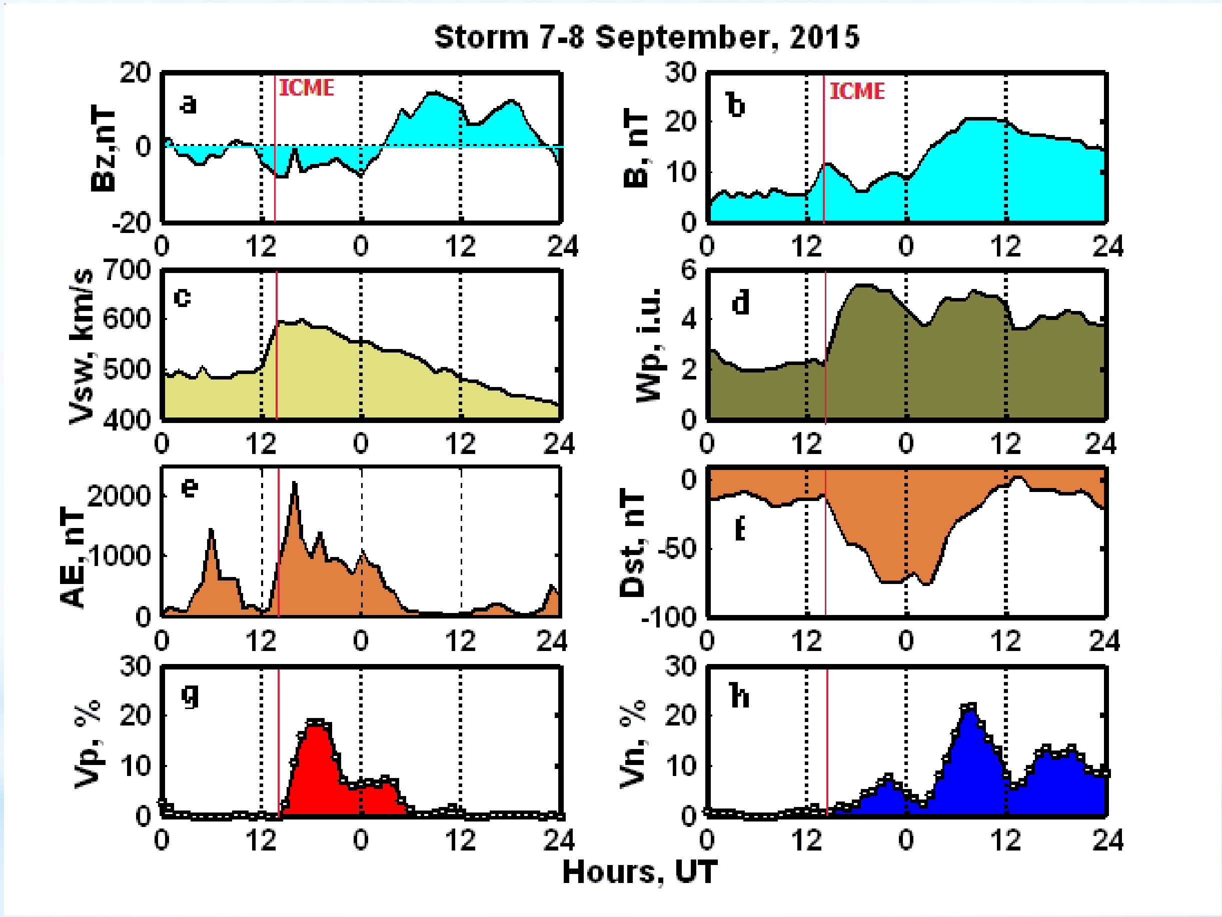
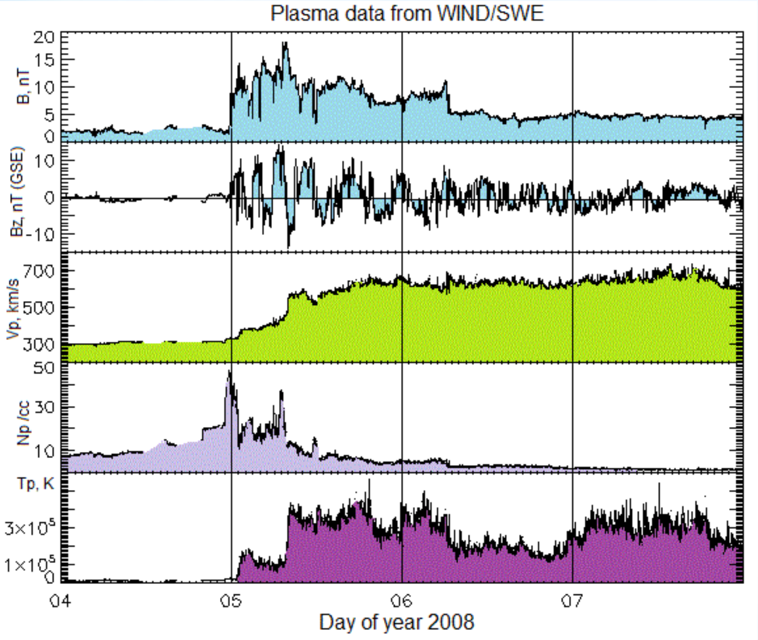
# Histogram of percentage occurrence of Post-ICME Vp index (left) and Vn index (right) for three categories of geomagnetic activity

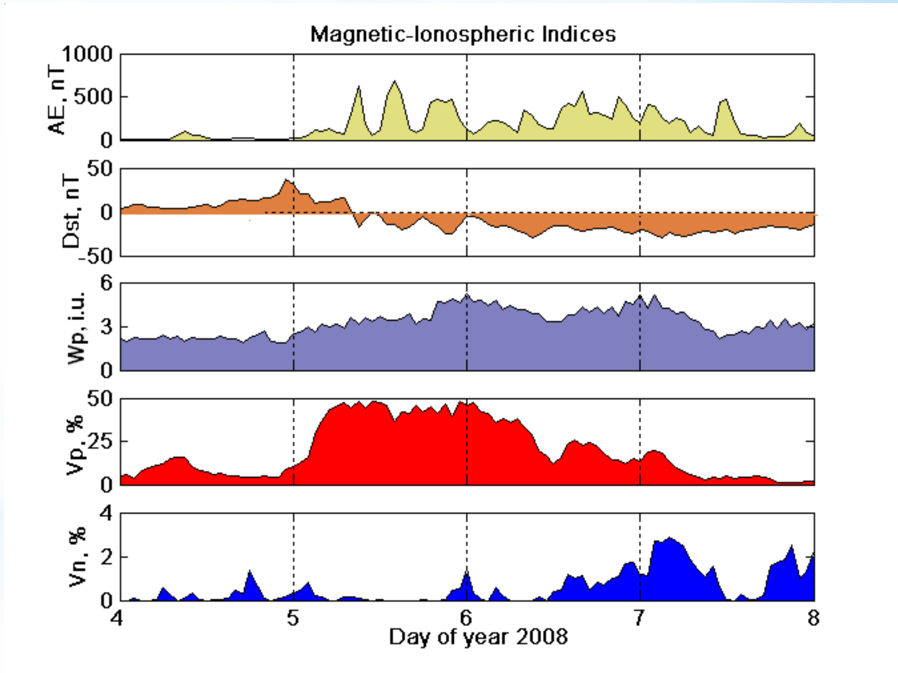


# Example of Vp, Vn indices during storm with ICME precursor at solar maximum 7-8.09.2015

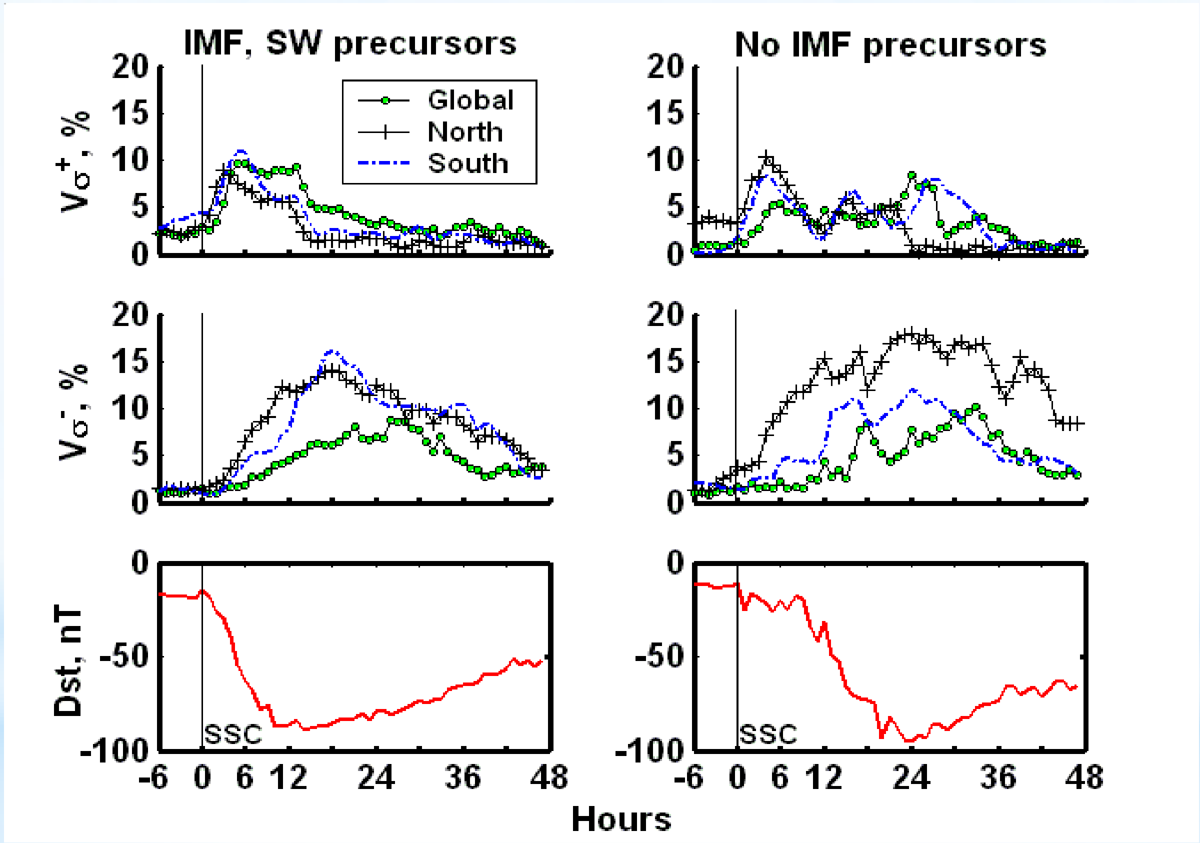


# Example of Vp, Vn storm with IMF B, dB/dt, Np and Tp increments but ICME is missing at solar minimum 4-7.01.2008



# Typical profiles of ionospheric storm Vp and Vn indices and Dst storm during [$t_0$-6h:$t_0$+48h], $t_0$=0 at SSC. Left – with IMF and SW precursors, right – none IMF and SW precursors.




Vp and Vn global occurrence; North and South high latitudes (dip > ±60°).

# Efficiency and risk of false alarms of ICME precursors for the intense storms of AE≥1000 nT, Dst≤-100 nT, and planetary TEC storms

Efficiency of ICME and other precursors, Ef:

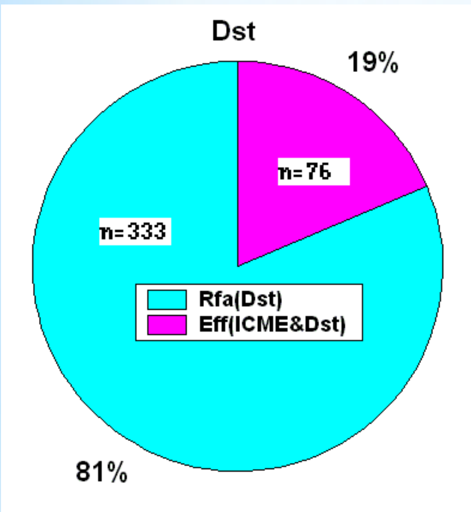
*Ef = n1 /n2* (1)

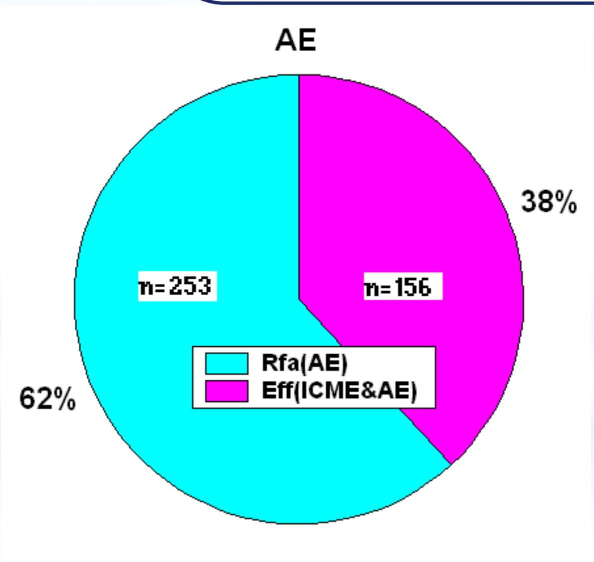
Risk factor of false alarm, Rf, %:

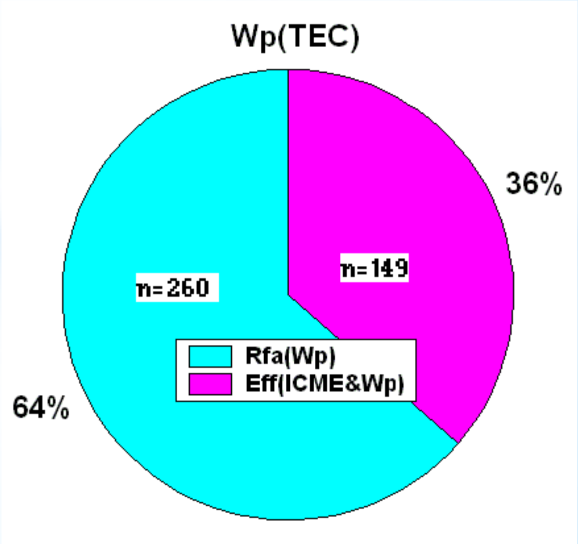
*Rf = (n2 – n1)/n2×100%* (2)

*n1 – number of Storms-with-Precursors*

*n2 – total number of Precursors*




Risk of false alarms:

***Rf(ICME, Dst) = 81%***

***Rf(ICME, AE) = 62%***

***Rf(ICME, TEC)= 64%***

# Criteria for IMF and SW precursors of the intense storm of AE>1000 nT, Dst<-100 nT, V(TEC) index

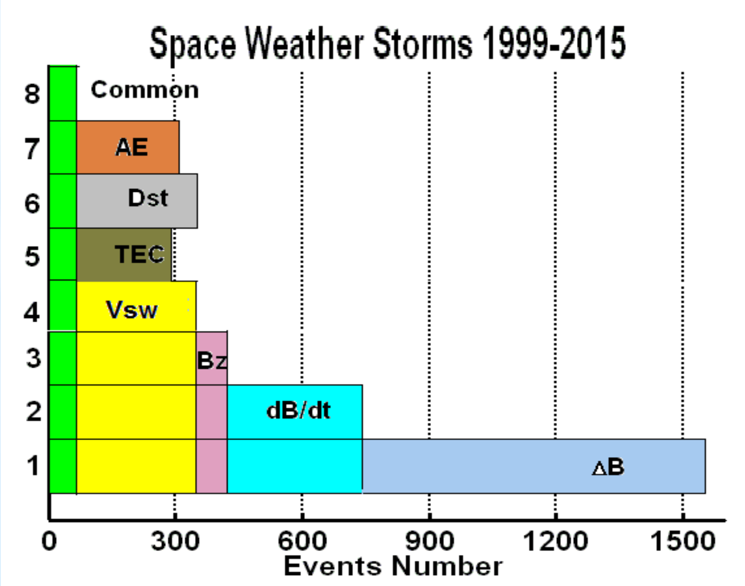
The storm onset ($t_0$ =0) is determined from IMF and SW parameters with the following thresholds [*Tsagouri and Belehaki, 2006; Yenen et al., 2015; Gulyaeva, 2015*] :

(1) IMF ΔB is increased by ΔB ≥ 3 nT for 3h [$t_0$ , $t_0$ +1h : $t_0$ +2h]

(2) max dB/dt ≥ 3 nT/h during [$t_0$ : $t_0$ +6h]

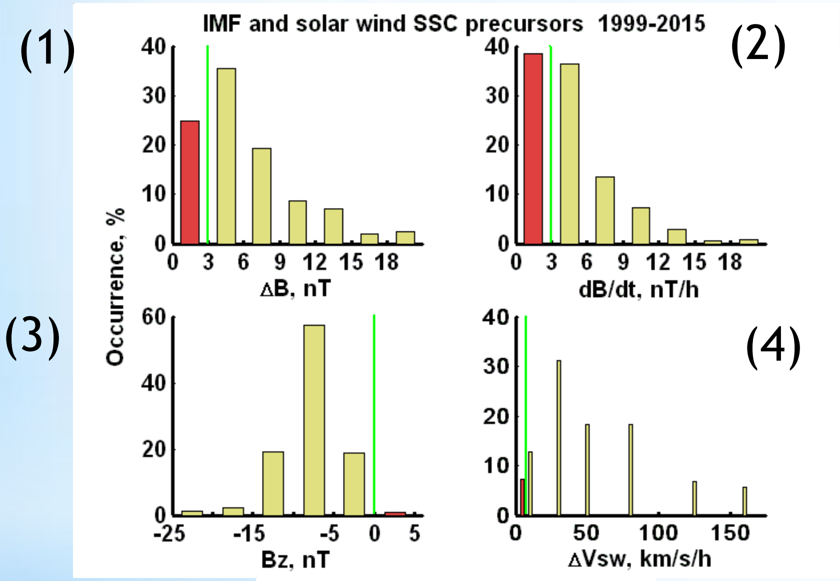
(3) Bz<0 at $t_0$ or after the storm onset [$t_0$ : $t_0$ +6h]

(4) The solar wind acceleration **dVsw/dt** > 5 km/s/h during [$t_0$ : $t_0$ +6h]

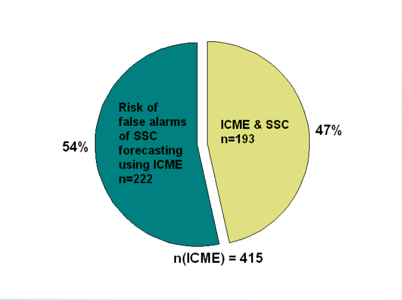



**The list of intense geomagnetic and ionospheric storms is decreasing in process of combining impact (1)+(2)+(3)+(4) of IMF and SW precursors**

# Occurrence of 457 SSCs during 1999-2015 for specified (1)-(4) precursors of IMF, SW and ICME; $t_0$ = 0 - time of SSC.




Red – SSC happens while IMF and SW precursors are missing: (1) -111 SSC; (2) -171 SSC; (3) -4 SSC; (4) -32 SSC. Yellow – SSC associated with IMF and SW precursors. Green line – IMF and SW storm threshold.




Proportion of ICME and SSC events:
Green : ICME events without SSC
Yellow: ICME associated with SSC

# Efficiency of IMF and SW precursors for the intense geomagnetic and ionospheric storms

n1 – number of storms-with-precursors (SSC, Dstmin≤ –100 nT, AEmax>1000 nT, positive TEC storm Vp>50% and negative TEC storm Vn>50%;

n2 – Number of IMF and SW precursors and their combination

Efficiency factor: Ef = n1 / n2   (Eqn.2)

| Precursors | SSC to+12h | AE to+12h | Dst to+24h | Vp to+12h | Vn to+24h |
|---|---|---|---|---|---|
| IMF ∆B ≥ 3 nT (1) n2=1556 | 0.213 n1=332 | 0.105 n1=164 | 0.064 n1=100 | 0.247 n1=385 | 0.114 n1=172 |
| dB/dt ≥ 3 nT/h (1+2) n2=226 | 0.212 n1=48 | 0.164 n1=37 | 0.119 n1=27 | 0.248 n1=56 | 0.133 n1=30 |
| Bz<0 (1+2+3) n2=201 | 0.219 n1=44 | 0.169 n1=34 | 0.129 n1=26 | 0.269 n1=54 | 0.139 n1=28 |
| ∆Vsw> 5 km/s/h (1+2+3+4)n2=196 | 0.224 n1=44 | 0.173 n1=34 | 0.133 n1=26 | 0.276 n1=54 | 0.138 n1=27 |

1line – condition (1); $2^{nd}$ line – combined conditions (1+2); $3^{rd}$ line – conditions (1+2+3); $4^{th}$ line – conditions (1+2+3+4) at IMF and SW

# Conclusions

1. Analysis of ICMEs, IMF and SW precursors shows their limited predictive capabilities for the major geomagnetic and ionospheric storms.
2. Combined specification of geomagnetic activity with AE, aa, ap, ap(τ) and Dst indices with relevant thresholds is allowed referring to ICME events of three categories: (1) quiet conditions; moderate disturbance; and the major geomagnetic storm with relevant thresholds.
3. Percentage of false alarms for major Dst storms (Dstmin≤-100 nT) with ICME precursors is 81%, the AE storms (AEmax≥1000 nT) is 67%, and the planetary TEC storms - 64%.
4. The intense ionospheric storms in positive storm phase (Vp) and/or negative storm phase (Vn) are derived from the global ionospheric maps GIM-TEC during 1999-2015.
5. Typical efficiency of IMF and SW precursors to induce the SSC events, major geomagnetic and ionospheric storms varies from 0.1 to 0.3 so the risk of false alarms can happen for the rest of the IMF and SW events.

# Acknowledgements

GIM-TEC maps are provided by Jet Propulsion Laboratory at:
ftp://sideshow.jpl.nasa.gov/pub/iono_daily/
Geomagnetic AE, ap, and Dst indices are provided by WDC for Geomagnetism at:
http://wdc.kugi.kyoto-u.ac.jp/
Geomagnetic aa indices are provided by WDC for STP at RAL:
http://www.ukssdc.ac.uk/
The ICMEs Catalogue compiled by **Ian Richardson and Hilary Cane** is available at
http://www.srl.caltech.edu/ACE/ASC/DATA/level3/icmetable2.htm
The solar wind and IMF data are provided at OMNI web:
http://omniweb.gsfc.nasa.gov/
The geomagnetic SSC Catalogues is provided by WDC
ftp://ftp.space.dtu.dk/WDC/indices/kp-ap/ssc.dat
The Ionospheric indices and Catalogues of storms are available at IZMIRAN web:
http://www.izmiran.ru/services/iweather/
http://www.izmiran.ru/services/iweather/storm/
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# Thank you!