Extreme Space Weather events of Colaba: Estimation of interplanetary conditions.

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SCOSTEP
Scientific Committee on Solar-Terrestrial Physics

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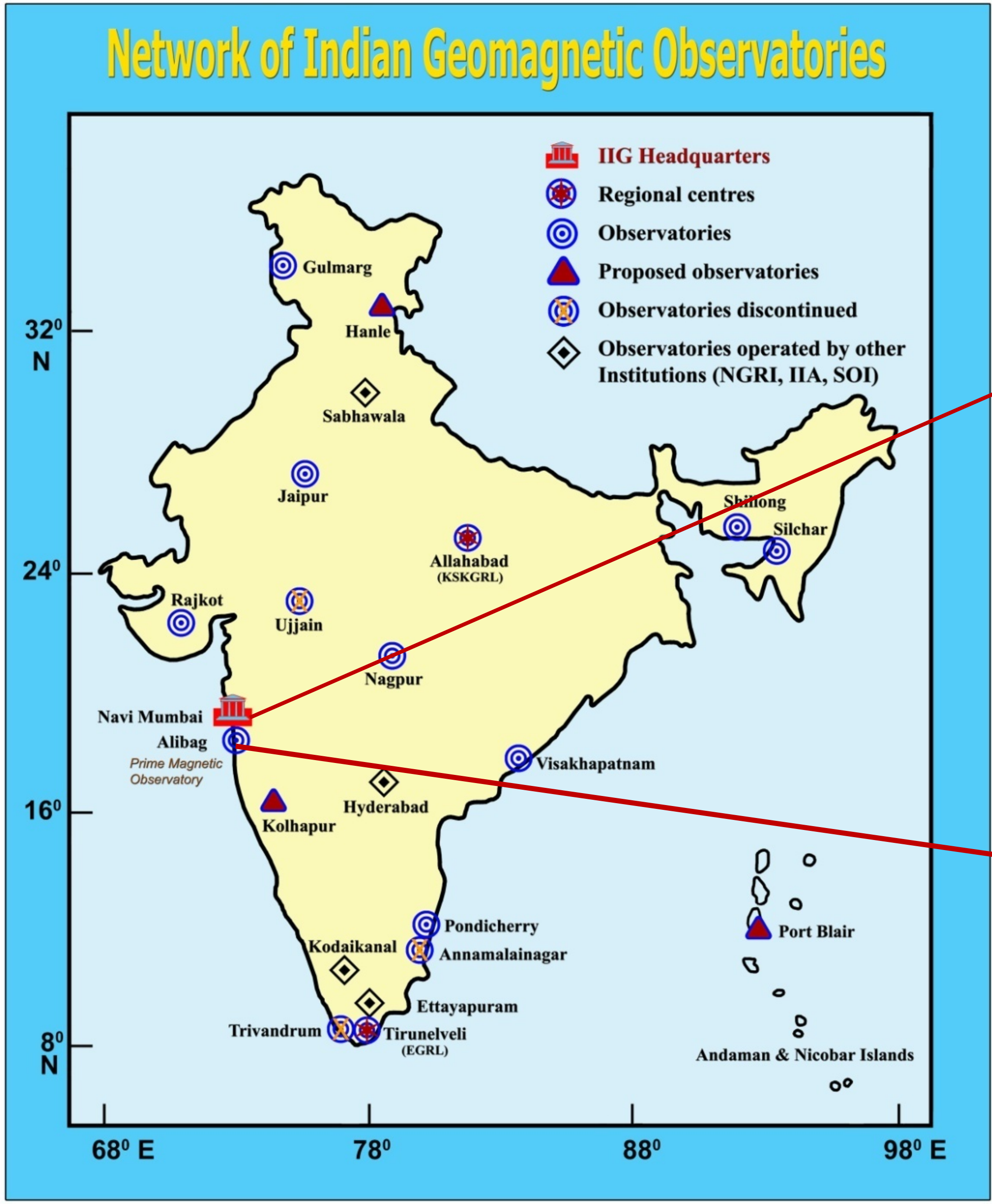
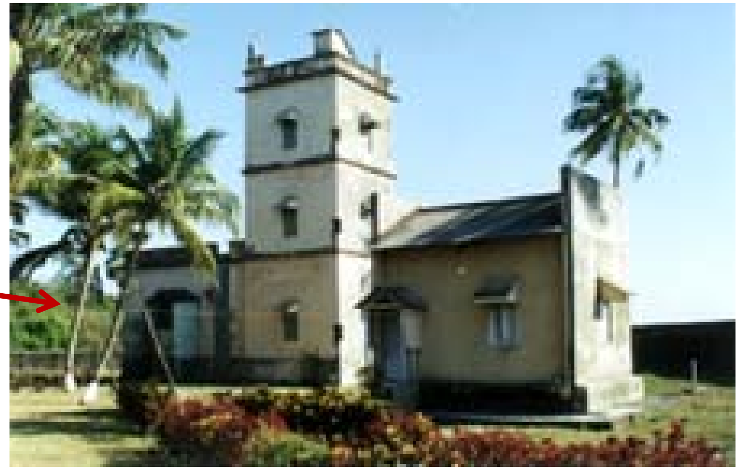
ICSU
WORLD DATA SYSTEM

Out line

- WDC- Mumbai : Activities
- Colaba - Bombay old magnetic records
- Extreme Space weather events – Geomagnetic storms
- Solar and Interplanetary drivers, estimation of interplanetary conditions.
- Some characteristics of Severe magnetic storms of solar cycle 23
- summary



Colaba observatory, Bombay
1846-1904



Indian magnetic observatory at Alibag, established in 1904....

History of Geomagnetism in India

The Indian Institute of Geomagnetism (IIG) is a premier research Institute actively engaged in basic and applied research in Geomagnetism and allied fields, is the successor to COLABA-ALIBAG observatories.

The Colaba observatory was built at one of the original islands of Mumbai, to support British navigation and shipping interest at its thriving port. The Observatory was set up in 1826; though the regular Geomagnetism and Meteorological measurements were started here in 1841. The Colaba-Alibag observatory has the distinction of having an uninterrupted record of magnetic data since 1841, and the only such observatory in the world.

During (1846-1872) only eye observations were taken and recorded at Colaba whereas photographic recordings of the variations in magnetic elements and absolute observations started between 1872 -1906.

Colaba Observatory

World Data Center- Geomagnetism, Mumbai

- The World Data Centre for Geomagnetism (WDCG), Mumbai was the first World Data Centre in India during 1971 as WDC-C2 (India and Japan) in Asian region as part of World Data Centre system (WDC System) by ICSU.

- It got re-recognised as WDC for geomagnetism, Bombay (Mumbai), INDIA in 1991.

- The WDC Center is the national data depository for geomagnetic data sets in Indian region for international scientific community.

- The data center is responsible for maintaining the data catalog and provide the adequate data storage facility to handle the large geomagnetic datasets (Analog and Digital datasets).

Activities of WDC-Mumbai

- Institute has taken major steps to improve the data quality by incorporating international standards like Intermagnet standards. The Development of various customize data processing and analysis softwares are also taken care, data center also carryout final data checks/mining before converting into final internal data formats like WDC exchange, Intermagnet, IAGA 2000 and IAGA 2002.

- The centre has responsible for preserving data in all forms to ensure they remain usable over time. Also responsible for the Metadata Extraction & preservation from Old Data Volumes.

- It is currently located at the historic Colaba Geomagnetic Observatory. Now 12 magnetic observatories operated by IIG, ranging from the dip equator to the latitude of Sq focus in the Indian longitudinal chain.

- WDC has a long series of geomagnetic records from Indian, as well as international geomagnetic observatories, and is providing its vast magnetic data to the scientific community with the help of WDC–Geomagnetism, Kyoto.

- Recently WDC-Mumbai is inducted into the new ICSU World Data System(WDS) as a Regular Member since April 2014.

Modern Digitization Technology Equipment

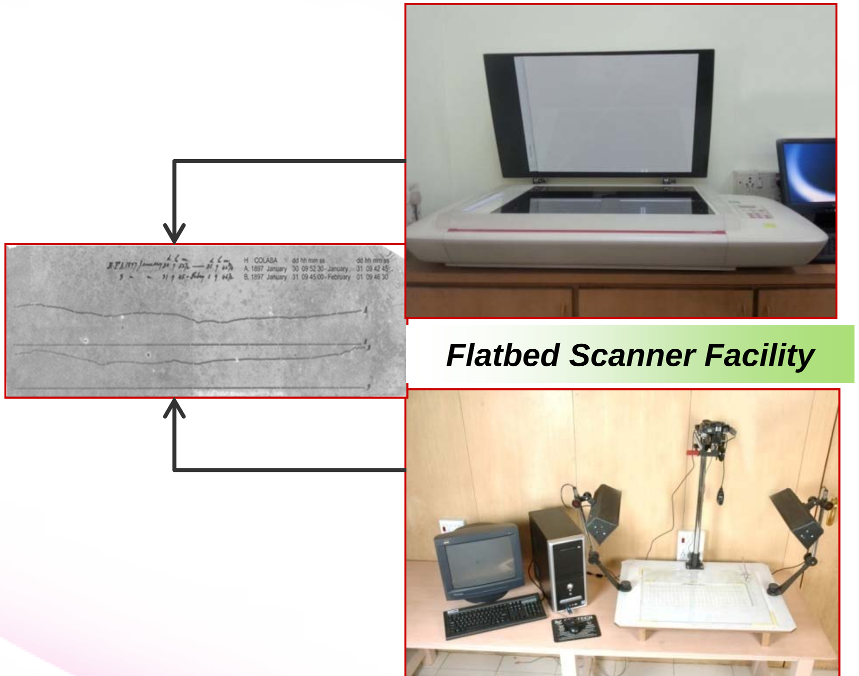
Digital Microfilm Scanner Setup:

Specialized microfilm scanner converts records stored on microfilms / microfiches into the high resolutions digital images

Digital Microfilm Scanner setup

High Resolution Camera & Scanner Setup:

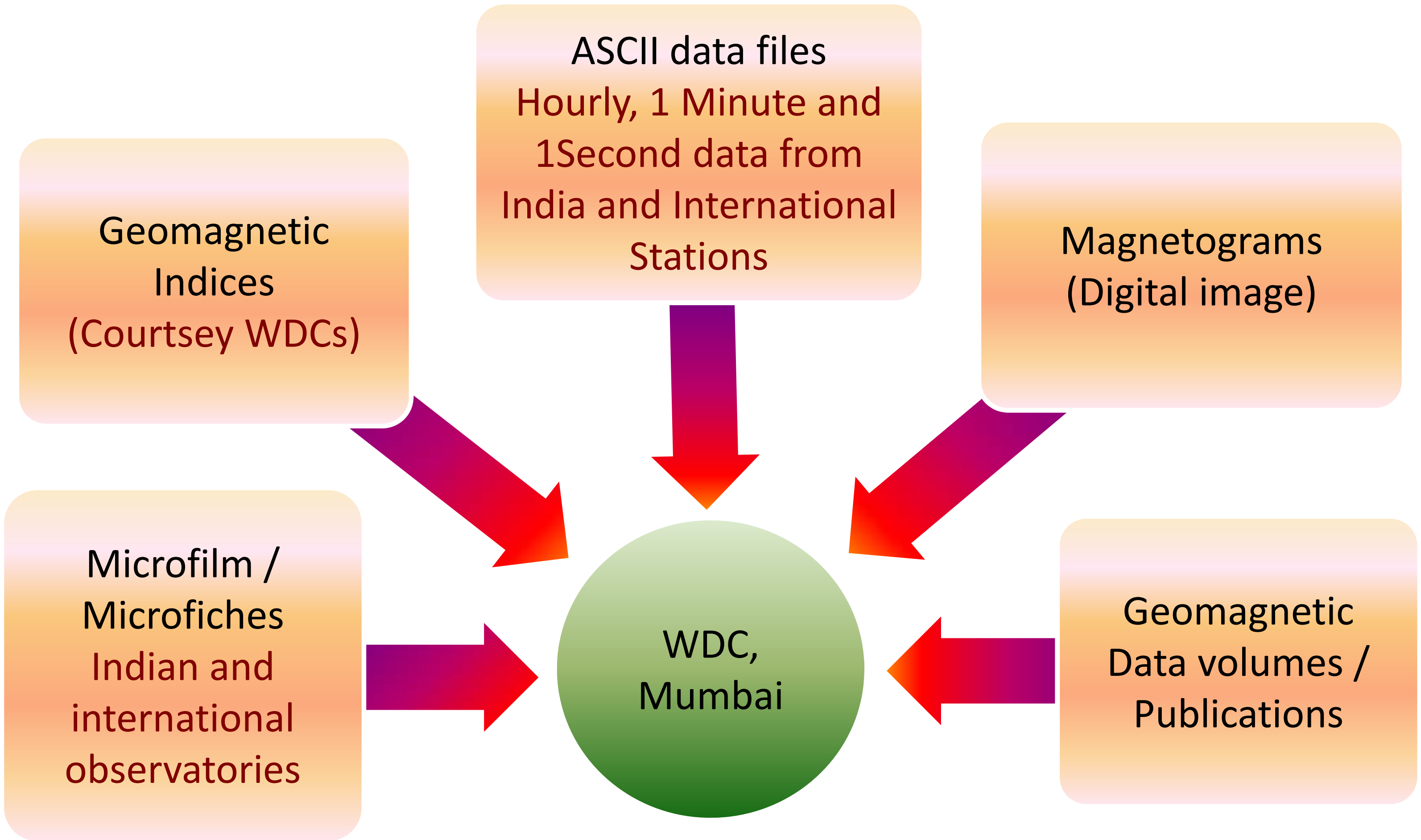
This unit has special high resolution digital camera & Scanner (For high resolution digital images of the magnetograms i.e.photographic records).



Flatbed Scanner Facility

Digital Imaging setup for Magnetograms

Present state of Data at the centre



- Centre is receiving the real-time data from Indian observatories and the real-time plots are displayed on the website (http://wdciig.res.in)
- The center has upgraded it's web portal with more online data services like Quick look plots, Real-Time variation plots, magnetogram images, etc

Preservation of Historic Data

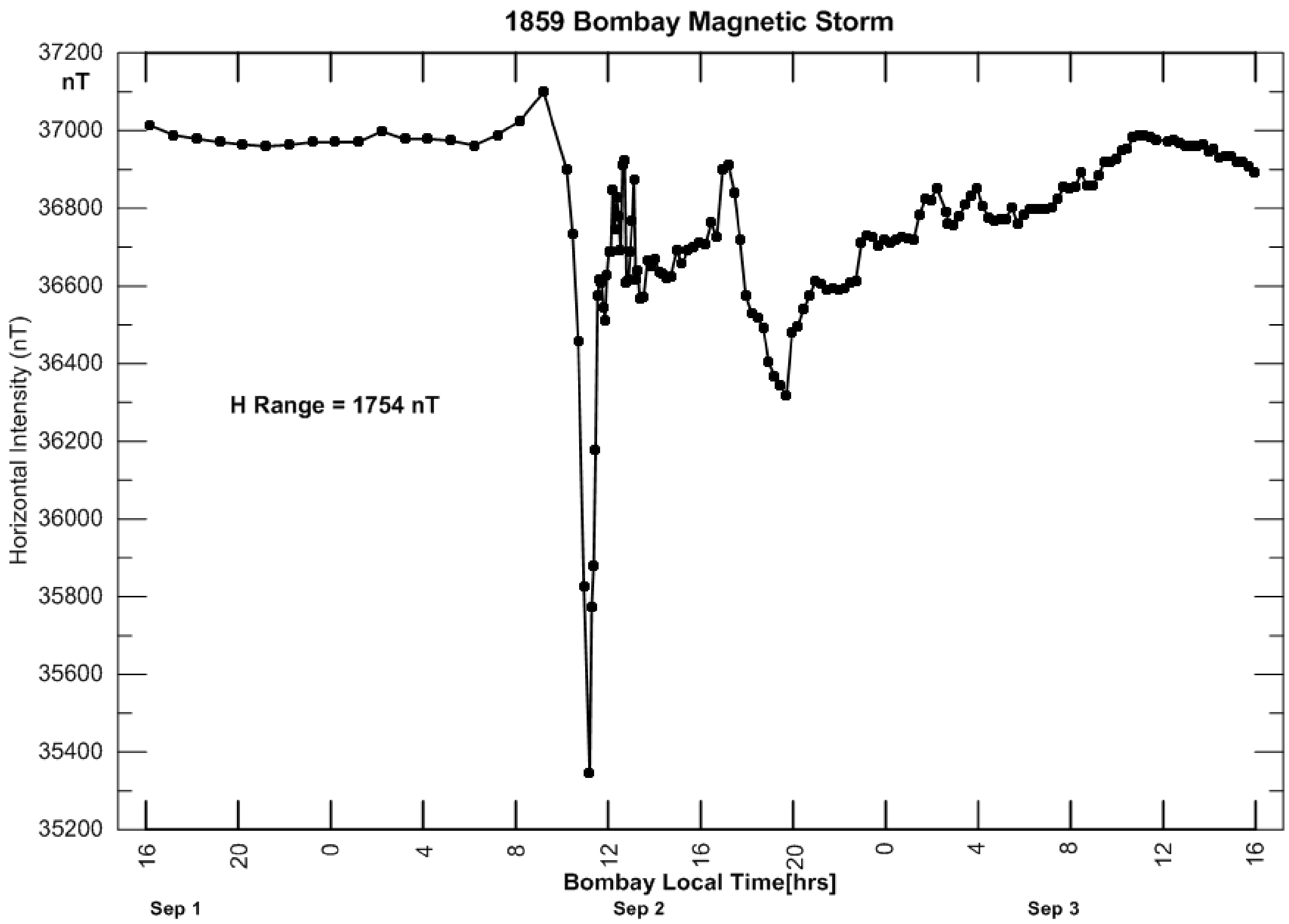
Digitization (Magnetograms)	Imaging		Curative Conservation	Preventive Conservation
	Magnetograms	Volumes		
1890 to 1924 Alibag *(variation Data)*	1872 to1904 Colaba 1905 to 1924 1953 to 1999 Alibag	1845 to1904 Colaba 1905 to1924 Alibag	1859 onwards (Data Volumes)	1894 onwards (Data volumes)
1995-2000 Alibag, Tirunelveli / Trivandrum	2000 to 2010 (ABG, NGP, PON, VSK, TIR)			

•All old data is available on request to

wdc@iigs.iigm.res.in

Key Targets of WDC for Geomagnetism, Mumbai

- New digitization software is developed and will be used to digitize the old analog data in the form of magnetograms prior to year 1900.
- To make available these old valuable geomagnetic datasets for National and International scientific community.
- Improve data sharing and exchange policies to match with WDS standards.
- Collaborate with other WDS members to implement new technologies to fast data handling. To standardize and Implement data storage facilities at the data center.



Solar flare ejecta/CME was the cause of super magnetic storm of September 2, 1859.

Tsurutani, Gonzalez, Lakhina and S. Alex, JGR, 2003

The 1-2 September 1859 Carrington solar flare most likely had an associated intense magnetic cloud ejection which led to a storm on Earth of Dst, 1760 nT.

This is consistent with the Colaba, India local noon magnetic response of H = 1600 ± 10 nT.

It is found that both the 1–2 September 1859 solar flare energy and the associated coronal mass ejection speed were extremely high but not unique.

- Although there is a record of only one or two super intense magnetic storms during the space age, many much storms may have occurred many times in the last 160 years or so when the regular observatory network came into existence.

- Thus, the *research on historical magnetic storms* can help to create a good data base for intense and super intense storms.

- From the application of knowledge of interplanetary and solar causes of the storms gained from the space age observations, to this super intense storm data set, one can deduce their possible causes and construct a data base for solar ejecta, e.g frequency of occurrence of extremely large solar flare, evolution of solar ejects, etc.

Solar Drivers

Solar flares

Coronal Mass Ejections

High Speed Streams from coronal holes

Interplanetary drivers

Interplanetary coronal mass ejections (ICMEs)

High speed solar ejecta or magnetic clouds

Corotating Interaction Regions (CIR)

Interplanetary shocks

Solar wind discontinuities

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Space Physics

RESEARCH ARTICLE

10.1002/2015JA021661

Key Points:

- The estimation of interplanetary E field conditions for intense magnetic storms
- The historical geomagnetic storms recorded at Colaba Observatory, India
- Variation of ring current injection rate during intense storms

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Estimation of interplanetary electric field conditions for historical geomagnetic storms

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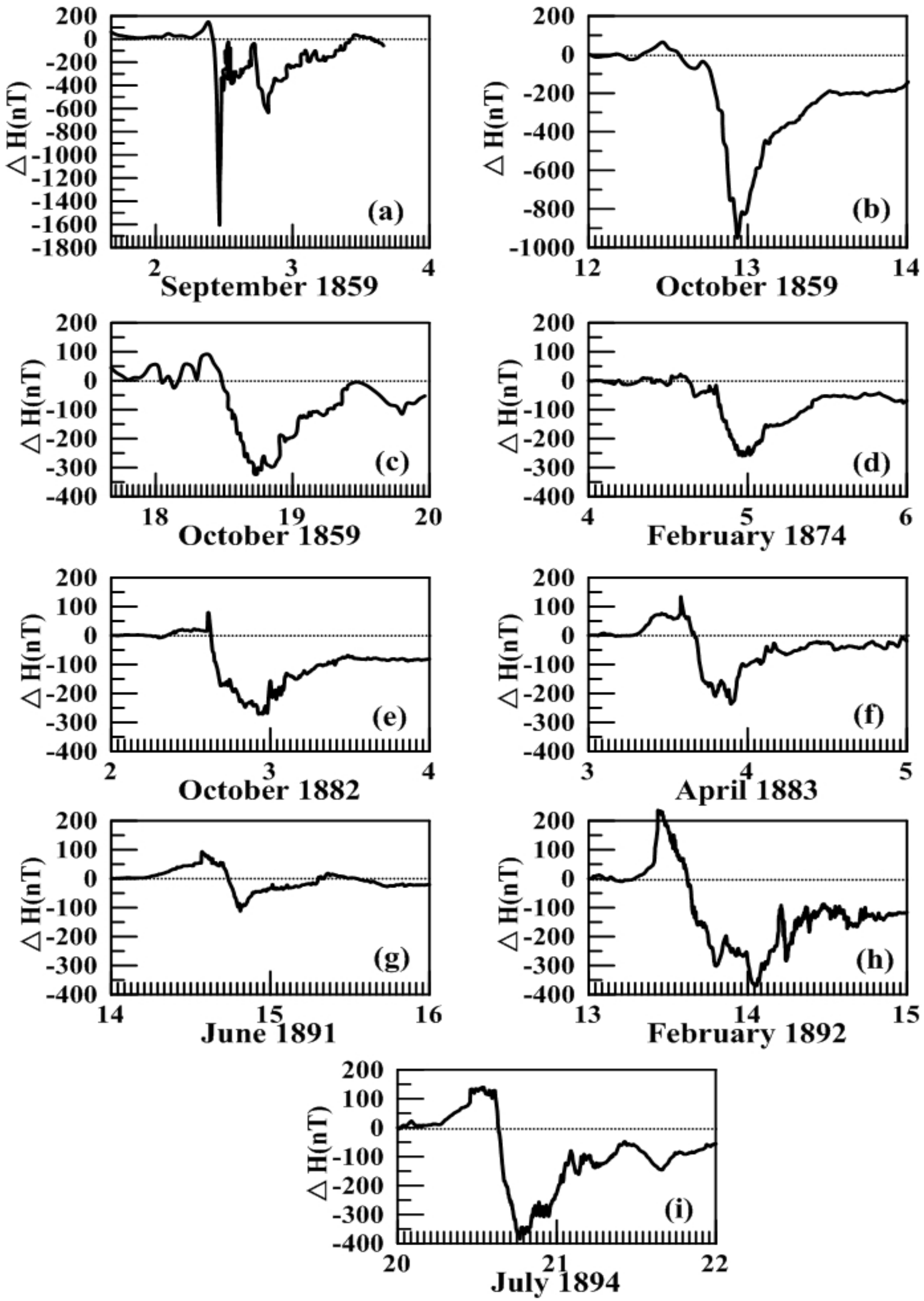
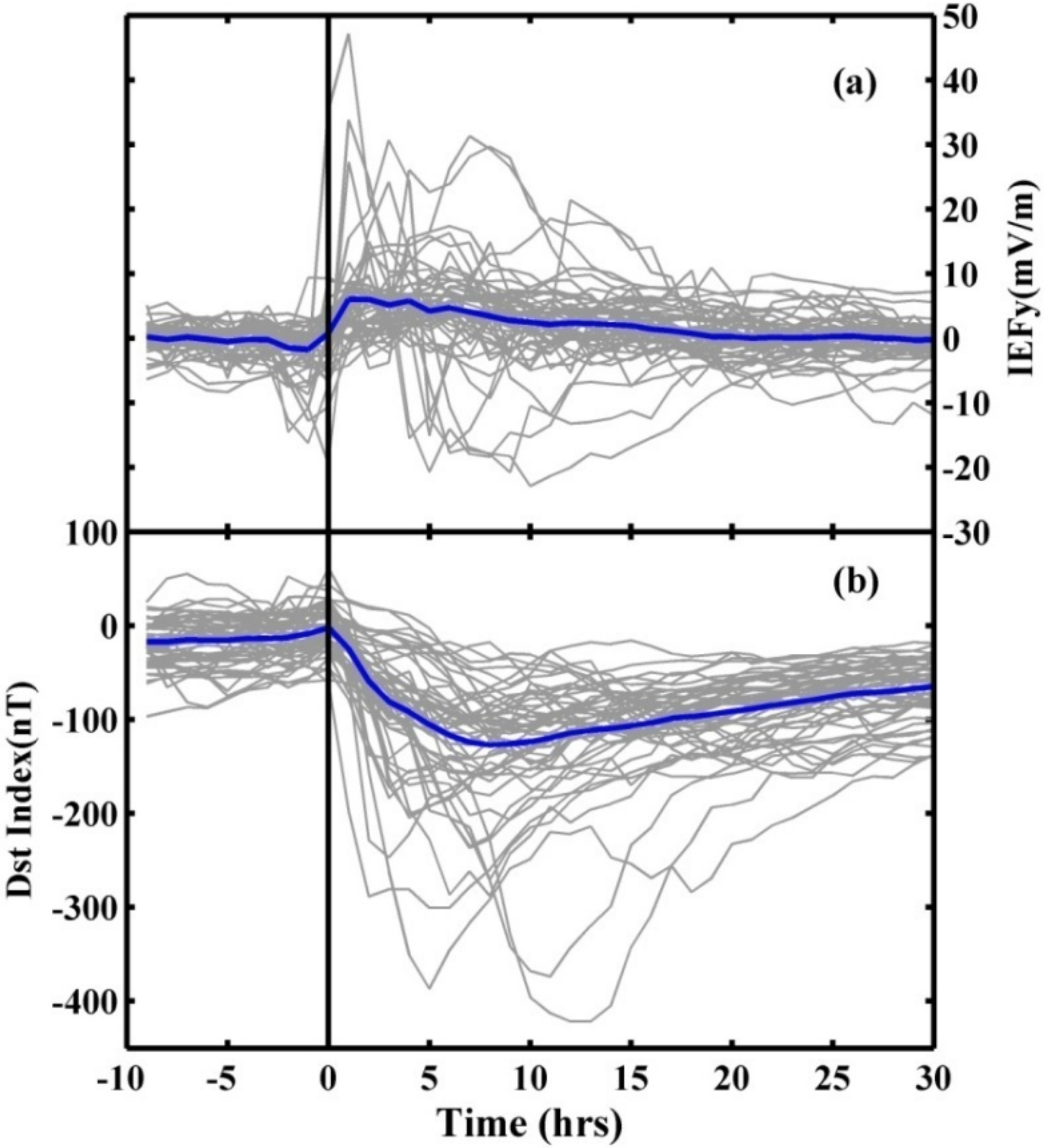
Abstract Ground magnetic measurements provide a unique database in understanding space weather. The continuous geomagnetic records from Colaba-Alibag observatories in India contain historically longest and continuous observations from 1847 to present date. Some of the super intense geomagnetic storms that occurred prior to 1900 have been revisited and investigated in order to understand the probable interplanetary conditions associated with intense storms. Following Burton et al. (1975), an empirical relationship is derived for estimation of interplanetary electric field (IEFy) from the variations of *Dst* index and ΔH at Colaba-Alibag observatories. The estimated IEFy values using *Dst* and ΔH_{ABG} variations agree well with the observed IEFy, calculated using Advanced Composition Explorer (ACE) satellite observations for intense geomagnetic storms in solar cycle 23. This study will provide the uniqueness of each event and provide important insights into possible interplanetary conditions for intense geomagnetic storms and probable frequency of their occurrence.



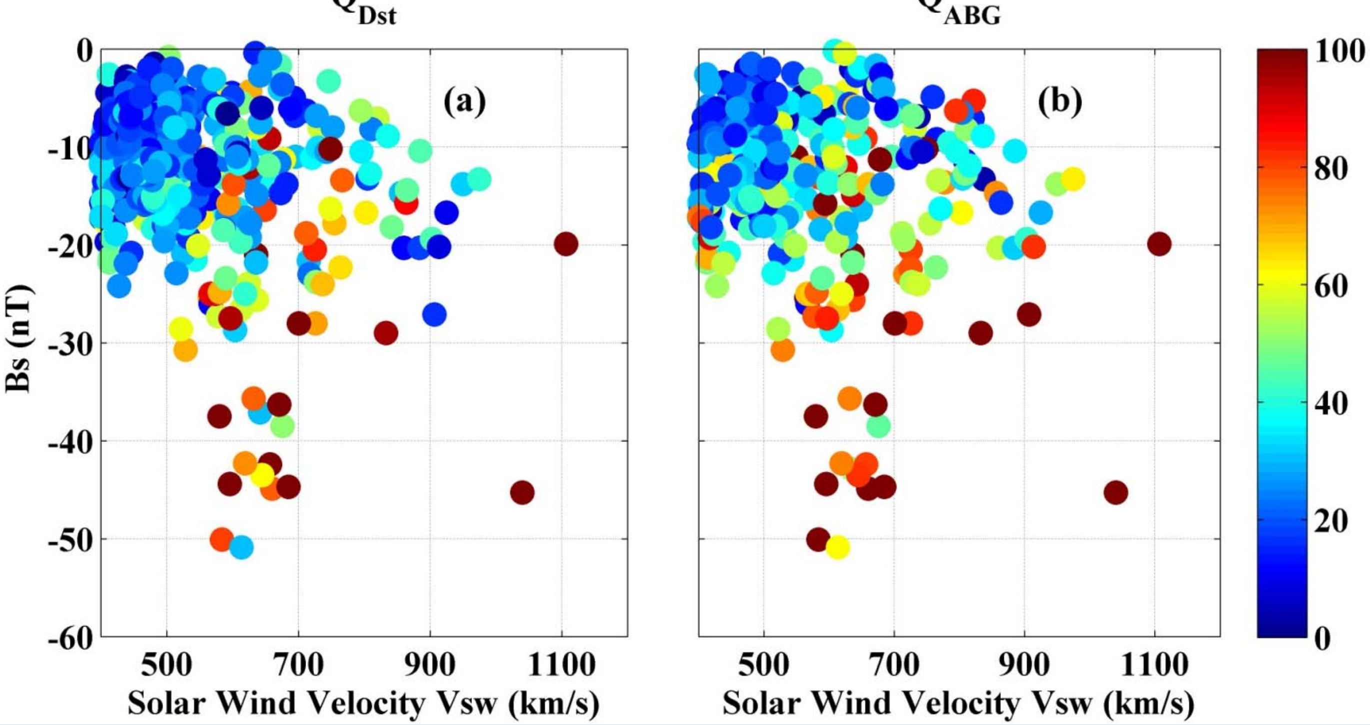
Some of the intense magnetic storms consider for this study.



Superposed epoch plot of 69 magnetic storms (-100nT) with clear main phase were selected during the solar cycle 23 period.

(a)the associated interplanetary electric fields
(b)the Dst index.
The solid black line shows the main phase onset.

Role of IMF Bz and Vsw on Ring Current injection



Dst is directly related to the total energy of the ring current and hence is a good measure of energetic of a magnetic storm.

The variation of ring current energy (Q) with IMF Bs and solar wind velocity (Vsw). The panel (a) and (b) shows the variations of Q_{Dst} and Q_{ABG} respectively. The color bar shows the strength of Q.

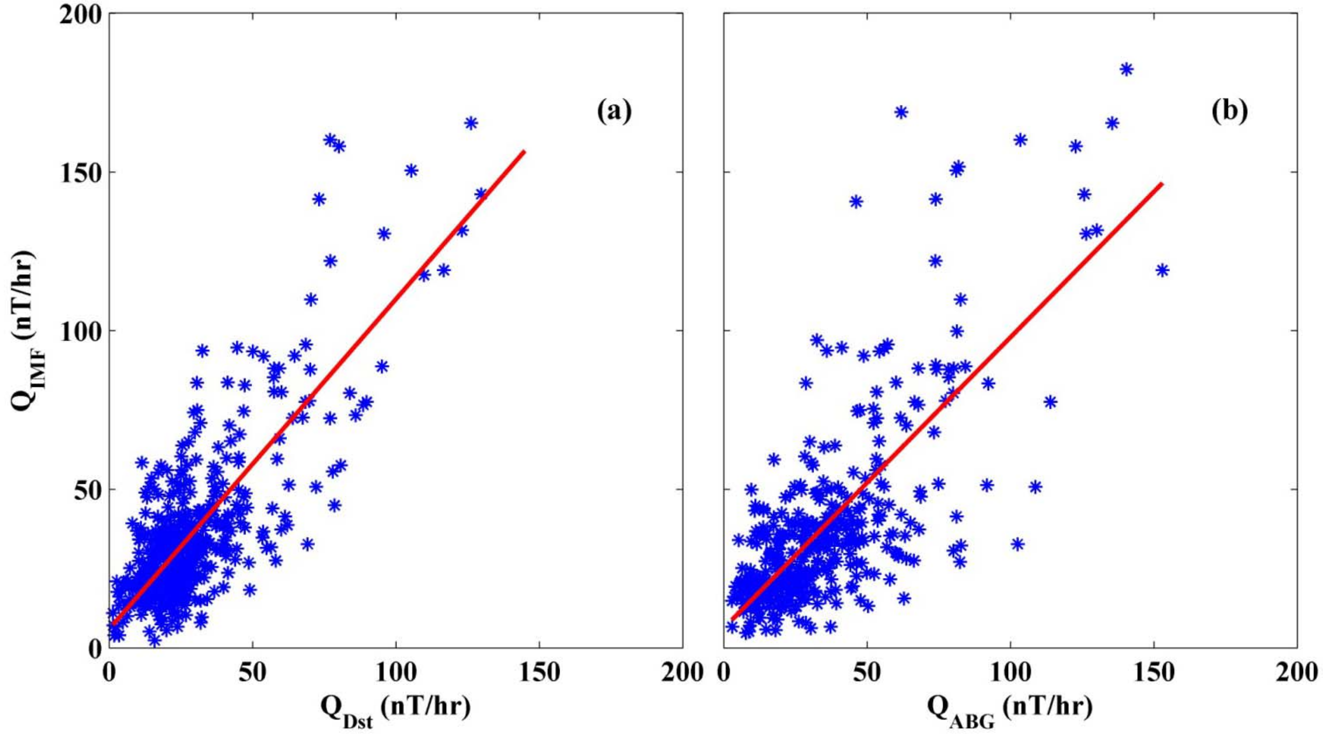
$$\frac{dDst}{dt} = Q_{Dst} - \frac{Dst}{\tau}$$

$$\frac{d\Delta H_{ABG}}{dt} = Q_{ABG} - \frac{\Delta H_{ABG}}{\tau} \quad (2)$$

Burton et al., 1975

Where Q is the input energy and τ is the decay constant

Relationship between Q_{Dst} and Q



$$Q = \alpha V_{sw} B_s$$

where α = -1.5x10^{-3} nT/s(mV/m)$^{-1}$ Vsw and Bs is the solar wind velocity and Magnetic field

(Burton et al., 1975)

$$Q = 1.04 * Q_{Dst} + 5.87$$

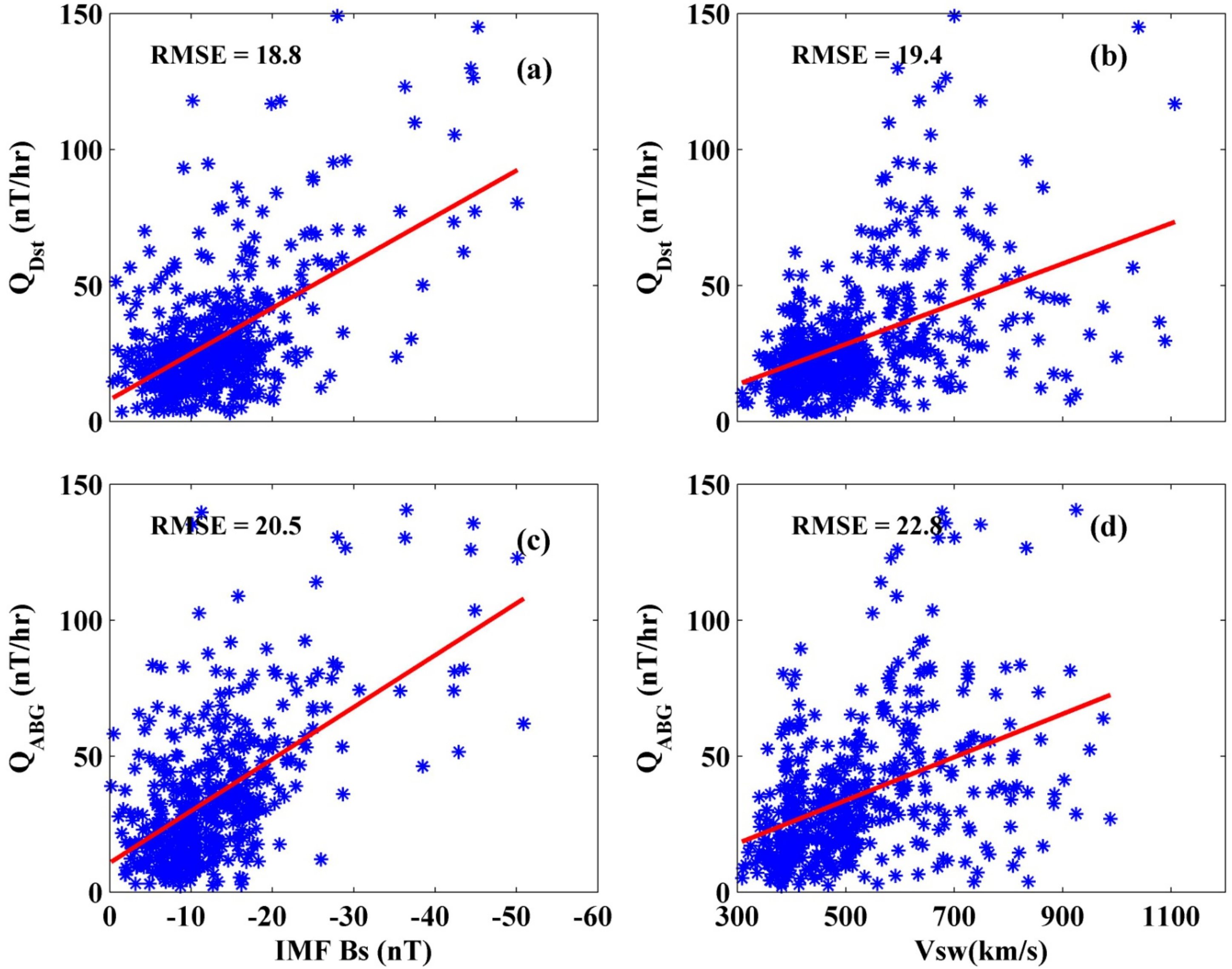
$$Q = 0.92 * Q_{\Delta H_{ABG}} + 6.12$$

We can write Q in terms of IEFy

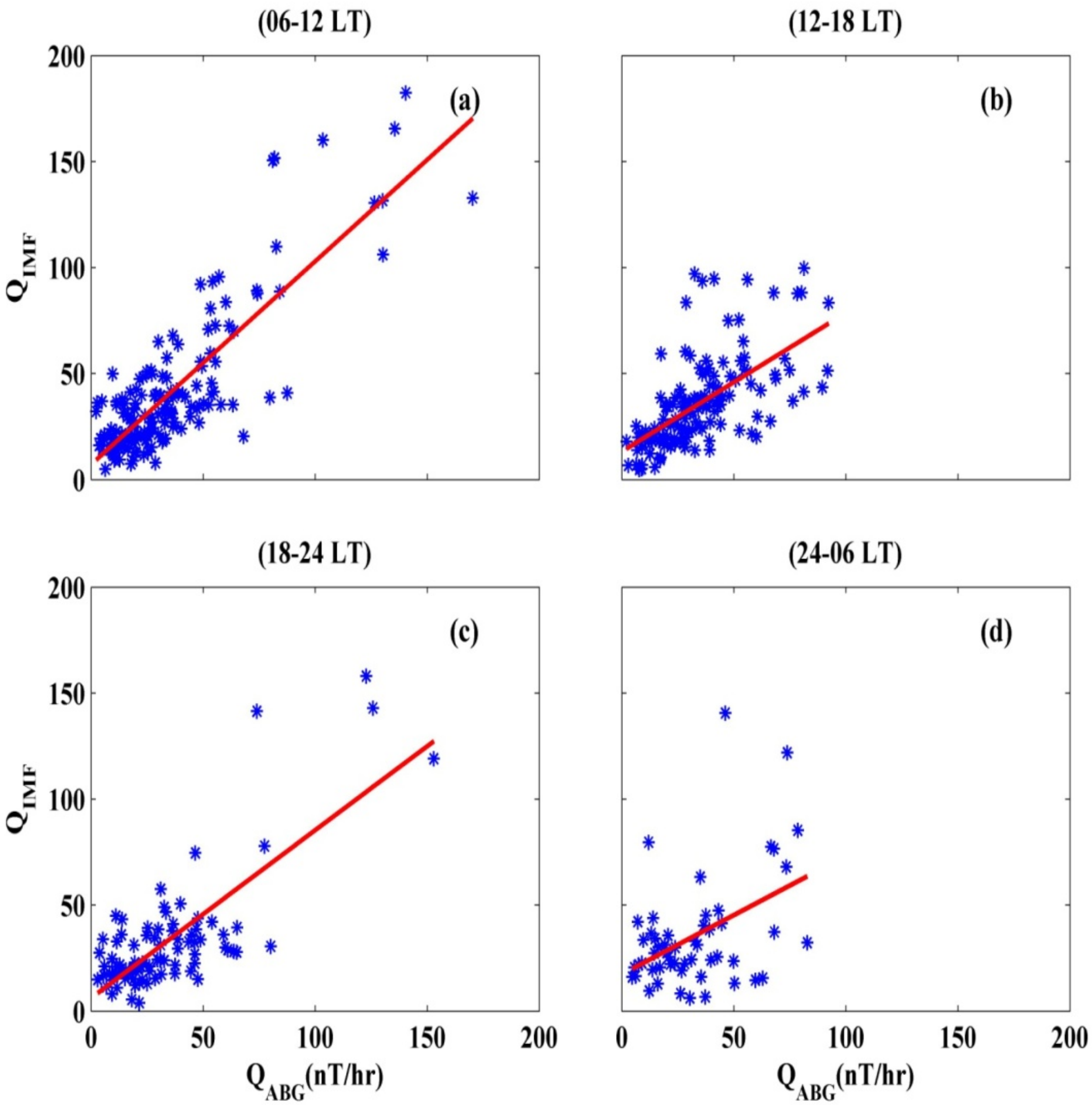
$$IEFy = 0.19 * Q_{Dst} + 1.08$$

$$IEFy = 0.17 * Q_{\Delta H_{ABG}} + 1.13$$

Q_{Dst} / Q_{ABG} with Vsw and Bz for all values of Bz/Vsw



Variation of Q_{ABG} with Q_{IMF} for different local time intervals.



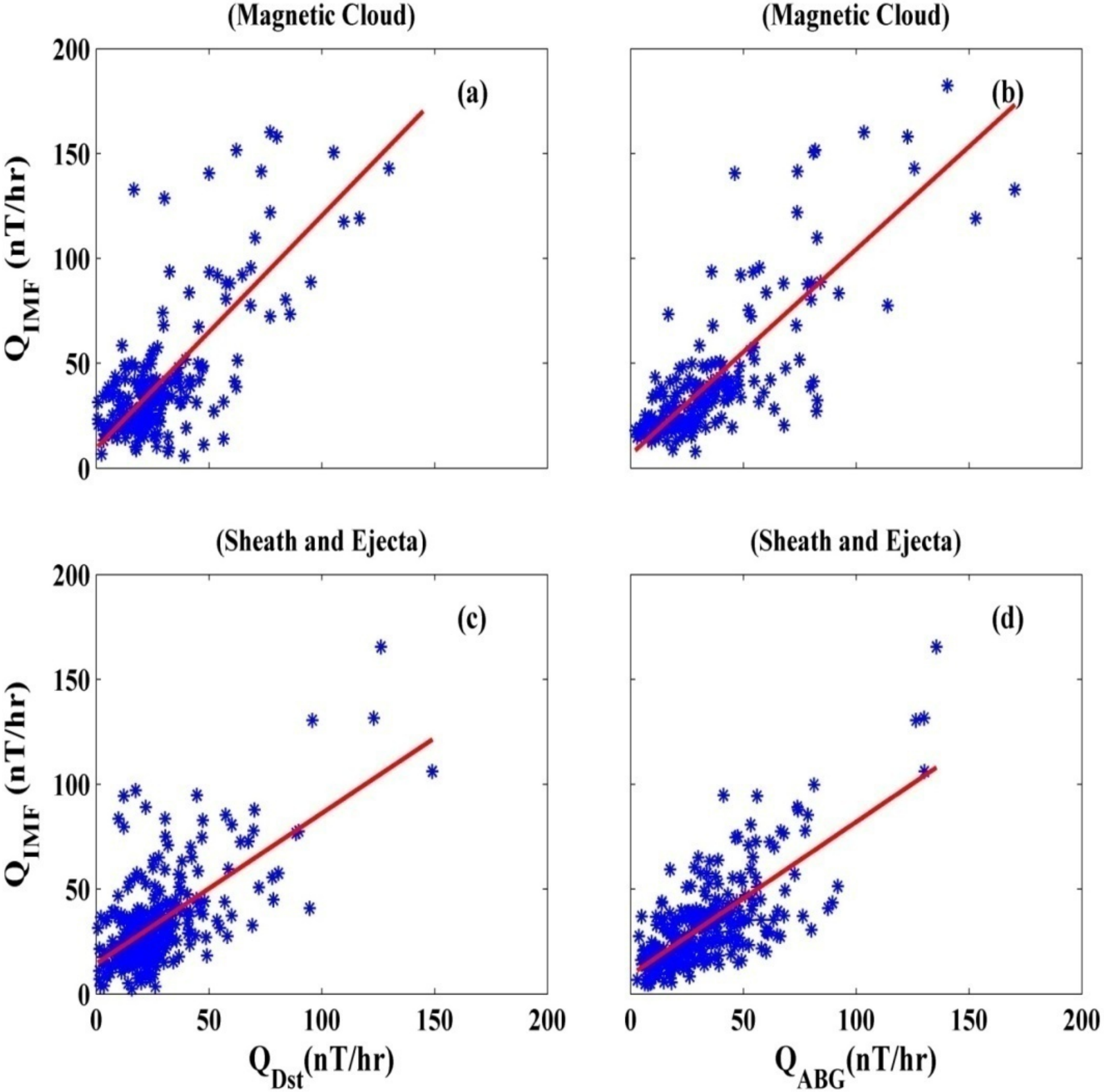
✓ **Echer et al., [2008] studied the interplanetary cause and conditions that led to intense(Dst≤ -100nT) geomagnetic storms during solar cycle 23 (1996-2006) and they found that the storm drivers varies with the phase of the solar cycle.**

Table 2 Interplanetary Structures That Caused Intense Geomagnetic Storms Per Year During Cycle 23

Year/IP Structure	CIR	sMC	Sh+MC	Sh	nsMC	nonMC	Sh+nonMC	nonMC+HCS	Sh+HCS	S.compr MC	nonMC+CIR	Complex	Total
1996	1	-	-	-	-	-	-	-	-	-	-	-	**1**
1997	-	1	2	1	1	-	-	-	-	-	-	-	**5**
1998	1	2	1	2	-	1	-	1	1	1		1	**11**
1999	-	1	-	1	-	1	-	-	-	-	1	1	**5**
2000	1	4	3	1	-	2	-	-	-	-	-	1	**12**
2001	-	2	3	6	1	1	-	-	-	-	-	-	**13**
2002	4	2	2	4	1	-	1	-	-	-	-	-	**14**
2003	1	2	1	3	-	-	-	-	-	-	-	-	**7**
2004	1	3	2	2	-	2	-	-	-	-	-	-	**10**
2005	3	3	-	2	1	1	-	-	-	-	-	-	**10**
2006	-	2	-	-	-	-	-	-	-	-	-	-	**2**
Total	**12**	**22**	**14**	**22**	**4**	**8**	**1**	**1**	**1**	**1**	**1**	**3**	**90**

CIR: corotating interaction region;
MC: ICME that shows the signature of a magnetic cloud;
sMCs: MC preceded by a fast shock;
nsMC: MC not preceeded by a fast shock;
Sh+MC: sheath field followed by a magnetic cloud;
Sh: sheath field;
nonMC: ICME that does not shows the signature of a magnetic cloud;
HCS: crossing of the heliospheric current sheet;
S compr MC: magnetic cloud compressed by shock.

The relationship between the Q_{Dst}/Q_{ABG} with Q_{IMF} for different interplanetary structures



Date	M P onset (LT)	M P Range[a] (nT)	Σ IEFy Estimated (mV.m-1.h)
02/09/1859	**11**	**1600**	**273**
12/10/1859	17	915	355
18/10/1859	9	415	260
04/02/1874	19	220	67
02/10/1882	14	350	102
03/04/1883	14	371	86
14/06/1891	10	173	41
13/02/1892	10	607	95
20/07/1894	14	513	102
13/03/1989[b]	**02(UT)**	**572**	**275**

- List of intense historic magnetic storms recorded at Colaba with main phase onset, range and estimated time integrated interplanetary electric fields using ΔH_{COL}.

[a]*The Main phase range is the difference between maximum and minimum of H.*

[b]*For March 13,1989 storm Dst index is used and time is in UT*

Summary

- The ring current injection rate variation depends on IMF Bs, Vsw. Its intensity is more dependable on IMF Bs strength and duration

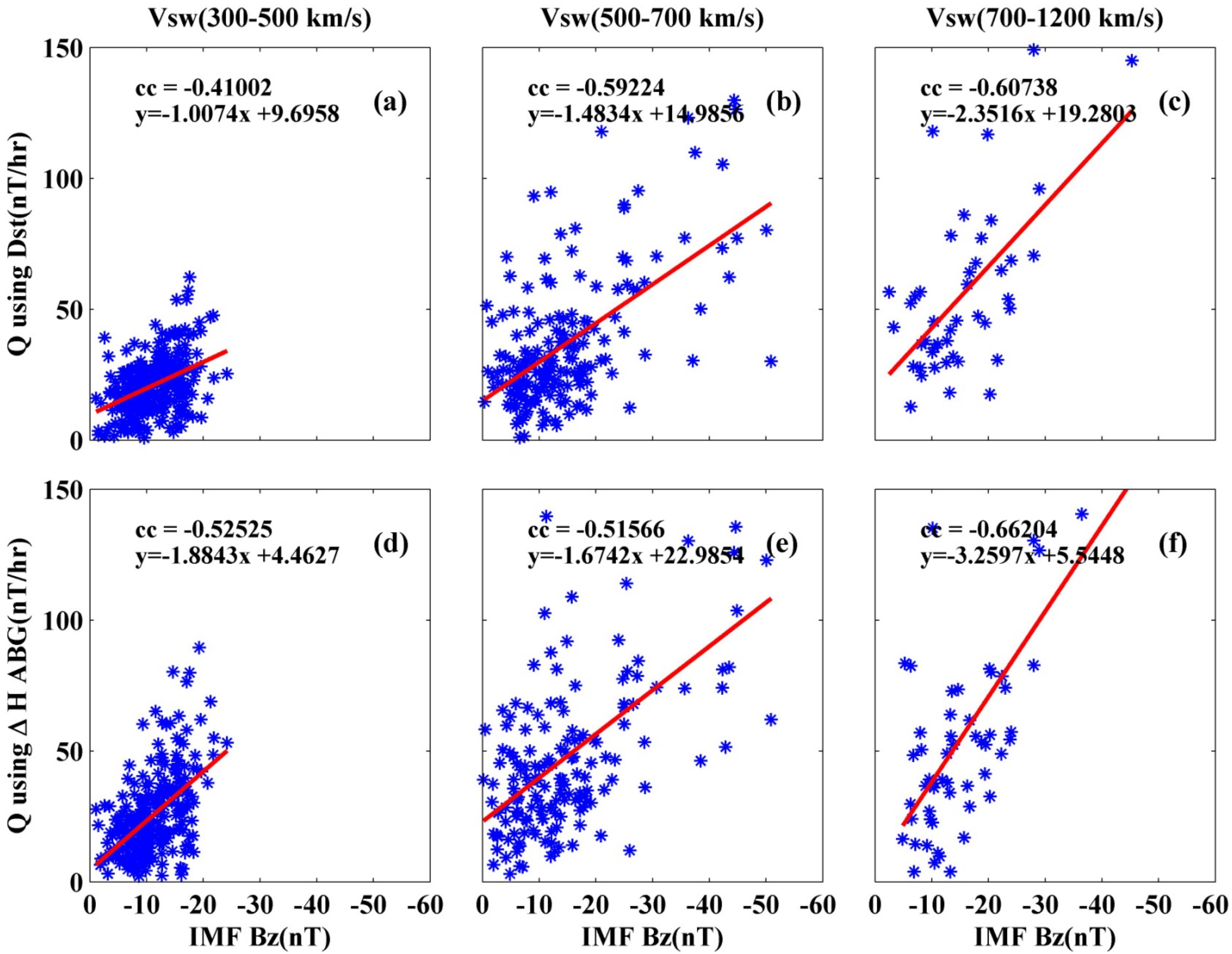
- The ring current injection rate computed using Dst and ΔH ABG is almost in good agreement. The empirical equations are obtained from that linear relationship, which are used to estimate the integrated electric field of historical magnetic storms

- The Magnetic cloud events show the significant correlation with Dst and ΔH ABG rather than sheath and ejecta events

- The IEFy obtained for Carrington event, 1-2 September, 1859 is close to the value computed by *Tsurutani et al.*, [2003]

Thank you

Q_{Dst} / Q_{ABG} with Bz for different values of Vsw



Q_{Dst} / Q_{ABG} with Vsw for different values of Bz