Space weather research in India: An overview

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The regime of space weather includes the sun, solar wind, interplanetary space, magnetosphere, ionosphere and the thermosphere. The immediate manifestations of space weather events are the result of solar flares and coronal mass ejections (CMEs) leading to the occurrence of geomagnetic storms and substorms, appearance of auroral forms, ionospheric disturbances, etc. The solar-terrestrial environment has a wide range of effects on many aspects of our everyday life. This paper discusses various aspects of space weather and presents an overview of the space weather research activities in India. There is a need for a comprehensive space weather prediction programme for India in view of the fact that the space-based systems are already being exploited for a variety of applications such as remote sensing and meteorology, radio communications, broadcasting, earth resources survey, etc.

1 Introduction

In broad terms, space weather refers to the disturbed conditions in the near-earth’s space environment due to the changes or events taking place in the sun. The primary source of space weather is the explosive events on the sun. Space weather sparks off on the surface of the sun, which is the major source of electromagnetic and particle energy and it can produce tremendous impact on the near-earth space environment. Sunspots are often associated with violent activity on the sun. They, thus form a major tool in predicting the space weather disturbances.

The sun emits electromagnetic radiation in broad spectrum of wavelengths, from the short wavelength high energy X-rays and ultra-violet (UV) emission to visible light, infrared and solar radio emission. Space environment of the earth responds within eight minutes to the changing nature of these primary solar emissions. The short wavelength radiations from the sun, like X-rays, UV and extreme ultra-violet (EUV), ionize the neutral constituents in the upper atmosphere of the earth, forming an ionized atmosphere called the ionosphere.

In addition to electromagnetic radiation, the sun emits continuously a stream of charged particles called solar wind. The solar wind is a tenuous and highly conducting gas consisting mainly of electrons and protons with a little bit of alpha particles and other heavier ions. At the earth’s orbit, the solar wind has density of about 5 particles cm$^{-3}$, and speeds of $\sim 400$ km s$^{-1}$. Both density and velocities are variable, and the speeds can exceed 1500 km s$^{-1}$ during high-speed streams. The solar magnetic field embedded in the corona is dragged out by the constantly expanding and highly conducting solar wind, thus forming the interplanetary magnetic field. Solar wind interaction with the geomagnetic field gives rise to the earth’s magnetosphere (Fig. 1). Magnetopause boundary separates the plasma and fields connected to the geospace and the interplanetary medium. The magnetopause boundary layer is the site where energy

Fig. 1—Schematic 3-dimensional view of the earth’s magnetosphere formed by the interaction of solar wind with the geomagnetic field. [Small arrows indicate the direction of the magnetic field lines. Thick arrows show the direction of electric currents. Various current systems present in the magnetosphere are shown.]
and momentum is exchanged between the solar wind plasma and the magnetospheric plasma. This energy is dissipated by several complex current systems arising due to the solar wind-magnetosphere interaction. When the energy accumulated in the cross-tail current is released suddenly in the form of hot plasma jets, it gives rise to the phenomenon of substorm. During substorms, a large fraction of the energy released from the magnetotail gets deposited in the high latitude ionosphere where it excites the aurora. The formulation, characteristics of the deposition and release processes of the energized plasma into the auroral regions cause various space weather phenomena. Thus, the solar wind acts as an agent for establishing the sun-earth plasma connection.

Periodically the sun becomes highly eruptive. Solar flare event is a mightiest eruption from the tenuous atmosphere of the sun, and it occurs predominantly during periods of large-scale changes in the sun’s magnetic field. The frequency of occurrence of solar flares becomes high during the high solar activity cycle or solar maximum. The intense radiation from the solar flare travels to the earth in eight minutes and their effects are visible in the magnetic field records from the ground observations. Often, following the explosion in the sun’s surface, there is an eruption of a cloud of electrified magnetic gas from the corona, called coronal mass ejection (CME), and almost 10 million tons of plasma travelling at speeds extending up to 2000 km s⁻¹ is hurled into the interplanetary space (Fig. 2). There is often a magnetic cloud within the CME. Magnetic clouds that are geoeffective have a southward and then northward (or vice versa) magnetic field directional variation. When this magnetic cloud has a very high velocity, it compresses the plasma ahead of it and forms a collisionless shock. Behind this shock is a sheath

Fig. 2—White light image of solar corona during a coronal mass ejection (CME) on 23 Nov, 2001, at 0018 hrs UT, from the Large Angle Spectroscopic Coronagraph (LASCO) instrument on the Solar Heliospheric Observatory (SOHO) spacecraft [Solar flare and CME emanate a large amount of energy; Image Courtesy: "SOHO/LASCO (ESA/NASA)"]
which contains heated plasma and compressed magnetic fields. These intense sheath magnetic fields can also cause magnetic storms. The internal structure of an interplanetary coronal mass ejection (ICME) is shown schematically in Fig. 3. If both the sheath field and the cloud field (if present) have the proper orientation, double storms can result. In complex cases, where there are multiple solar flares, there will be multiple shocks and multiple plasma and field compressions, and thus triple storms, etc. will result. Tsurutani et al. demonstrated that the storm generation mechanism can be identified by examining the profile of the magnetic storm using ground magnetic field data. As far as the space weather effects are concerned, solar flares and coronal mass ejections, associated with large energetic particle events and major shockwave disturbances in the solar wind, are the two main causes that can give rise to geomagnetic storms, intense auroral activity and other space weather related disturbances in the earth's near space.

2 Geoeffectiveness

All solar flares and CMEs may not give rise to any big magnetic storm. The capability to cause big magnetic storms depends on several factors. The most important is the trajectory of the solar flare/CME ejecta. Obviously those solar flares/CMEs that do not hit the magnetosphere could not give rise to any disturbance or geomagnetic activity. The geoeffectiveness of the ejecta, as far as the capability to cause geomagnetic storms is concerned, depends upon the structure of the magnetic field and the shock waves associated with the ejecta. It has been well established that the primary cause of magnetic storms is intense long-duration southward interplanetary magnetic field (IMF) which interconnects the earth's magnetic field and allows solar wind energy transfer into the earth's magnetosphere. Therefore, depending on the orientation of the magnetic fields carried by the CME cloud, earth directed ejections could produce big magnetic storms by dumping a large amount of solar wind energy into the magnetosphere mainly by the process involving magnetic reconnection. The interplanetary (IP) shocks compress the magnetosphere and could cause instantaneous spurt in the magnetopause current, leading to abrupt increase in the horizontal component of the magnetic field recorded on the ground magnetometers. This stage of the storm, known as the initial phase, may persist from 0 to 16h. Recent developments on the investigations on storm dynamics attribute the solar antecedents of intense storms to coronal mass ejections during solar maximum. Whereas in the descending phase of the solar cycle, the high speed streams emanating from coronal holes can cause recurrent geomagnetic storms at 27-day interval. Following the shock wave, the main phase of the storm sets in, during which average global feature of a magnetic storm is the unmistakable reduction in the horizontal intensity of the terrestrial magnetic field lasting for a few hours to days. This decrease in intensity of the horizontal component of the magnetic field is due to the increased population of energetic charged particles, which make their entry by the injection from the near-earth magnetotail into the inner magnetosphere. Singer suggested that the gradient drift of the energetic particle trapped in the geomagnetic field carries a westward flowing ring current encircling the earth in the equatorial plane. During magnetic storms a large amount of energy is dissipated in the polar regions, leading to profound changes in the global morphology of the upper atmosphere. An example of the solar flare/CME, causing a big geomagnetic storm, is shown in Fig. 4.

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![Schematics of an interplanetary coronal mass ejection (ICME)](image)
Fig. 4—Magnetogram from Tirunelveli Magnetic Observatory showing the geomagnetic storm caused by a solar flare/CME [The effect of a powerful X-class solar flare that occurred on 10 Apr. 2001, at about 0525 hrs UT modified the ionospheric current and affected the magnetic field within a few minutes as shown. The CME eruption following the flare led to an intense shock as observed by the ACE spacecraft on 11 Apr at 1520 hrs UT; after almost 34 h. The impact of the shock on the magnetosphere is seen as a sudden impulse on the magnetic record at around 1545 hrs UT. Subsequently, the development of the intense main phase associated with the westward ring current is evident.]

Coinciding with the decrease in the field, a magnetic storm is generally accompanied by intense auroral brightening. Occasionally the auroral ovals expand equatorward with the occurrence of auroral substorms or magnetospheric substorms. McPherron, Rostoker et al., and Iyemori and Rao defined the phenomenon as a transient process initiated on the nightside of the earth resulting in the energy transfer mechanism between auroral ionosphere and magnetosphere in these expanded ovals. Severe magnetic storms are relatively rare. However, during magnetic storms intense substorms are observed in the polar regions and subsequent development of intense ionospheric currents. Apparently, perturbations of solar origin form an important link in the complex chain of solar-terrestrial relations. A flow chart showing the chain of solar-terrestrial processes that are involved in causing magnetic storms is shown in Fig. 5.

It is believed that most of the thermospheric density perturbations are transported from high latitude polar region, which is affected most due to the energy dumped in this region, to low latitudes. This transport is affected by travelling ionospheric disturbances (TIDs) and large-scale wind circulation. These perturbations take significant time (more than 3 h) in propagating from polar to low latitude region and may affect communication severely. Recent observations have shown that energy and momentum do not flow only in one direction, i.e., from solar wind to the magnetosphere, there are also important flows in the opposite direction, i.e., from magnetosphere to the interplanetary space as well. An important recent discovery by Daglis concluded the dominance of oxygen ions in the energetics of the storm time ring current. It is a puzzle how the oxygen ions are extracted from the ionosphere, energized to few hundreds keV energies and then injected into the ring current. Recent results from Imager for Magnetopause to Aurora Global Exploration (IMAGE) have shown that extraction of oxygen ions takes place almost instantaneously in response to the interplanetary disturbances, giving rise to magnetic storm. Some observations have pointed out the inadequacy of $D_s$ index as a reliable indicator of the kinetic energy content of the ring current, and questioned the use of this index as proxy for the perturbation field.

3 Effects of geomagnetic storms on technology

(i) Solar eruptions directed towards the earth are potentially harmful to advanced technology. Advancement in technology has taken effective turning points in the communication link, navigation and space-borne satellite systems. Modern instruments and links around the globe are increasingly dependent on electricity and
Electromagnetic radiation

Solar Flare

CME

Solar Wind

Sudden Ionospheric Disturbance

Solar Cosmic Rays

Disturbed Solar Wind

Impact on Earth's Magnetopause / Magnetospheric compression & tremendous energy input

Flare effect on Magnetic records

Disturbed Magnetosphere

Rapidly changing Ionospheric Current

Intense ring current

Geomagnetic storms recorded at Magnetic Observatories

Fig. 5—Flow chart representing schematically the chain of solar-terrestrial processes giving rise to space weather disturbances in the near-earth’s space environment.

Electronics. Technological systems in space and on the earth’s surface are subject to adverse effects from geomagnetic disturbances. During such events, the magnetospheric compression by the solar wind forces the magnetospheric boundary inward past the geostationary satellite position (Fig.6).

(ii) Geosynchronous Communication Satellites orbiting the earth are many in number. A large geomagnetic storm can enhance the number of electrons and ions hitting these satellites, leading to intense spacecraft charging, which would cause damage to the spacecraft.

(iii) Enhanced levels of solar radiation associated with intense flare activity on the sun can also cause heating and expansion of the neutral atmosphere and increase the amount of atmospheric drag that a satellite experiences in an unpredictable manner.

(iv) Auroral activity and intense substorm disturbances cause dropouts and changes in paths of HF communication and increased scintillation degradation of radio signals at high frequencies, and disrupt surveillance tracking of the satellite.

(v) The disturbance also induces extra currents in the wires of the electrical power grid, producing temporary overload. Such severe geomagnetic disturbances can induce DC currents in power lines and can cause destruction of power station transformers.

(vi) Geomagnetically induced currents and volatages can also damage long pipelines and communication cables. These currents affect the conductors used for telecommunication.

(vii) Very high energy (~1MeV) charged particle fluxes released during storms and substorms
pose a serious radiation health hazard for astronauts.

The effects of geomagnetic activity on technological systems are becoming crucial as components are miniaturized with advanced electronic components. Increased demands of appropriate descriptions and accurate predictions of geomagnetic disturbances are becoming a crucial factor in the modern advanced technology system.

4 Geomagnetic field measurements and space weather

Geomagnetic indices are widely used to represent the global nature of disturbances associated with solar terrestrial phenomena. Geomagnetic observatories around the globe have the regular recordings of the variations in the geomagnetic field at various time resolutions ranging from average hourly and one minute to one second. Considerable time and effort was put in since 1940 by various researchers to develop an authentic index to represent the terrestrial effects of the solar particle radiation. Diurnal variation pattern in the horizontal component of the magnetic field from various observatories is being used to derive various indices of geomagnetic activity on a planetary scale. The $K$ index is one of the widely used indices, computed from several stations distributed all over the globe, especially mid and high latitude locations. Currently, one minute digital magnetic data from many observatories are used to
derive the near-real-time geomagnetic conditions. A quantitative measure of the magnetic characteristics is provided by the three hourly $K$ index. A linear index derived from the quasi-logarithmic $K$ index represents the equivalent amplitude by $ak$. The daily arithmetic means of the amplitudes of $K$ and $ak$ are expressed as $K_p$ and $A_p$ indices. The $K_p$ as a global magnetic activity index is a representative of the stations mostly at subauroral latitudes and the locations mainly cover the northern hemisphere and the European continent.

The large-scale influence of the magnetosphere-solar wind interaction is much stronger in the auroral zones as well. An index to project the intensity of the aurora-related geomagnetic activity is the AE index. It is well established that the major manifestation of the geomagnetic phenomena, associated with the injection of energetic electrons and ions into the inner magnetosphere, is the formation of the westward storm ring current. Low latitude ground magnetic observatory records show systematically the depression in the horizontal component in response to this westward flowing zonal current system in the equatorial distance of 4-6 $R_e$ (1 $R_e$=6370 km). Suiguri defined the index $D_s$ as an ensemble of magnetospheric and ionospheric fields detected at middle and low geomagnetic latitudes on the earth. This index normally depicts the strength of magnetic storm and is considered as a proxy for the strength of the symmetric component of the ring current. The data used in the computation of $D_s$ index are based on the observatories located at low latitudes away from the subauroral zone and from equatorial electrojet region.

Extensive use of automated magnetic observatories and satellite links has made it possible for near-real-time dissemination of magnetic measurements. Geomagnetic variations depict the role of electric currents of ionospheric and magnetospheric origins, and of electromagnetic waves in wide range of frequencies. Regular geomagnetic variations are attributed mainly to sources of ionospheric tidal origin caused by the sun and moon. These forces induce an appreciable magnitude of day-to-day variability in the geomagnetic field. Perturbations in the magnetic field vary in time scales of the order of a few minutes to some hours. The intensity of perturbation largely varies with latitude, with enhanced magnitude at auroral latitudes and with minimum in the mid-latitudes. However, the enhancement of this phenomenon over the equatorial latitude is a special feature attributed to the ionospheric conductivity structure. These perturbations are mostly global in nature, but sometimes restricted to high latitudes.

Understanding the changes in the equatorial electrojet in response to the electrodynamics processes involved in the coupling between solar wind, magnetosphere and ionosphere is of great scientific interest. This is due to the dynamo region electric fields being communicated to higher altitudes along the highly conducting geomagnetic field lines. Dynamics of this nature, in turn, affects the distribution of plasma, plasma motions, temperatures, winds and other processes of the equatorial ionosphere extending to higher latitudes. Studies based on ground magnetic data have shown consistent and near instantaneous response of equatorial electrojet variations to geomagnetic disturbances at high latitudes. Monitoring the upper atmosphere by coherent and incoherent backscatter radar observations has confirmed that the disturbances in the dynamo region electric fields at equatorial latitudes originate in the corresponding electrodynamic disturbances at high latitudes.

5 Existing international forecast services

Solar and geophysical data are monitored in real time from a large number of ground-based observations and satellite sensors distributed all over the world. The preliminary reports and forecasts are published by Space Weather Operations (SWO) in Boulder jointly by NOAA and AFWA (Air Force Weather Agency). The ten warning centres of the International URSI (Union Radioscientific Internationale) gram and World Days Service (IUWDS) deal with the daily reports and forecasts of geomagnetic activity. One regional warning centre (RWEC) is being operated from National Physical Laboratory, New Delhi, as a part of the International Space Environment Service (ISES) chain, and it caters to the needs of Indian region. The NOAA’s Space Environment Center (SEC) in Boulder, Colorado, is the official centre for forecasting disturbances and alerts to safeguard the people and equipments in the space environment. Space Environment Laboratory (SEL) of the NOAA centre is the prime agency, which undertakes the task of monitoring almost 1400 data streams that include solar, magnetospheric and ionospheric parameters. The launch of ACE and SOHO satellites in the L1 point orbit at about 240 earth radii ($R_e$) has made the
space warnings more accurate to provide advance warning on the space weather status almost an hour prior to the impact of the solar ejecta that could produce geomagnetic storm.

Existing forecasting models are heavily dependent on the geomagnetic data inputs from mid and high latitudes. The low latitude ionosphere is protected from direct impact of the high energy particles and ionospheric storms are rarely observed in the low latitude regions. However, communications at all frequency ranges are affected by space weather to a greater extent. The HF communication is affected more often, as this frequency depends on the reflection from the ionosphere as signal carriers. Thus, the electron density fluctuations associated with the irregularities in the ionized atmosphere contribute to signal fading during highly disturbed conditions, resulting in the deterioration in HF communications. Establishing a study of well integrated and coordinated investigational activities of real time geomagnetic, ionospheric and satellite data, would come as a breakthrough in elucidating the complex dynamics of the low latitude space environment. It is well established that there exists a direct correlation between the time variations of IMF as measured by satellites and the ground magnetic measurements, suggesting the change of low latitude electric fields or current in response to the varying interplanetary conditions. However, no effort was initiated in quantifying the cause and effect of the solar-terrestrial relation from the low latitude observations.

It is desirable to make an attempt in this direction by mainly focusing on the day-to-day geomagnetic and ionospheric variation characteristics from the low latitude measurements in India, in conjunction with the high and mid latitudes. It is indeed crucial, because the global geomagnetic activity index, $D_s$, is the resultant of the complex electrodynamics interaction processes originated from the magnetosphere-ionosphere coupling.

6 Infrastructure for space weather research in India

Several Institutions and University Departments have been participating on various programmes associated with solar physics, interplanetary plasma and magnetic field, magnetospheric physics, ionospheric physics and atmospheric physics that form backbone for the space weather programme. Most of the scientists have utilized solar, interplanetary and magnetospheric data from various NASA missions from 1970 onwards, for modelling the medium and for the study of dynamics and instabilities in these regions. On the experimental side, expertise for the HF Doppler radar, VHF, MST and Partial Reflection radars exist in the country. Several ionosonde and airglow experiments are being conducted to understand the ionospheric irregularities. Excellent facilities for monitoring the sun exist at solar observatory at Udaipur, Ooty, Kodaikanal and some other places in the country. A brief summary of the existing infrastructure in the country for space weather related research activities is given in Table I.

The Indian scientific community has participated in a number of national and international programmes related to the dynamics of the upper atmosphere and ionosphere-magnetosphere and interplanetary medium characteristics, like All India Coordinated Programme on Ionosphere-Thermosphere Studies (AICPTS), International Equatorial Electrojet Year (IEEY), Indian Solar-Terrestrial Energy Programme (ISTEP), International Geosphere Biosphere Programme (IGBP), SROSS, Magsat, Oersted, Polar Cluster, etc. and is ready for the CRABEX. Several strong theoretical groups dealing with the problems of magnetic storms and substorms, solar wind-magnetosphere-ionosphere coupling and wave-particle interactions exist in the country. Unfortunately, the activities and programmes of various Institutions/Departments are independent of each other as far as the space weather is concerned. Hence, there is an urgent need to evolve a national programme on space weather under ISRO, which will provide an umbrella to the scientists from national laboratories, and Universities to carry out relevant activities in a cohesive manner. It would also generate lots of interest among the researchers from the universities to accelerate or reorient their research efforts toward space weather.

7 Space weather programme: Main science and application oriented objectives

The application oriented objectives of the space weather programme are:

(i) Energization and injection of ionospheric oxygen ions into ring current system and decay of storm-time ring current.
(ii) To develop computer simulations of spacecraft charging.
(iii) Geomagnetic activity predictions with different time scales using data from Indian observatories.
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<tr>
<th>Organizations/Universities</th>
<th>Experiments</th>
<th>Investigations/activities</th>
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<tr>
<td>Andhra University, Waltair</td>
<td>Airglow photometer; Digital ionosonde; HF Doppler radar</td>
<td>Ionosphere-thermosphere study; E- and F-region dynamics</td>
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<tr>
<td>Banaras Hindu University</td>
<td>Fabry-Perot spectrophotometer; Dual frequency microwave radiometer; ELF; VLF experiments by whistler observations</td>
<td>For measuring thermospheric temperature and winds, air pollution; Whistler studies; Ionosphere magnetosphere dynamics</td>
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<tr>
<td>Banjara University, Waltair</td>
<td>Radio beacon studies; Whistler measurements</td>
<td>Plasma irregularities; Ground based technique for probing the inner magnetosphere</td>
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<tr>
<td>Bhabha Atomic Research Centre, NRL, Trombay</td>
<td>Cerenkov telescope at Mt.Abu</td>
<td>Study of gamma ray sources and the cosmic ray mass composition</td>
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<tr>
<td>Indian Institute of Astrophysics, Bangalore</td>
<td>Digital magnetometer; Digital ionosonde</td>
<td>Ionosphere-thermosphere coupling; Solar-terrestrial relationships</td>
</tr>
<tr>
<td>Indian Institute of Geomagnetism, Mumbai</td>
<td>Network of H magnetic observatories; Digital Bx-gate magnetometer set-up at 6 observatories; MF (1.98 MHz) radars at Thiruvanantapur and Kolhapur; Radio beacon experiments; Scanning photometer; Tilting photometer; All sky imaging camera at Kolhapur; TEC deduced from GPS measurements; CRABEX Experiment</td>
<td>Solar-Terrestrial physics; Magnetic storms and substorms; Secular variations; Geomagnetic activity; Forecasting and space weather; Theoretical and simulation studies on storm-substorms phenomena; Mesosphere winds, tides and planetary waves; Plasma irregularities; Monitoring nightglow emissions at different wavelengths; Atmospheric gravity waves and F-region irregularities; Ionosphere-thermosphere dynamics and Ionospheric tomography</td>
</tr>
<tr>
<td>ISRO Satellite Centre, Bangalore</td>
<td>Scanning sky monitor (SSM) for Indian Astronomy satellite; Solar X-ray spectrometer for GSLV; CRABEX</td>
<td>To study the long term variability in bright X-ray sources for studies of variable stars; To study X-ray flux from sun over 2 keV to 10 MeV energy range; Ionospheric tomography</td>
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<tr>
<td>Kentia University</td>
<td>HF Doppler radar data</td>
<td>To study the ionospheric plasma drift</td>
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<tr>
<td>National Geophysical Research Institute</td>
<td>Magnetometers at 2 locations</td>
<td>Studies related to low latitude magnetic variations</td>
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<tr>
<td>National MST Radar Facility (NMRF), Thirupati</td>
<td>MST (53 MHz) radar at Gadanki; Rayleigh lidar system</td>
<td>Studies of long period atmospheric waves, ionospheric irregularities, Temperature profiles at 5-85 km altitude range</td>
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<tr>
<td>National Physical Laboratory, New Delhi</td>
<td>Digital ionosonde; GPS, Radio beacon studies; RPA experiment on SROSS-C2; SASCOM Data Center Lidar; Laser heterodyne system</td>
<td>Ionospheric plasma parameters and plasma irregularities; Total electron contents; Dissemination of data for global change related studies; Measurements of ozone, water vapour, etc.</td>
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Table I—Infrastructure available in the country for space weather related activities—Contd

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<th>Experiments/Investigations/activities</th>
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<tr>
<td>Osmania University, Hyderabad</td>
<td>High resolution IR Fabry-Perot spectrometer; Observations of ionospheric irregularities</td>
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<td>Physical Research Laboratory, Ahmedabad</td>
<td>Ionospheric scintillation experiment</td>
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<td>Survey of India, Dehradun</td>
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<tr>
<td>Tata Institute of Fundamental Research (TIFR), Mumbai</td>
<td>Ooty radio telescope; GMRT</td>
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<tr>
<td>Udaipur Solar Observatory of PRL, Ahmedabad</td>
<td>GONG telescope; Sun photometer; To probe interior of the sun using heliospectroscopy;</td>
</tr>
<tr>
<td>University of Rajkot, Gujarat</td>
<td>ELF, VLF Measurements; Radio beacon experiments</td>
</tr>
<tr>
<td>Vikram Sarabhai Space Centre, Trivandrum</td>
<td>HF and VHF Doppler radar; Measurements of Doppler velocities and spectral width to study the ionospheric irregularities;</td>
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(iv) Evaluation of thermospheric wind induced effects vis-a-vis electrodynamic effects. These are intended to throw light on the neutral-plasma dynamics as well as the magnetospheric electric field effects at low latitudes.

(v) Development of models on ionospheric variability including for storm-time conditions and ionospheric irregularities. Development models for ionospheric scintillations and time-delay models for use in SATCOM.

(vi) Development of thermospheric models for satellite drag for low earth orbiters for different storm intensities.

Some of the problems to be tackled in space weather predictions are the following:

(i) Long-term solar activity predictions which are used in determining the satellite life times and optimization of orbital parameters of low orbiting satellites, and for HF communication planning.

(ii) Short-term solar activity (solar indices) predictions are necessary to aid in satellite tracking and also in updating long-term HF predictions.

(iii) Forecasts on solar flares (X-ray flares) are needed to give warning on sudden ionospheric disturbances (SIDs).

(iv) Predicting the hazards to orbiting geostationary satellites due to solar energetic particles resulting in partial or permanent damage.

(v) Forecasts on geomagnetic storm occurrences are needed for their ionospheric and thermospheric effects. During storms, HF communications can be severely affected and can pose serious problems to orbiting satellites.

8 Conclusions
The geographical location of India in the global scenario is ideal for monitoring the developments in the equatorial and low latitude dynamics and its associated effect in the global $S_q$ current system,
equatorial ionization anomaly and equatorial and low latitude ionospheric irregularities. The existing extensive network of magnetic observatories through Russia, from magnetic pole to peninsular India centred along 145° geomagnetic meridian, provides unique data set of magnetic variations from pole to dip equator. Various aspects of equatorial ionosphere like spread-F, bubbles, equatorial anomaly, ionospheric scintillations, etc. have been extensively investigated at several institutions. The availability of the VHF backscatter radar measurements with high time resolution and rocket launching facilities at Thumba and Sriharikota are extremely useful in providing the ionospheric parameters to supplement the ground-based magnetometer data. In addition to these, existing experimental facilities, such as measurements of ionospheric parameters from ionosonde observations, MST radar measurements, drift measurements from partial reflection radars, scintillation and airglow measurements are already operational at various institutions in India. Scientists at National Physical Laboratory, New Delhi, have been actively involved in developing ionospheric prediction models for the Indian region during quiet and disturbed ionospheric conditions. Contributions from all these areas towards formulating a coordinated programme for space weather mission would place the country in the global arena.

Monitoring the changes in the geomagnetic field on a continuous basis yields information on the electromagnetic state of the near and far space environment of the planet earth. Magnetic recordings are a comparatively inexpensive method to monitor the signatures associated with the large-scale currents generated in the ionosphere and magnetosphere of the earth. The magnetic measurements from the Indian longitudinal chain form a unique database in view of investigating the ionosphere magnetosphere-coupling processes, as the entire network can cover the locations spanning from equator to the north pole in the Indo-Russian longitude.

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