SPACE WEATHER AND REAL-TIME MONITORING

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ABSTRACT

Recent advance of information and communications technology enables to collect a large amount of ground-based and space-based observation data in real-time. The real-time data realize nowcast of space weather. This paper reports a history of space weather by the International Space Environment Service (ISES) in association with the International Geophysical Year (IGY) and importance of real-time monitoring in space weather.

Keywords: Space Weather, Real-time Monitoring, International Space Environment Service (ISES)

1   INTRODUCTION

The International Geophysical Year (IGY) took place between 1957 and 1958. In the IGY, the first artificial satellite, Sputnik 1, was launched on 4 October, 1957. After approximately 50 years since the Sputnik, now we use many satellites for communication, broadcast, navigation, meteorological observation, and so on. After several failures of satellites, we notice that we can not neglect the space environment, which affects manmade technology systems. It is called "space weather." Researches of space weather are on going all over the world now.

During the IGY, the information of Alert and Special World Interval (SWI) was exchanged among participated institutes for coordinated observations of the Sun and geophysical environment. The Alert was distributed whenever solar activity is unusually high and significant geomagnetic, auroral, ionospheric or cosmic ray effects are probable. The SWI was distributed whenever a possibility of an outstanding geomagnetic storm is high during the period of the Alert. These Alert and SWI are a root of space weather information by the International Space Environment Service (ISES). The information was coded and transferred via telegram and was also broadcasted by HF radio wave using the Morse codes. The Radio Research Laboratories (RRL) (present NICT; the National Institute of Information and Communications Technology) in Japan contributed the SWI or the forecast of outstanding geomagnetic storms and functioned as the Western Pacific Regional Warning Center (RWC). The data were exchanged through the RWCs located in the world. During the IGY, the exchanged data and information were limited because of ability of data transfer. Figure 1 shows the data exchange in IUWDS; the International URSIgram and World Days Service (present ISES) formed in 1962 after the IGY (International URSIGRAM and World Days Service, 1973) and Figure 2 shows an example of the coded data exchanged in the IUWDS. In 1996, the IUWDS became the ISES which has a mission to encourage and facilitate near-real-time international monitoring and prediction of the space environment, to assist users reduce the impact of space weather on activities of human interest. Now there are thirteen ISES RWCs in Sydney (Australia), Brussels (Belgium), Sao Jose dos Campos (Brazil), Ottawa (Canada), Beijing (China), Prague (Czech Republic), New Delhi (India), Tokyo (Japan), Warsaw (Poland), Moscow (Russia), Hermanus (South Africa), Lund (Sweden), and Boulder (USA). An Associate Warning Centre is in France (Toulouse). The European Space Agency (Noordwijk) works as a collaborative expert centre for space weather activities in Europe.

Now broad-band internet enables to share a large amount of observation data in real-time. This largely improves capability of carrying out the coordinated observations. For space weather, a large amount of real-time data improves capability of nowcasting and forecasting. The real-time data enable to automatically detect occurrence of hazardous events (e.g. occurrence of sudden ionospheric disturbances, arrival of high energy particles, arrival of interplanetary shocks, and so on) and to send warnings to users. In space weather, the real-time data are used not only to understand present condition but also to drive models as inputs. Utilization of models can improve accuracy of space weather forecasts. The NICT has developed the neural network forecast model of Dst index (Watanabe et al., 2003) and the real-time MHD simulation model of Earth's magnetosphere driven by real-time ACE solar wind data (Den et al., 2006).

Satellite communication is useful for real-time data collection from areas without communication infrastructures although its cost is high. The International Real-time Magnetic Observatory Network (INTERMAGNET) is a pioneering project of the real-time data collection. This project started in the end of 1980s and uses the communication channels of the metrological satellites (e.g. GOES, Himawari, and METEOSAT) for data collection. Now the INTERMAGNET also uses internet for data collection (http://www.intermagnet.org/Welcom_e.html).

This paper reports a role of real-time monitoring in space weather from the points of (1) warning, (2) forecast model, (3) research, and (4) education and public outreach.
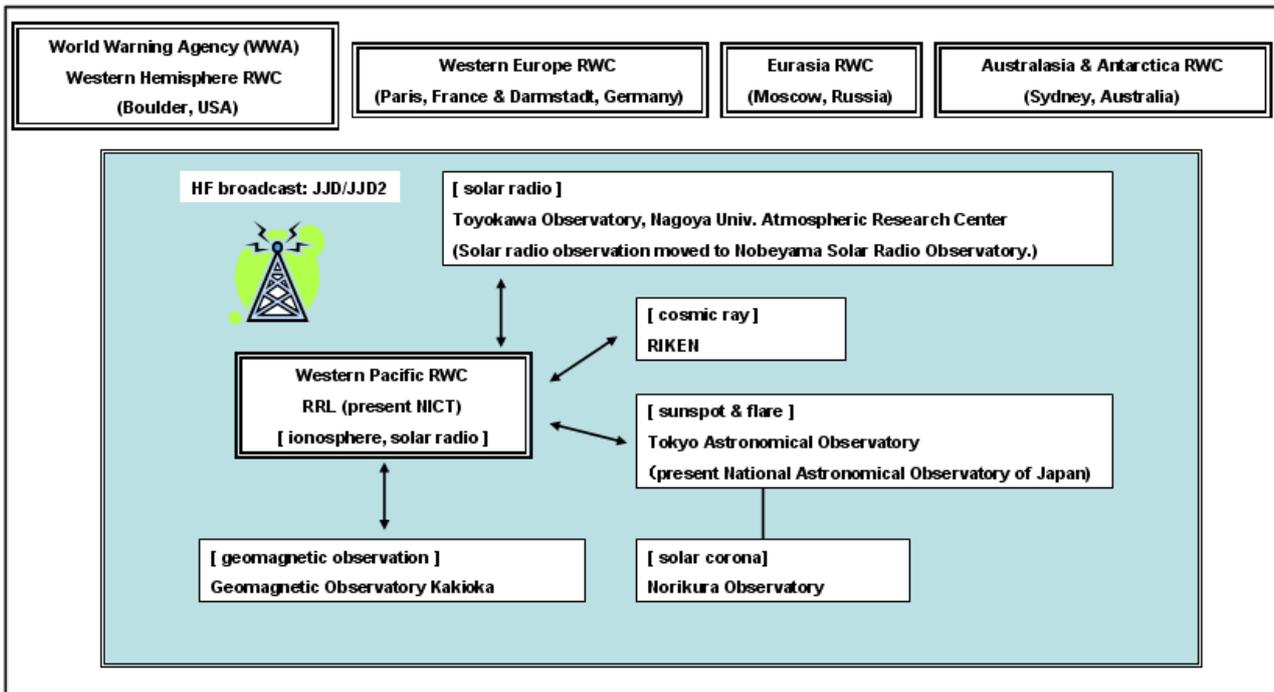
Figure 1. Data exchange in the IUWDS (International URSIGRAM and World Days Service, 1973).

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BOUTOK 31051
USSPS 32404 31077 ///32 29003 11335 21405 UMAGF 32505 81031
0930/ 30097 1/014 22344 33222 99999 UMAGF 36701 81030 0900/
29098 1/144 22366 35322 21600 52001 29356 UMAGF 33603 81031
0000/ 30007 1/015 23213 32532 21630 UMAGF 43501 81031 0300/
30005 1/018 2///3 34432 UMAGF 39601 81031 0300/ 30009 1/015
22223 33443 ///// UMAGF 47701 81031 0300/ 30038 1/095 22145
36321 UMAGF 45601 81031 0300/ 30002 1/017 23224 34432 UMAGF
38501 81031 0330/ 30037 1/010 22122 34311 UMAGF 36801 81031
0000/ 30006 1/647 24544 33964 10600 91630 99999 URANJ 32404
81031 00245 11110 01311 URANJ 32404 81031 00410 11110 03411
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11110 05311 URANJ 32404 81031 02695 11110 06911 URANJ 32404
81031 04995 11110 12111 URANJ 32404 81031 08800 11110 19311
URANJ 32404 81031 15400 11110 47111 UMAGF 31523 81031 /////
3000/ 1/019 23223 33543 99999 URANJ 34502 81031 03000 07120
06509 URANJ 34502 81031 00204 07120 00609 USSPS 21305 31165
///32 37006 13505 01209 URANJ 17401 81031 00245 16160 01016
URANJ 17401 81031 00410 16160 02116 URANJ 17401 81031 00610
16160 03816 URANJ 17401 81031 01415 16160 05416 URANJ 17401
81031 02695 16160 06316 URANJ 17401 81031 04995 16160 12516
URANJ 17401 81031 08800 16160 20416 URANJ 17401 81031 15400
16160 46016 URANJ 22501 81030 02800 16170 07017
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Figure 2. Coded data exchanged in the IUWDS.

2   SPACE WEATHER WARNING USING REAL-TIME DATA

Real-time data enable to monitor and to understand current space environment, and to nowcast space weather. Figure 3 shows the space weather forecast center in the NICT. In this center, we continuously monitor near real-time data of solar images, solar energetic particle, solar x-ray flux, solar wind, high-energy electron flux at geosynchronous orbit, geomagnetic field, ionosphere vertical soundings, total electron contents, results of simulation of the Earth's magnetosphere, and so on. Referring those data, we make a forecast of occurrence of solar flare, geomagnetic disturbance, and solar energetic particle events every afternoon (Watari, 2009).

Figure 2. Space weather forecast center in the NICT.

Using the real-time data, it is possible to automatically detect occurrence of hazardous events and to deliver warning of space storms, such as arrival of solar energetic particles, occurrence of geomagnetic storms, enhancement of energetic electron at geosynchronous orbit, and so on.

The NOAA/Space Environment Prediction Center (SWPC) defined space weather scales for geomagnetic storms, solar radiation storms, and radio blackouts of ionosphere based on GOES measurements and geomagnetic Kp index as shown in (http://www.swpc.noaa.gov/NOAAscales/). It is possible to deliver warnings based on this table using measurements by the GOES satellites and Kp index.

Figure 3 shows an example of the warning service of NICT through a web page using real-time data (http://swc.nict.go.jp/contents/index_e.php). This warning service system automatically detects the warning levels using the GOES measurements of x-ray flux, solar energetic particle flux, and energetic electron flux. We determine the warning levels based on the NOAA space weather scales. On geomagnetic storm, we use value of Dst-index forecasted by the neural network model (see Section.3). Those warnings are also delivered using RSS 2.0 (Really Simple Syndication).

Shinohara et al. (2005) developed an automatic detection and warning system of geomagnetic sudden commencements (SCs) using real-time data from ground-based geomagnetic observations. It is important for a warning of space weather to detect the SC because the SC is a good indicator of onset of the geomagnetic storm. They developed a method to detect the SC/SI (Sudden Impulse) using amplitude and increasing rate of geomagnetic field based on their statistical analysis of the SCs. The system sends information of onset time, amplitude, and observation sites of SC/SI to registered users by e-mail as soon as the system detects the SCs.

3   REAL-TIME DATA AS INPUT TO FORECAST MODEL

Utilization of models has a possibility to improve forecasts of space weather. The real-time data are used not only to understand present condition but also to drive models as input parameters.
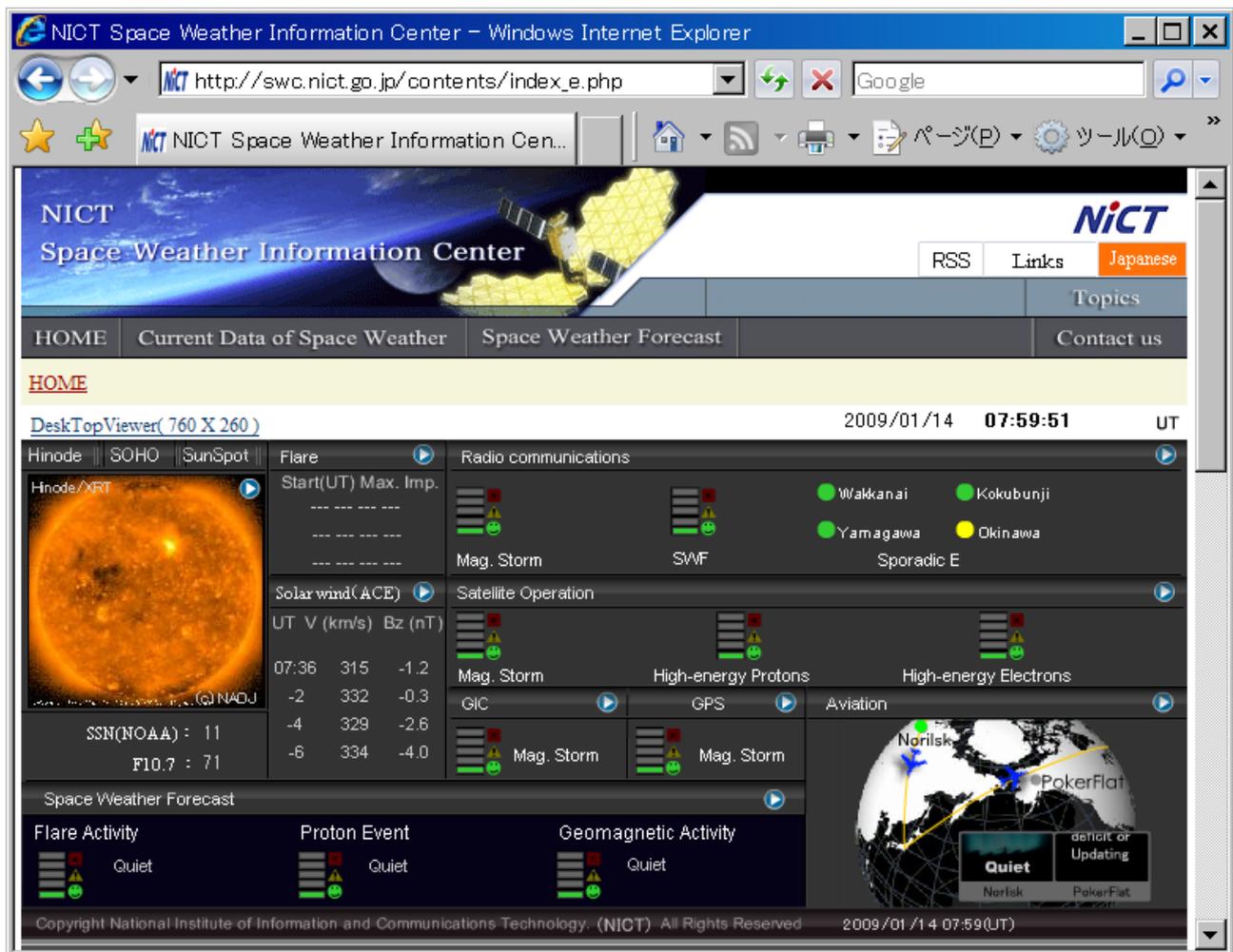
Figure 4. NICT warning service using web (http://swc.nict.go.jp/contents/index_e.php).

Now we can use real-time solar wind data from the ACE; Advanced Composition Explorer (Zwickl, et. al., 1998). The ACE is stationed in a halo orbit about the Sun-Earth libration point L1 and contentiously has sent us the solar wind data in real-time since 1997. It enables advance warning of disturbances because the ACE is in approximately 1.5 million km upstream from the Earth and observes the solar wind approximately 30-60 minutes before it reaches the Earth. As a pioneering work of real-time solar wind data, the NOAA/SESC; Space Environment Service Center (present SWPC) received real-time solar wind data from the International Sun Earth Explorer 3 (ISEE-3) between March of 1980 and mid-1982 in collaboration with NASA for early warnings of geomagnetic storms (Joselyn, 1986).

There are several examples of forecast models using real-time solar wind data as inputs. Watanabe et al. (2003) developed a neural network forecast model of Dst index. Dst index is a measure of geomagnetic storms. They use velocity, density, magnitude of interplanetary magnetic field (IMF), and x, y, z components of IMF of the real-time solar wind data. Watari et al. (2008) developed a neural network forecast model of high-energy electron flux at geosynchronous orbit using the real-time data as inputs. It is known that high-energy electrons cause deep dielectric charging of spacecraft.

Den et al. (2006) developed a real-time MHD simulation model of Earth's magnetosphere. The model is driven by the real-time ACE solar wind data and the result of the calculation is delivered every 5 minute through the web (http://www2.nict.go.jp/y/y223/simulation/realtime/). Geomagnetic AE index, a measure of aurora activity, is calculated using the result of this simulation (Den et al., 2006; Kitamura et al., 2008). Shinagawa et al. (2008) have developed a real-time ionosphere-thermosphere simulation model using the ionospheric parameters given by the real-time Earth's magnetosphere model (http://www2.nict.go.jp/y/y223/simulation/ionos/ion/index.html).

4   REAL-TIME DATA AND RESEARCH

The real-time data are also useful for research. The real-time data increase a capability of carrying out the coordinated observations because it is possible to check the results of the ongoing observations and to flexibly change a target according to activity. Continuous monitoring of the real-time data increases a chance to find new phenomena in the data.

An internationally coordinated campaign, the Whole Heliosphere Interval (WHI) ran between March 20 and April 16, 2008 (http://ihy2007.org/WHI/WHI.shtml) as a part of the International Heliophysical Year (IHY) program, the 50th anniversary program of the International Geophysical Year (IGY). The WHI offered a valuable opportunity to look at the ground-state of the Sun- Earth system during solar minimum of Cycle 22. The participating researcher could flexibly determined their solar targets according to their scientific objects using real-time data. This is quiet different from the campaign during the IGY era.

The real-time data is effective for collaboration of space and ground-based observations. In a case of the Hinode satellite (Japanese satellite for solar observation launched in September 2006), pointing information of the onboard telescopes and latest images are opened through the web page (http://www.isas.jaxa.jp/home/solar/)). This information is useful for ground-based solar observers to select their observation targets.

As an attempt of a research assist system using real-time data, the Solar-Terrestrial Research Environment Laboratory (STEL), Nagoya University developed Geospace Environment Data Analysis System (GEDAS) (Kamide, 2006). GEDAS is to exchange data from satellite, radar, and other ground-based observations, as well as from simulation algorithms, and to analyze the data and run the computer codes, all on a real-time basis (http://st4a.stelab.nagoya-u.ac.jp/index-e.html). It is essential to have this kind of system in which ground-based observations and theoretical research are fully integrated to better understand the mutual linkages of the sun, the interplanetary medium, the magnetosphere, the ionosphere, the thermosphere and the neutral atmosphere.

Automated detection of events using real-time data is also useful for research. Nose et al. (1998) developed an automated detection system of Pi2 pulsations using wavelet analysis for substorm research (http://swdcli40.kugi.kyoto-u.ac.jp/pi2/). They use geomagnetic stations each separated 120 degrees in longitude to locate at least one station on the nightside at all times. As a result, this system enable to detect substorm onsets in real-time even if we are on the dayside and becomes an useful tool for research.

The Space Environment Research Center (SERC) of Kyushu University has constructed a real-time global magnetometer chain called MAGDAS (MAGnetic Data Acquisition System, http://magdas.serc.kyushu-u.ac.jp/) (Maeda, Yumoto, and the MAGDAS group, 2009). It is very useful for electromagnetic and plasma environment research in the geospace if we can get 1-second resolution data from all MAGDAS station in real-time.

5   REAL-TIME DATA AS EDUCATION AND PUBLIC OUTREACH

Space weather information using real-time data is a good content for education and public outreach material. Real-time data give us an excitement of seeing current space weather, such as aurora, solar images. For example, solar images taken by SOHO, the Solar and Heliospheric Observatory mission, are provided in near real-time through web-site (http://sohowww.nascom.nasa.gov/data/realtime-images.html). We can enjoy the current solar images taken by white light and extreme ultraviolet (EUV) and coronal mass ejections (CMEs) taken by the coronagraph on board SOHO.

We can notice a relation between our daily lives and space weather through the space weather effect because space weather events affect manmade technology systems (Lanzerotti, 2001). For example, the blackout of power system occurred by geomagnetically induce current (GIC) in associated with the March 1989 geomagnetic storm. Communications or broadcast satellite services are sometimes disrupted because of failures of satellites caused by space weather events.

On education using real-time data, there is an example of an activity in the SERC of Kyushu University (http://www.serc.kyushu-u.ac.jp/index_e.html). Students in Department of Earth and Planetary Sciences check real-time data and make daily summaries of space weather. This activity trains abilities to analyze space environment data and to find something different in the data.

6   SUMMARY

Figure 4 shows a schematic picture of space weather information center. Recent advance of information and communications technology enables to collect large amount of data in real-time. This expands application of the data in operation and research of space weather. General public can also refer current space weather information and enjoy beautiful auroras and solar images through web pages.

It is important for space weather to collect ground-based observation data in arctic and equatorial regions (Antarctica, Siberia, Amazon, Africa, and so on) because the effect by space weather tends to appear in those regions. However, it is usually not easy to get electricity and communication line for data transfer in those regions. On the power, it is possible to use solar panels or wind generators. However, it is difficult to get the communication line. Wireless network system is useful for this situation. The wireless network equipments become cheaper and can provide long-distance internet

connection between an observation point and a nearby internet entrance. Satellite communication is also useful for the data collection although its cost is still expensive. For example, the National Institute of Polar Research (NIPR), Japan has collected data from the unmanned magnetometer network in Antarctica using the Iridium (Yamagishi et al., 2007). The Iridium is a constellation of 66 cross-linked satellites orbiting at an altitude of about 780 km and provides global coverage.

Resent ground-based observations tend to produce a large amount of data such as atmospheric imagers. A low-cost high-speed communication service with global coverage is necessary to construct a dense real-time space weather monitoring network. This will be realized by a satellite communication system. Development of a small low-power transmitter is necessary for this.
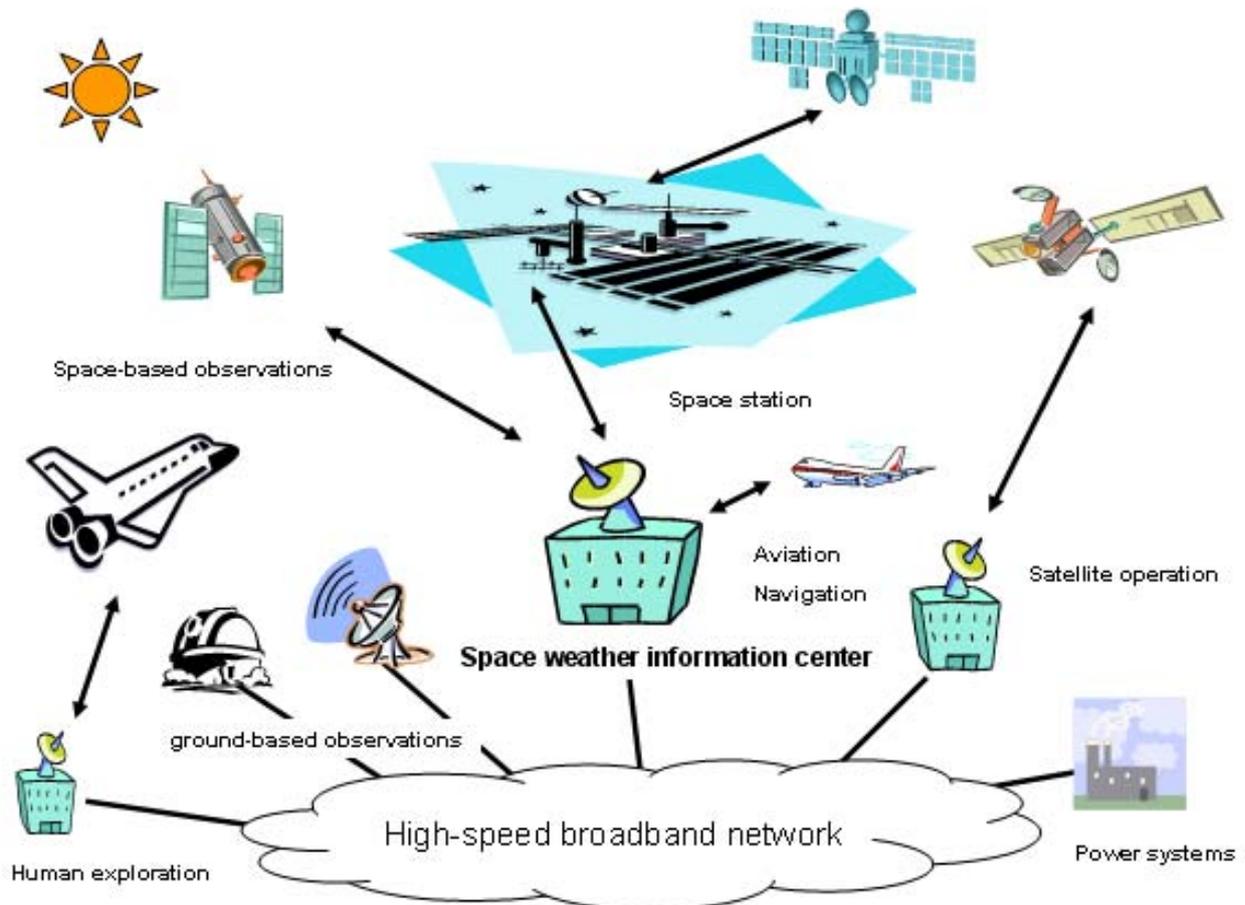

Figure 5. A schematic picture of space weather information center.

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