May 2012 Solar Activity ~ Radio and Geomagnetic Effects

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Abbreviations in this article:

ACE:	Advanced Composition Explorer
AGC:	Automatic Gain Control
CME:	Coronal Mass Ejection
GLE:	Ground Level Enhancement
HF:	High Frequency
IMF	Interplanetary Magnetic Field
NOAA:	National Oceanic and Atmospheric Administration
RF:	Radio Frequency
RFI:	Radio Frequency Interference
RSP:	Radio-SkyPipe
SDR:	Software Defined Radio
SSB:	Single SideBand
SWPC:	Space Weather Prediction Center

1. Introduction

Solar activity in May was very high with a series of flares, filament eruptions, radio bursts and some Earth-directed coronal mass ejections (CME). Flares can occur without a CME and a CME can occur without a flare. However, in May many of these occurred in combination resulting in both solar radio emissions and related geomagnetic activity. This article discusses two combination events that were observed 17 and 18 May at Anchorage, Alaska, 61.6 °N geomagnetic latitude, and resulted in both solar radio emissions in the high frequency (HF) band and geomagnetic variations. The associated active regions on the Sun were 1476 and 1482, respectively (figure 1).

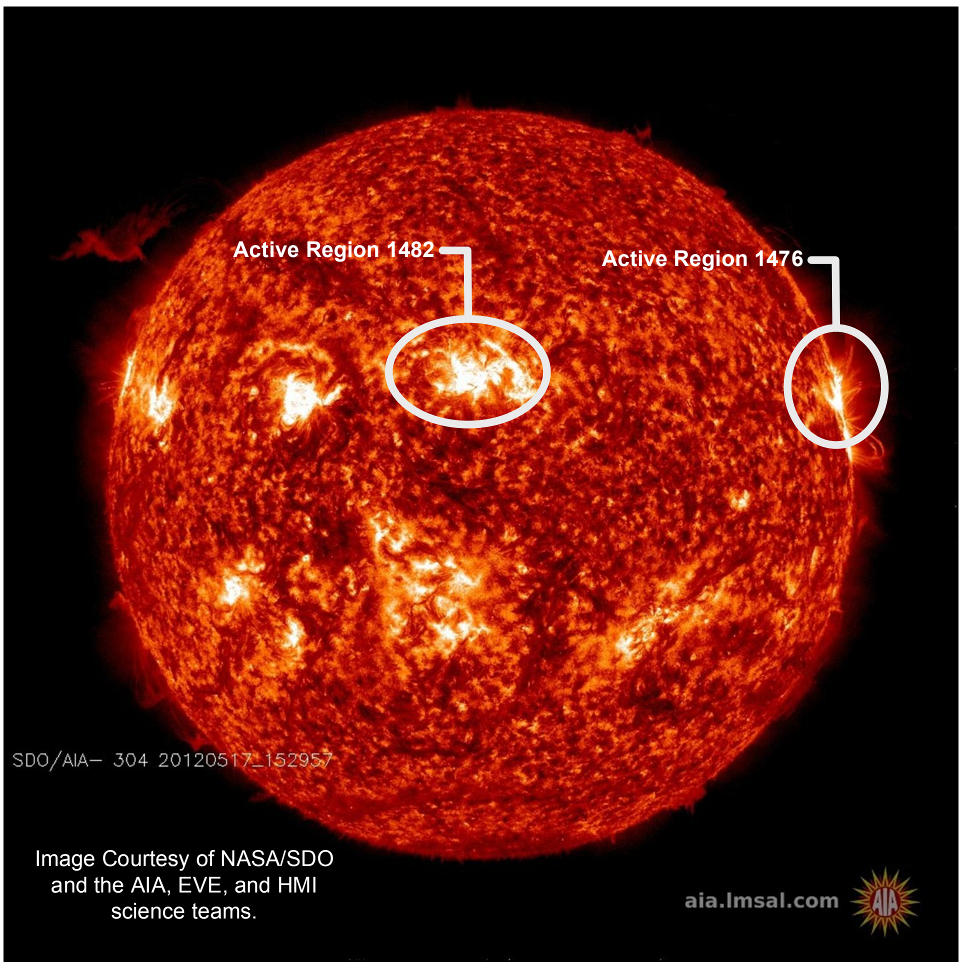

Fig. 1 ~ Image of the Sun taken on 17 May 2012 at 304 angstroms wavelength by the Solar Dynamics Observatory Atmospheric Imaging Assembly. The high-lighted active regions are associated with the radio and magnetic phenomena described in this article.

Solar radio emissions can result from the acceleration of charged particles when there is an explosion caused by rapid changes in the Sun's magnetic field usually above a sunspot. Such explosions can result in a large mass of particles, perhaps millions or billions of metric tons, and an attendant magnetic field being ejected. If the mass of particles is Earth-directed and collides with Earth's magnetosphere, the interaction usually results in a geomagnetic sudden impulse. Depending on how the interplanetary magnetic field (IMF) associated with the solar wind and the CME is oriented with respect to the geomagnetic field, Earth's magnetosphere may show additional disturbances following the sudden impulse. It is when the two magnetic field polarities are opposite that the greatest geomagnetic activity occurs.

Solar radio emissions travel at speed of light (300 000 km/s) and are received about 8.3 minutes later, while CMEs are much slower at 300 to 1000 km/s and are detected a few days later. The time differences makes it difficult to determine cause and effect (that is, what solar event caused what geomagnetic activity) especially when there is a lot of solar and associated geomagnetic activity. However, USA's Space Weather Prediction Center (SWPC), which is operated by NOAA (National Oceanic and Atmospheric Administration), provides a wealth of space weather information and identification, making correlation much easier.

In particular, SWPC issues Indices, Events, and Region Data Solar Event Reports, which list flare and related data and are updated every 30 minutes. SWPC also issues daily Reports of Solar-Geophysical Activity, which summarize solar events as well as related geophysical activity. Anyone can sign up for a free email subscription to these reports or view them online. Links to the various reports that I use daily are listed at the end of this article in **References and further reading**.

2. HF radio effects

Many solar eruptive events result in radio emissions over a wide frequency range. Some emphasize frequencies at HF. However, Earth's ionosphere usually blocks frequencies below around 15 MHz so emissions below this frequency generally cannot be received by terrestrial receivers (figure 2). Solar emissions are noise-like and when demodulated by an ordinary radio receiver manifest themselves as an increase in audio noise level. Powerful solar events can increase the background noise level by 40 dB (a factor of 10 000) or more. Solar radio bursts are categorized according to their radio spectrographic characteristics as Type I through Type VI. Readers are referred to the links at the end of this article to download an excellent explanation of these categories by Australia's Ionospheric Prediction Service (IPS) called *A Brief Introduction to Radiospectrogram Analysis*. For particular types of solar radio bursts that also may include a CME, the type II and III, it is possible to derive the CME speeds from spectrograms. A future issue of *Radio Astronomy* will have an article by Christian Monstein describing how to make these calculations.

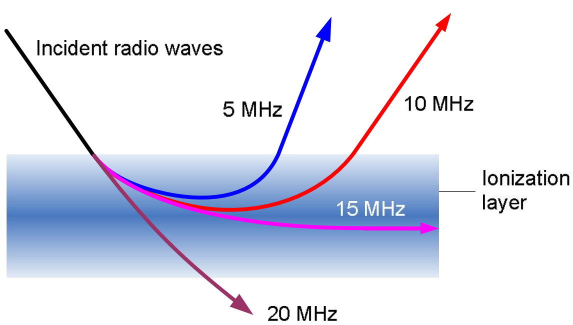

Fig. 2 ~ On Earth's sunlit side, the ionosphere acts like a high pass filter to celestial emissions and blocks incident radio waves below about 15 MHz.

3. Geomagnetic effects

Although very strong solar events can result in near-instantaneous geomagnetic effects, the effects of most events are felt on Earth a few days later. Generally, a geomagnetic sudden impulse (SI) occurs when a CME hits Earth's magnetosphere. NASA's Advanced Composition Explorer (ACE) spacecraft, located about 1.5 million km away from Earth at the L1 libration point (also called L1 Lagrangian point) in line with the Sun, provides about 40 to 50 minutes warning of the CME shock arrival at Earth.

A sudden impulse usually manifests itself on a magnetogram as a spike or step change in the charted magnetic flux density (magnetic induction). SI amplitudes range from several nT to 40 nT or more. Sudden impulses may be masked by the naturally higher geomagnetic activity at high latitudes (an example of this is shown later).

I use SWPC's daily Report of Solar-Geophysical Activity (RSGA) to identify sudden impulses and other manifestations of solar eruptive events on my magnetograms. Interested readers are referred to the links at the end of this article to download a Geomagnetism Tutorial. All magnetograms in this article show a 24-hour period from 0000 to 2400. The amplitude scales are normalized to the magnetic flux density measured at midnight (2400) the previous day (the charts begin the new day with zero relative amplitude).

4. Equipment setup – radio

The HF observations described here were made with two Icom R-75 general coverage receivers with Radio-Sky Publishing Radio-SkyPipe charting software and an RFSpace NetSDR software defined radio receiver with Moetronix SpectraVue spectrogram software. These receivers were connected through a multicoupler to a Sun-tracking log periodic antenna, which has a design frequency range of 18 to 32 MHz (but it operates well outside this range).

A block diagram shows these and other essential components used in my setup (figure 3). I usually setup my software defined radio receiver to operate in the 15 to 32 MHz frequency range and one of my general coverage receivers is set to a frequency between 19 and 20 MHz and the other between 24 and 30 MHz. The actual frequency settings depend on the radio frequency interference (RFI) level at the time of the observations

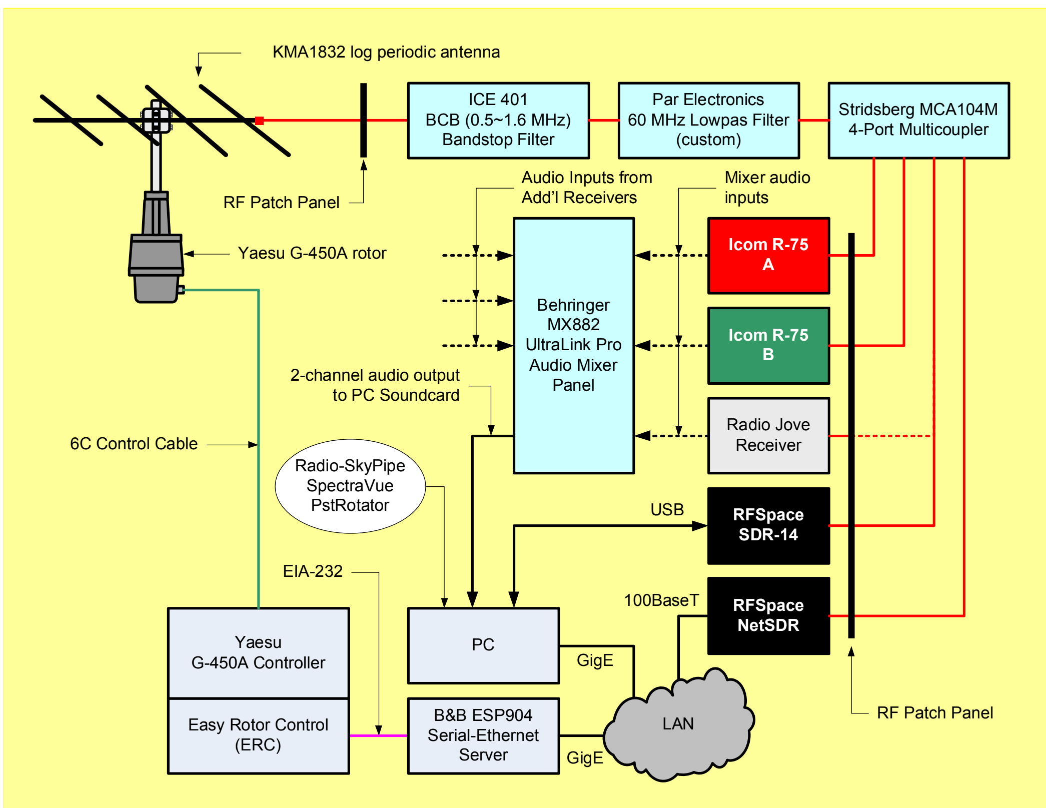

Fig. 3 ~ Block diagram of observatory HF equipment setup. In addition to receivers and antenna, the system includes RF filters, a multicoupler, transmission lines, patch panels, audio mixer, power supplies (not shown), antenna rotator, and a PC with a soundcard and running a variety of control, operating and charting software.

The SDR and associated software provide a spectrogram. A spectrogram shows a range of frequencies on one axis and time on the other axis. I usually setup the spectrogram to display a rolling 5-minute time interval on the horizontal axis corresponding to the same interval on the HF receiver charts. The received power is indicated by varying colors – black and blue indicates lower power and orange and red indicates higher power. Different colors can be matched to power levels displayed in decibels with respect to 1 mW, or dBm. Unlike the two HF receivers, I do not have the SDR receiver setup to demodulate the received emissions. Instead, the emissions are processed directly by the receiver and associated software to determine the received RF power level in narrow frequency bands (called bins). The power level is then translated to a colored pixel in the spectrogram.

The audio outputs of the two general coverage receivers are connected to a stereo soundcard in the PC. Radio-SkyPipe (RSP) is used to chart the audio levels and, optionally, record the audio itself. RSP is set to power mode and a sample rate of 10 samples/second. The chart vertical axis is calibrated in terms of antenna temperature in kelvin (K), which is proportional to audio power level. The chart is equivalent to a lightcurve.

As with the spectrograms, the RSP charts are setup to display a 5-minute rolling interval. Because the charts are recorded at a fixed frequency for any given observation period, they show a detailed but very narrow slice of the spectrum. The general coverage receivers are set to single-sideband (SSB) mode with a bandwidth of approximately 2800 Hz. The receivers' automatic gain control (AGC) functions are disabled so that their audio output power tracks the radio frequency input.

5. Equipment setup – geomagnetic

All geomagnetic measurements were made with a SAM-III magnetometer. This unit is equipped with three sensors oriented in a geographic coordinate system with X-component (north-south), Y-component (east-west) and Z-component (vertical). The SAM-III is setup to sample the geomagnetic flux density at a 0.1 Hz rate (1 sample every 10 seconds). The data is plotted in real-time on a magnetogram with flux density (nT) on the vertical axis and time on the horizontal. All magnetograms shown in this article are for a 24-hour period. A block diagram shows the overall magnetometer setup (figure 4).

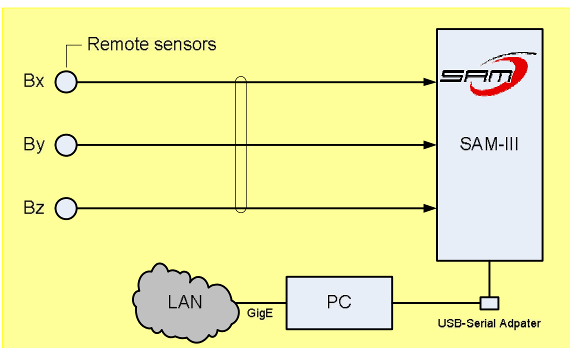

Fig. 4 ~ Block diagram of SAM-III magnetometer equipment setup. The SAM-III uses dedicated software to log and display data for the three magnetic field components, X, Y and Z.

6. Observations

Although I obtained many solar radio observations during May 2012, I only will show results for solar eruptive events on 17 and 18 May and geomagnetic sudden impulses resulting from the associated CMEs that arrived on 20 and 21 May.

For 17 May, SWPC reported a class M5 flare lasting from 0125 to 0214 along with a variety of radio phenomena. These included a slow drift radio burst (Type II), a fast drift radio burst (Type III) and a broadband smooth continuum radio burst (Type IV). Also associated with the flare was a partial halo CME (a halo CME is directed toward the imaging device and because of the occulting disk in the imager, it appears as a halo. A partial halo indicates the CME was not centered with respect to the imager). At that time, SWPC predicted that a shock enhancement in the interplanetary magnetic field was expected from the event and it could affect Earth's magnetic field.

Another interesting aspect of this solar activity was a huge mass of high-energy particles that reached Earth after only 20 minutes, traveling at about 40% the speed of light. This resulted in a rare *ground level enhancement* (GLE) at Earth during which neutrons cascaded to the ground. GLE events can have biological and technological ramifications. See **Reference and further reading** at the end of this article for additional information.

The radio spectrogram for this event shows a complex structure, including fast and slow drift radio emissions (figure 5). The corresponding RSP chart (figure 6) shows two narrow horizontal slices of the spectrum at 19.339 and 24.908 MHz. These slices also are indicated by the annotated red and green lines on the spectrogram. About three days later, the CME associated with this event arrived at Earth causing a sudden impulse at 0216 and some follow-on geomagnetic disturbances (figure 7).

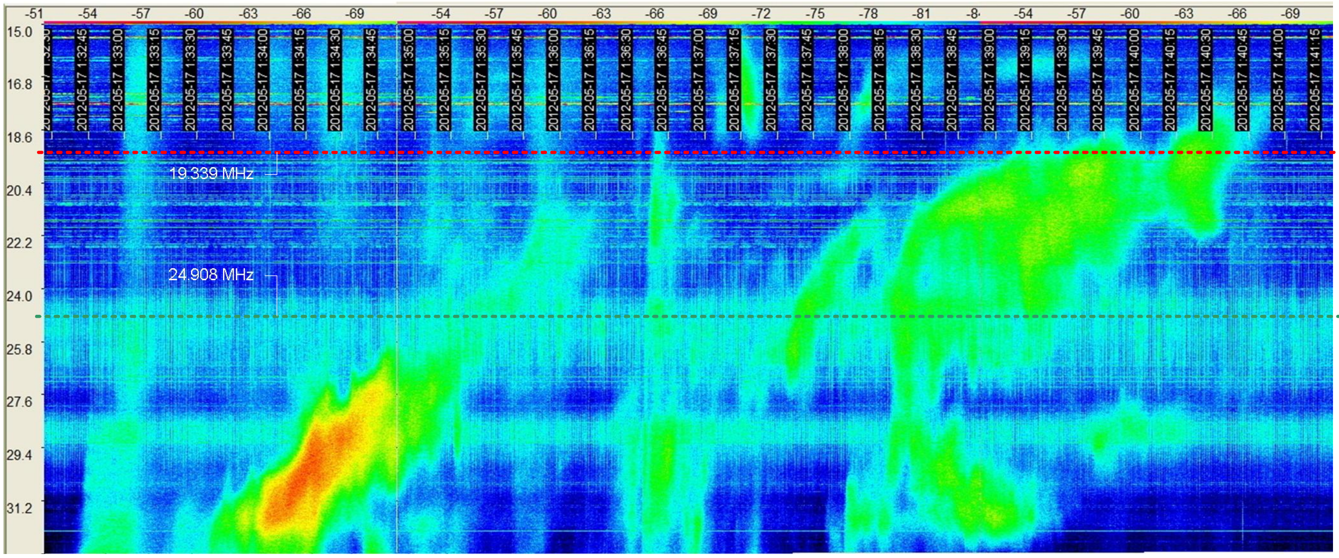

Fig. 5 ~ Type II, III and IV solar bursts on 17 May for the 9-minute period between 0132 and 0141 measured over a frequency range of 15 to 32 MHz. An initial Type III burst is shown early in the spectrogram at 0133, but the most intense emissions occurred about one minute later at the higher frequencies, indicated by the orange and red color (frequency decreases from bottom to top and time increases from left to right). Several 5-minute spectrograms were spliced to show this sequence. Horizontal red and green dashed lines have been added to indicate the narrow spectrum slices shown on the Radio-SkyPipe chart for the same time period. The wide and narrow horizontal turquoise bands at about 25 and 28 MHz are radio frequency interference (RFI).

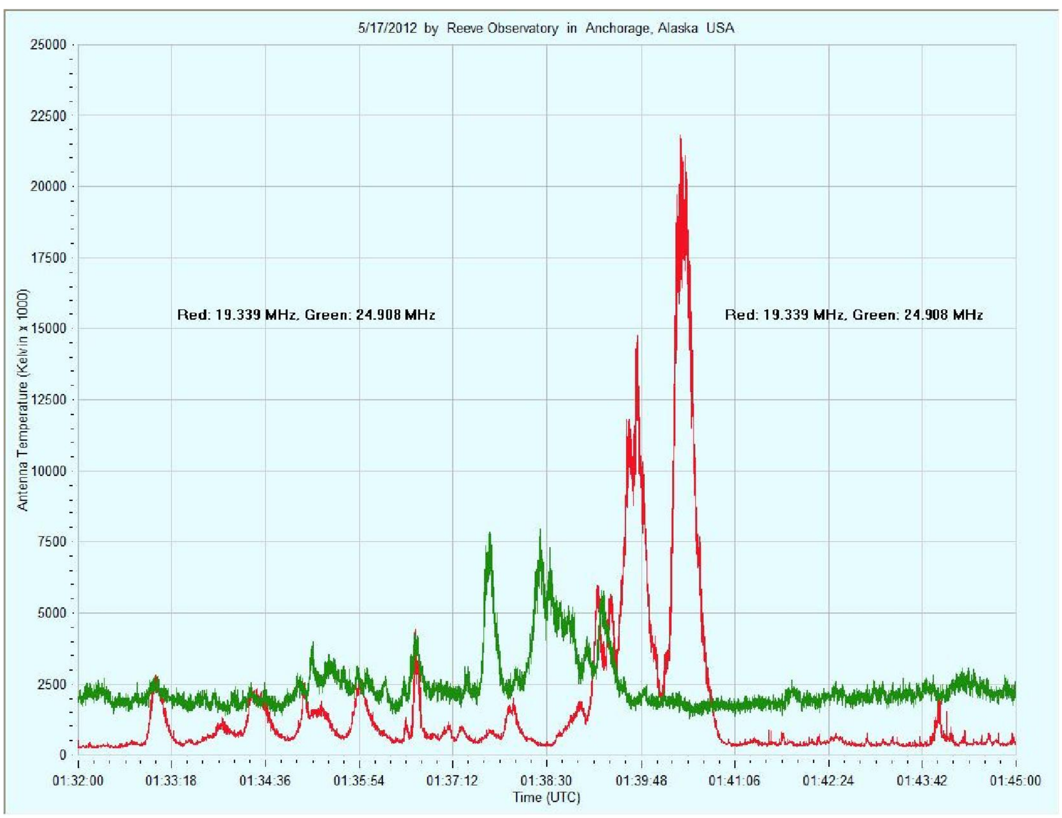

Fig. 6 ~ Narrow slices of spectrum at two frequencies indicated. The peak power (antenna temperature) at 19.3 MHz was about 22 million K. Most solar radio emissions sweep from high frequencies to low frequencies but this is not obvious in this chart due to the complexity of the solar burst.

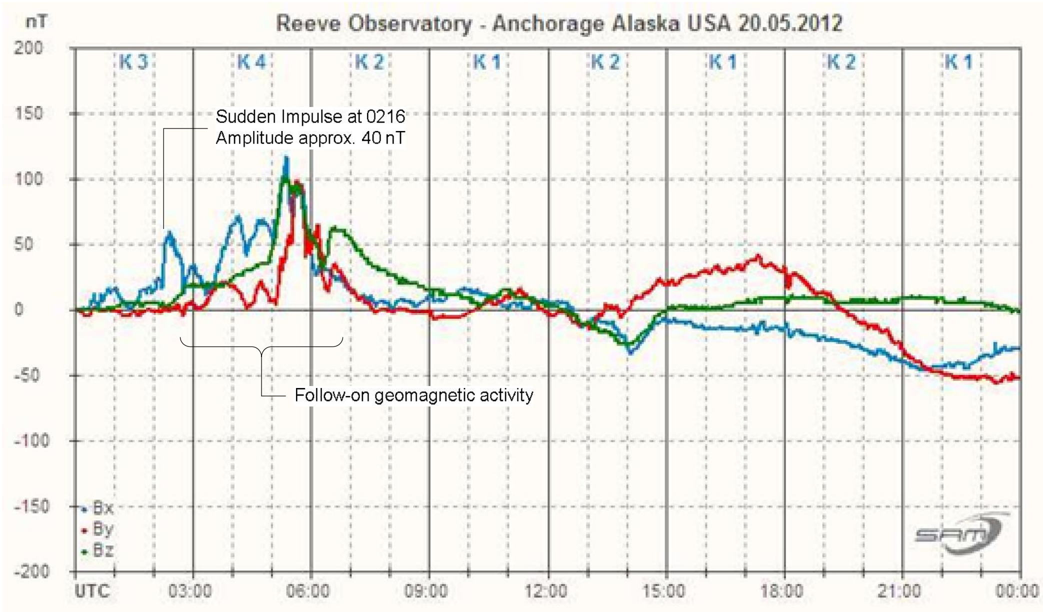

Fig. 7 ~ The CME associated with the 17 May solar event arrived at 0216 on 20 May as indicated by the sudden impulse. The average Earth-directed speed for the CME works out to about 570 km/s. This sudden impulse was followed for a few hours by somewhat weak geomagnetic activity indicating that the magnetic polarities of the IMF and magnetosphere were not much different. A key to the magnetic field components and their corresponding traces is provided in the lower-left corner of the chart.

The magnetogram showing the 20 May sudden impulse illustrates one of the problems identifying magnetically weak events at higher latitudes. Earth's magnetosphere is naturally more active at higher latitudes and some of this activity looks like impulses. It is for this reason that I use SWPC to identify and confirm sudden impulses on my magnetograms. SWPC uses a magnetometer in Boulder, Colorado (48 °N geomagnetic latitude) to identify sudden impulses. As seen on my 20 May magnetogram, the natural geomagnetic activity over-shadowed the weak sudden impulse. Some of the follow-on activity about 3 hours later looks impulsive but it is not considered a sudden impulse.

For 18 May, SWPC reported a filament eruptive event at 0510 with a CME predicted to hit Earth with a glancing blow. Associated with this event, SWPC reported a fast drift (Type III) sweep-frequency radio burst and a brief continuum burst (Type V) between 0447 and 0506. I detected the radio bursts between 0448 and 0450 (figure 8). The measured intensity at 19.2 MHz was about 35 million K, as seen on the Radio-SkyPipe chart (figure 9). The magnetogram for 21 May shows the sudden impulse at 1937 associated with the solar event (figure 10). This one is much easier to spot because it was a magnetically quiet day at my observatory latitude.

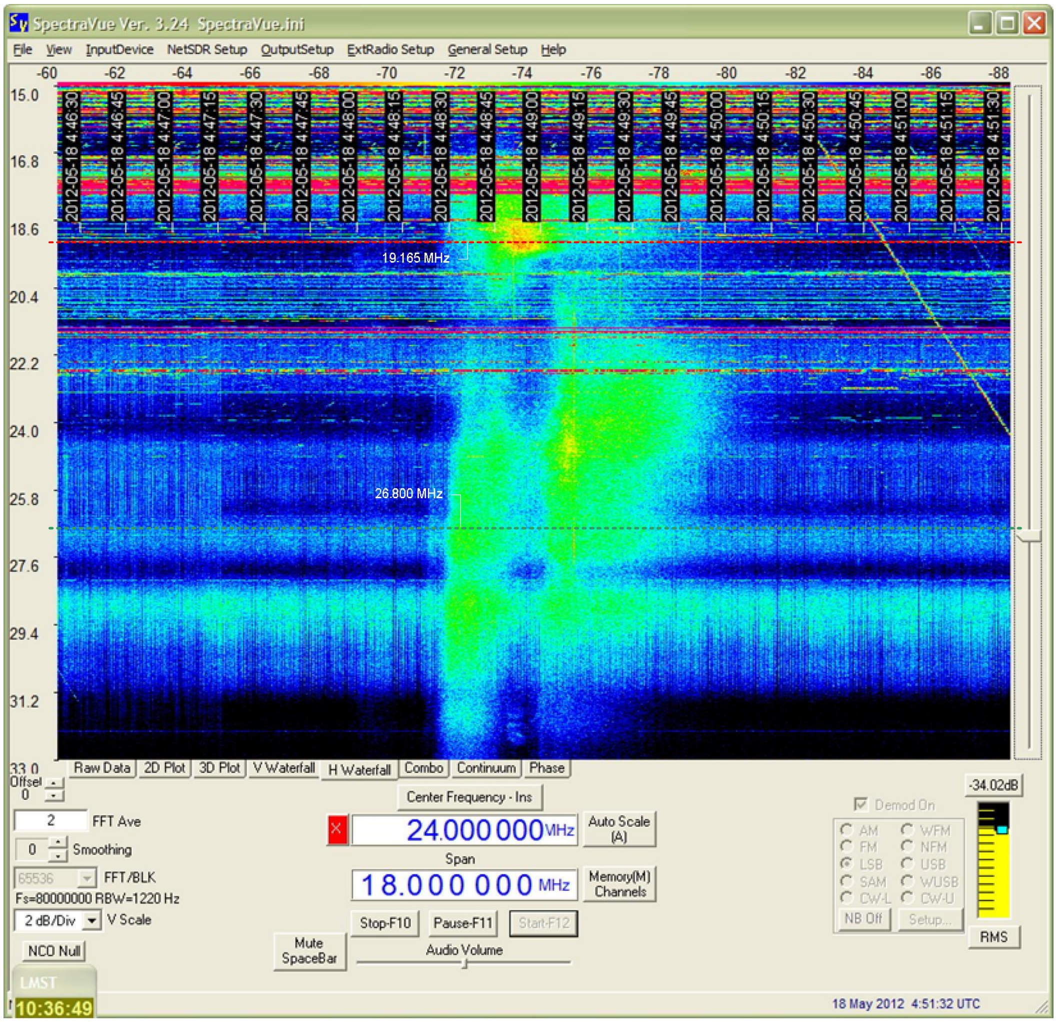

Fig. 8 ~ Type II I (fast drift) and Type V (brief continuum) solar bursts on 18 May between 0448 and 0450 measured over a frequency range of 15 to 32 MHz. The most intense solar emissions occurred at the lower end of the frequency range (top of scale). The spectrogram also shows SDR and software setup parameters including center frequency (24 MHz), frequency span (18 MHz) and color scaling. Horizontal red and green dashed lines have been added to indicate the narrow spectrum slices shown on the Radio-SkyPipe chart for the same time period. The thick red horizontal bar near the top at about 17 MHz is strong RFI.

7. Sudden impulse effects on magnetic field components

Sudden impulses generally have their greatest affect on the horizontal component (vector sum of X- and Y-components) of Earth's magnetic field and have less effect on the vertical component (Z-component). Examination the 20 May magnetogram reveals that Bx (the symbol for the X-component magnetic flux density) shows an impulse of about 40 nT at 0216, while By and Bz show almost nothing. On the other hand, the 21 May magnetogram clearly shows the SI on all three components (about 50 nT on By, 20 nT on Bx and around 10 nT on Bz) with the effect most obvious on Bx and By.

8. Conclusions

The active Sun during May 2012 offered an opportunity to study related events that were separated in time by about three days. Some of the events included both radio emissions and geomagnetic effects; the latter delayed by the much slower speed of CMEs that cause them. Additional radio and geomagnetic activity is reported in the Observations section of this journal issue.

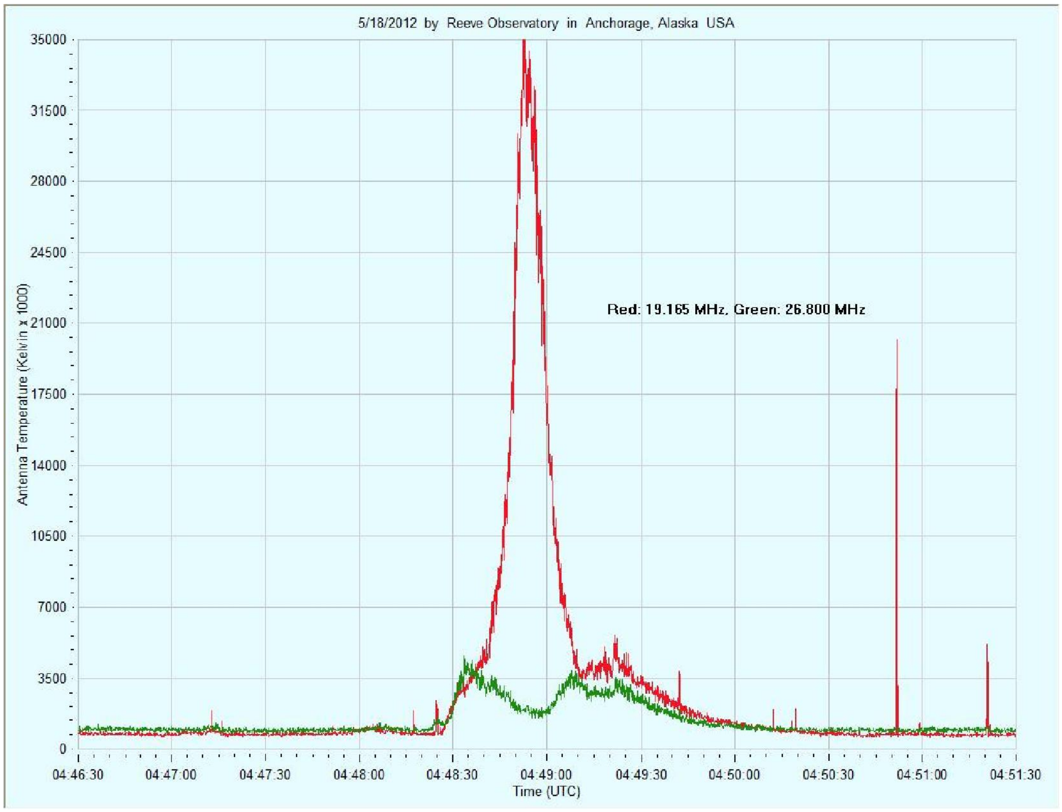

Fig. 9 ~ Narrow slices of spectrum at two frequencies. The peak power (antenna temperature) at 19.2 MHz was about 35 million K. The descending frequency sweep of this burst is more obvious than the previous one – note that the green trace (26.8 MHz) peaks before the red trace (19.165 MHz).

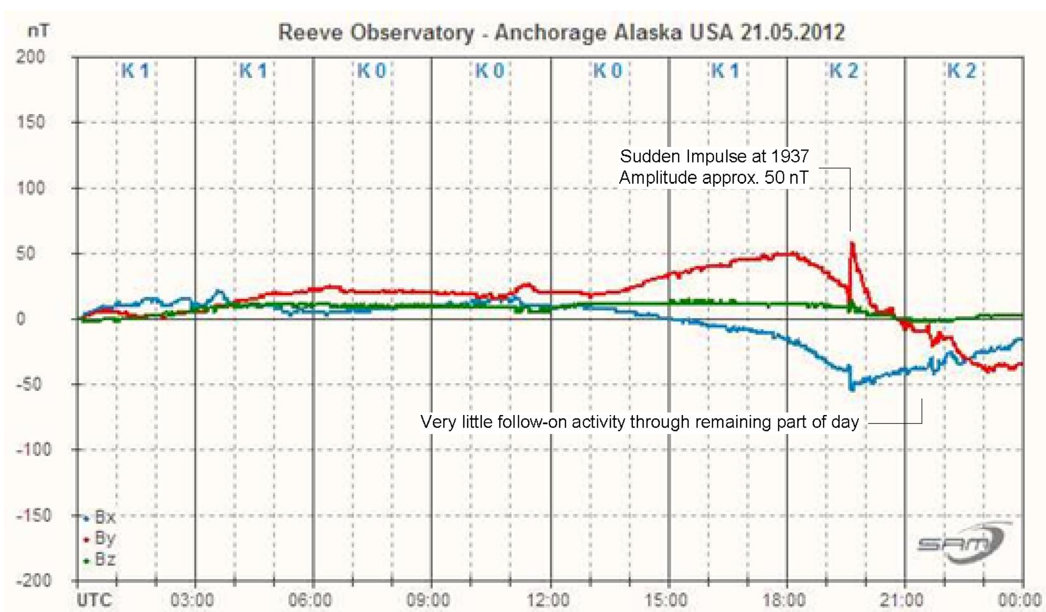

Fig. 10 ~ The CME associated with the 18 May event arrived at 1937 on 21 May and is clearly indicated by the spikes in the X- and Y-components. Earth's magnetic field was quiet throughout the day prior to the impulse, and there was very little additional geomagnetic disturbance after it arrived. The average Earth-directed speed for this CME was about 485 km/s.

9. References and further reading

Space Weather Prediction Center reports and subscriptions

- ☼ Indices, Events, and Region Data Solar Event Reports for the last 90 days: http://www.swpc.noaa.gov/ftpmenu/indices/events.html
- ☼ Readme file that explains all the abbreviations used in the above reports: http://www.swpc.noaa.gov/ftpdir/indices/events/README
- ☼ Report of Solar-Geophysical Activity: http://www.swpc.noaa.gov/ftpmenu/forecasts/RSGA.html
- ☼ Historical space weather data warehouse of all reported activity from 1996: http://www.swpc.noaa.gov/ftpmenu/warehouse.html
- ☼ SWPC product subscription service: https://pss.swpc.noaa.gov/LoginWebForm.aspx?ReturnUrl=%2fproductsubscriptionservice%2fMainMenuWebForm.aspx

Additional information

- ☼ A Brief Introduction to Radiospectrogram Analysis, Ionospheric Prediction Service (IPS): http://www.ips.gov.au/Category/World%20Data%20Centre/Data%20Display%20and%20Download/Spectrograph/A%20Brief%20Introduction%20of%20Radiospectrogram%20Analysis.pdf
- ☼ Geomagnetism Tutorial, Reeve, W., http://www.reeve.com/Documents/SAM/GeomagnetismTutorial.pdf
- ☼ News announcement in Universe Today of 17 May ground level enhancement: http://www.universetoday.com/95582/a-rare-type-of-solar-storm-spotted-by-satellite/#ixzz1wggGqESP
- ☼ The Effect of Cosmic Rays on Biological Systems – An Investigation During GLE Events, N. K. Belisheva1, N., Lammer, H., Biernat, H., Vashenuyk, E., Astrophys. Space Sci. Trans., 8, 7–17, 2012, www.astrophys-space-sci-trans.net/8/7/2012/, doi:10.5194/astra-8-7-2012: http://www.astrophys-space-sci-trans.net/8/7/2012/astra-8-7-2012.pdf