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Solar radio astronomy in Space Weather applications

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Abstract. Various kinds of solar radio events are associated with and can be used as proxies of geoeffective phenomena, such as e.g. the radio flares at 10 cm wavelength, metric type II bursts and type III bursts as well as metric radio flares. The Trieste Solar Radio Systems routinely detects these radio emissions and produces radio indexes representative of the solar coronal activity level. In this work we analyze two representative cases of solar flares, respectively a driver and a non-driver of solar-terrestrial perturbations, both identified through their radio signatures by TSRS observations, and emphasize the suitability of TSRS for Space Weather applications.

Key words. solar radio astronomy – radio flare – solar flare – space weather

1. Introduction

Solar radio emissions are signatures of thermal and non-thermal plasma processes occurring at different levels in the chromosphere, in the corona and in the interplanetary plasma. Despite the fact that both the phenomenology and its interpretation are quite complex (see e.g. Dulk 1985, Benz 1993, Bastian et al. 1998), some specific solar radio events are clearly associated with transient solar activity such as flares and prominence eruptions, which drive geoeffective perturbations through e.g. the orders-of-magnitude enhancement of the radio background noise (see e.g. Nita et al. 2002) and the generation of Earth-directed coronal mass ejections (CME). For example, in Space Weather monitoring and predicting the Space Environment Center (NOAA/SEC) issues alerts when the following events are observed: a) a 245 MHz radio burst with peak flux $\geq$ 100 sfu (solar flux units); b) a 245 MHz noise storm with peak flux $>$ 5 times background; c) a 10 cm burst with peak flux $>$ 100% background; d) any type II bursts; e) any type IV bursts. Hence the real-time detection of the solar radio emission at different wavelengths with high time resolution is an important diagnostic tool for Space Weather (see e.g. Messerotti 2001). In this framework the Trieste Solar Radio System (TSRS) (Messerotti et al. 2001) performs

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a continuous radio surveillance of the solar coronal emissions at metric (237, 327, 408 and 610 MHz) and decimetric frequencies (1420 and 2695 MHz) and publishes the relevant solar radio indexes in near real-time. The latter ones are computed as the average radio flux over 1-minute time intervals at each receiving frequency and are effective indicators of radio activity associated with flares, such as "Tenflares" at 2695 MHz (11 cm) and "Radioflares" in the metric domain. In the following we comment on two representative cases with special attention to the associated radio phenomenology and its timings: a) a moderate X-intensity flare occurred on 16 August 2002, which originated geoeffective phenomena, and b) a high X-intensity flare occurred on 30 August 2003, which did not produce any significant solar-terrestrial perturbations.

2. Radio signatures of a M5/2N flare

On August 16, 2002 the active region NOAA 69 with a δ magnetic configuration and located at S14 E20 (Fig. 1) produced an M5/2N flare with SXR peak at 12:32 UT. Radio signatures of the flare and secondary phenomena were: a) a 1600 sfu Tenflare (Fig. 2); b) a type II burst, originated by a propagating hydrodynamic shock; c) an intense type IV burst, i.e. a broadband radio flare (Fig. 3). The 11-cm Tenflare was quite intense and long-lasting (more than 1 hour) as depicted by the 1-min-average TSRS solar radio index, indicating a prolonged response of the deeper plasma layers. The 1-min-ahead index prediction algorithm proved successful in outlining the subsequent time evolution of the great burst (Fig. 2). The response of the higher coronal plasma layer was instead much more prolonged as shown by the type IV solar radio burst which lasted for hours until the end of the daily observing run (Fig. 3). As typically occurs, the metric ra-

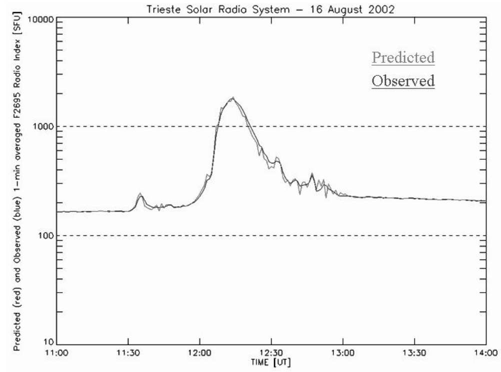

Fig. 2. Observed (dark line) and predicted (light line) time evolution of the TSRS 2695 MHz radio index on 16 August 2002.

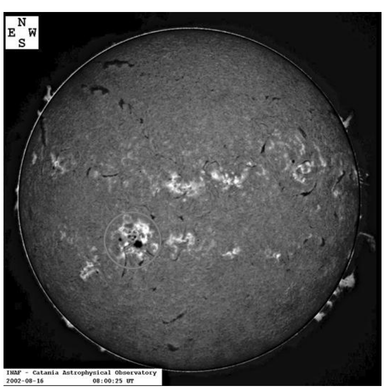

Fig. 1. $H\alpha$ picture of NOAA AR 69 (encircled) on 16 August 2002. Courtesy of INAF-Catania Astrophysical Observatory.

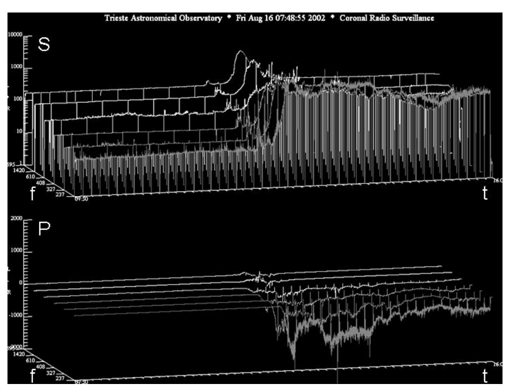

Fig. 3. TSRS multichannel synoptic graph showing the intense radio flare associated with the 16 August 2002 flare.

dio flare experienced an enhancement later when the Tenflare was decaying. In Fig. 3 the GOES SXR lightcurve is superimposed to point out the relevant timing of the radio signatures with respect to the SXR emission. Possible radio precursors are visible before the main start of the flare. A full-halo CME was originated which reached the Earth after 1.5 days at an average speed of 1154 km/s. The related shock arrived on August 18 and the geomagnetic field (GMF) was highly perturbed on August 19 as indicated by the high values of the estimated Kp index (Fig. 5).

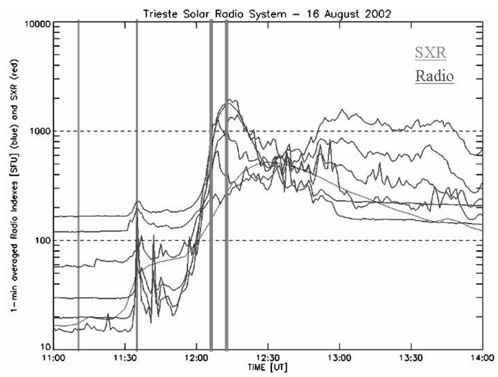

Fig. 4. Timing of the radio events observed by TSRS with respect to the GOES SXR flare on 16 August 2002. Vertical bars indicate the beginning and maximum of the associated optical flare.

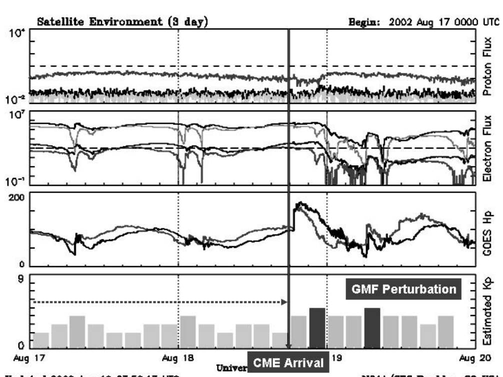

Fig. 5. NOAA/SEC 3-days satellite environment data for the period 17-19 August 2002.

3. Radio signatures of a X1/SN flare

On August 30, 2002 the active region NOAA 95 with a $\beta\gamma$ magnetic configuration and located near the solar limb at S15 E74 (Fig. 6) produced an X1/SN flare with SXR peak at 13:29 UT. Radio signatures of the flare and secondary phenomena were: a) a 780 sfu Tenflare; b) a type II burst (Fig. 8); c) an intense but short-lasting type IV burst (Fig. 7). Despite its relatively high peak intensity, the duration of the 11-cm Tenflare observed by TSRS was limited to a few minutes and the prediction algorithm failed to some extent mainly due to the impulsive nature of the event and its short duration. An unpolarized, harmonic emission type II burst was observed at the start of the event (Fig. 8) at metric wavelengths with a frequency drift rate of -4.1 MHz/s and the following start times: - 13:27:30 UT at 610 MHz; - 13:28:50 UT at 408 MHz; - 13:29:00 UT at 327 MHz; - 13:29:00 UT at 237 MHz. A type IV burst was observed in the metric channels with a duration of a few tens of minutes (Fig. 7). This flare did not produce any significant solar-terrestrial effect.

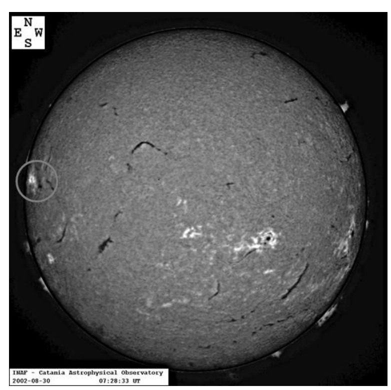

Fig. 6. $H\alpha$ picture of NOAA AR 95 (encircled) on 30 August 2002. Courtesy of INAF-Catania Astrophysical Observatory.

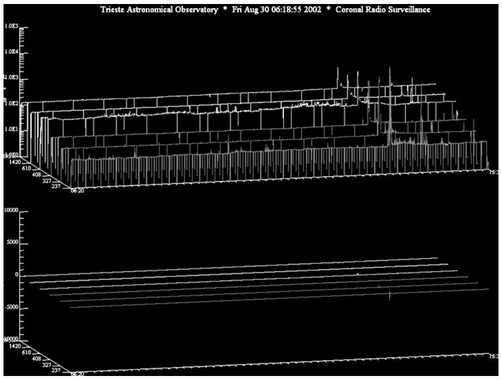

Fig. 7. TSRS multichannel synoptic graph showing the intense impulsive radio flare associated with the 30 August 2002 flare.

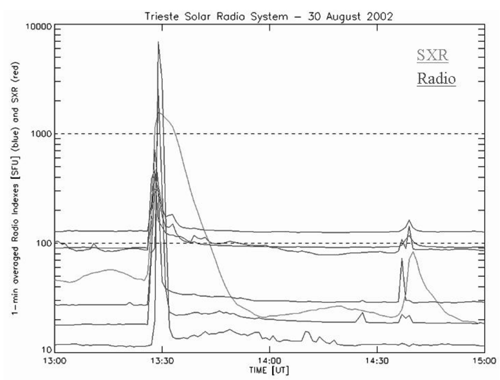

Fig. 8. Timing of the radio events observed by TSRS with respect to the GOES SXR flare on 30 August 2002.

4. Conclusions

The Trieste Solar Radio System proves an effective observational tool for coronal surveillance purposes. Daily solar radio indexes are global descriptors of the solar activity level, whereas solar radio indexes averaged over 1-minute time intervals are effective proxies of transient coronal activity. Hence these short-term activity descriptors are suitable inputs to a variety of nowcasting and forecasting models in Space Weather predictions when their association with the non-radio phenomenology is unambiguous. To reach such a level of confidence a detailed systematic and in-depth multi-band analysis of activity phenomena is required based on ground- and space-based data capable to determine: a) the multi-band event timings; b) the potentiality levels in driving geoeffective events; c) the existence of (multi-band) precursors. Thanks to its operational flexibility and diagnostic capabilities TSRS can play a fundamental role in providing diachronic radio observations suitable for comparative analyses of solar and interplanetary perturbations relevant to Space Weather such as the selected radio flares discussed respectively in Section 1 and in Section 3.

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