



Statistical study of the relationship between the solar energetic particle events and associated solar phenomena

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Introduction

Unique accelerator ??

correlation with SEP peak intensities

were not conclusive so far ☹️

← Similar correlation coefficients
(SXR peak flux & CME speed)

→ Solar parameters are not independent
(BFS; Kahler 1982)

Soft X-ray (SXR)

Available from GOES satellites

Reveal the state of flare heated plasma, not of flare-accelerated particles

Microwave (mw)

Gyro-synchrotron process by near relativistic electrons at energies between 100 keV and few MeV

Routinely observed from ground

Goals

***New Investigation of statistical relationship between
SEP peak intensities
and
characteristic quantities of the associated solar
activity***

Electrons (38-53 keV) $J_e(38 \text{ keV})$

Electrons (175-315 keV) $J_e(175 \text{ keV})$

Protons (15-40 MeV) $J_p(15 \text{ keV})$

CME speed V_{CME}

SXR peak flux I_{SXR}

SXR Peak fluence ϕ_{SXR}

mw fluence ϕ_{μ}

Observations and Data analysis

The data set is based on:

- SEP events associated with flares of X& M - classes
- At western longitudes
- during the period 1997-2006

SEP parameters:

- protons (15-40 MeV) observed by GOES satellite $J_p(15 \text{ keV})$
- Near relativistic electrons (38-53 keV & 175-315 keV) observed by EPAM/ACE spacecraft $J_e(38 \text{ keV})$ & $J_e(175 \text{ keV})$

Observations and Data analysis

Solar Activity Parameters:

- ❑ CME Speed V_{CME} : SoHO/LASCO Catalogue
- ❑ SXR peak flux I_{SXR} : GOES satellite
- ❑ SXR Peak fluence ϕ_{SXR} : GOES satellite
- ❑ Microwave fluence ϕ_{μ} :

NoRP: Nobeyama Radio Polarimeter, Japan

Freq: (1, 2, 3.75, 9.4, 17, and 35 GHz)

Obs. Time: (~ 23 UT to ~ 07 UT)

RSTN: Radio Solar Telescope Network, US Air Force

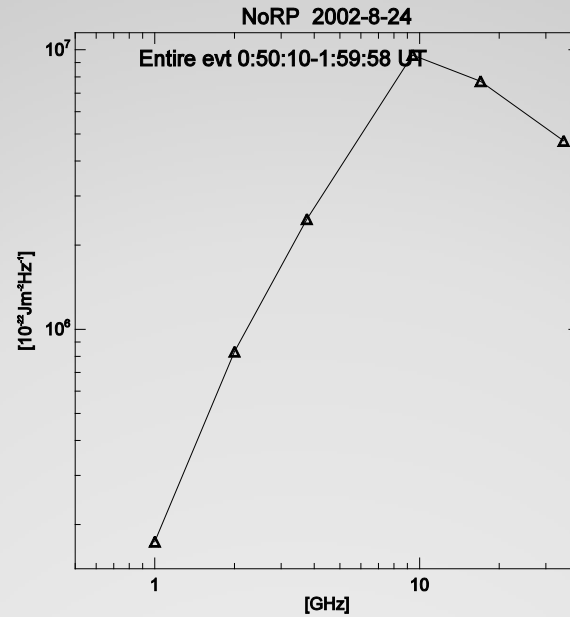
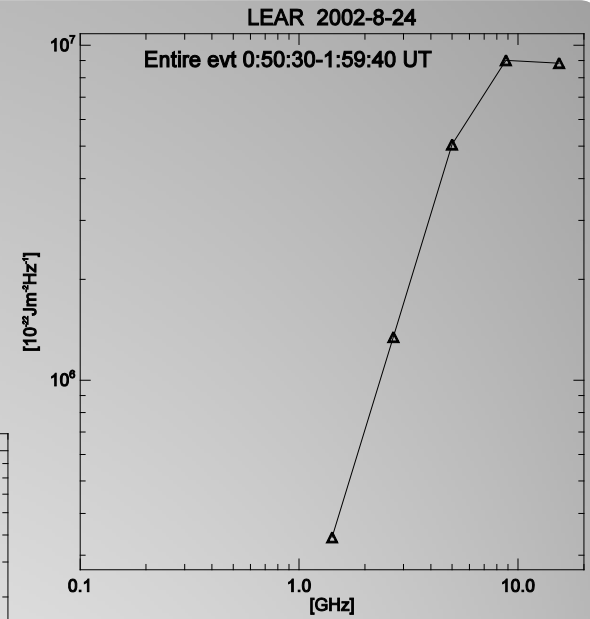
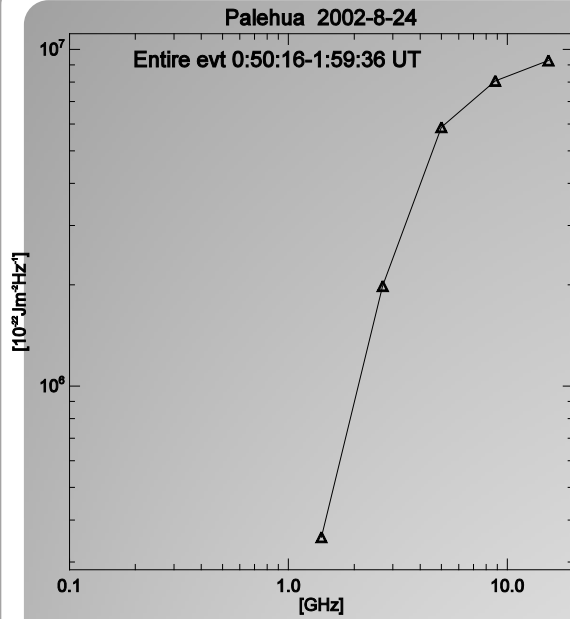
Freq: (0.24, 0.41, 0.61, 1.4, 2.7, 4.9, 8.8, and 15 GHz)

Obs. Time: (24 h per day)

Stations: Sagamore Hill, Palehua, Learmonth & San Vito

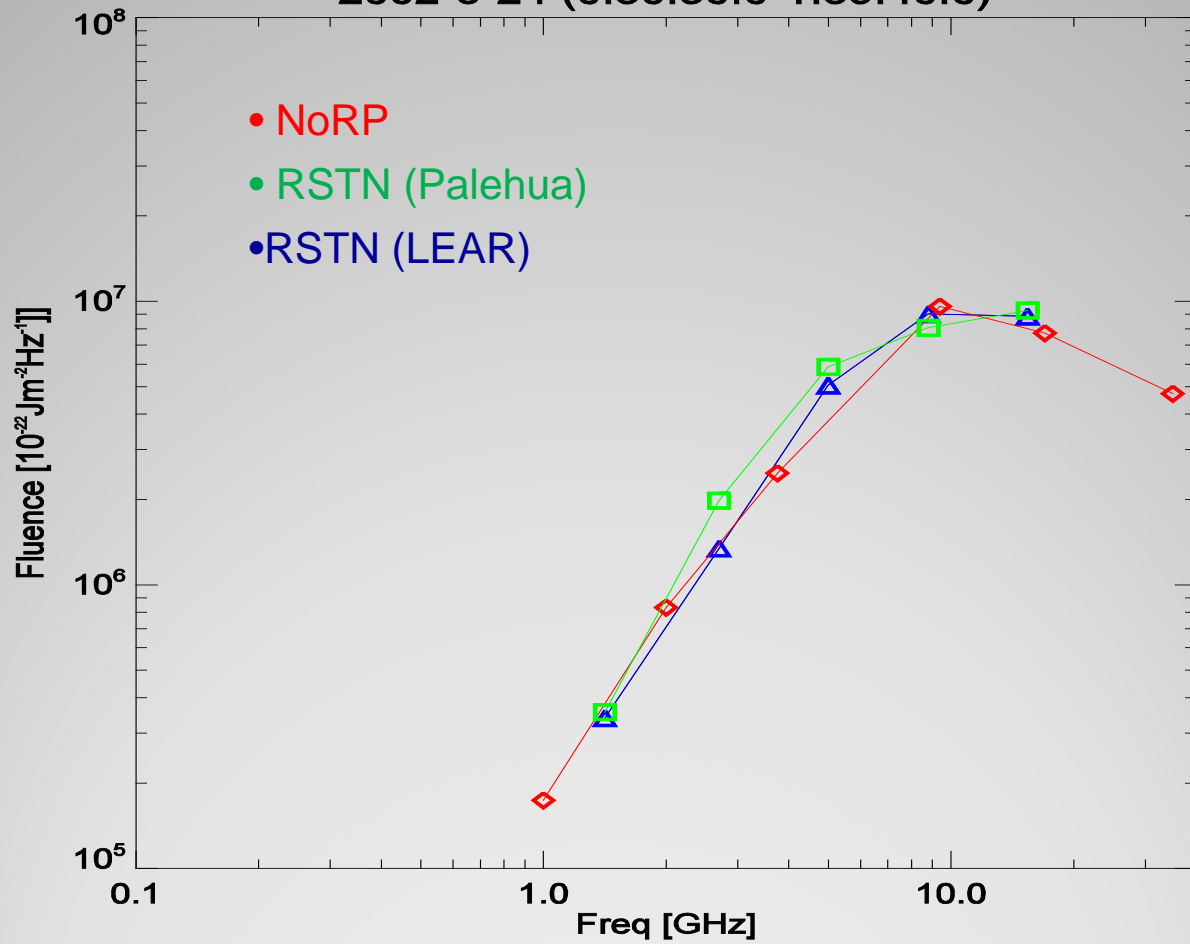
2002 Aug 24

00:49, 01:39, 01:12



The microwave fluence spectra of event at 2002 Aug 24 from:
RSTN stations (Palehua & Learmonth) & NoRP instrument

2002-8-24 (0:50:30:0-1:59:40:0)



Observations and Data analysis

Quality Flag

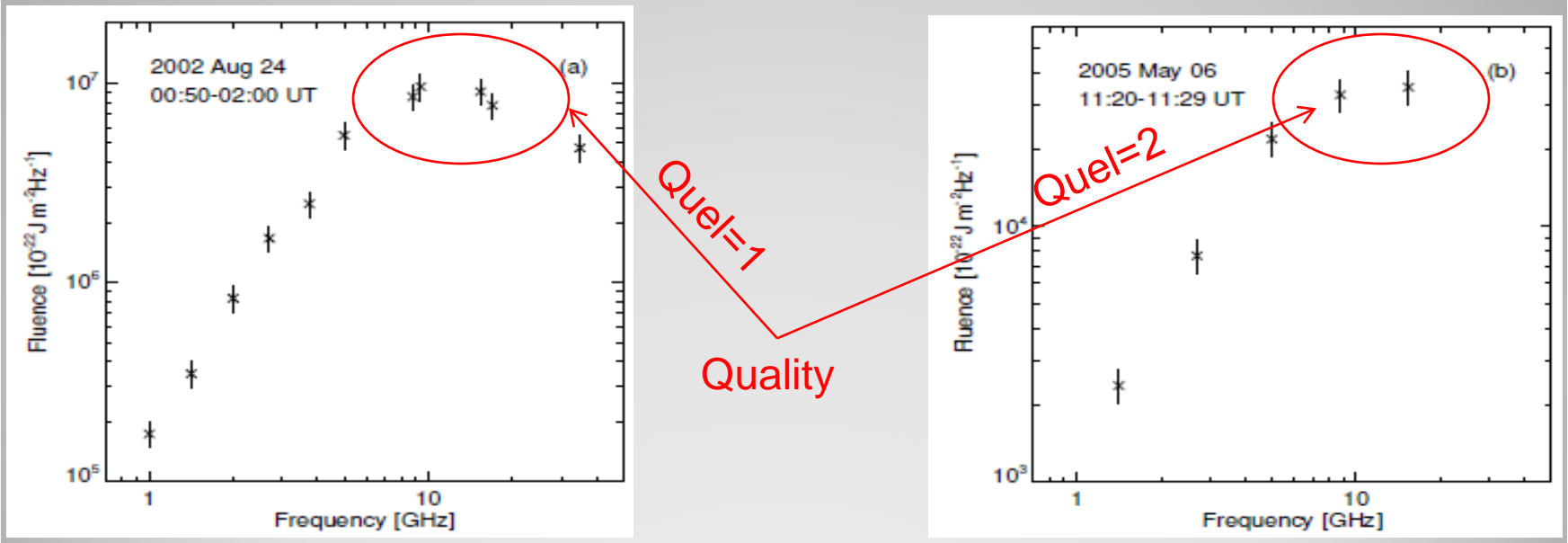
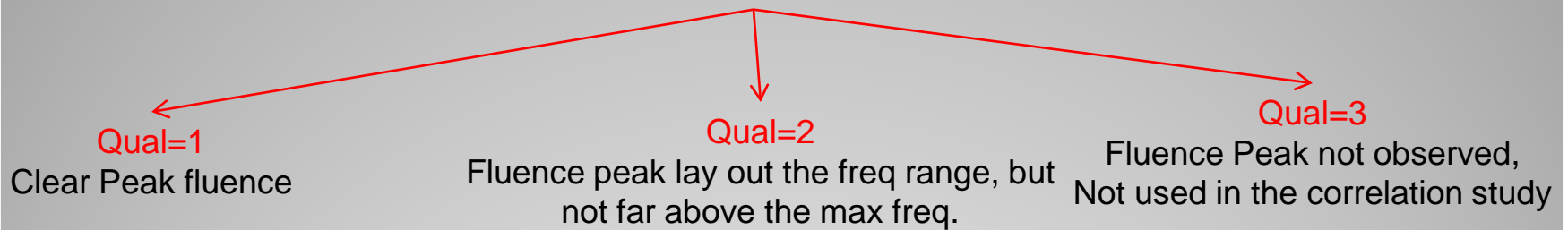


Figure 1. The microwave fluence spectra of two events with different values of the quality flag: *Left:* an event with quality flag 1, indicating that the maximum of the fluence spectrum lay within the observed frequency range (combined data from NoRP and one RSTN station); *Right:* an event with a quality flag 2, where the maximum of the fluence spectrum occurred outside of, but close to the observed frequency range (data from the San Vito RSTN station).

Observations and Data analysis

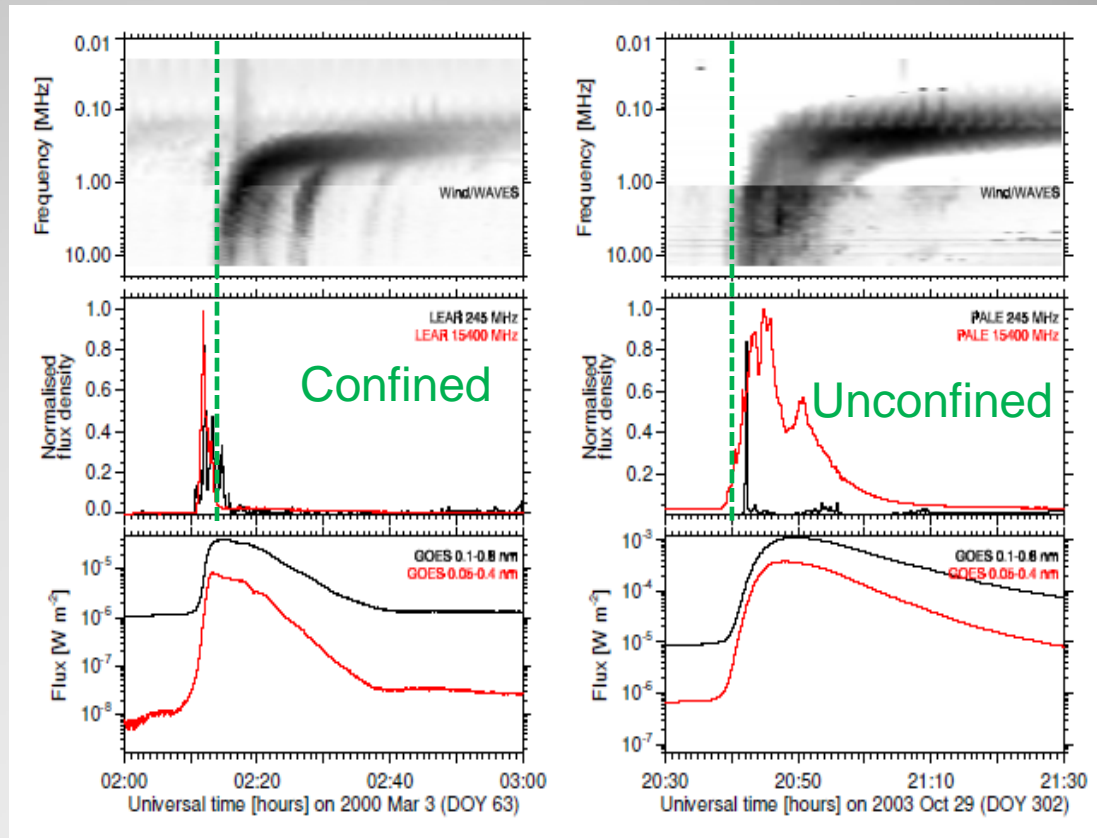
Particle escape from the flare site

Figure 2. Time histories of X-ray and radio emissions of a confined and an unconfined event, respectively.

(1) decametre-to-hectometre (DH) wave emission (Wind/WAVES)

(2) Flux density time profiles at two frequencies in the microwave (15.4 GHz) and metre wave (245 MHz) range (RSTN Network)

(3) soft X-ray flux (GOES; black line 0.1 - 0.8 nm, red line in 0.05 - 4 nm).



Results

Correlation between SEP parameters

	$\log_{10} J_e(175 \text{ keV})$	$\log_{10} J_p(15 \text{ MeV})$
$\log_{10} J_e(38 \text{ keV})$	0.95 ± 0.01	0.79 ± 0.08
$\log_{10} J_e(175 \text{ keV})$	-	0.88 ± 0.04

Correlation between solar activity parameters

	$\log_{10} I_{SXR}$	$\log_{10} \Phi_{SXR}$	$\log_{10} V_{CME}$
$\log_{10} \Phi_{\mu}$	0.65 ± 0.09	0.84 ± 0.03	0.65 ± 0.09
$\log_{10} I_{SXR}$	-	0.72 ± 0.07	0.31 ± 0.13
$\log_{10} \Phi_{SXR}$	-	-	0.61 ± 0.10

Results

Correlation between parameters of solar activity and SEPs

	$\log_{10} J_e(38 \text{ keV})$	$\log_{10} J_e(175 \text{ keV})$	$\log_{10} J_p(15 \text{ MeV})$
$\log_{10} \Phi_\mu$	0.61 ± 0.09	0.72 ± 0.07	0.67 ± 0.09
$\log_{10} I_{SXR}$	0.35 ± 0.11	0.53 ± 0.09	0.54 ± 0.10
$\log_{10} \Phi_{SXR}$	0.65 ± 0.08	0.75 ± 0.06	0.76 ± 0.08
$\log_{10} V_{CME}$	0.65 ± 0.09	0.68 ± 0.08	0.67 ± 0.08

Results

Partial correlations

	$\log_{10} J_e(38 \text{ keV})$	$\log_{10} J_e(175 \text{ keV})$	$\log_{10} J_p(15 \text{ MeV})$
Pearson's correlation coefficients:			
$\log_{10} \Phi_\mu$	0.61 ± 0.09	0.72 ± 0.07	0.67 ± 0.09
$\log_{10} I_{SXR}$	0.35 ± 0.11	0.53 ± 0.09	0.54 ± 0.10
$\log_{10} \Phi_{SXR}$	0.65 ± 0.08	0.75 ± 0.06	0.76 ± 0.08
$\log_{10} V_{CME}$	0.65 ± 0.09	0.68 ± 0.08	0.67 ± 0.08
Partial correlation coefficients:			
$\log_{10} \Phi_\mu$	-0.03 ± 0.17	0.05 ± 0.19	-0.10 ± 0.22
$\log_{10} I_{SXR}$	-0.14 ± 0.16	0.10 ± 0.16	0.06 ± 0.17
$\log_{10} \Phi_{SXR}$	0.31 ± 0.16	0.27 ± 0.18	0.42 ± 0.20
$\log_{10} V_{CME}$	0.35 ± 0.14	0.34 ± 0.16	0.36 ± 0.18

0.37 ± 0.16

0.52 ± 0.13

Summary & Conclusion

The present work analyzed statistically the relationship between SEP intensities and parameters of eruptive solar activity

The data set composed of a sample of 44 SEP events between 1997-2006, associated with strong flares (X and M classes) in the western solar hemisphere.

Near relativistic electrons in two energy ranges (38-53 keV & 175-315 keV), and deka-MeV protons (15-40 MeV) were considered as SEP parameters

CME speed, SXR peak flux and fluence and mw peak fluence were the parameters to describe the eruptive solar activity

The presence of type III bursts was used as indicator of the escape of the electrons along the open magnetic field lines

Summary & Conclusion

Partial Correlation was calculated in order to investigate the effect of correlations between the solar parameters themselves

Only the CME speed and SXR peak fluence are significantly correlated with the SEP intensities

mw fluence has no statistically significant relationship with SEP intensity.. ??

The research yields a new type of statistical evidence for a mixed flare-CME contribution to SEPs in space

Thank You