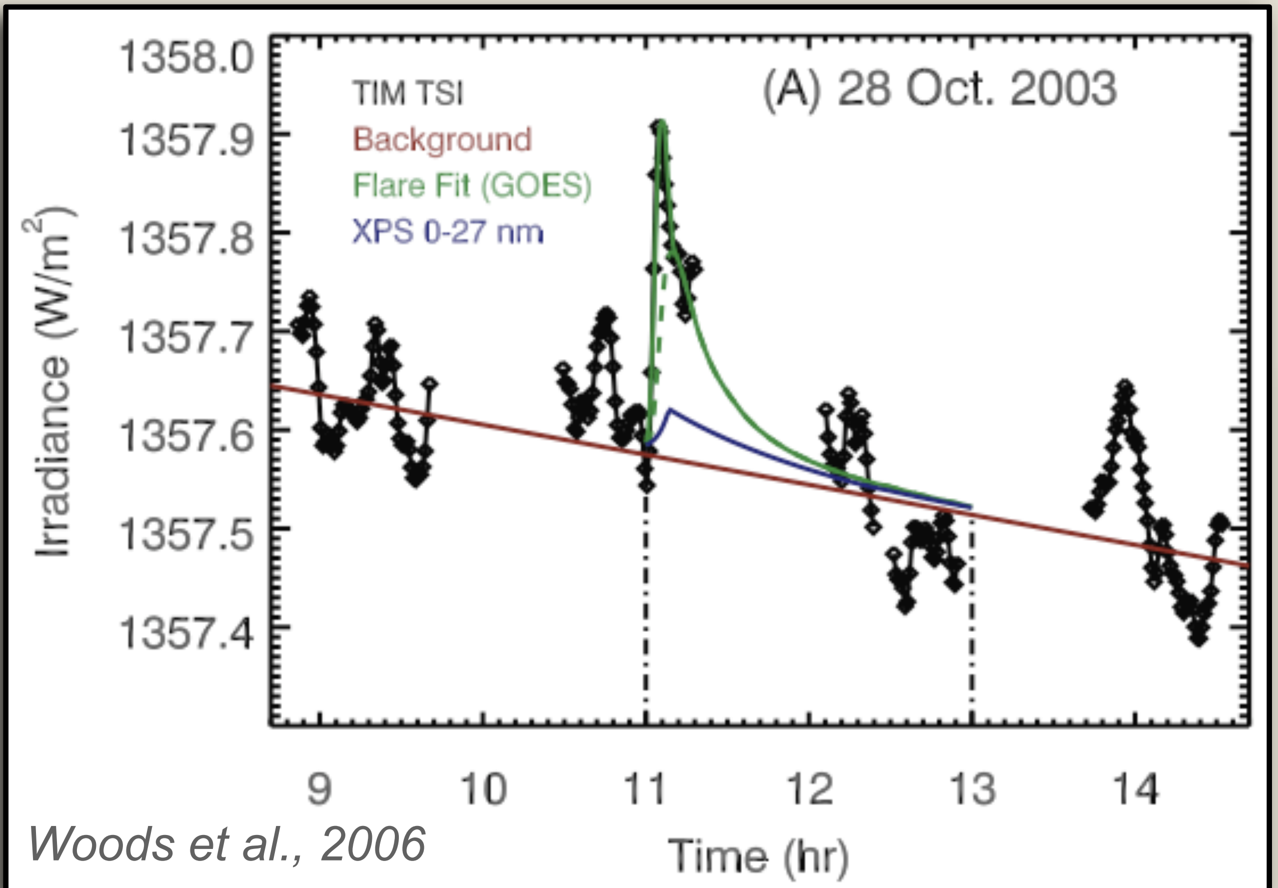
Can Flares Contribute to the Total Solar Irradiance Variations?

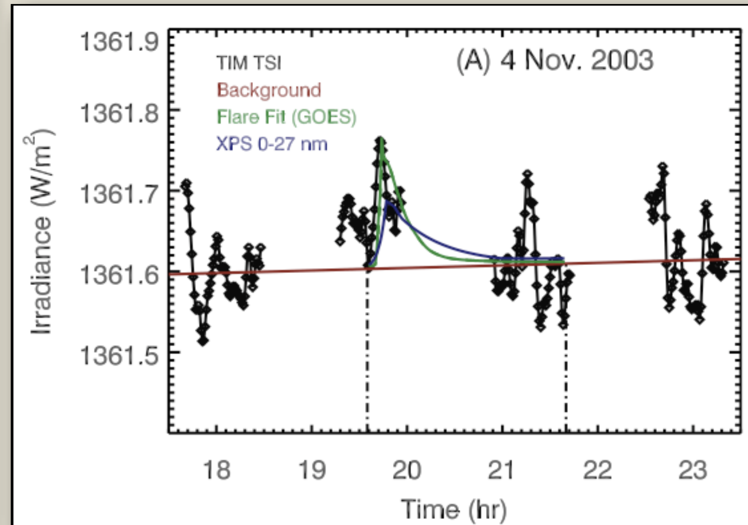
Matthieu Kretzschmar and T. Dudok de Wit
LPCE / CNRS, Université d'Orléans, France

- The response of TSI to flare.

- How could flares contribute to the TSI variations ?

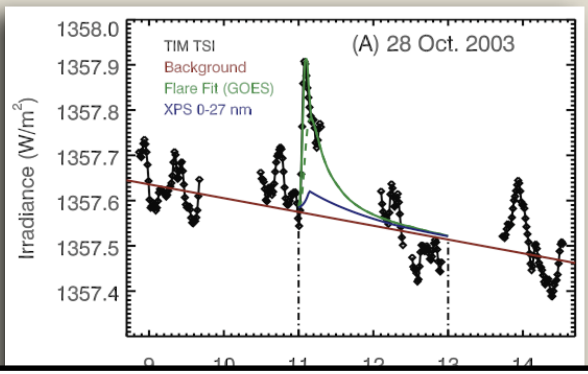
Flare signature in the TSI (I)

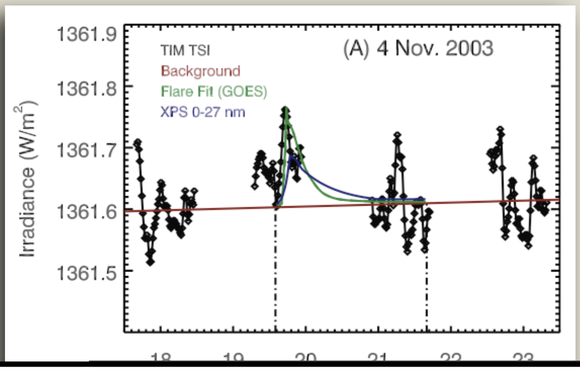




✓ TSI signature observed for only 4 flares. This is because the TSI fluctuations (due to p-modes and convection) are about ~70ppm=0.1W/m^2 and hide the emission increase due to flare.

Flare signature in the TSI (I)





Woods et al., 2006

Observation Date	GOES Class	Total Flare Energy for TSI, 10^{32} ergs	Ratio $\frac{TSI}{0.1-0.8\ nm}$	Ratio $\frac{0.1-27\ nm}{TSI}$	Ratio $\frac{0-190\ nm}{TSI}$
10/28/03	X17	6.0	162	0.22	0.43
10/29/03	X10	2.4	126	0.38	0.50
11/04/03	X28	2.6	49	0.85	0.69
9/7/05	X17	3.0	64	0.67	1.00

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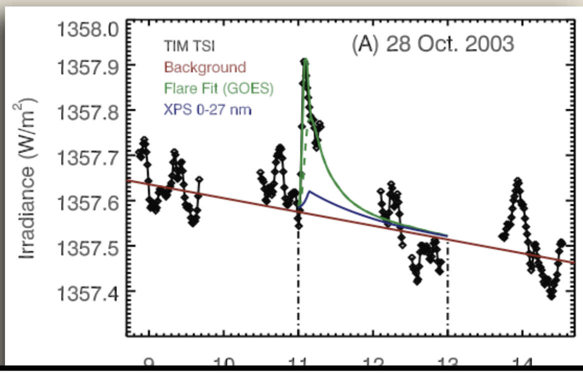

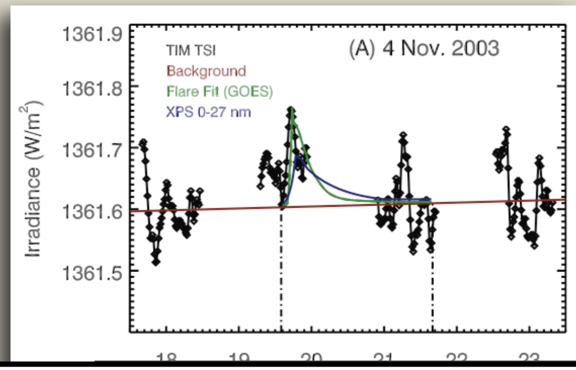

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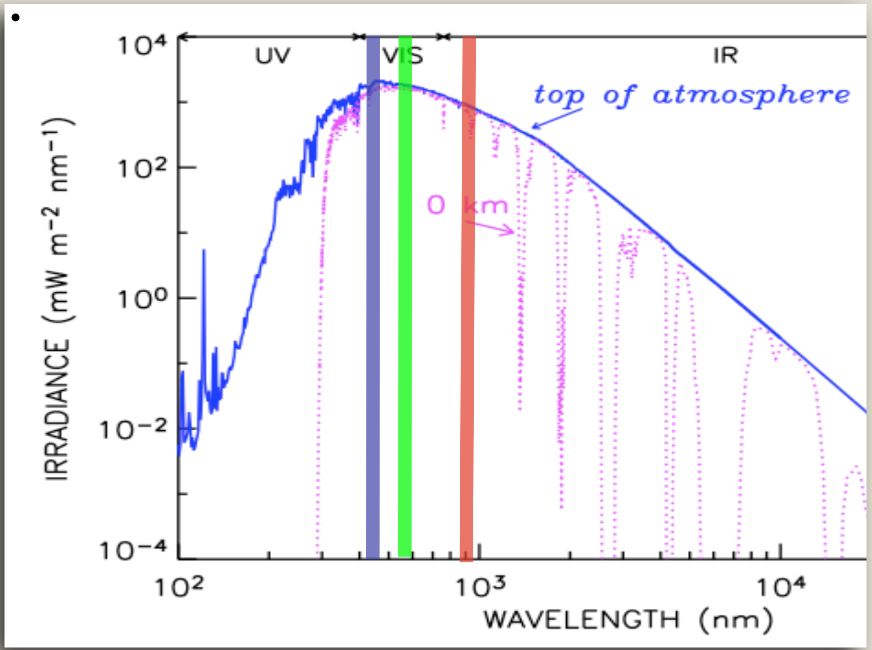
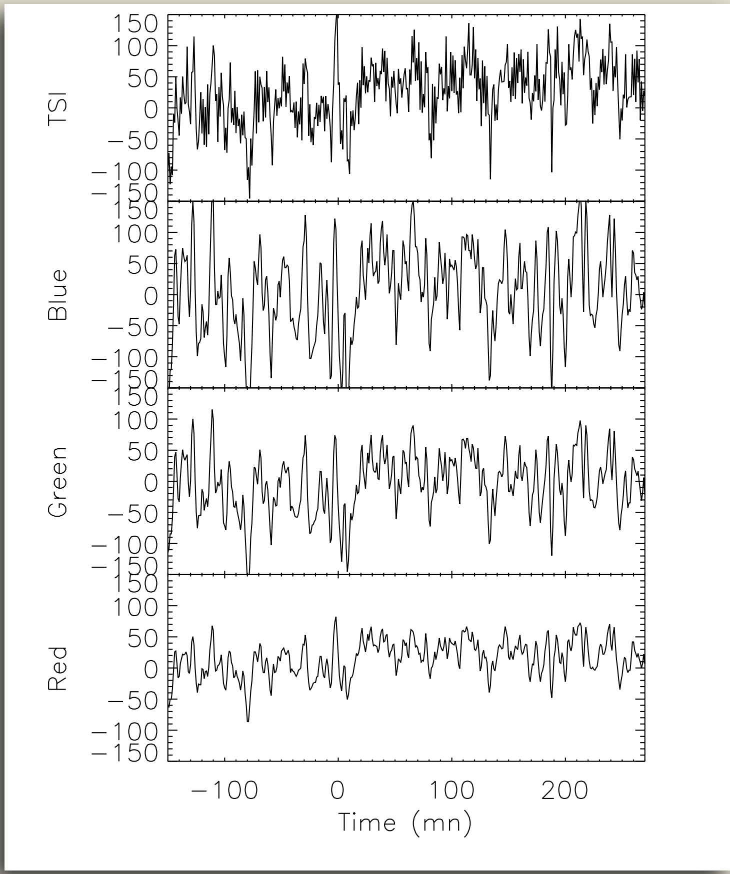
- ✓ What about the emission above 190 nm ?
- ✓ What is the spectral distribution of the radiative output ?
- ✓ What for others (less energetics) flares ?

Data & Analysis

✓ We analyze the irradiance data of PMO, DIARAD, and SPM (VIRGO/SoHO) from 1996 to 2007.





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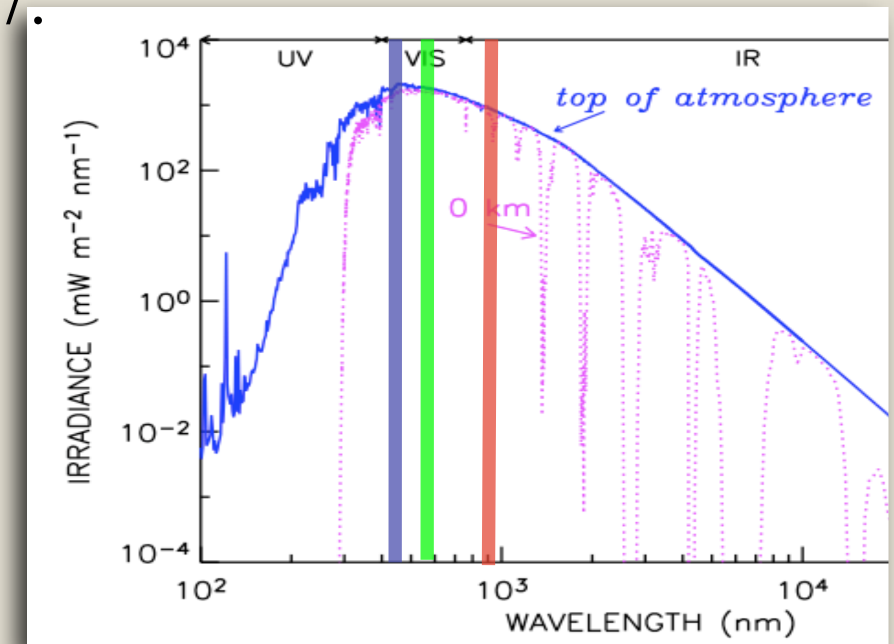

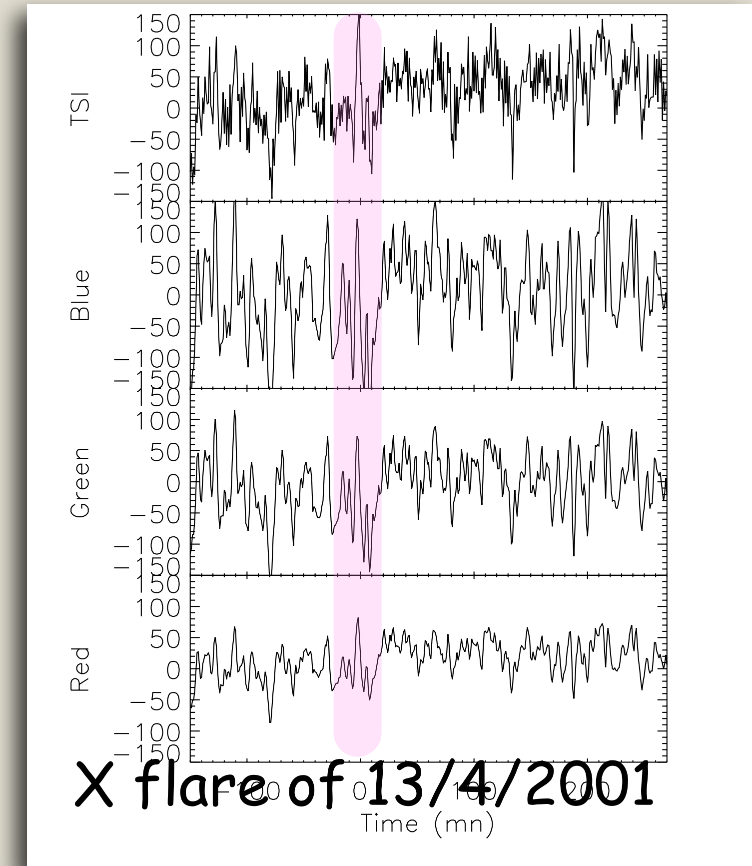

X flare of 13/4/2001

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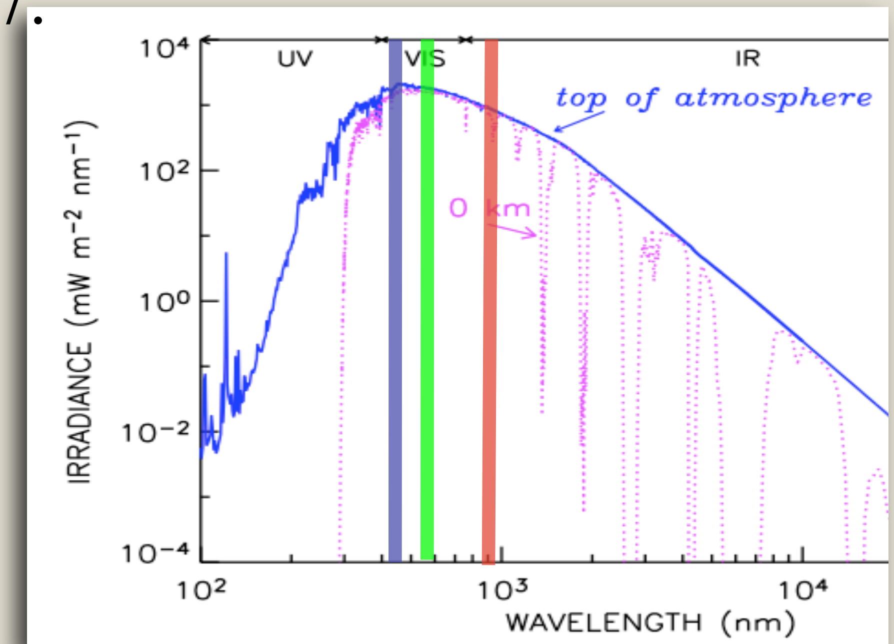
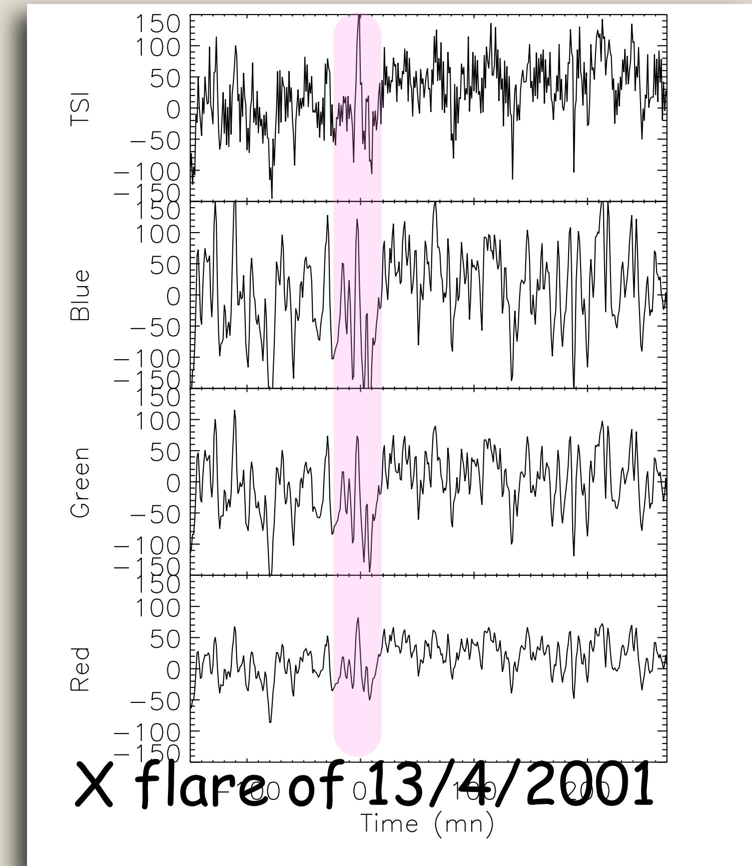


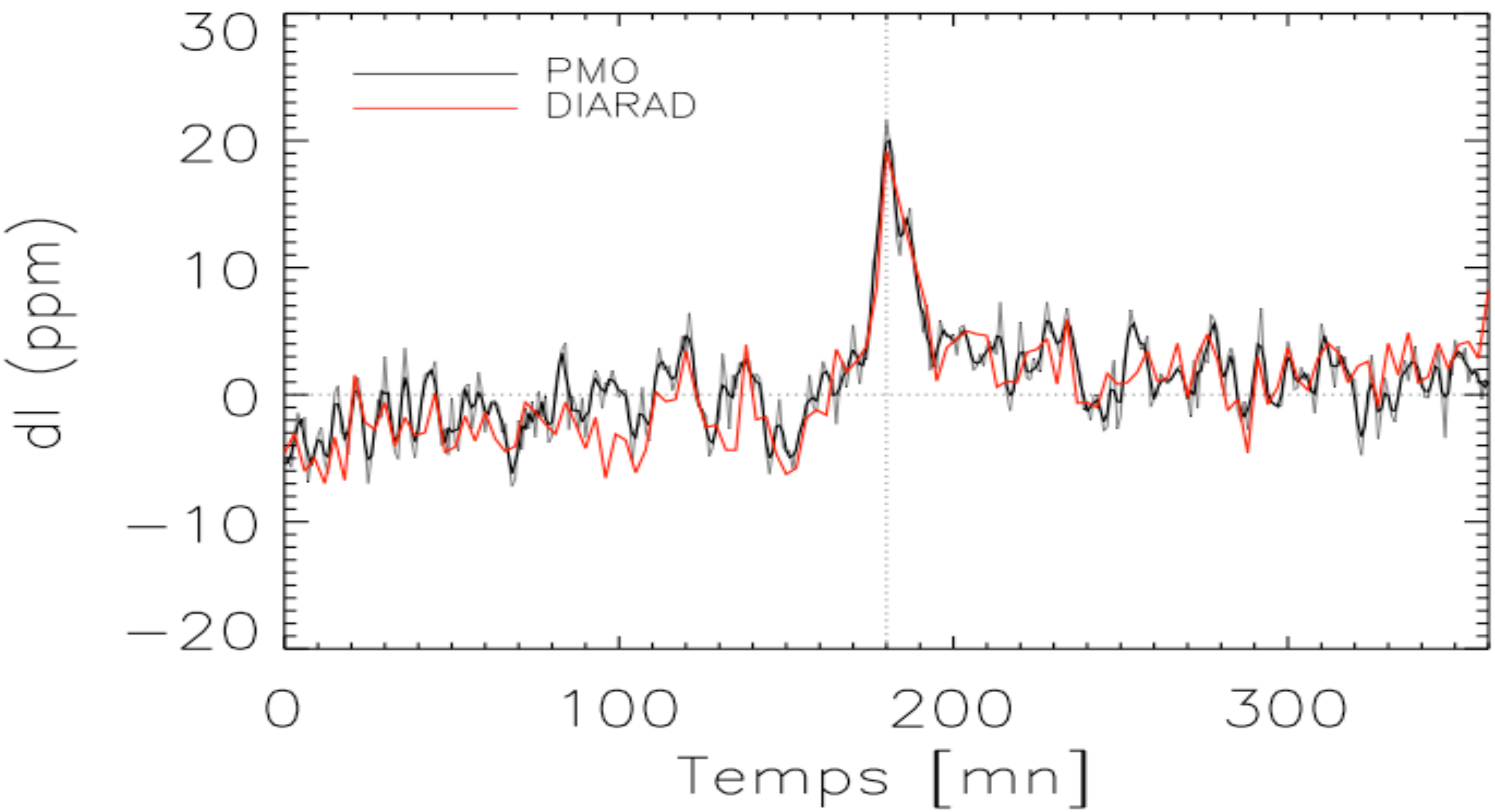


✓ To "see" the flares, we perform a *conditional average* or *superposed epoch analysis*:

1. Extract time series around each flare in the GOES db.
2. Sum them: if random noise, it goes to zero.

The TSI response to flares

Conditional average of TSI for all flares such that
$I_{0.1-0.8} > 10^{-4.3}$ W/m^2 (X and strong M ones,)

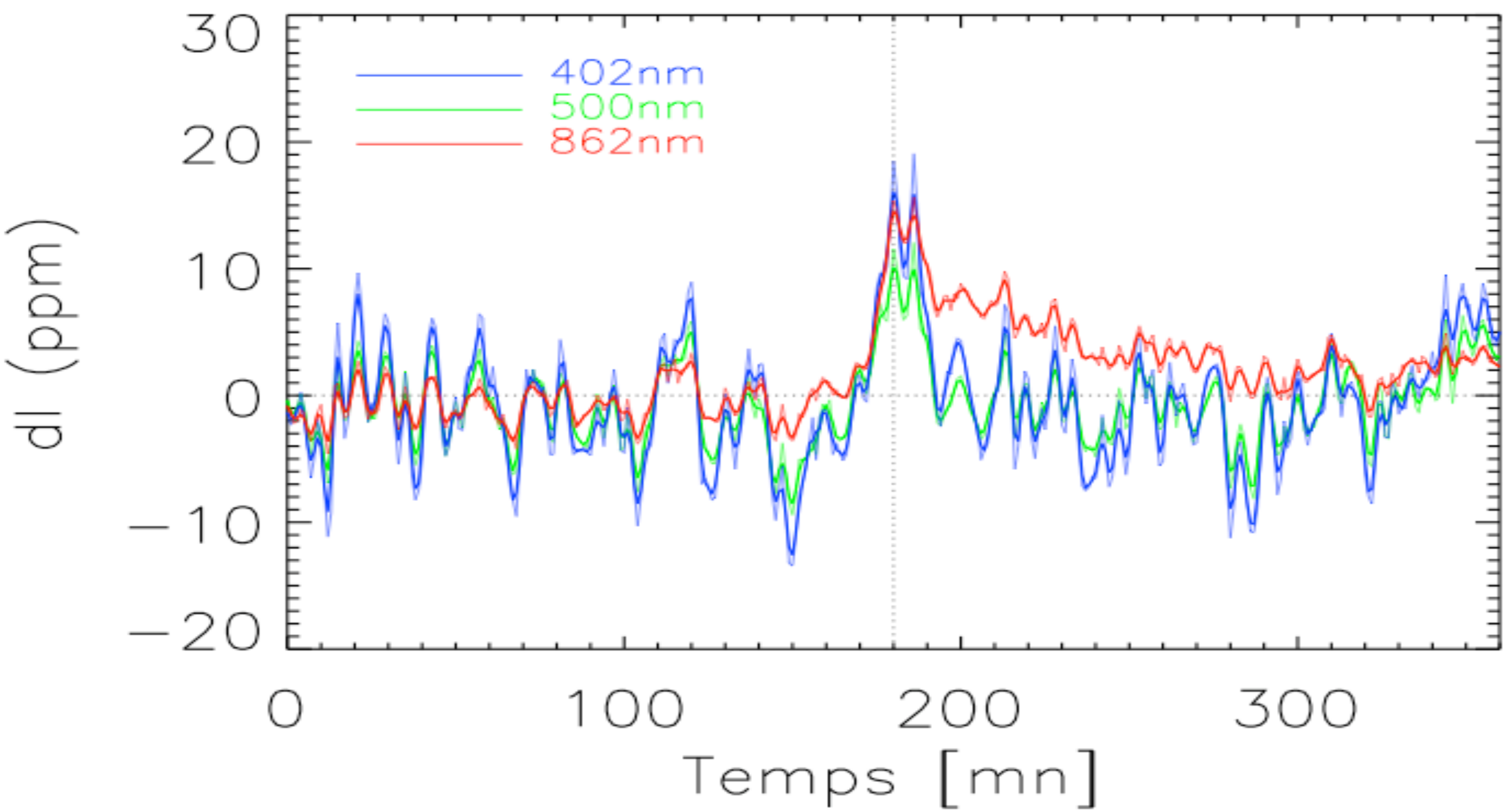


Averaged total radiative output of large flare

"Flare contribution to TSI", M. Kretzschmar et al. , SVECSE, Bozeman, June 2008

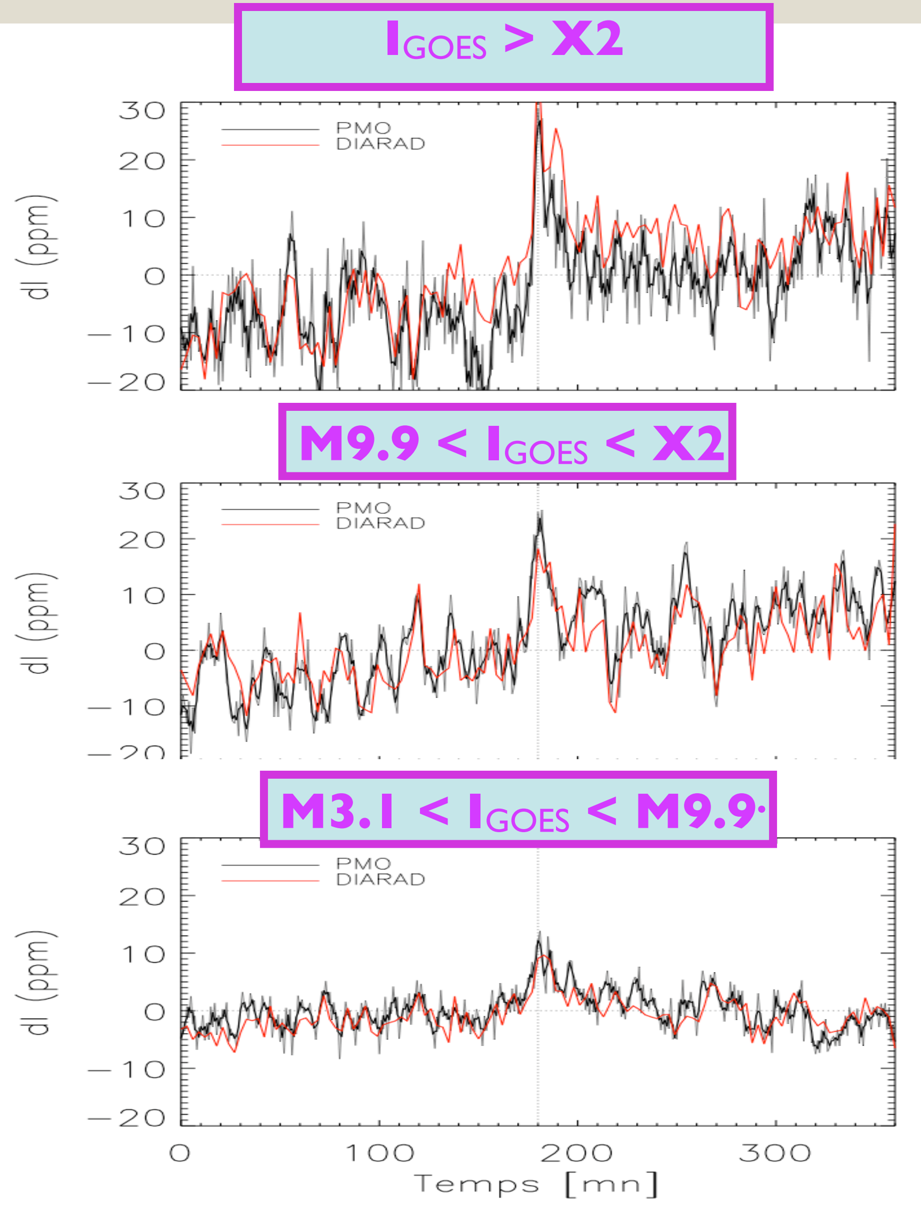
The visible irradiance response to flare

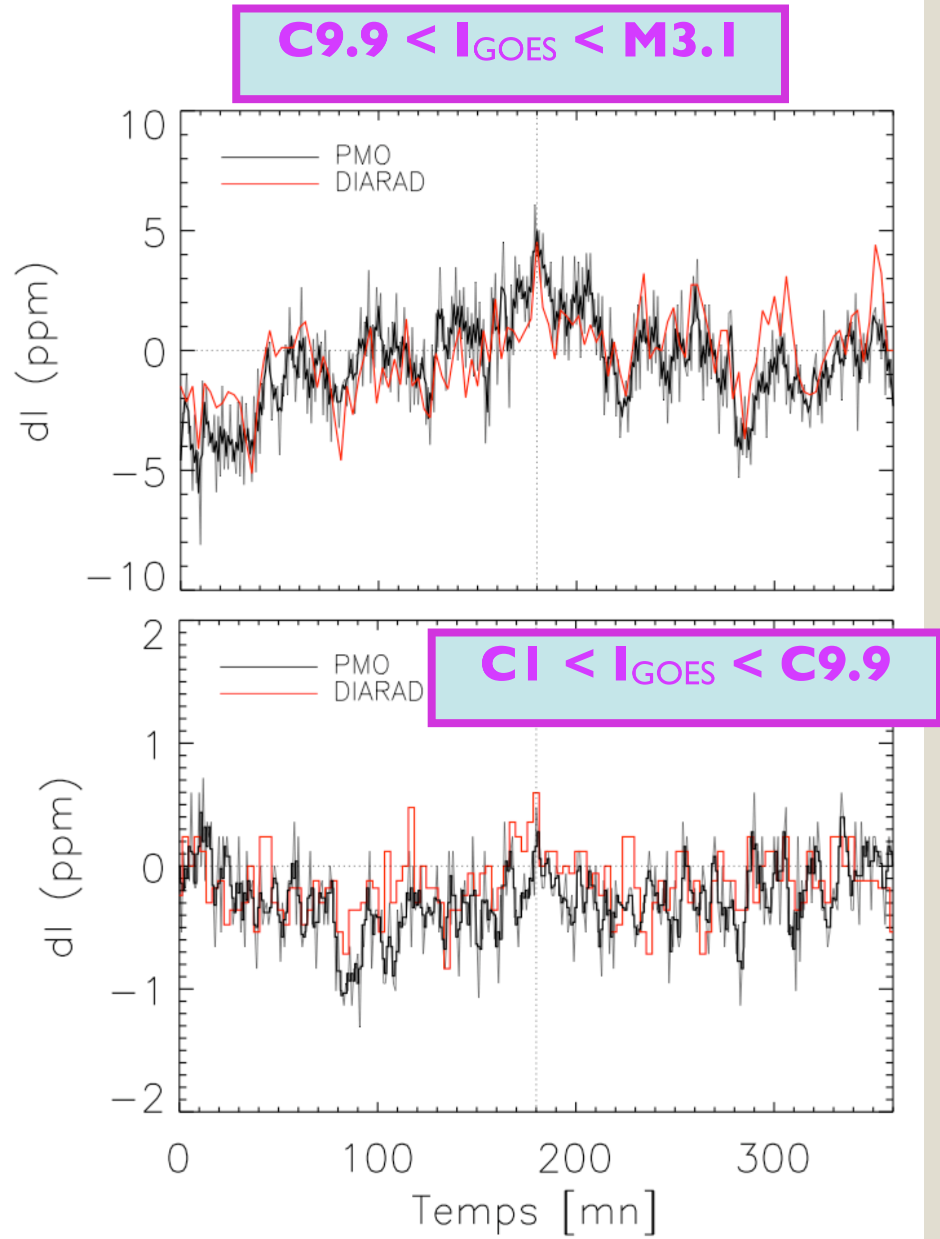
Conditional average of SPM color channels for all flares such that $I_{GOES} > 10^{-4.3}$ W/m^2 (X and strong M ones)

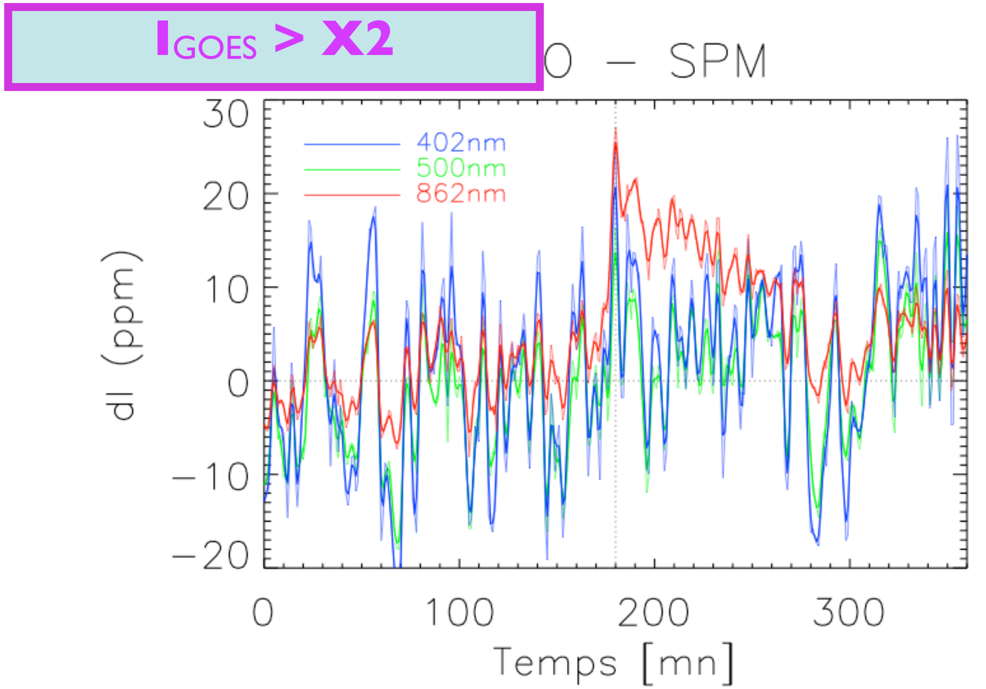


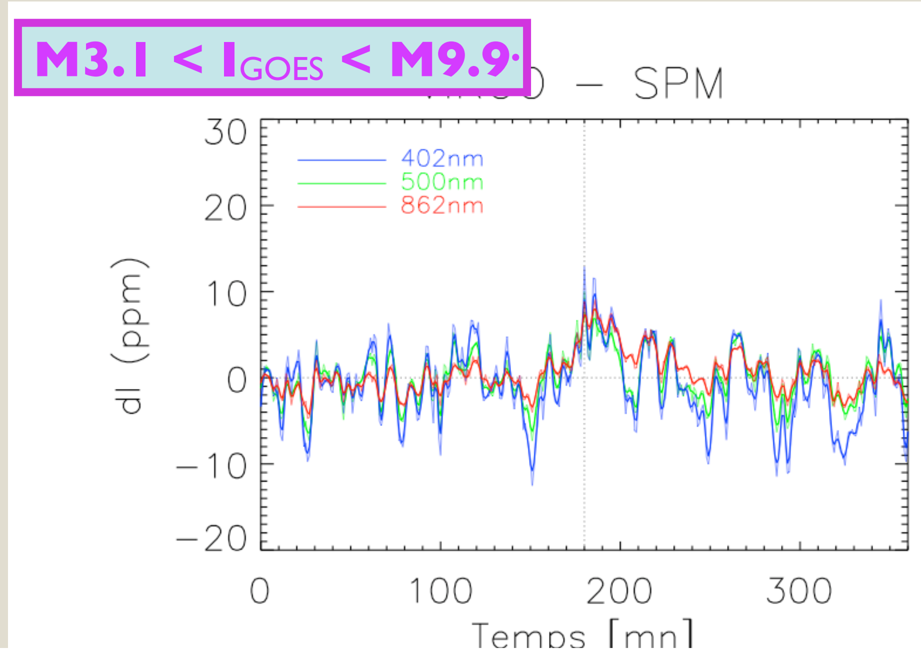
Averaged VISIBLE radiative output of large flares

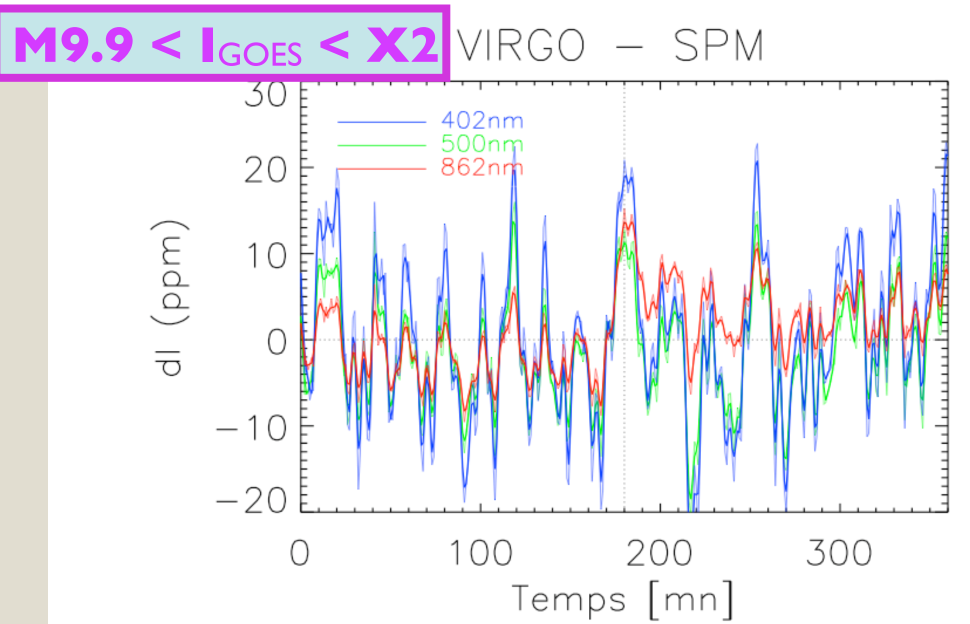
1ppm ~0.0013 W/m^2 ~1.1 10^{30} ergs/s

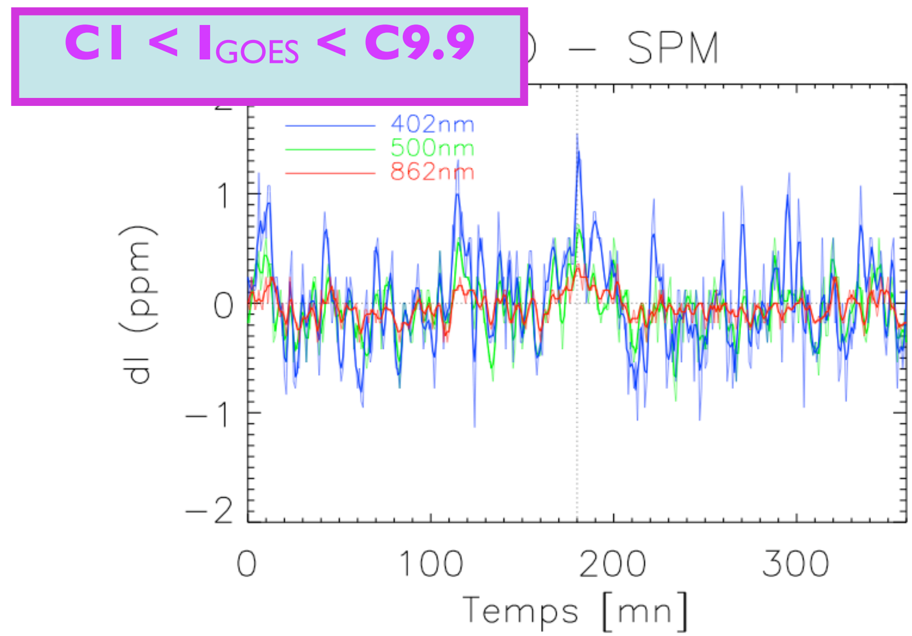






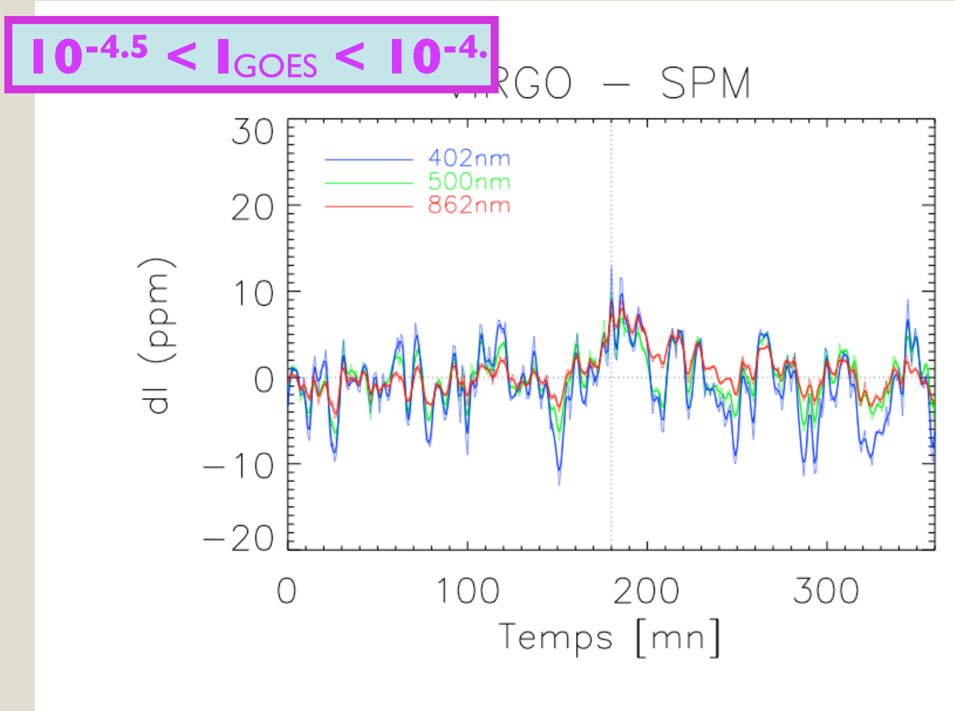


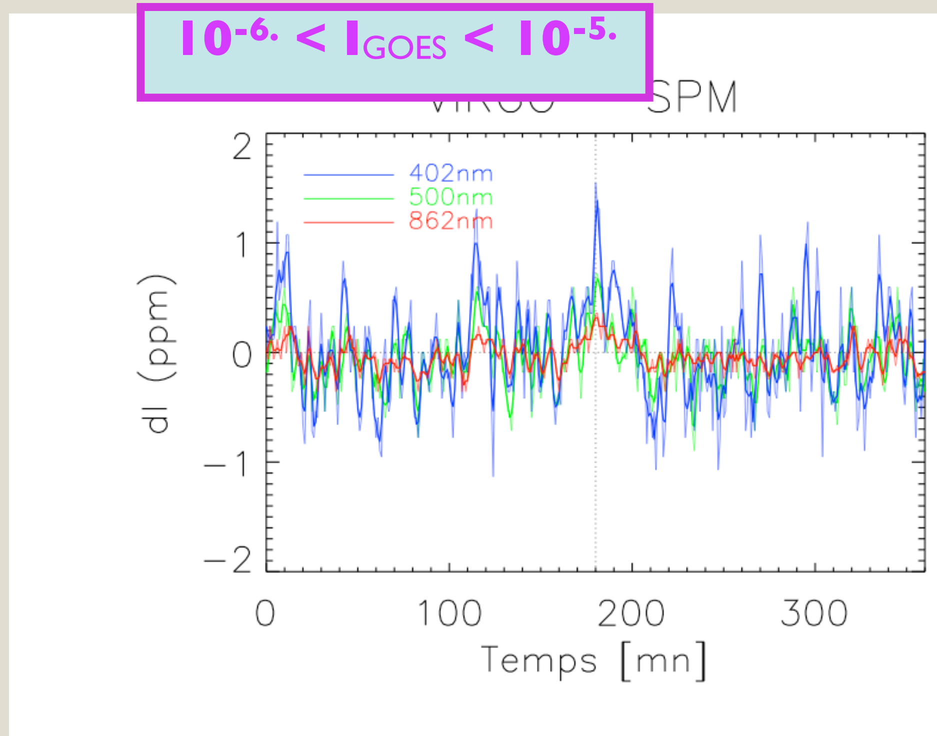


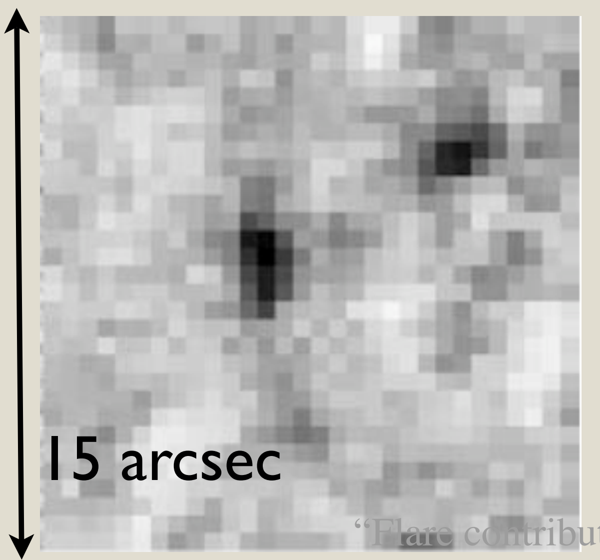


“Flare contribution to TSI”, M. Kretzschmar et al. , SVECSE, Bozeman, June 2008

White Light Flares



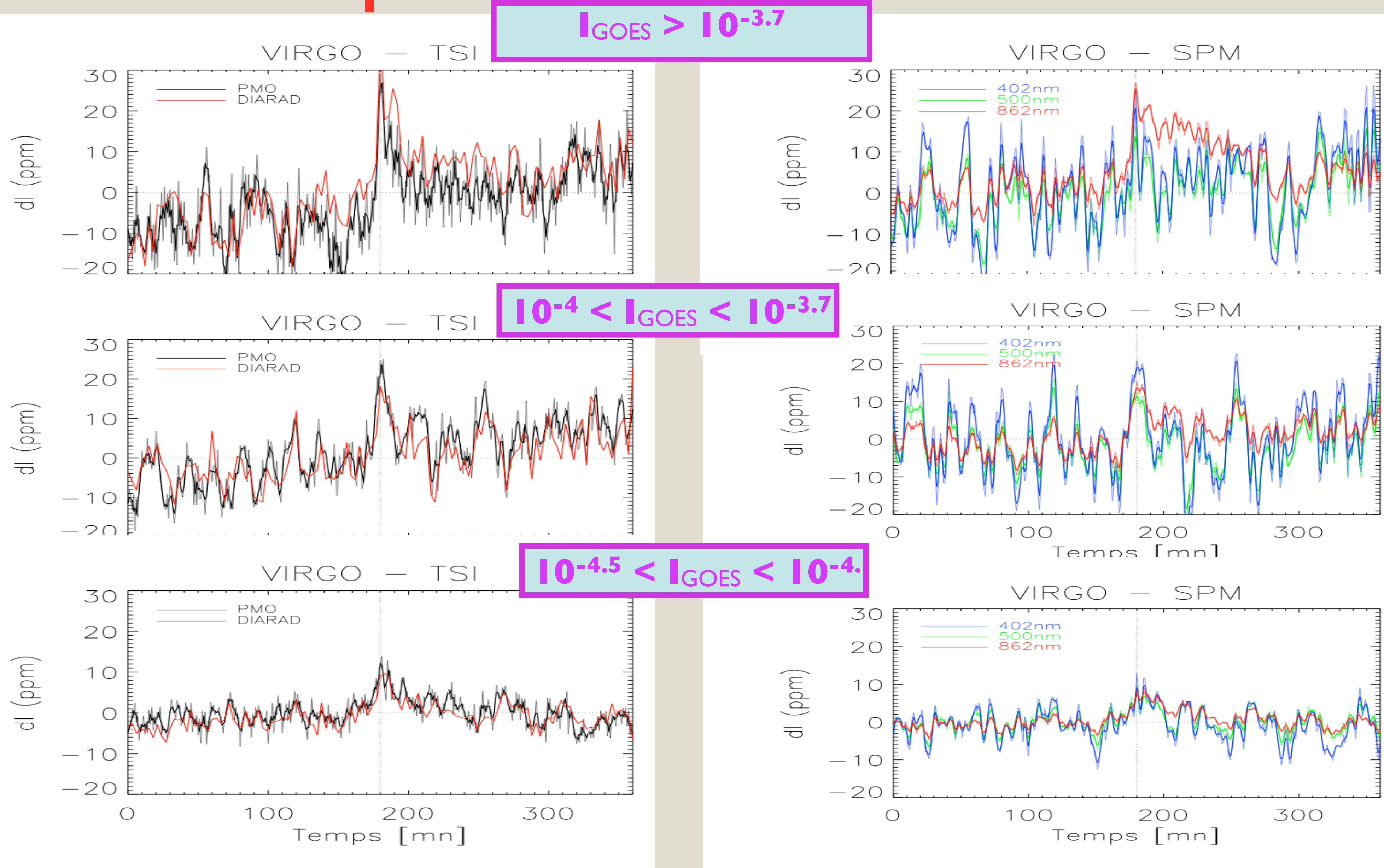




1ppm in the irradiance ~ 20% contrast in 5 arcsec^2. This agrees with other observations (Hudson, 2006)

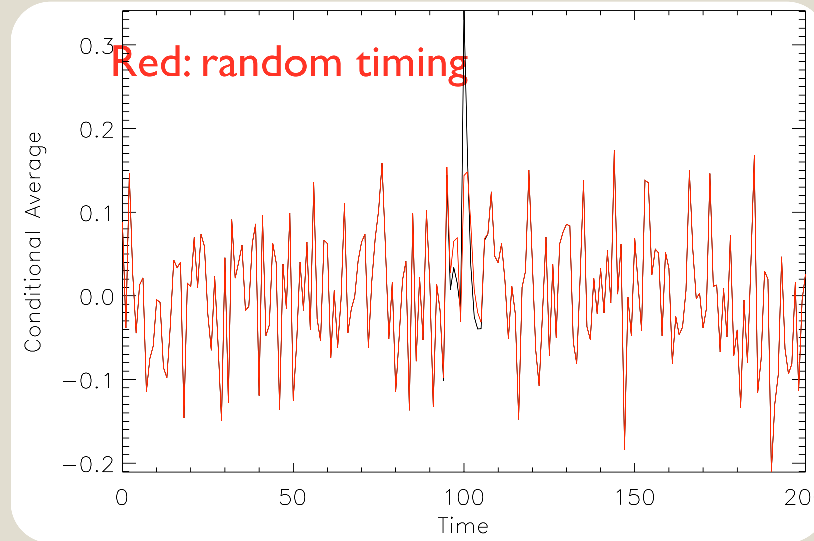
WL emission is ubiquitous during flare !!

Relative Optical and TSI increase

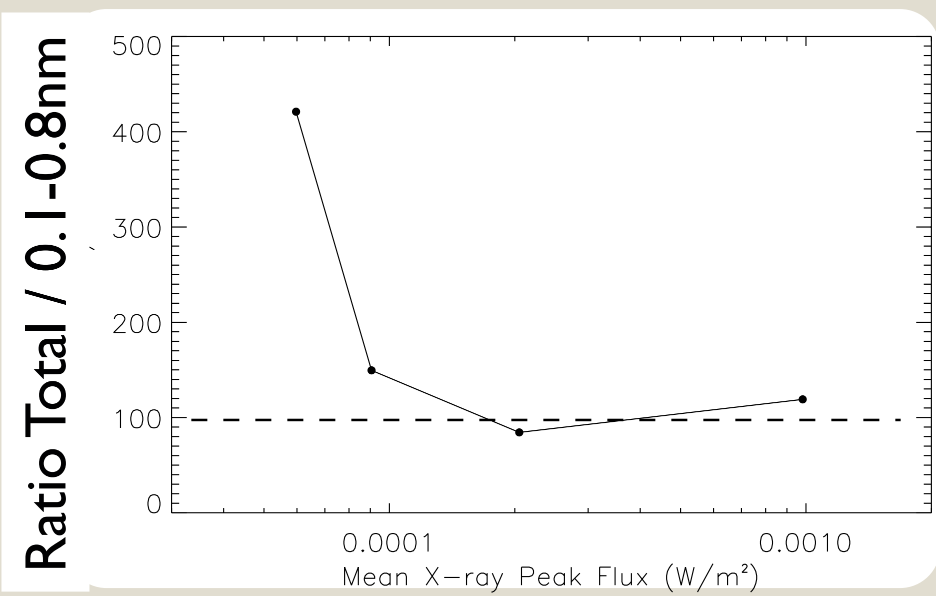


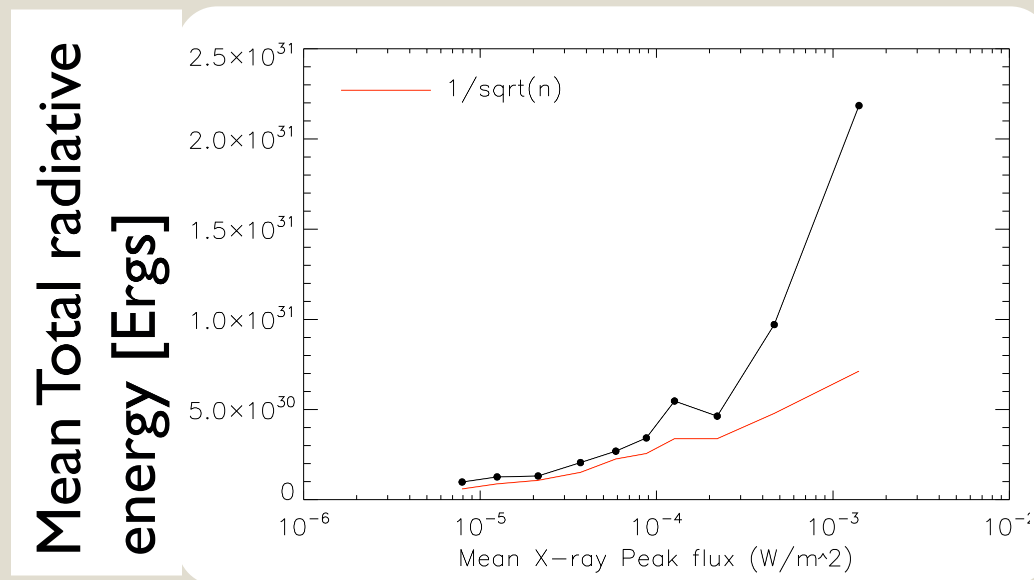
Energetics

✓ Confirm the value of *Woods et al. (2006)* for the effect of large flares on the TSI.



✓ Large uncertainty for smaller flares, due to timing and statistics.





✓ Largest flares radiate about 10^{31}-10^{32} ergs (in average, lower estimation)

Preliminary Conclusion

- ✓ Flares do impact the TSI, even small ones.
- ✓ The emission at short (SXR, EUV) wavelengths during a flare constitutes a *relatively small* part of the total radiated energy (E_{goes} ~0.01 E_{tot} for large flares).
- ✓ In particular, **visible emission** seems (quasi) systematic and to constitute an important contribution to the TSI increase.
- ✓ Largest flares have a total radiative energy of about 10^{32} ergs.

Could this imply a contribution of flares to long term (cycle) TSI variation ?

Flare contribution to TSI variation (I)

- ✓ TSI variations can be reproduced at about 90% by using the changing areas of bright (plages..) and dark (spot). Last 10% ? Change from cycle to cycle ?

- ✓ The idea is:
  - Each (nano)flare, in addition to heat the corona, produce an emission at short wavelength (visible, near UV, IR) that has been neglected before.
  - Heating of the corona requires a continuum of flares (Parker scenario).
  - There is a natural modulation of the number (or the energy) of flares in phase with the solar cycle due to the heating of active region.
- ✓ *Let's quickly test this idea, neglecting many aspects.*

Flare contribution to TSI variation (II)

- Heating of the corona requires a continuum of flares (Parker scenario).

The number of observed flares at energy W follows a power law:

$$N(W) = N_1 (\frac{W_1}{W})^\alpha$$

where α ~ 1.8. This is valid between respectively the low and upper energy cut-off W_1 and W_2 such that

$$\int_{W_1}^{W_2} W N(W) dW = W_{tot}$$

is the energy released by all flares per unit of time and surface

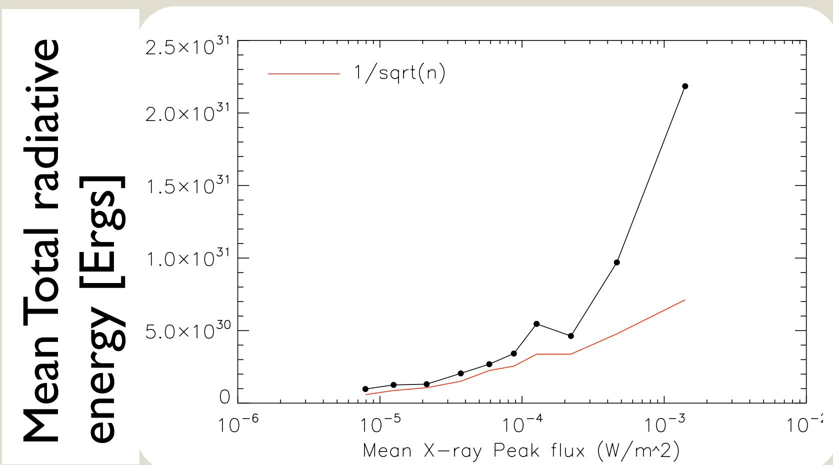
$W_{1,QS} \sim W_{1,AR} = 10^{24}$erg; $W_{2,QS} \sim 10^{30}$erg; $W_{2,AR} \sim 10^{32}$erg

$W_{tot,qs} \sim 3.10^5$ erg.cm^{-2}.s^{-1}; $W_{tot,AR} \sim 10^7$ erg.cm^{-2}.s^{-1} *Aschwanden (2006)*

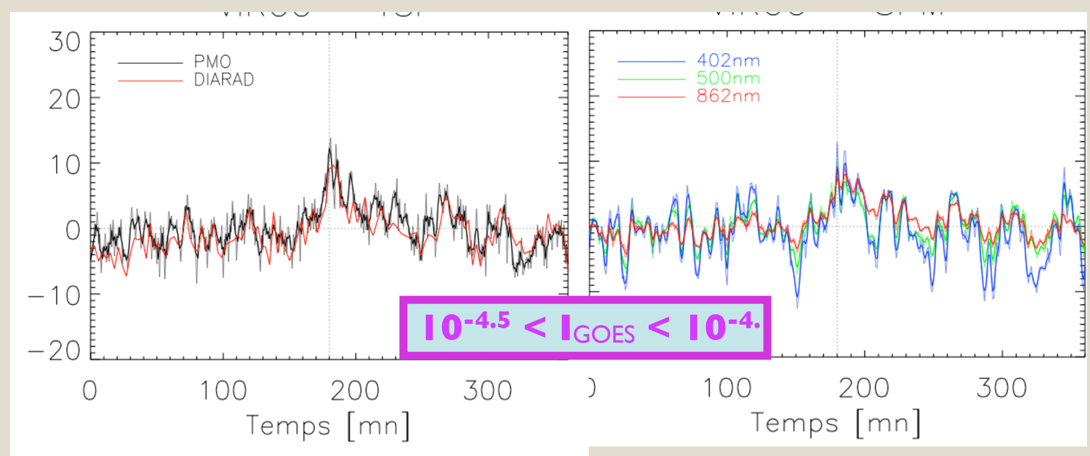
Flare contribution to TSI variation (II)

- Each (nano)flare, produce an emission at short wavelength (visible, near UV, IR) that has been neglected before.

✓ We need a relation: $dS \sim f(W) \sim f(E_{Goes})$



Or



✓Difficult ! ... still in progress..

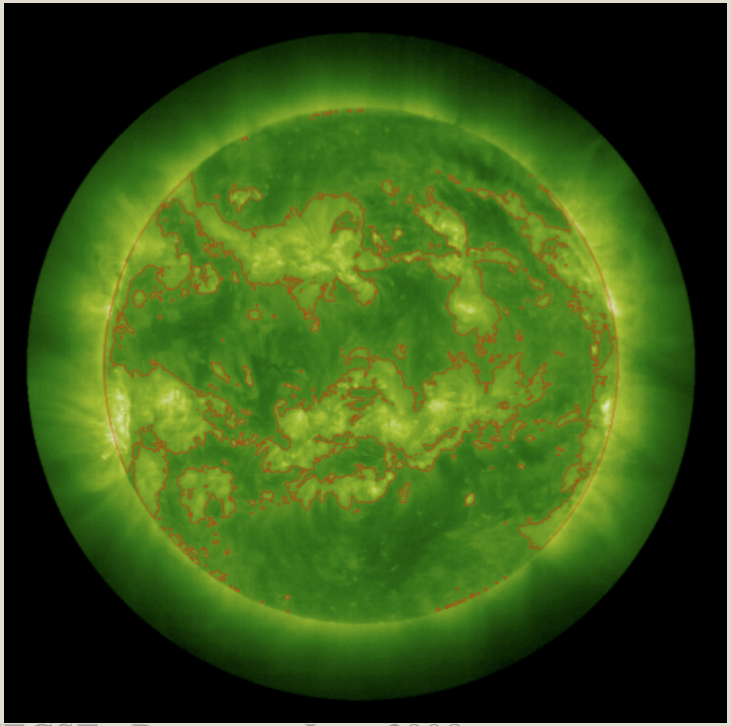
We will assume $dS \sim W_{tot,AR}$

Flare contribution to TSI variation (II)

- modulation of the number (or energy) of flares.

✓ With the active region we have a modulation of the energy:

$$f(W_{tot} * \sigma_{AR}(t))$$

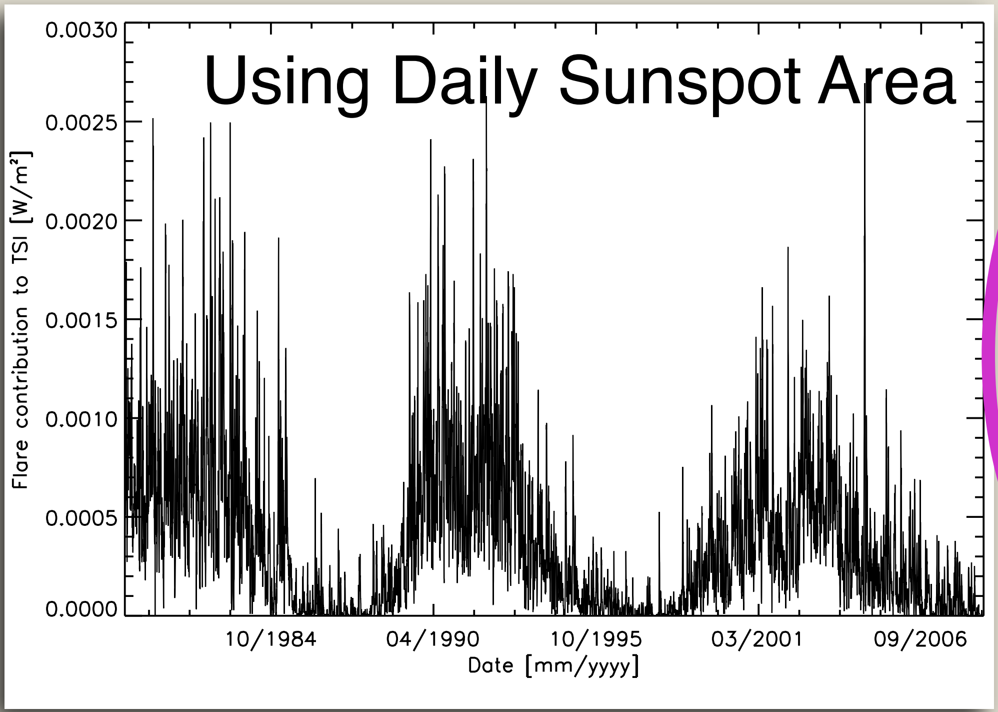


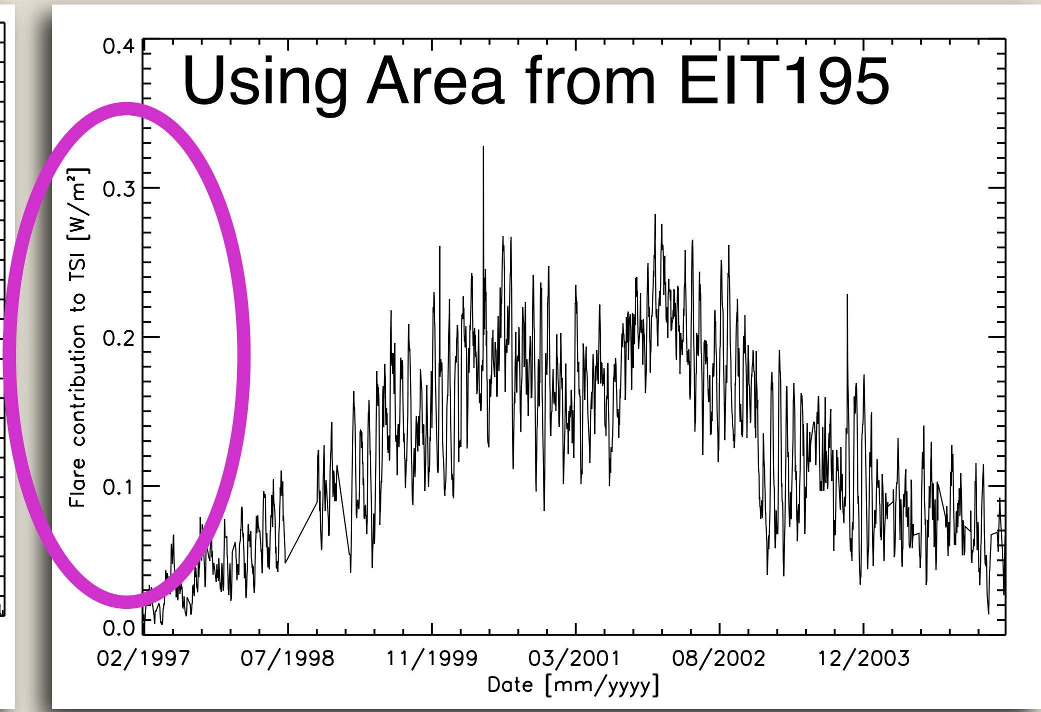
✓ Two ways to estimate $\sigma_{AR}(t)$:

- Use DSA (minimum estimate)
- Use EIT/195 AR area from segmentation (Barra et al., in, preparation)

Flare contribution to TSI variation (III)

- Results !





✓ This is about 10% of the 1W TSI variation with the cycle.

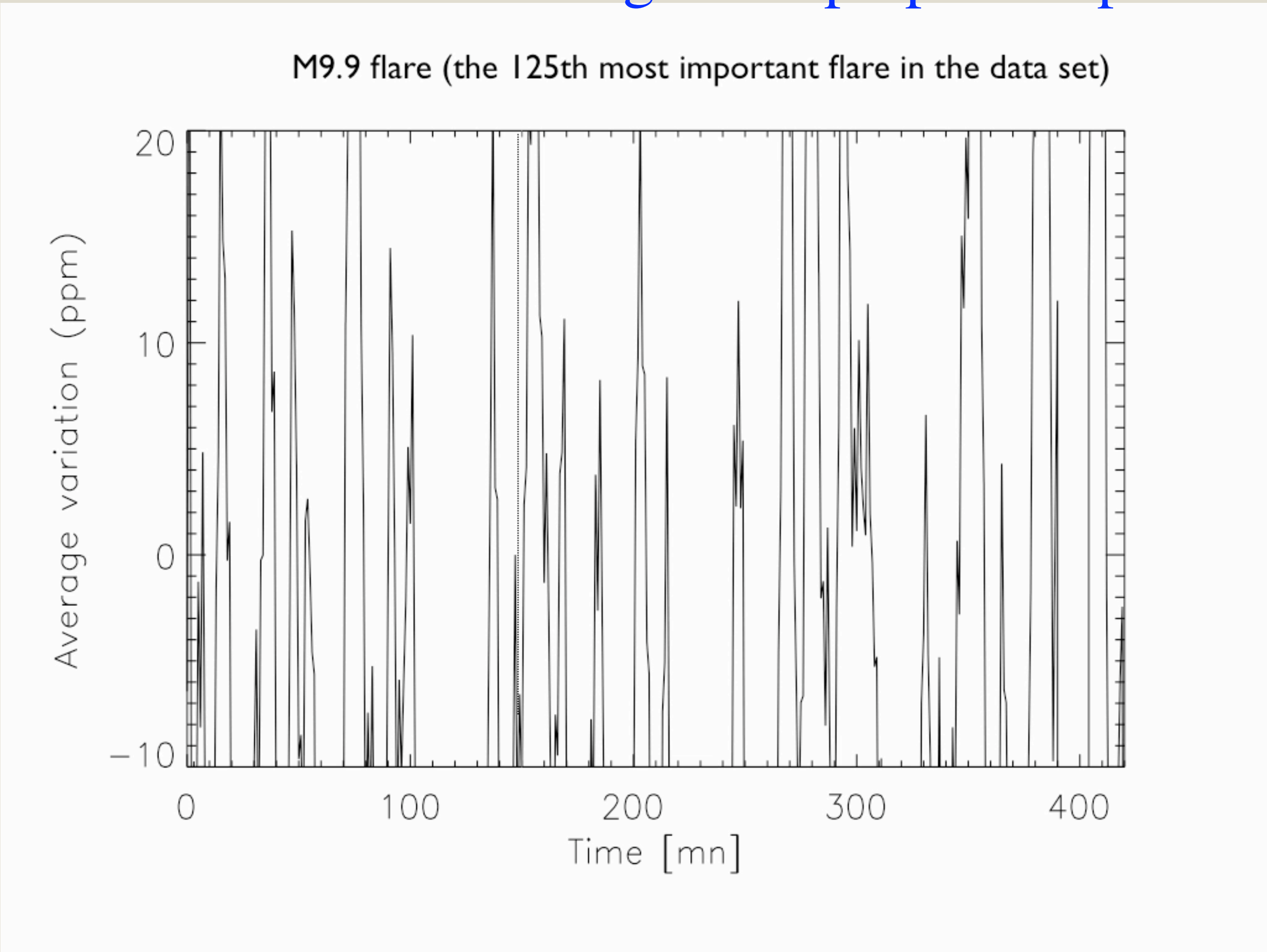
Conclusion

- ✓ **Flares do impact the TSI, even small ones**.
- ✓ Largest flares have a total radiative energy of about 10^{32} ergs.
- ✓ The emission at short (SXR, EUV) wavelengths during a flare constitutes a *small* part of the total radiated energy (E_{goes} ~0.01 E_{tot}).
- ✓ In particular, **visible emission** seems (quasi) systematic and to constitute an important contribution to the TSI increase.
- ✓ Flares COULD contribute to the TSI variation, but probably not much.

Thanks to W. Schmutz and S. Mekaoui for providing high cadence irradiance data !

Thank you !

Illustration of conditional average or superposed epoch analysis:

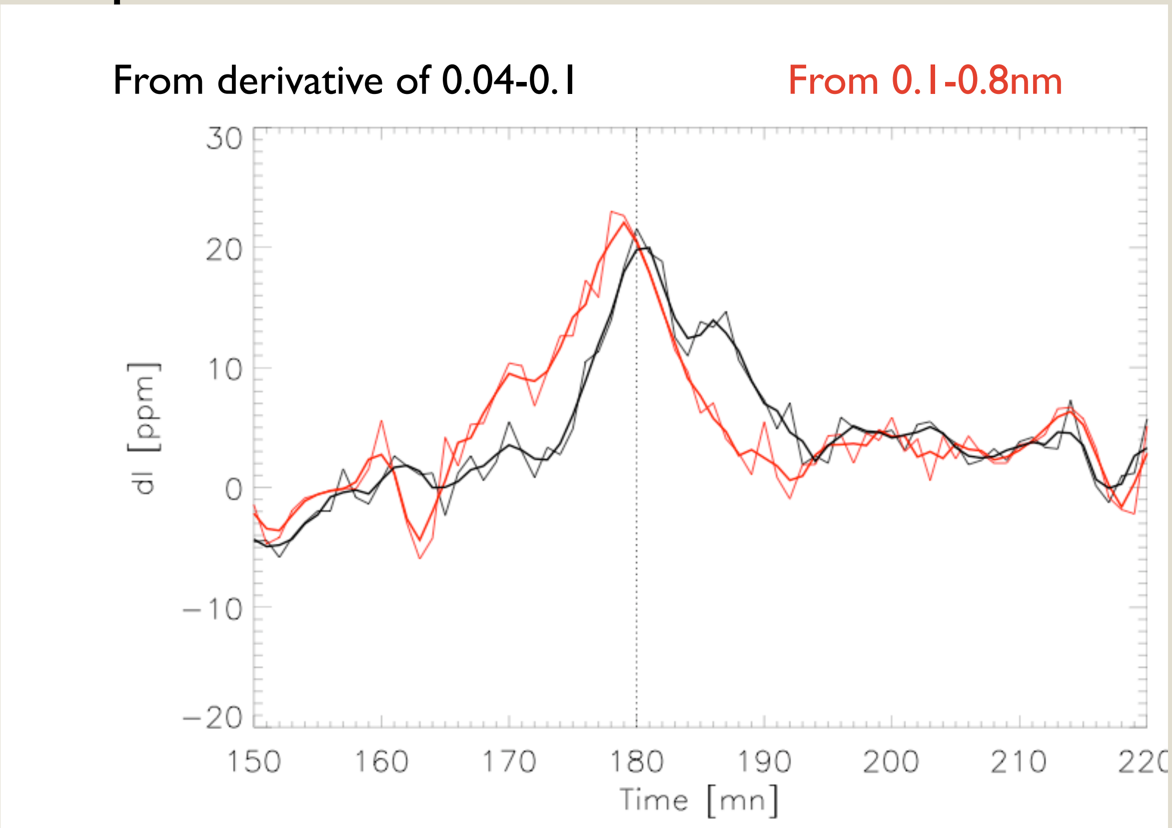


Backup slides

When does the TSI increase ?

✓ Conditional average for flare with $I_{0.1\text{-}.08nm} > 10^{-4.3}$ W/m^2

✓ Peak flare reference time comes either from 0.1-0.8nm peak time or from the peak time of the derivative of the 0.04-0.1nm channel



✓ Most of the TSI increase is before the maximum in 0.1-0.8nm, i.e. ***during the impulsive phase.***

Conditional averaging: details (1/3)

Thus we can represent each time series as :

$$z_i(t) = x_i(t) + y_i(t)$$

where $x_i(t)$ is the solar noise and $y_i(t)$ is the signal due to the flare, e.g. $y_i(t) = S_i \exp(-\frac{t - t_0}{\tau_i})\theta(t - t_0)$In the following, we concentrate on the time of the peak of the flare t_0., such that $y_i(t_0)=S_i$, and $z=z(t_0)$, $x=x(t_0)$.

Our objective is that the signal becomes higher than the noise in the average time-series; it is then natural to average on the first *n* largest (as deduced from GOES classification) events, noted $<...>_n$:

$$< z >_n = \sum_{i=1}^{n} z_i = < x >_n + < S >_n$$

Conditional averaging: details (2/3)

We make the reasonable assumption that the x_i are normally distributed with variance σ^2, thus:

$$< x >_n \sim \sigma/\sqrt{n}$$

The ratio signal-over-noise of the averaged time-series is

$$\frac{< S >_n}{< x >_n} = \frac{1}{\sigma}\sqrt{n} < S >_n$$

and depends thus on the distribution function of the S_i. If the average value decreases slower than $n^{-1/2}$, then the SNR ratio increase. For S_i, the reasonable assumption is to adopt the power law observed for flares at short wavelength:

$$f(S) \sim \frac{C}{S^{1+\mu}} = \frac{C}{S^{\alpha}} \qquad , \qquad \alpha \sim 1.8$$

Conditional averaging: details (3/3)

Remember that we average the signal over the n *largest* flares, i.e. $S_1>S_2>...>S_n$ and $\langle S\rangle_n=1/n.\sum_{i=1,n} S_i$

The rank ordering statistics gives us the most probable values of the *p-th* variable S_p :

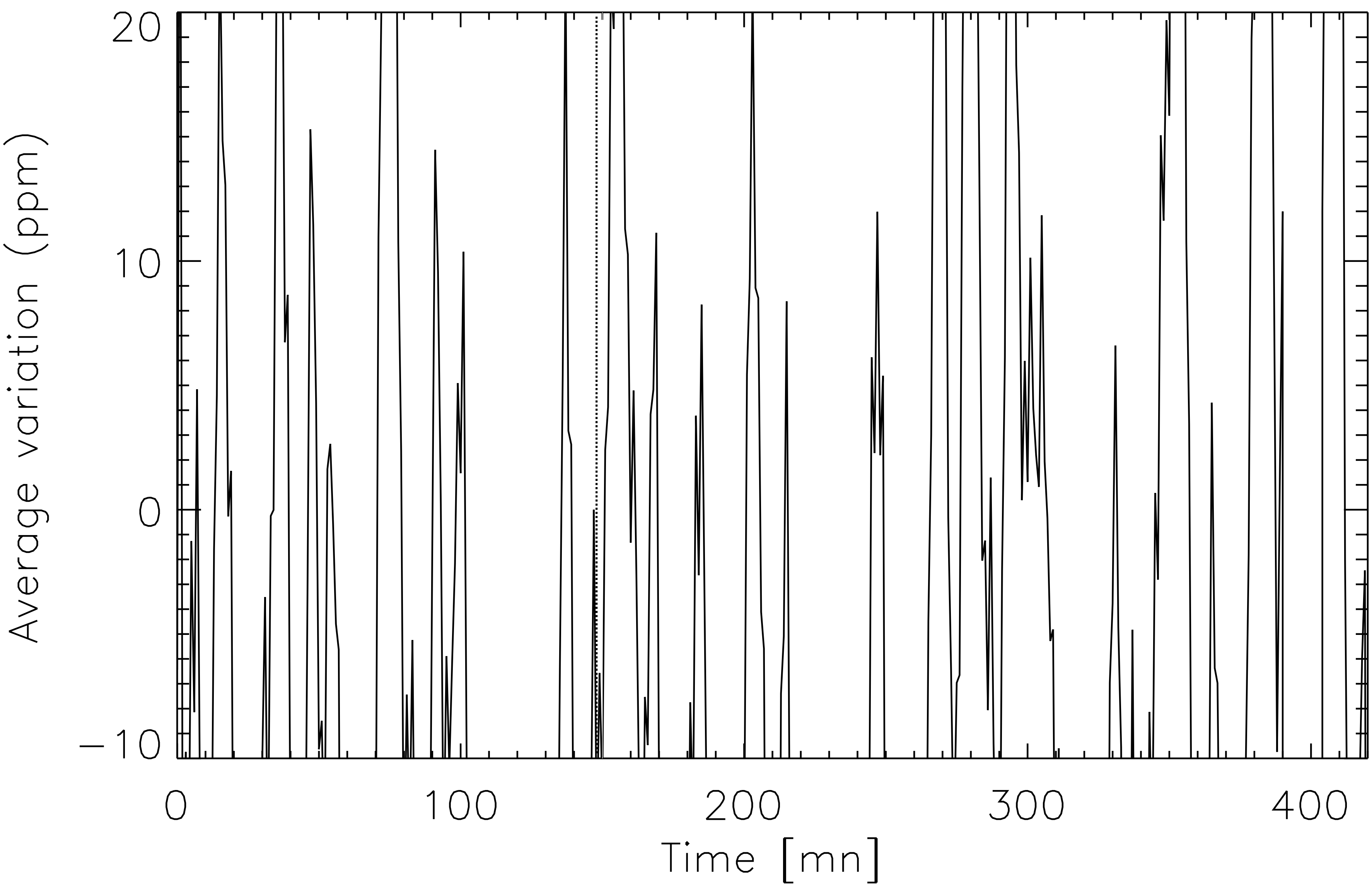
$$S_p^{mp} = \left[\frac{C(\mu N + 1)}{\mu p + 1}\right]^{\frac{1}{\mu}}$$

And thus,

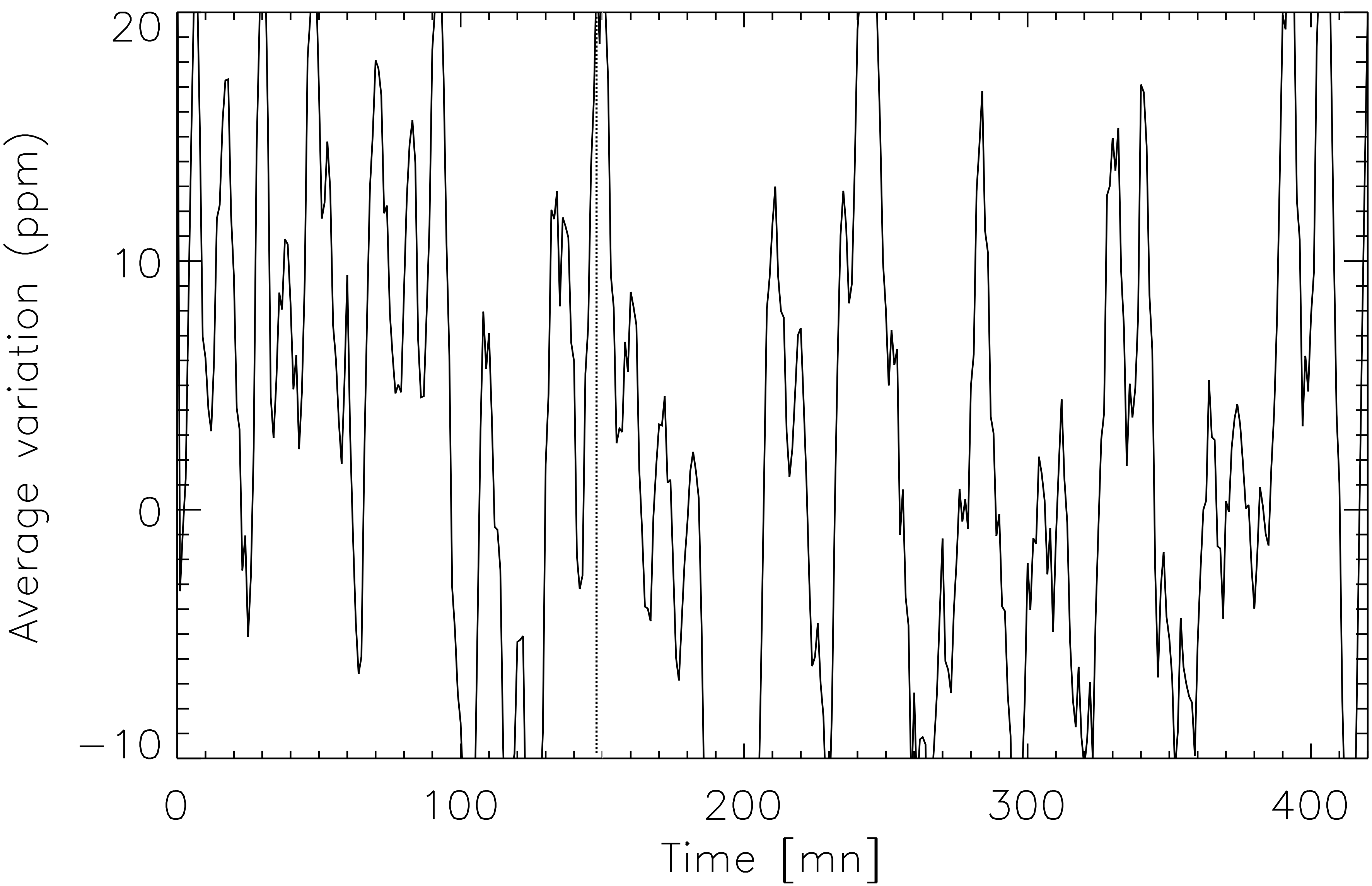
$$S_n = (C(\mu N + 1))^{\frac{1}{\mu}} \frac{1}{n} \sum_{i=1}^{n} \left[\frac{1}{\mu i + 1}\right]^{\frac{1}{\mu}}$$ or $$S_n \sim \frac{1}{n} \sum_{i=1}^{n} \frac{1}{i^{\frac{1}{\mu}}}$$

Manual Movie

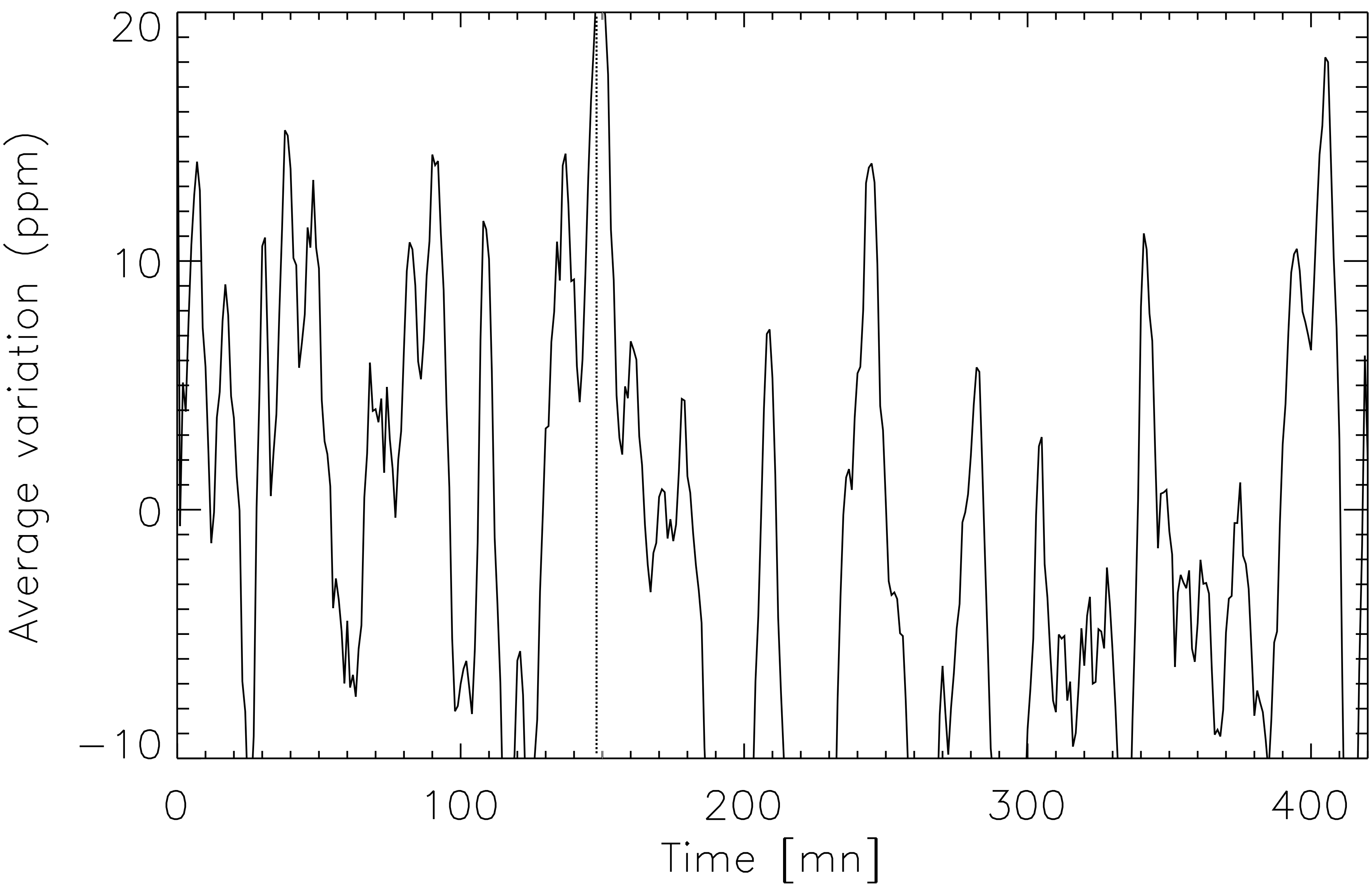
M9.9 flare (the 125th most important flare in the data set)

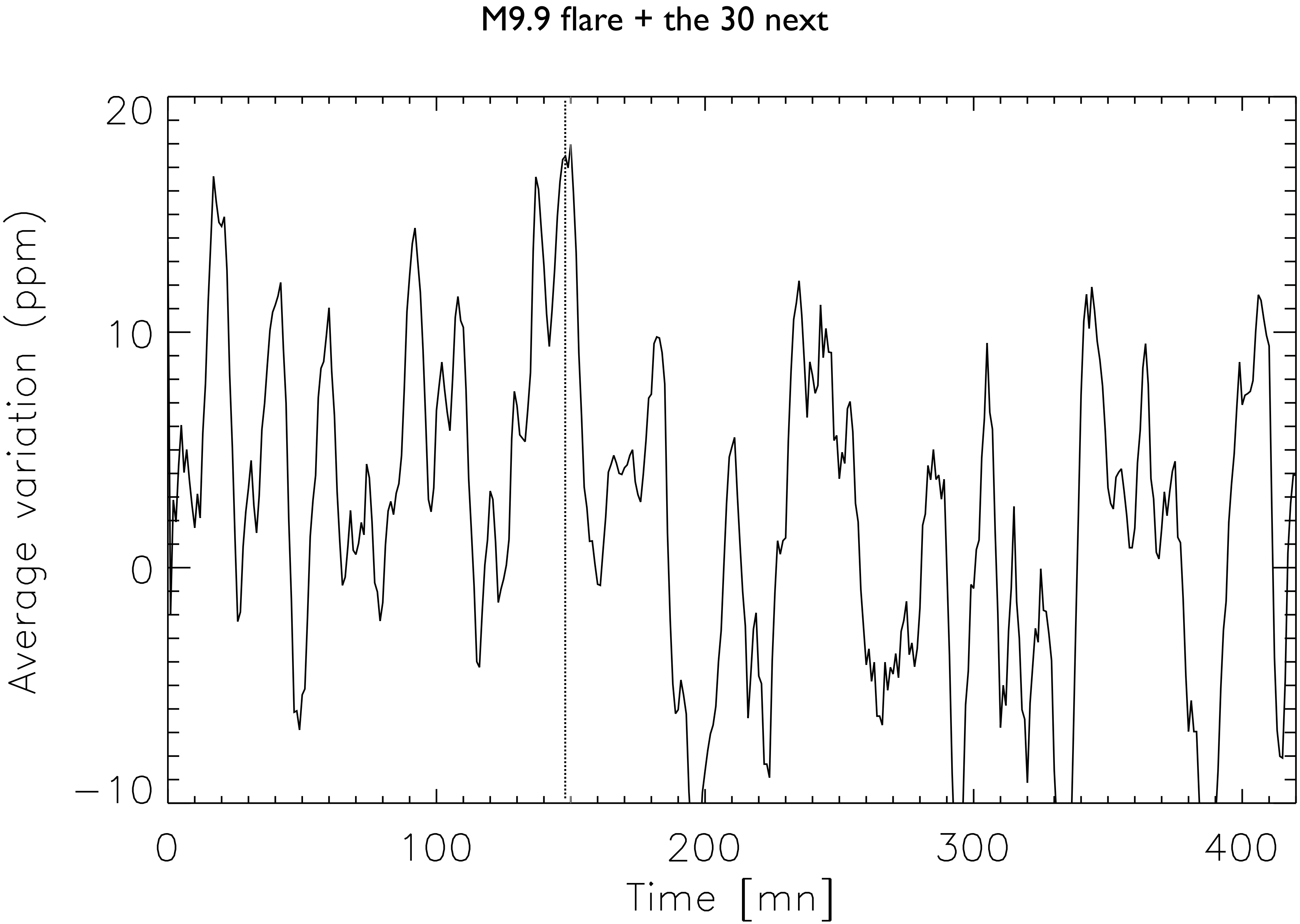


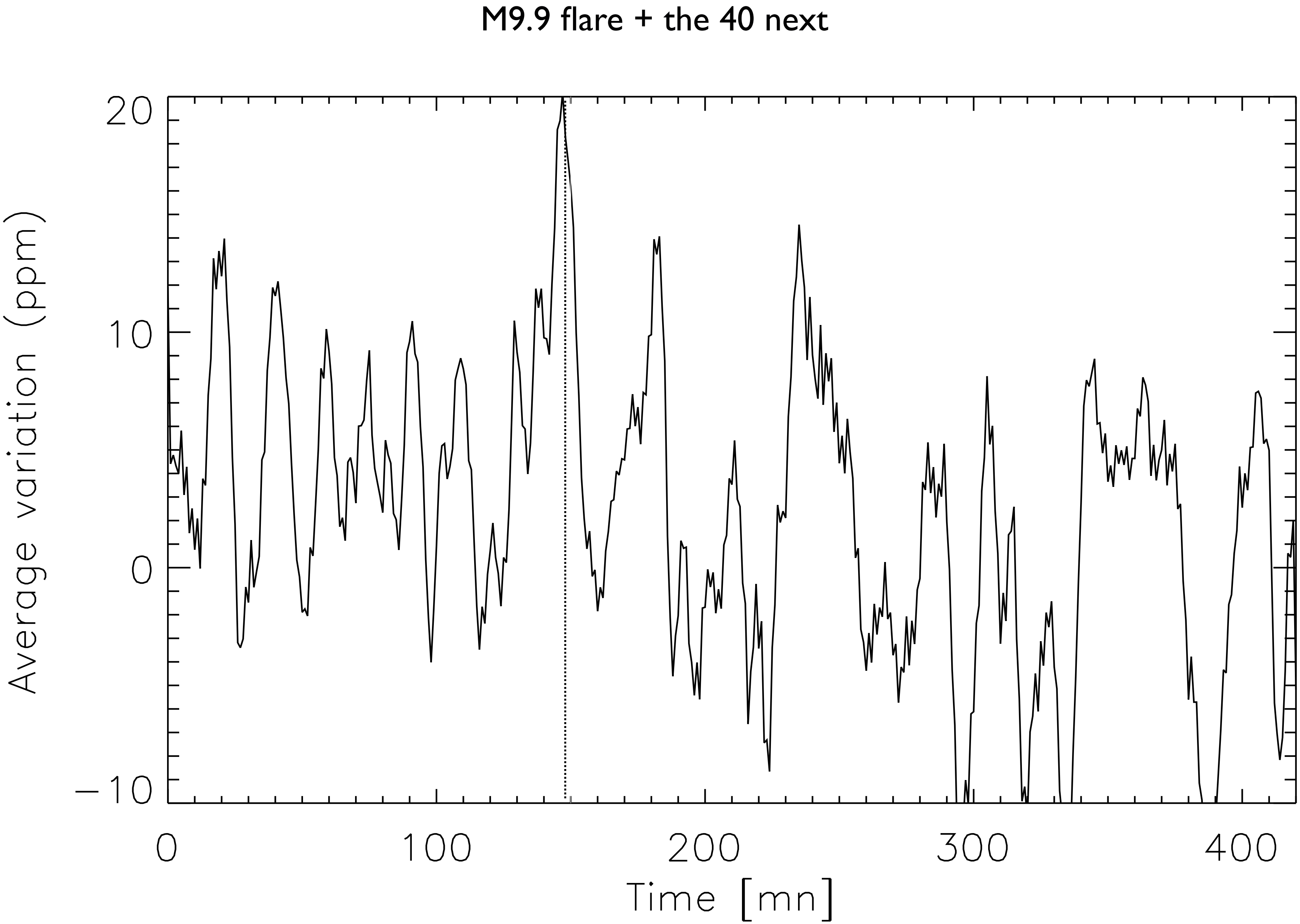
M9.9 flare + the 10 next



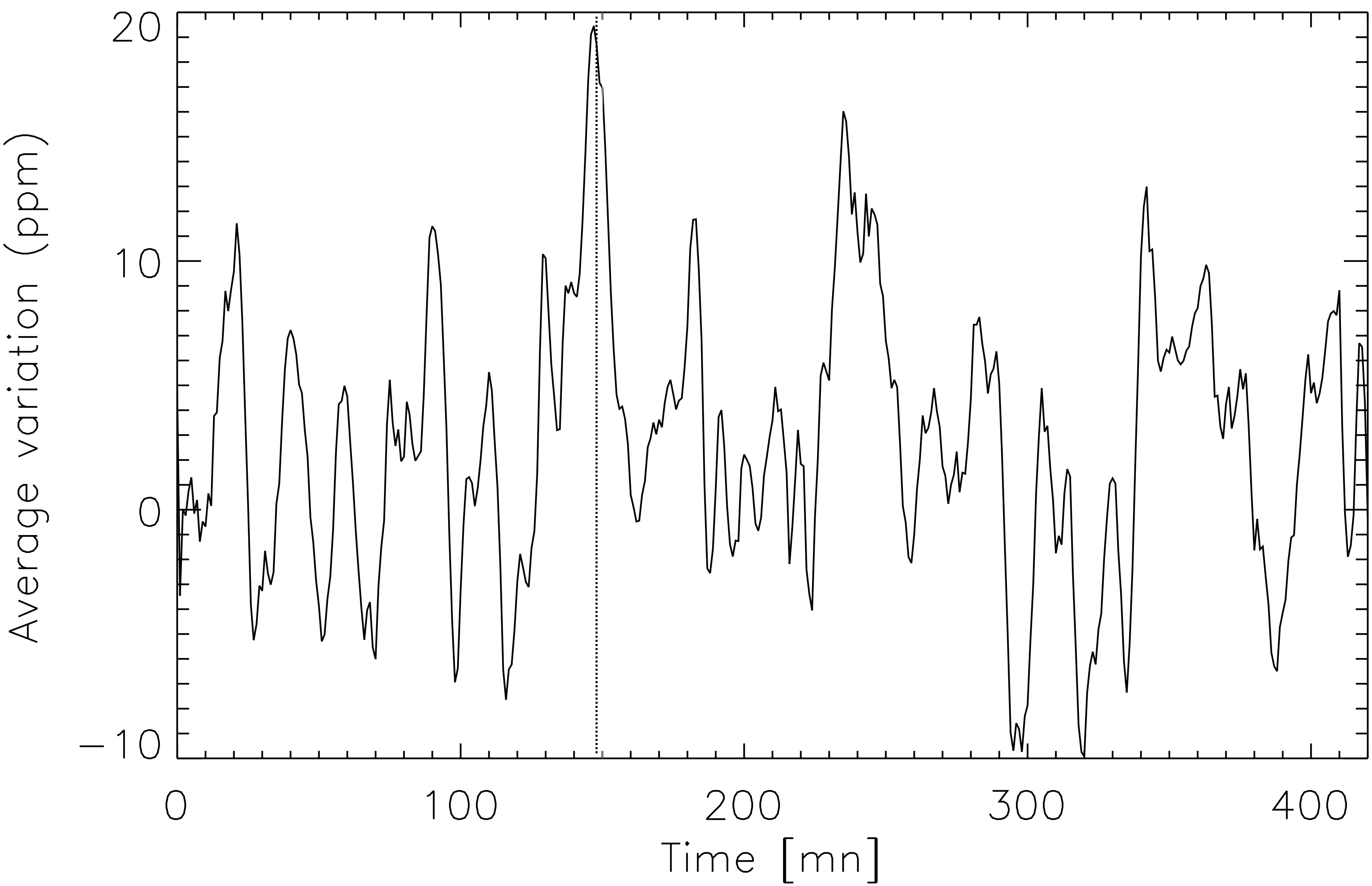
M9.9 flare + the 20 next



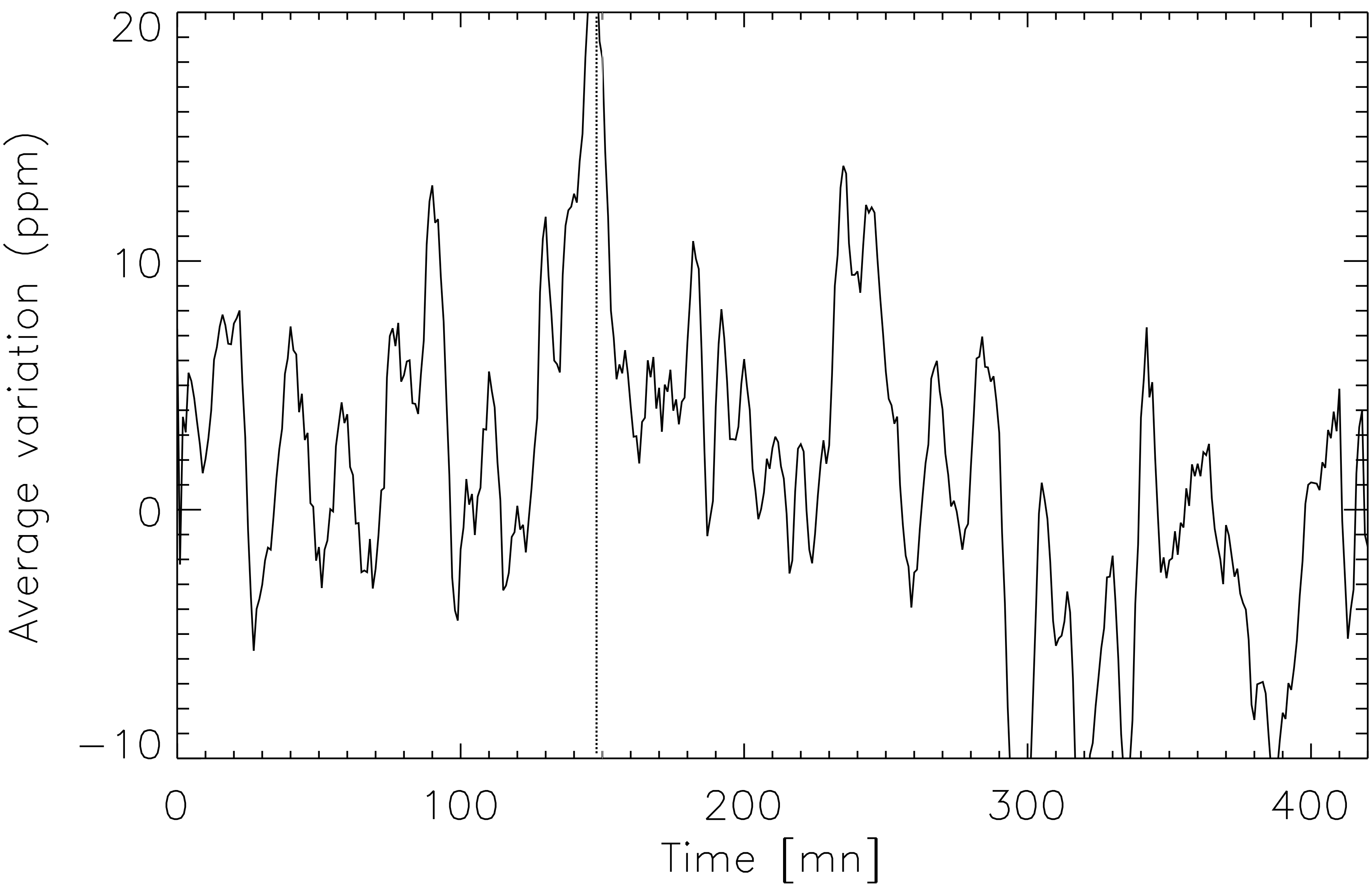

M9.9 flare + the 30 next
Average variation (ppm)
20
10
0
−10
0
100
200
300
400
Time [mn]


M9.9 flare + the 40 next
20
10
0
−10
Average variation (ppm)
0
100
200
300
400
Time [mn]

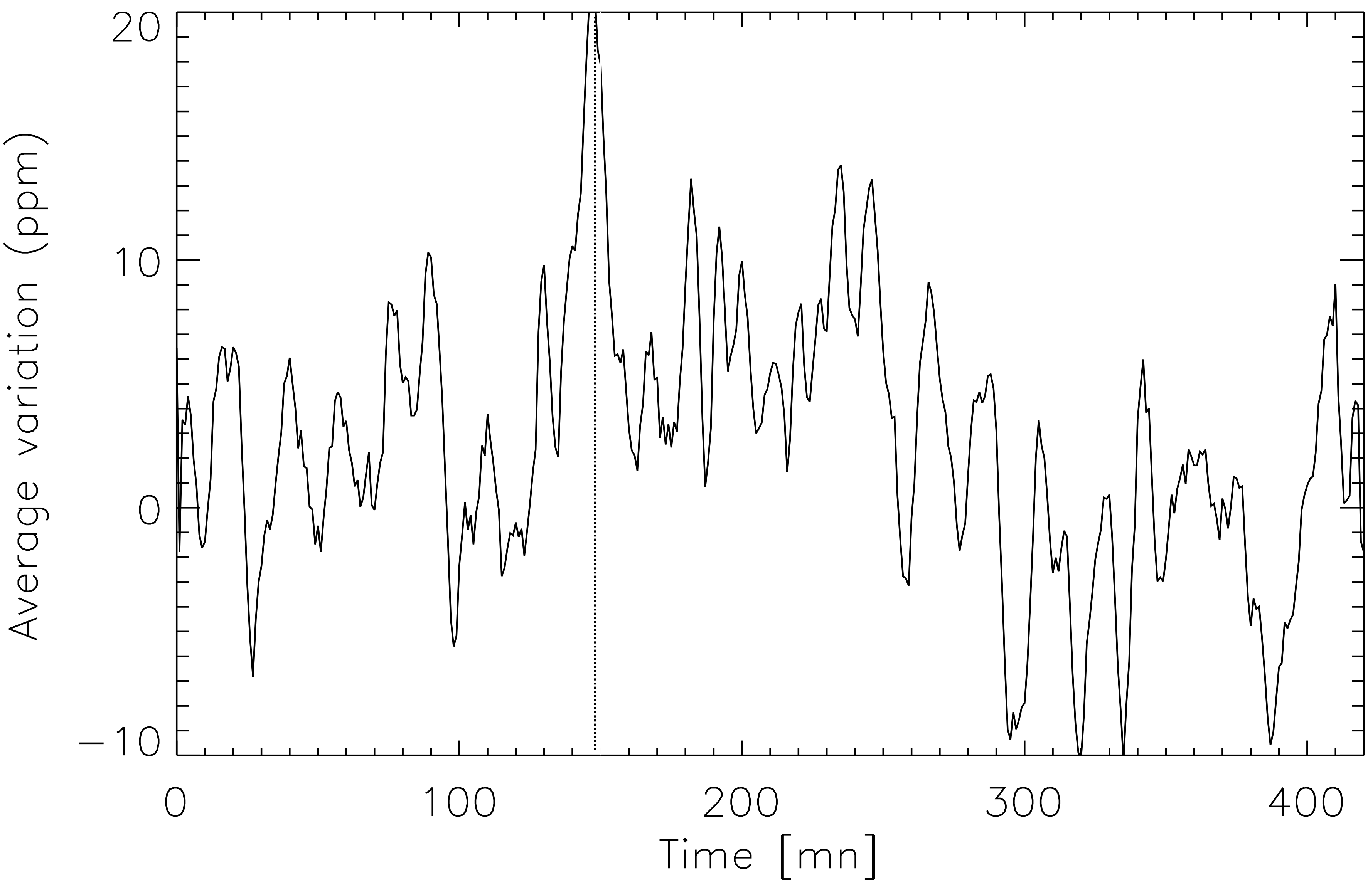
M9.9 flare + the 50 next



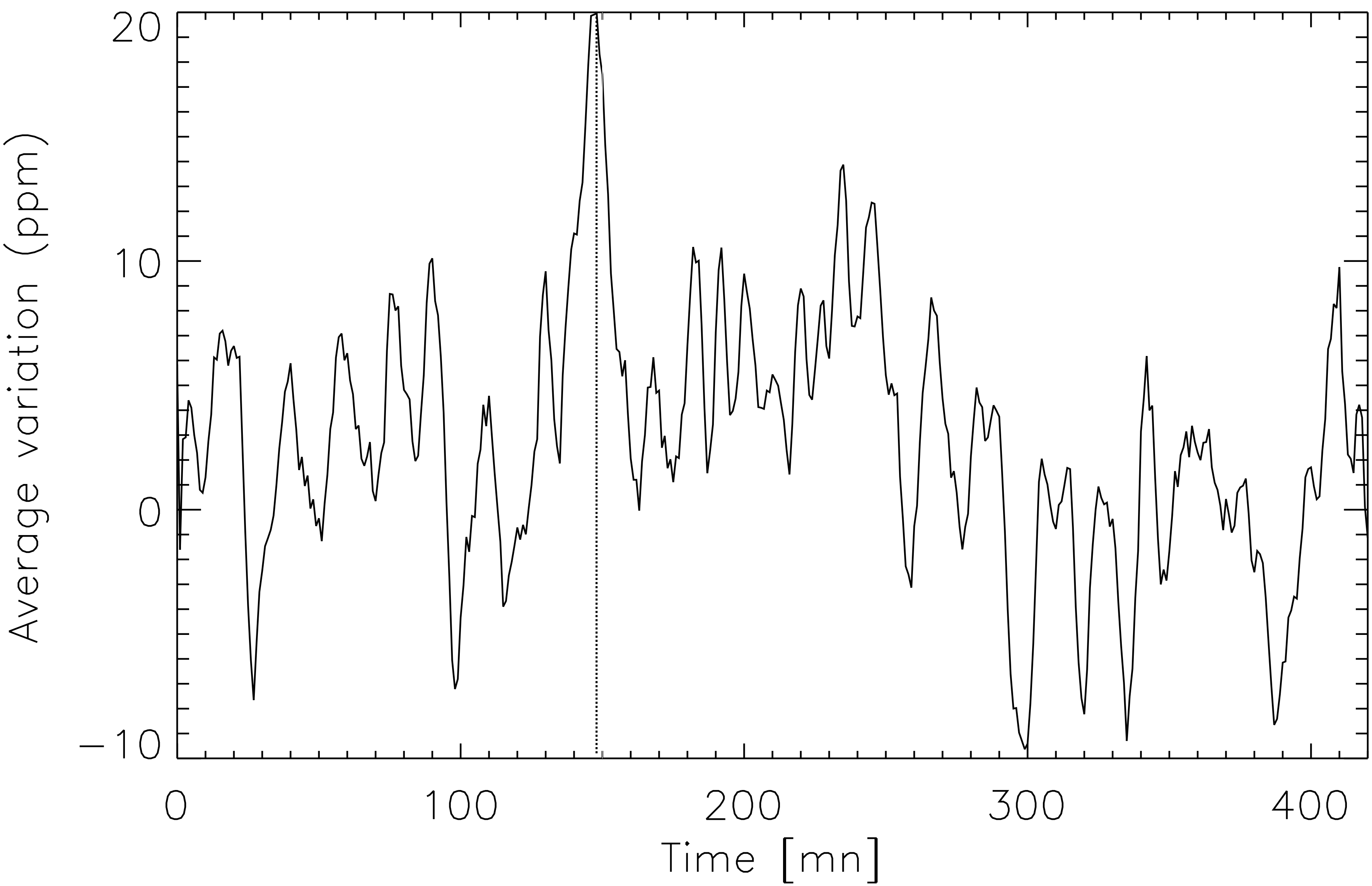
M9.9 flare + the 60 next

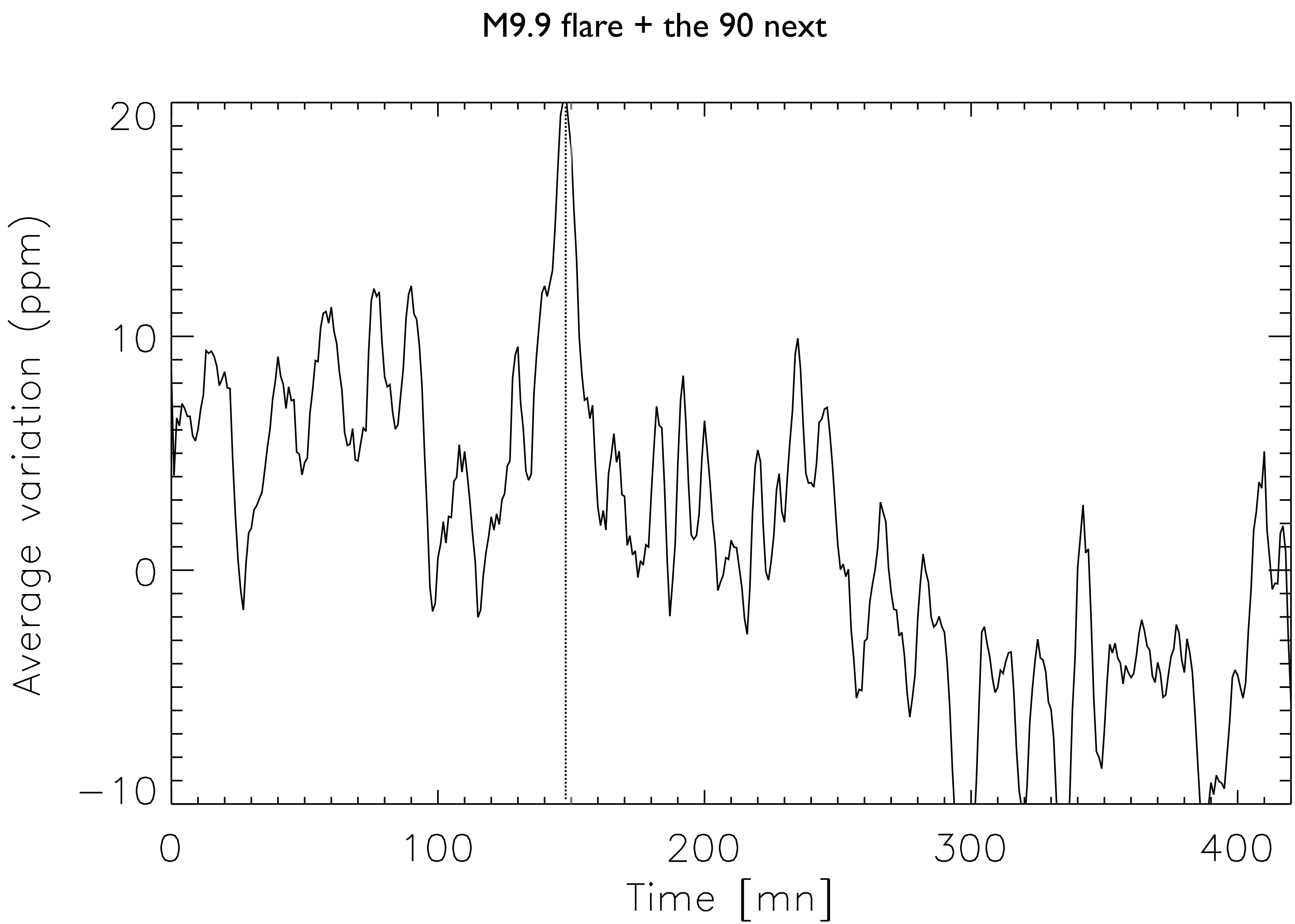


M9.9 flare + the 70 next



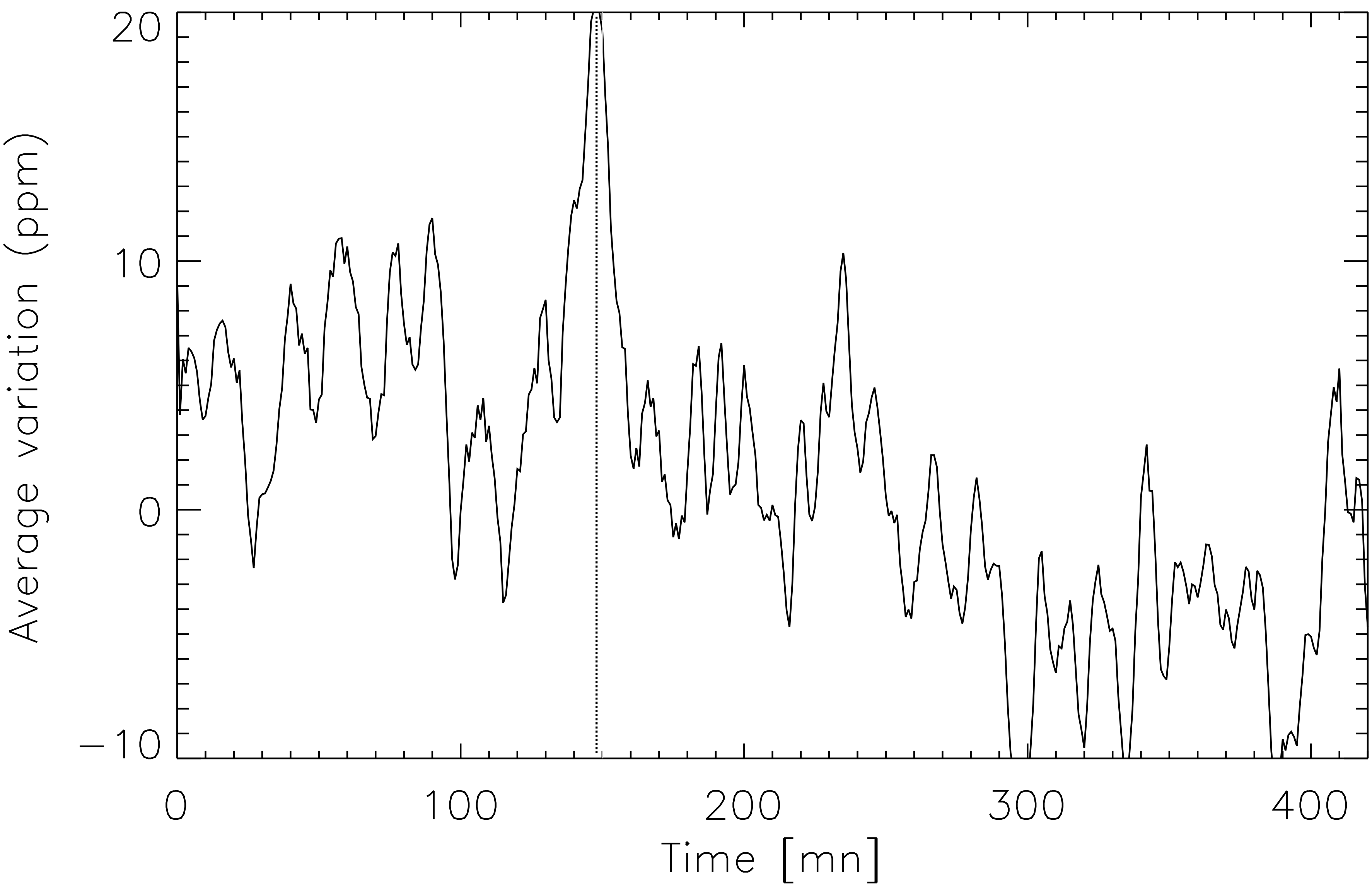
M9.9 flare + the 80 next





M9.9 flare + the 90 next
Average variation (ppm)
Time [mn]
20
10
0
−10
0
100
200
300
400

M9.9 flare + the 110 next



M9.9 flare + the 125 next. Last one is a M5.8 flare