Elimination of diurnal, annual and 11-year solar variations in the observations of the URAGAN muon hodoscope

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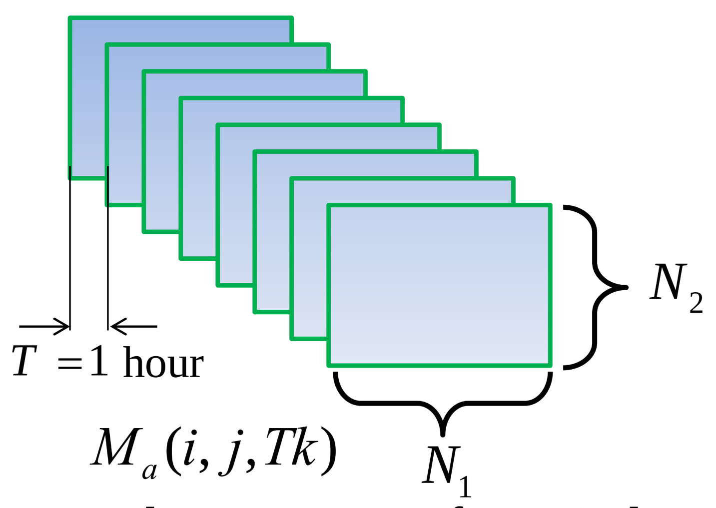
A method for elimination of periodical diurnal, annual and 27-day and 11-year solar variations in the matrix observations of the URAGAN muon hodoscope was developed. The analysis of the parameters of these variations in the time and frequency domains was performed. Two-dimensional bandpass filtering of sequences of muon hodoscope matrix observations was implemented. The structure of a two-dimensional filter is developed, based on the operation of elementwise matrix multiplications and additions. Examples of eliminating variations in the URAGAN muon hodoscope matrix observations are discussed.

1. INTRODUCTION

Muon hodoscope matrix data

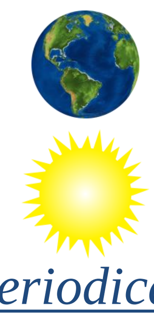


$M_a(i,j,Tk)$ - the sequence of matrix hourly data

$i=1,...,N_1,\ j=1,...,N_2,\ \ k=1,...,k_f$

Muon flux variations

Periodical:

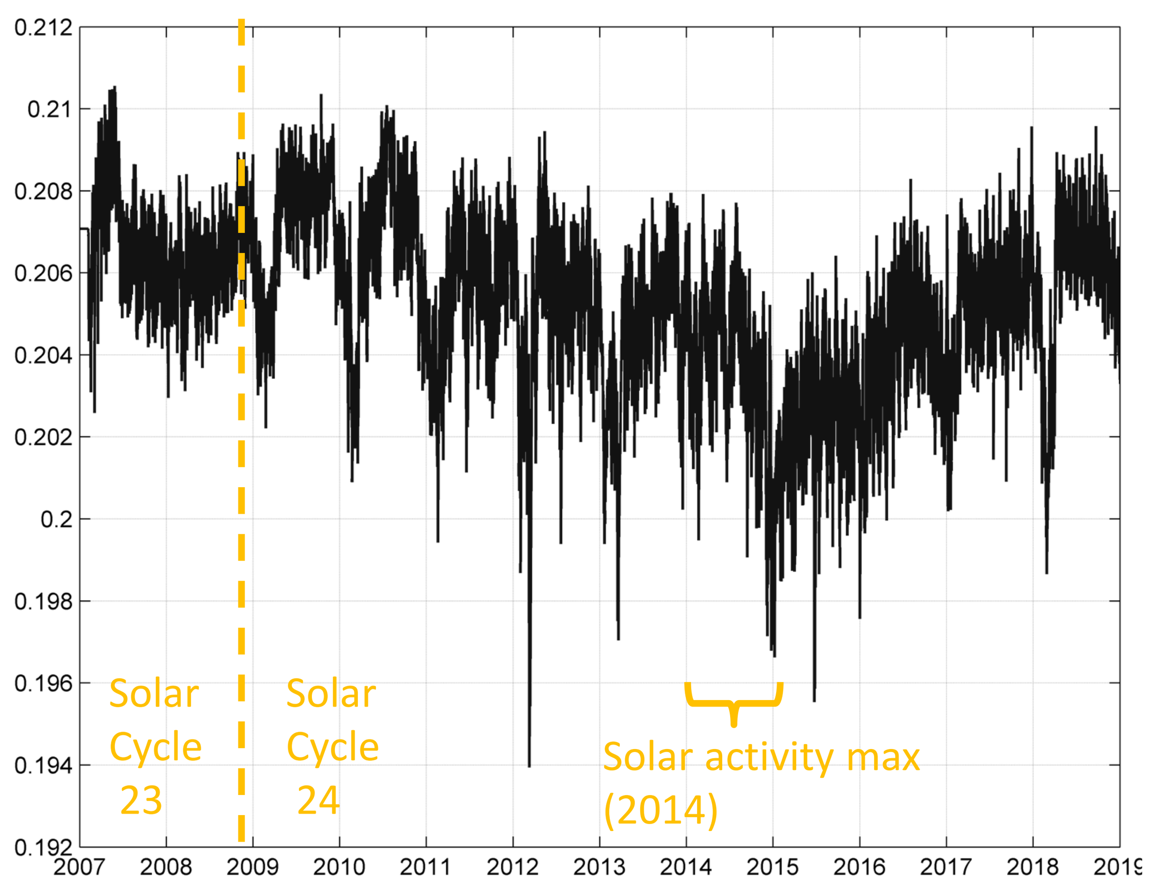


- Diurnal (due to the Earth's daily rotation)
- Annual (due to the Earth's motion in the solar orbit)
- Solar, due to 11-year activity cycle
- Solar, due to 27-day Sun rotation period

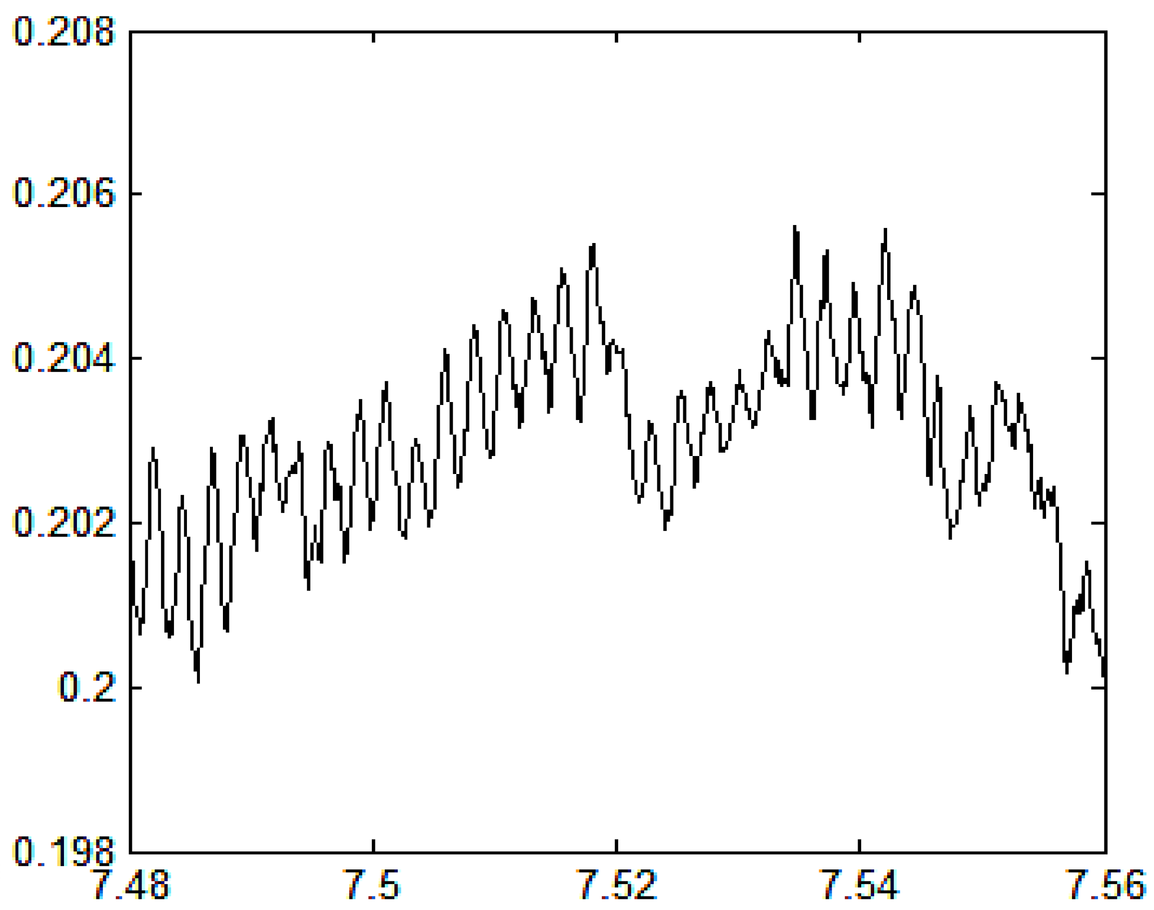
Aperiodical:

- from Forbush decreases
- from the atmosphere's impact

2. URAGAN MUON HODOSCOPE DATA ANALYSIS IN TEMPORAL AND SPECTRAL DOMAINS



Hourly averaged muon flux intensity function plot 06.02.2007, 11:00 UT - 31.12.2018, 23:00 UT.



Hourly averaged muon flux intensity function plot for nearly a month (29.06.2015–31.07.2015),

Averaged muon flux intensity $S(Tk)=\frac{1}{N_1N_2}\sum_{i=1}^{N_1}\sum_{j=1}^{N_2}M_a(i,j,Tk)$

On the hourly averaged muon flux intensity function plot for 06.02.2007, 11:00 UT - 31.12.2018, 23:00 UT, annual (seasonal) periodicity is clearly seen, as well as the extreme value periods related to the solar cycle minimum and maximum.

Hourly averaged muon flux intensity function plot for nearly a month (29.06.2015–31.07.2015), depicting a ~800-point interval includes about 32 diurnal oscillations.

Analyzing the oscillatory components in the MH data

DFT: $C_0(n)=\frac{1}{N}\sum_{s=0}^{N-1}S(Ts)e^{-jns/N},\quad n=0,1,...,N-1\qquad C(n)=C_0^*(n)C_0(n)$

Logarithmic spectrum: $LC(n)=20\log_{10}(C(n))$ Resolution: $\Delta f=1/NT$

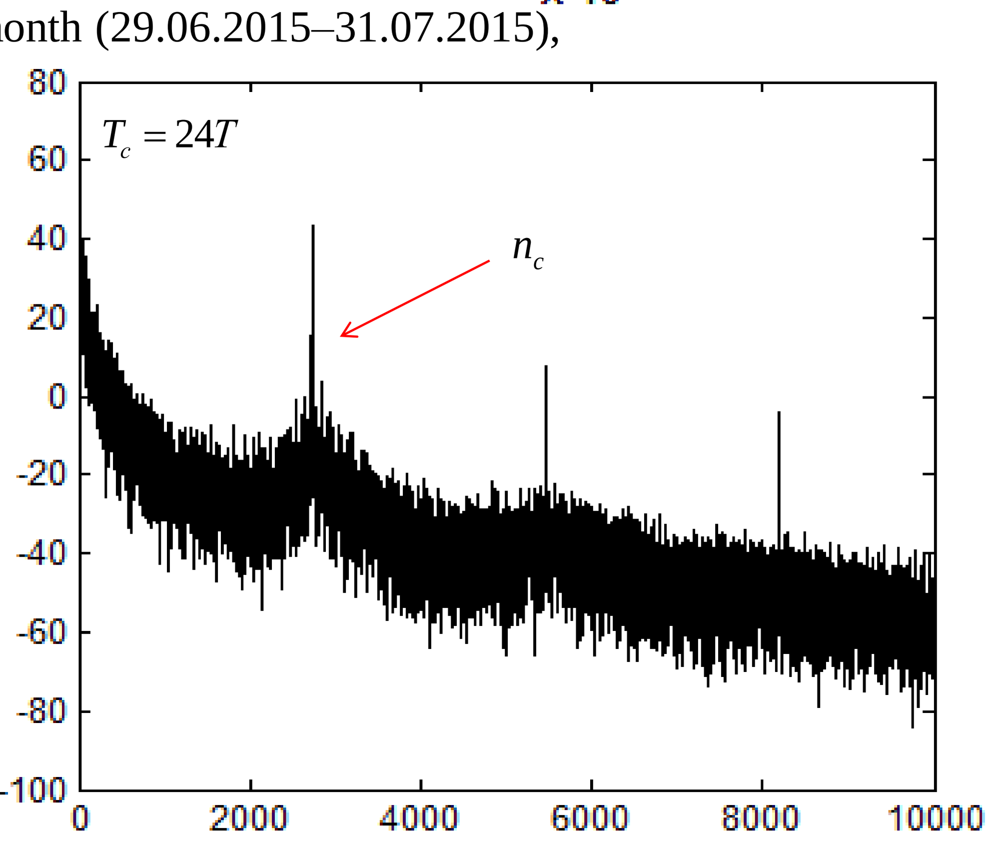
Two cases analyzed with different resolutions: $T_c=24T,\ T_y=365*24*T$

$n_c=2731$ the 1st harmonic number for a diurnal component.

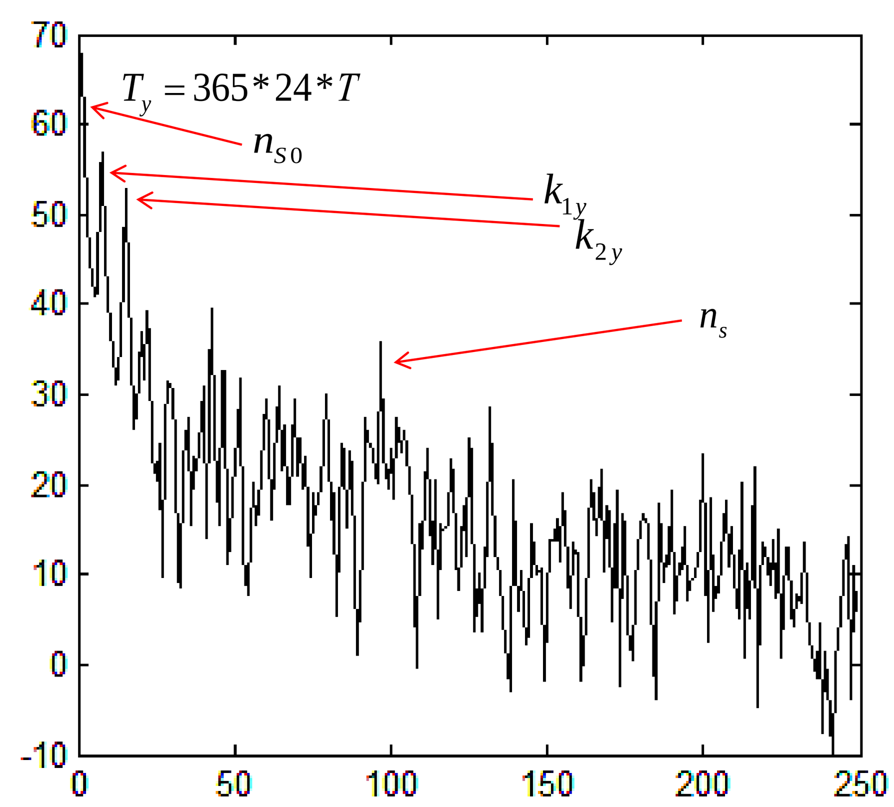
$n_{S0}=1$ for the 11-year solar component (for a more accurate spectral analysis of this component, at least 50-100 years needed)

$n_s=n_c/27\approx 102$ the first harmonic number for the component associated with the rotation of the Sun

$k_{1y}=7,\ k_{2y}=14$ two peaks representing the annual component harmonic



$LC(n)$, $n=0,1,...,9999$



$LC(n)$, $n=0,1,...,249$

3. TWO-DIMENSIONAL BANDPASS FILTERING FOR MH MATRIX OBSERVATIONS

Butterworth bandpass filtering for each $M_a(i,j,Tk)$: total N_1N_2 operations; weight coefficients $b_r(i,j), r=1,...,r_0,\ a_s(i,j), s=0,...,s_0$

$$M_{a,F}(i,j,Tk)=-\sum_{r=1}^{r_0}b_r(i,j)M_{a,F}(i,j,T(k-r))+\sum_{s=0}^{s_0}a_s(i,j)M_a(i,j,T(k-s))$$

Two-stage filtering approach

1) Two-dimensional filter based on one-dimensional difference eq.; elementwise matrix multiplication applied

$$M_{a,F}(Tk)=-\sum_{r=1}^{r_0}B_r\circ M_{a,F}(T(k-r))+\sum_{s=0}^{s_0}A_s\circ M_a(T(k-s))$$

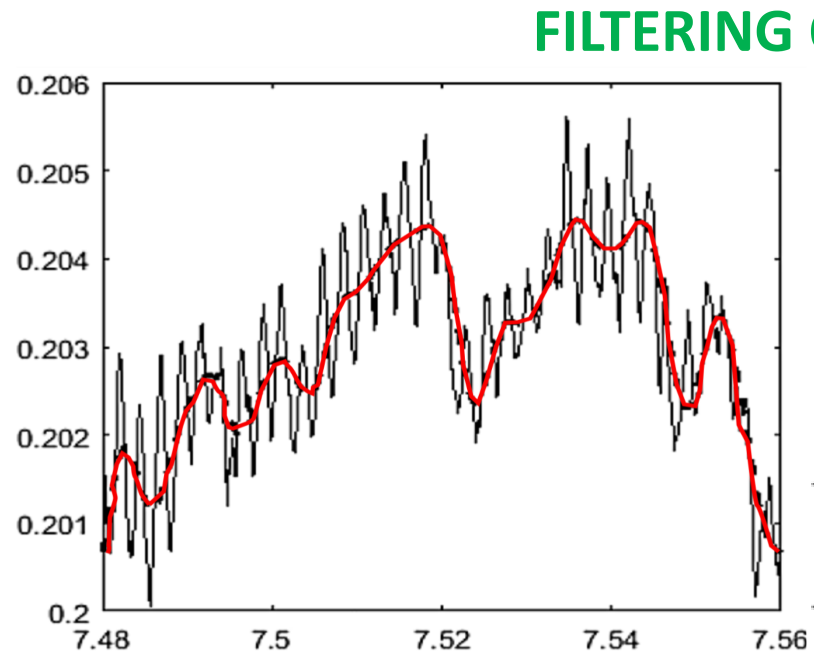
2) Elimination of phase shifts:

$$S_F(Tk)=\frac{1}{N_1N_2}\sum_{i=1}^{N_1}\sum_{j=1}^{N_2}M_{a,F}(i,j,Tk)$$

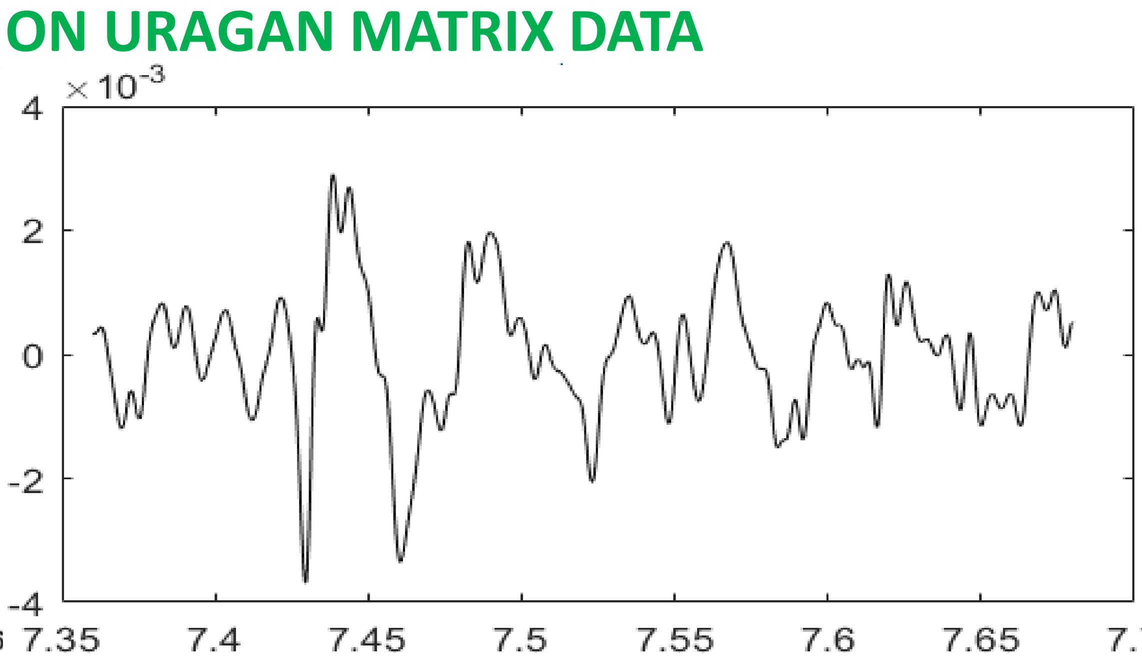
Functional $F(S,S_F,k_d)=\sum_{k=k_1}^{k_2}(S(Tk)-S_F(T(k-k_d))^2$ minimization:

$k_d^\circ=\arg\{\min_{1\le k_d\le k_{d0}}F(S,S_F,k_d)\},\qquad M_{a,F0}(i,j,Tk)=M_{a,F}(i,j,T(k-k_d^\circ))$

4. TESTING THE METHOD OF TWO-DIMENSIONAL BANDPASS FILTERING ON URAGAN MATRIX DATA



The elimination of diurnal variations: original averaged muon flux intensity (black) and the filtered one (red)



The elimination of diurnal, annual, and solar 27-day and 11-year variations: only aperiodic MF variations left.

The proposed method for eliminating periodic diurnal, annual, and solar variations in the matrix observations of the URAGAN muon hodoscope based on two-dimensional band-pass filtering appeared to be workable. It is established on the basis of computational experiments that: the time costs of the proposed filtering method, with appropriate ratios of parameters, are on average 5-10 times less than the time spent for filtering on the basis of one-dimensional filters; phase shift correction errors are of the order of 1-2 degrees. The method can be applied to many problems of experimental physics, associated with the elimination in the sequences of matrix observations of the components of periodic variations.

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