Neutron monitor altitude-dependent yield function and its application to an analysis of neutron-monitor data

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https://doi.org/10.1029/2019JA027433

https://doi.org/10.1029/2018JA026340

Neutron monitors (NMs) are the main detectors aimed to study the long-tern cosmic-ray variability, thanks to the long period (~70 years) of their operation. NMs register mainly the nucleon component of secondary particle showers, produced during interactions of primary cosmic rays with the nuclei of the atmosphere.

The most appropriate way of the NM analysis is the use of the NM yield function (YF) which allows to calculate the expected NM response *N* knowing the flux of the primary particles *J*:

$$N = \frac{1}{\kappa}\sum_i \int_{P_c}^{\infty} J_i(E)Y_i(E)dE,$$

where the summation is over the number of considered cosmic-ray species, P_c is the cutoff rigidity of a given NM. A scale factor κ is introduced to account for the non-ideality of a given NM, related to electronics, the material of the building where the NM is located.

Several YF were recently calculated using Monte-Carlo generators and latitude surveys data. Recent AMS-02 observations of time variations of proton and helium fluxes allowed us to validate different Yfs. In particular we found the dependence of scale factor variability slope as a function of cutoff rigidity for period of 2011-2017 for several stable NMs (Fig. 1). The best performance was shown by Mishev et al. 2013 YF. The only once caveat of this YF was that it was suited only for sea-level NMs. Here we made additional computations for different altitudes.

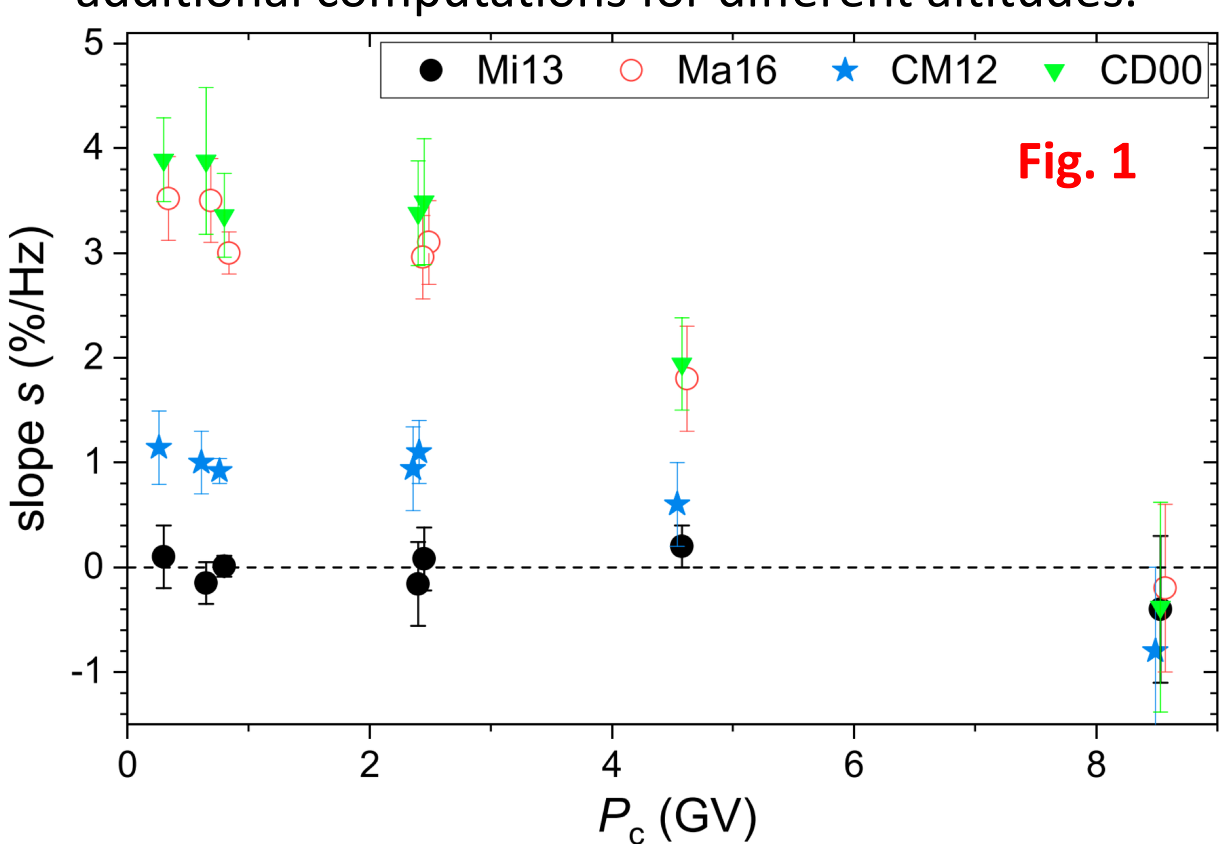


Fig. 1

The NM YF can be generally computed as follows:

$$Y_i(E,h) = G(E)\sum_j \int\int S_j(E',\theta)\cdot F_{i,j}(E,h,E',\theta)dE'd\Omega$$

where *G*(*E*) is the geometrical correction factor, accounting for the finite lateral expansion of the CR-induced atmospheric cascades and the detector's electronic dead time; S_j (*E*, θ) is the detector's response function, equal to the geometrical area times the registration efficiency for a secondary particle of type *j* with energy *E* impinging on the detector with the zenith angle θ; $F_{i,j}$(*E*,*h*,*E*,θ) is the differential flux of secondary particles of type *j* (neutrons, protons, muons, and pions) for a primary particle of type *i* with kinetic energy per nucleon *E*, impinging isotropically on the top of the atmosphere; and the integration is over the energy of secondary particles *E*′ and solid angle Ω. All the computations were done for the standard 6NM64 NM. Here, the propagation and interaction of primary particles in the atmosphere were simulated with the PLANETOCOSMICS simulation tool based on the GEANT4 package, considering the NRLMSISE-00 atmospheric model. The simulation scheme was the same as in the previous computations by Mishev et al. 2013. First, we calculated fluxes of secondary particles at prescribed atmospheric depths and then convoluted them with the registration efficiency. The computations were carried out separately for primary cosmic-ray protons and helium nuclei with an isotropic incidence. Calculations were performed for atmospheric depths of 1000, 900, 700, and 500 g/cm^2 (example is shown in Fig. 2).

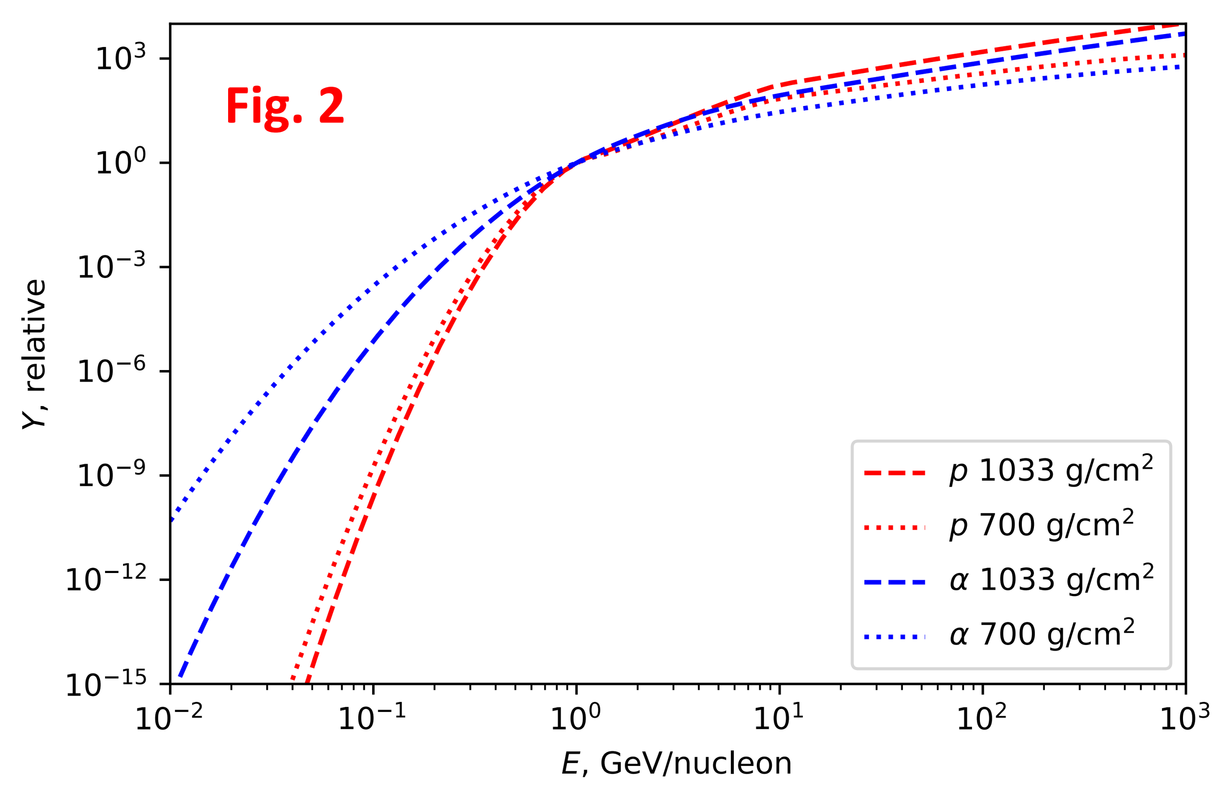


Fig. 2

We applied the derived yield function to the data of the global NM network, collected using Neutron Monitor Data Base, IZMIRAN database and dedicated servers for several NMs. NMs active during the period 2011-2017 (corresponding to the period of CR observations by AMS-02) were considered, moreover, only NMs having the observational data during at least half of the considered 2011–2017 timespan were included in the analysis, this condition was satisfied by 42 NMs.

Daily NM count rates were integrated on Bartels rotation time basis to make them comparable with AMS-02 data. Heavier-than-helium nuclei species were represented by helium nuclei, scaled according to the number of nucleons, with the same energy per nucleon. Their combined spectrum was reconstructed using experimental data from AMS-02 and another space-borne experiments and rebinned correspondingly, so that for each helium nuclei energy bin the corresponding contribution of heavier-than-helium nuclei was calculated and added. After that, the fluxes of protons and helium nuclei (together with heavy-than-helium CR fluxes data) were used for the computation of theoretical NM response and were compared to NM real data. For each NM, the most stable count rate series among different databases was taken into the analysis. Example of the analysis is given in Fig. 3 and scale factor k for all analyzed NMs is shown in Fig. 4.

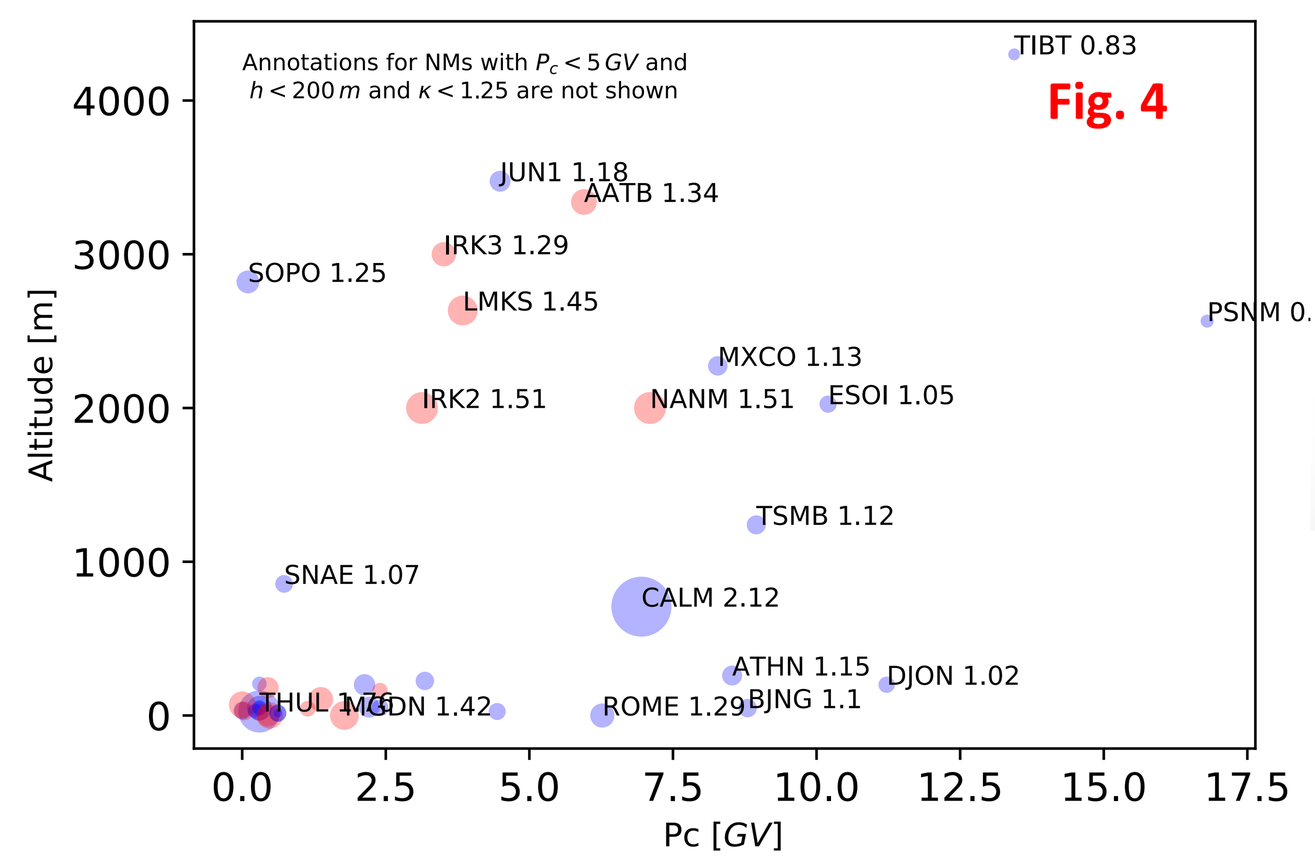
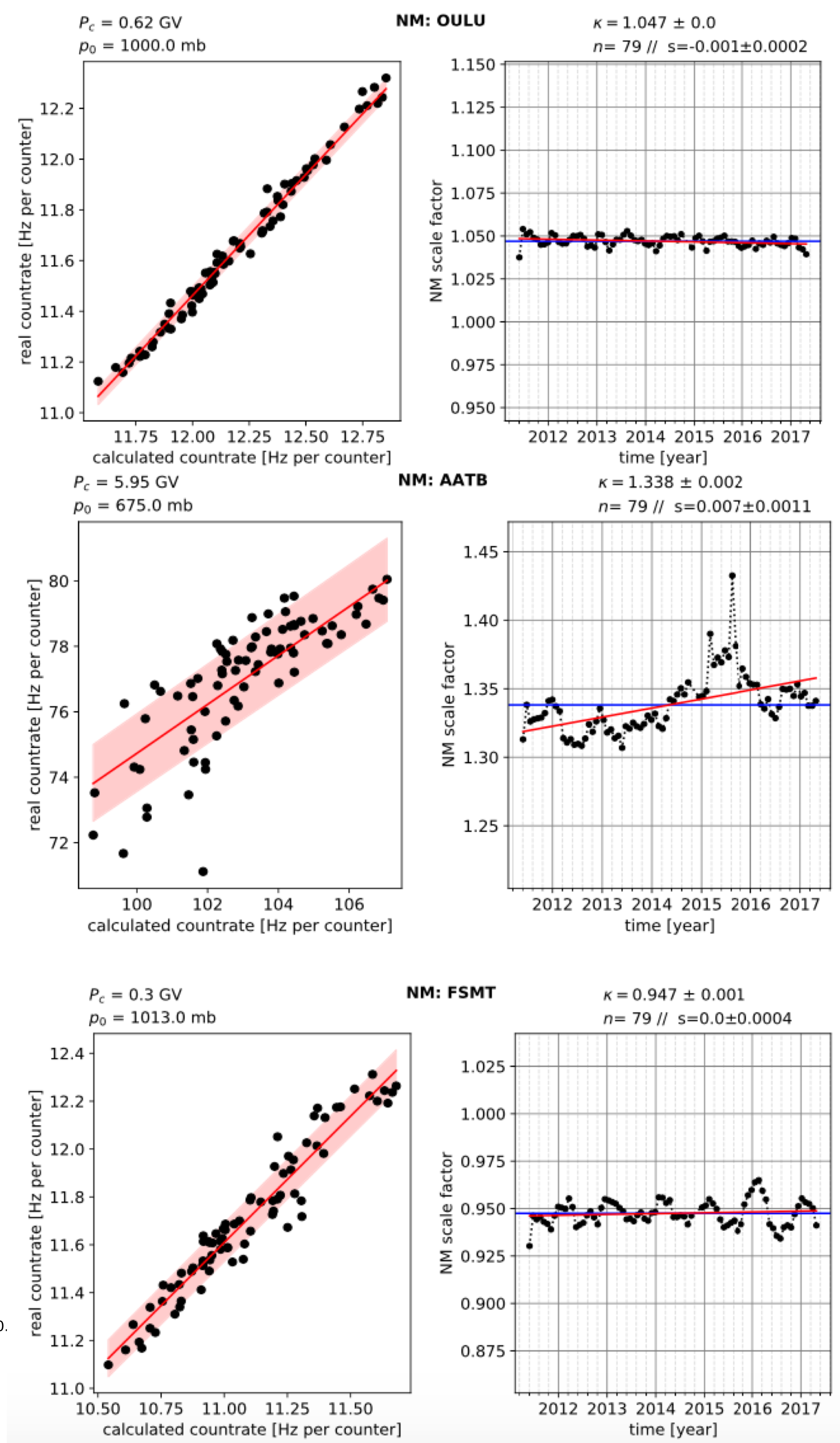


Fig. 4

Fig. 3



We identified more than half of analyzed NMs to be stable during the considered time period, while the other part suffer from jumps and trends in data. The typical k values is in range from 0.8 to 1.2, being slightly greater for NMs produced in former Soviet Union.