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Solar-cycle dependence of selected turbulence quantities at Earth

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Abstract

Ab initio modulation models require a number of turbulence quantities as input for any reasonable diffusion tensor. While turbulence transport models describe the radial evolution of such quantities, they in turn require observations in the inner heliosphere as input values. We analyzed 1-minute resolution data for the N-component of the magnetic field, from 1974 to 2012. We assume a very simple three-stage power-law frequency spectrum, and calculate the second-order structure function, which is then fitted to data. We find that the variance of the N-component has a clear solar-cycle dependence, with smaller values (~6 nT^2) during solar minimum and larger during solar maximum periods (~17 nT^2), well correlated with the magnetic field magnitude, in agreement with previous studies. The inertial range index is almost identical to the Kolmogorov value –5/3. Our results suggest that the dominant change in the spectrum of fluctuations of the N-component of the magnetic field, over a solar magnetic cycle, is its level.

1. Introduction

- Novel data analysis technique assumes three-stage power-law spectrum (see Fig. 3 for examples). Spectrum forced to be flat or decreasing with decreasing frequency in cutoff range to ensure finite energy density.
- Second-order structure function (Matthaeus et al. 2012, ApJ, 750) constructed with lags from 4 minutes to 320 hours (see Fig. 3 for examples) for 27-day and longer averages.
- Technique benchmarked with synthetic data.
- Technique yields good results for data coverage 25% and higher.
- N-component of 1 minute resolution magnetic field data from *IMP* and *ACE* analyzed for 38-year period from 1974 – 2012.

2. Benchmarking of technique

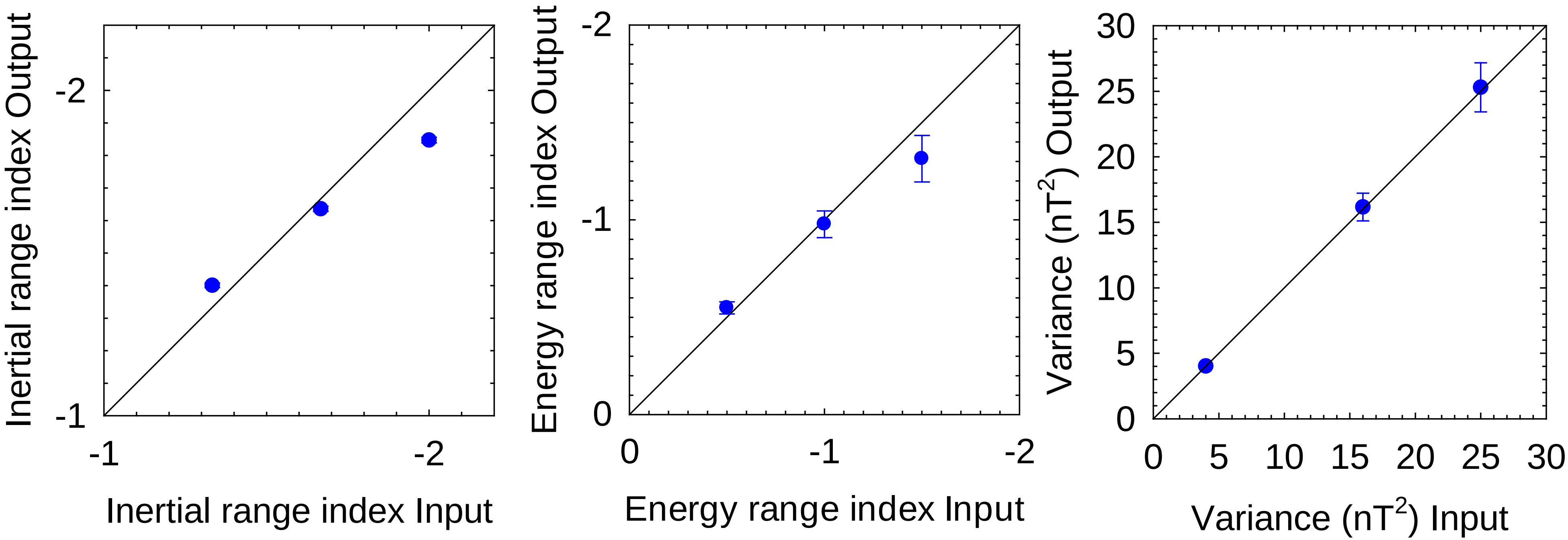


Fig. 1 Comparison of a range of values specified for generated data (horizontal axes) and values obtained with current analysis technique (vertical axes). Average of 26 runs shown with standard deviation.

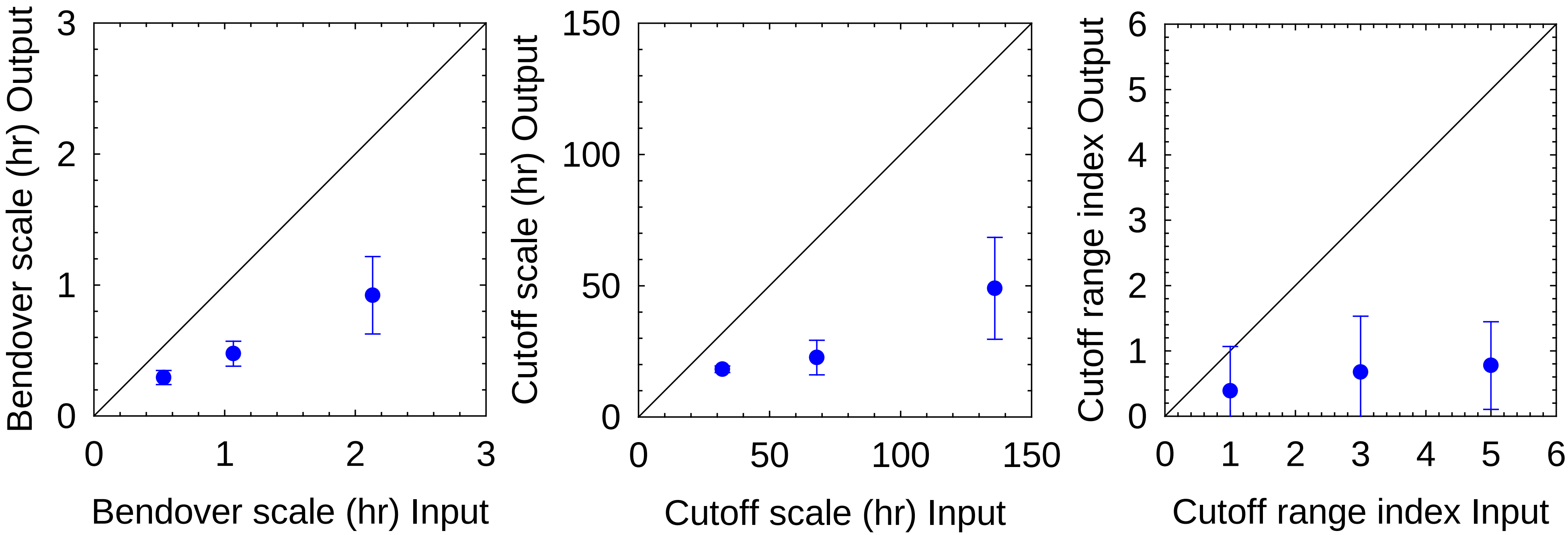


Fig. 2 Comparison of a range of values specified for generated data (horizontal axes) and values obtained with current analysis technique (vertical axes). Average of 26 runs shown with standard deviation.

3. Data analysis

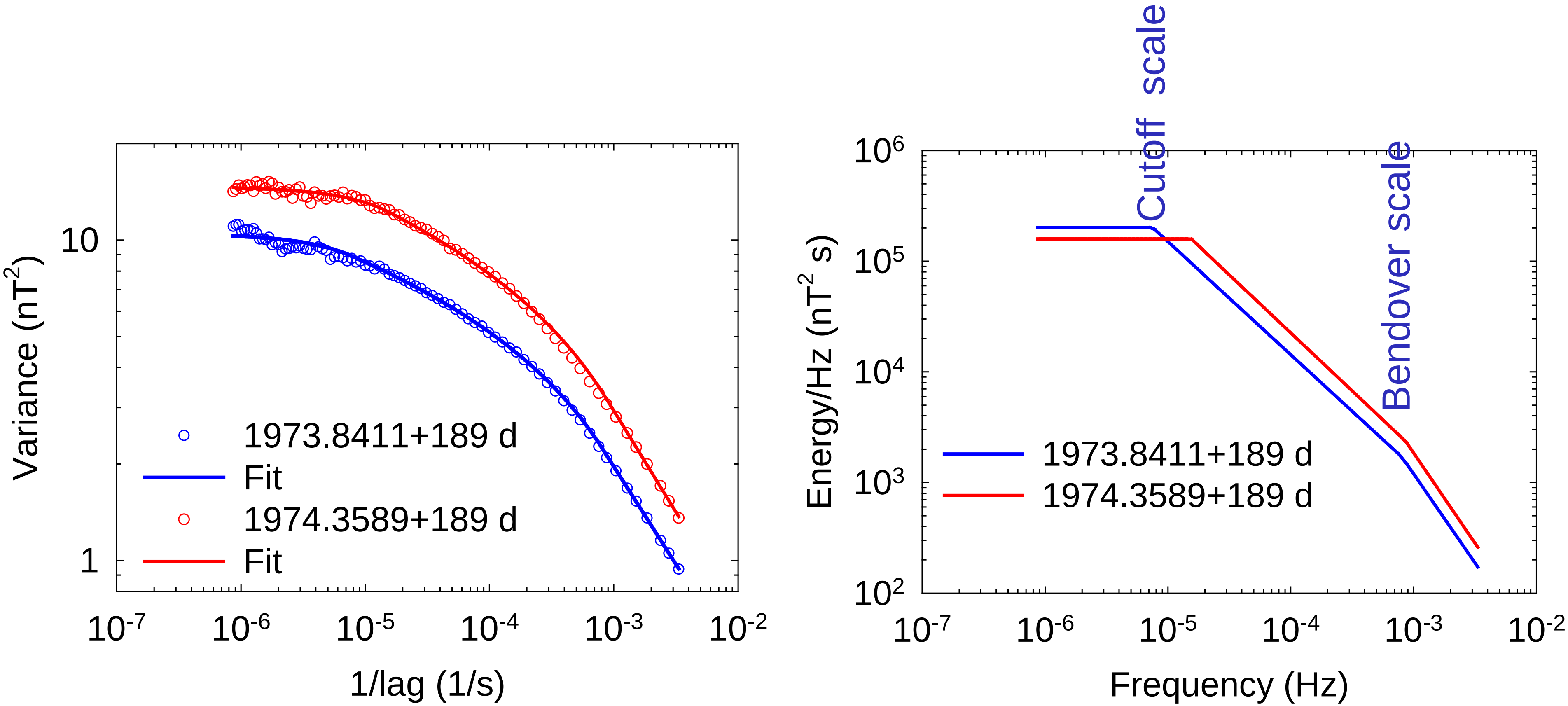


Fig. 3. Samples of fits and inferred spectra **Left:** Fit of second-order structure function with lags 4 minutes to 320 hours for two 189-d intervals of IMP data. **Right:** Inferred spectra for intervals.

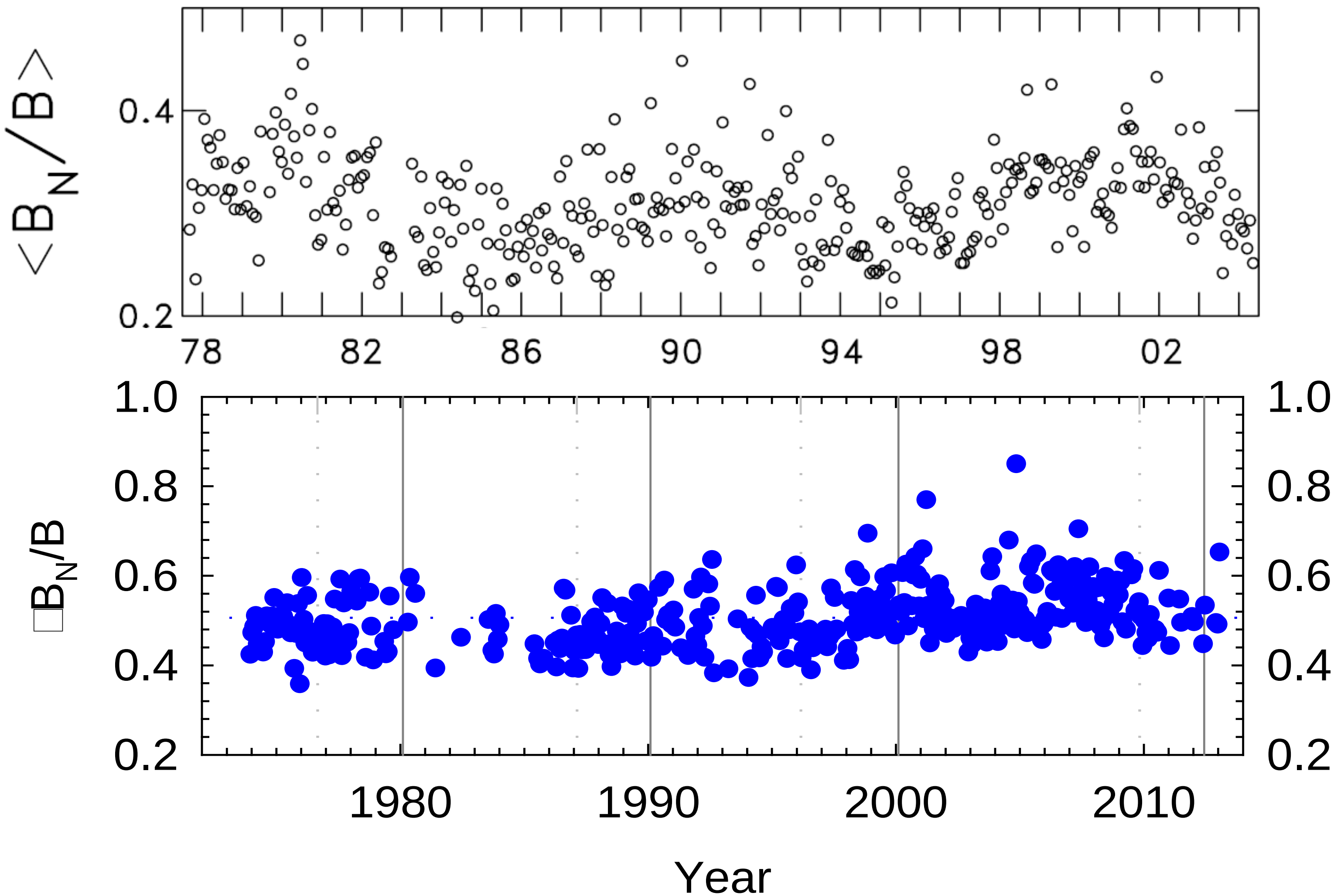
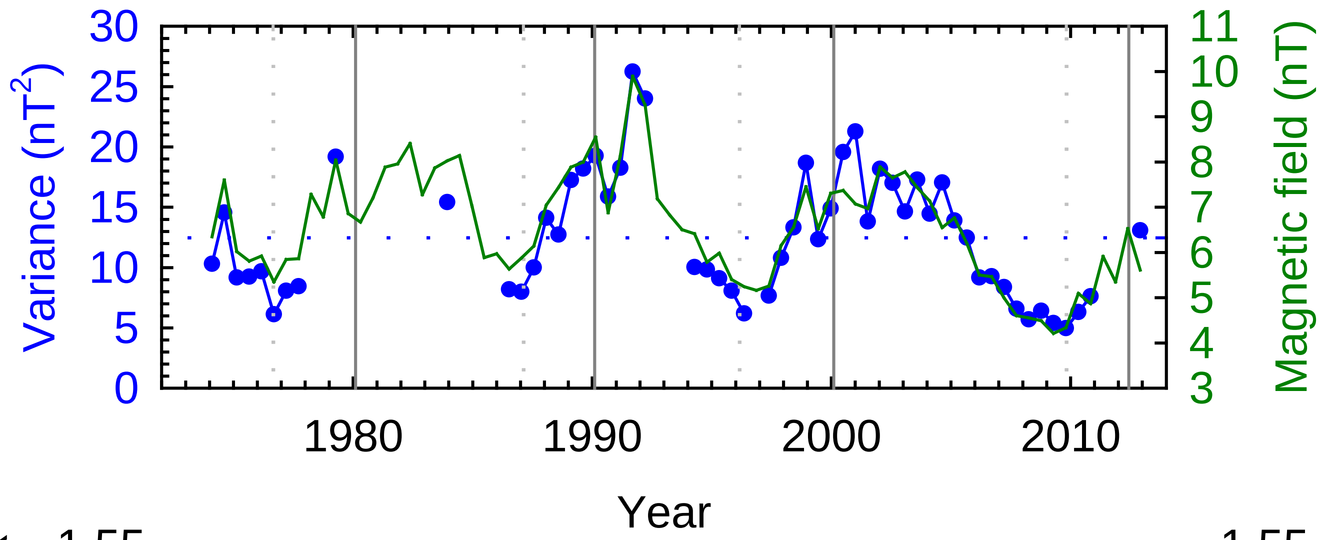


Fig. 4 Comparison of 27-d averages of $\delta B_N/B$ with Smith et al. (2006, ApJ, 638; top). Current analysis (bottom) shows significantly higher values of this quantity, and a periodicity of 8 years, with 98.4% significance (2.4σ).



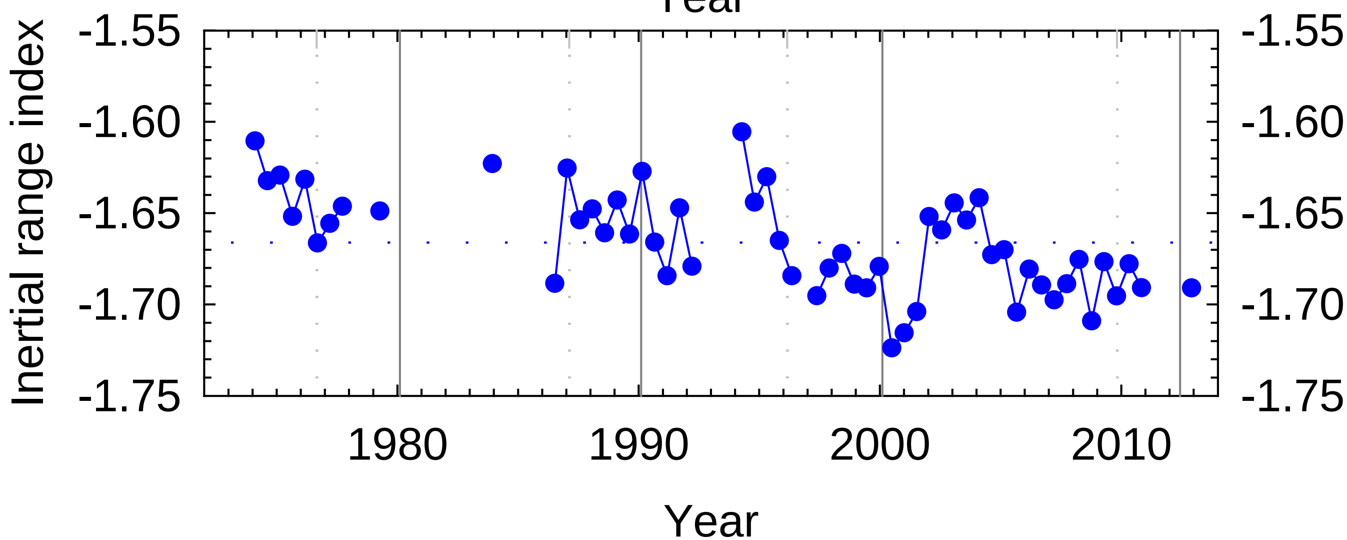


Fig. 5 Top: 189-d average of variance (320 hr lag) and magnetic field magnitude (both 11-yr periodicity). **Bottom:** 189-d average of inertial range spectral index; no significant periodicity.

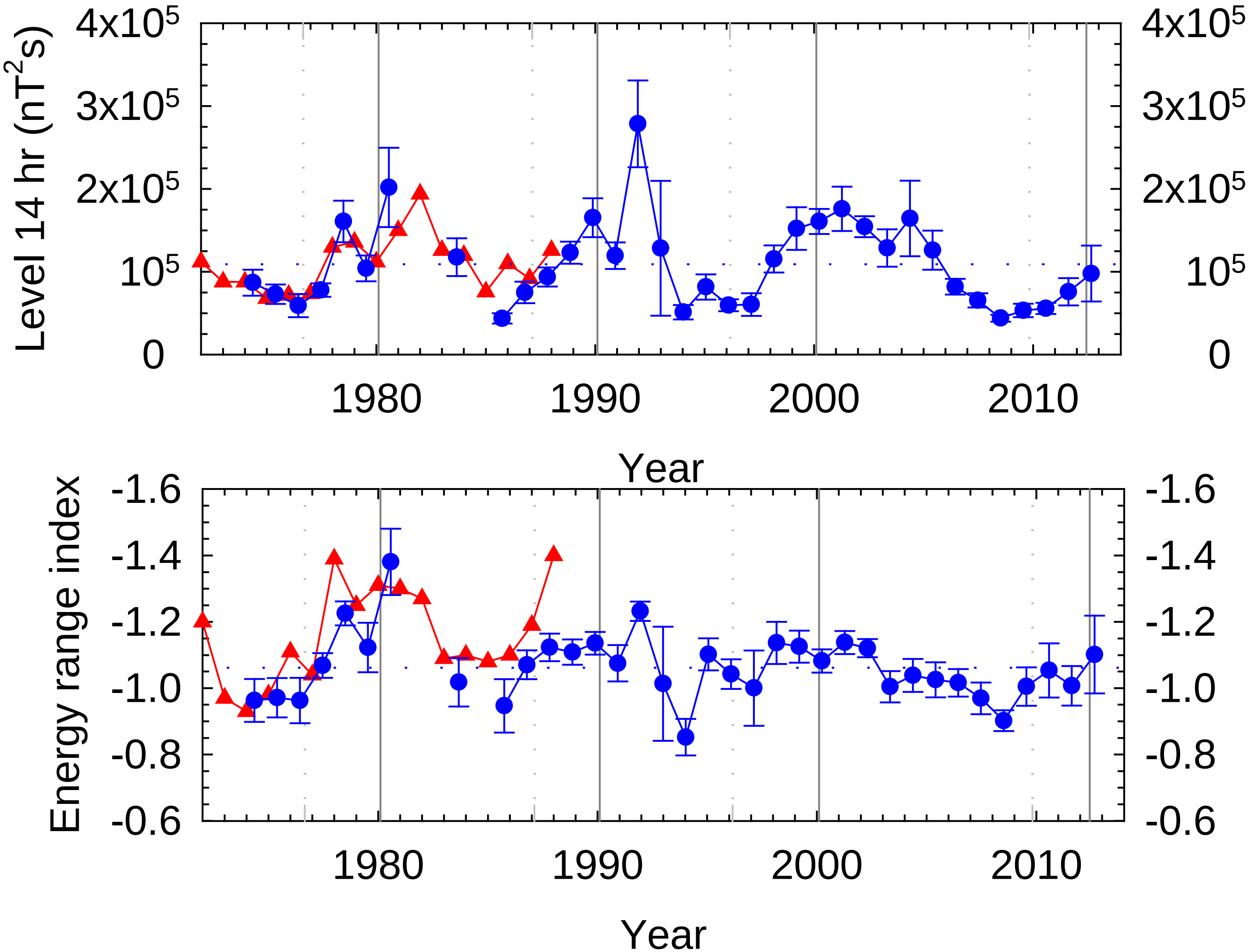


Fig. 6 Top: Level of spectrum at 14 hrs in blue from binned 27-d averages (11-yr periodicity), compared with results from Bieber et al. (1993, JGR, 98) in red. Bottom: Energy range spectral index (11-yr periodicity).

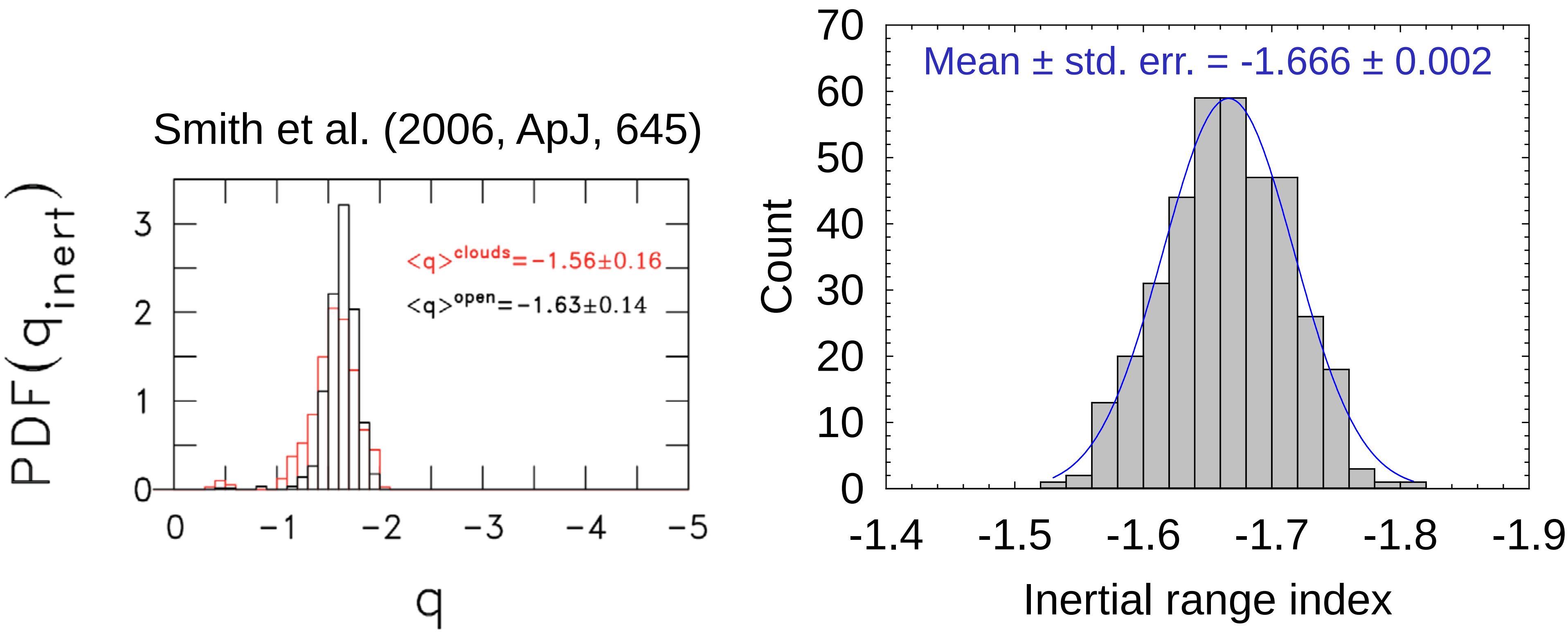


Fig. 7 Comparison of PDF for inertial range spectral index for 1998 – 2002 from Smith et al. (2006, ApJ, 645) (left panel) and distribution obtained in present study for 1974 – 2012 (right panel).

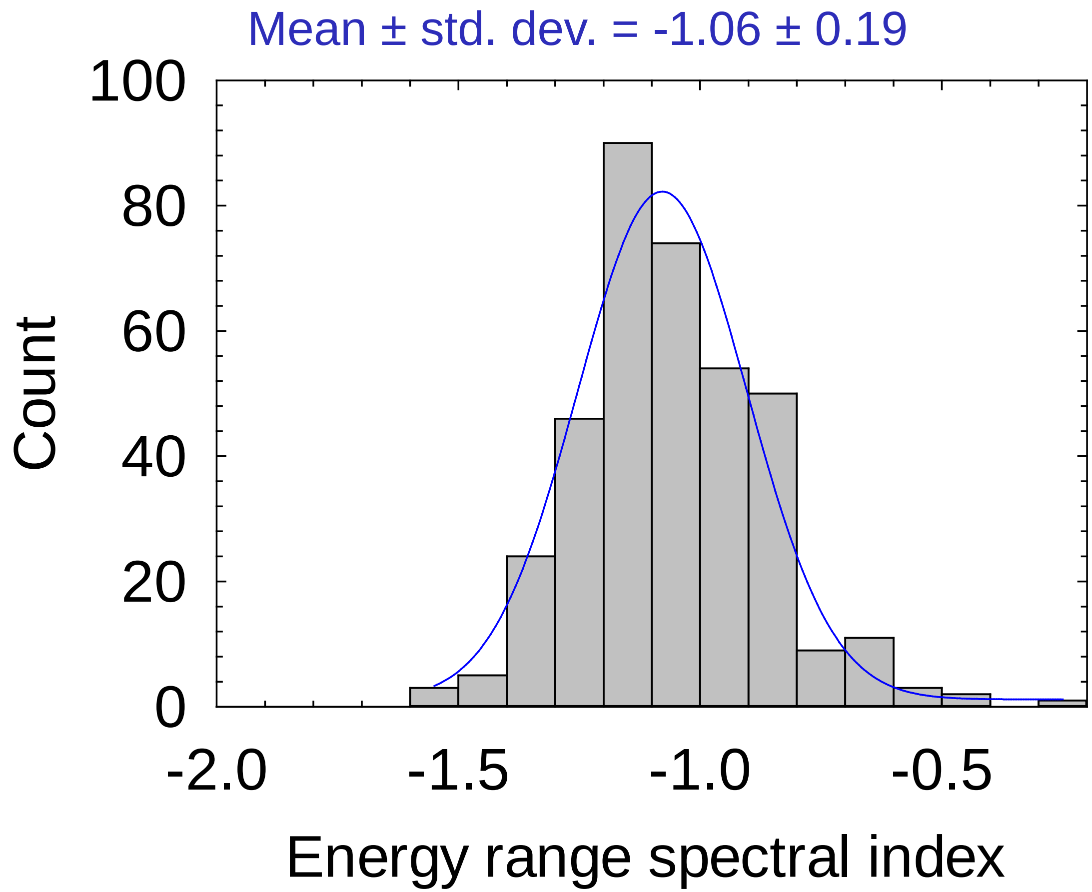


Fig. 8 Distribution obtained for the energy range spectral index. Good agreement for 1974 – 2012 with value of –1.2 obtained by Bieber et al. (1993, JGR, 98) for the period 1965 – 1988.

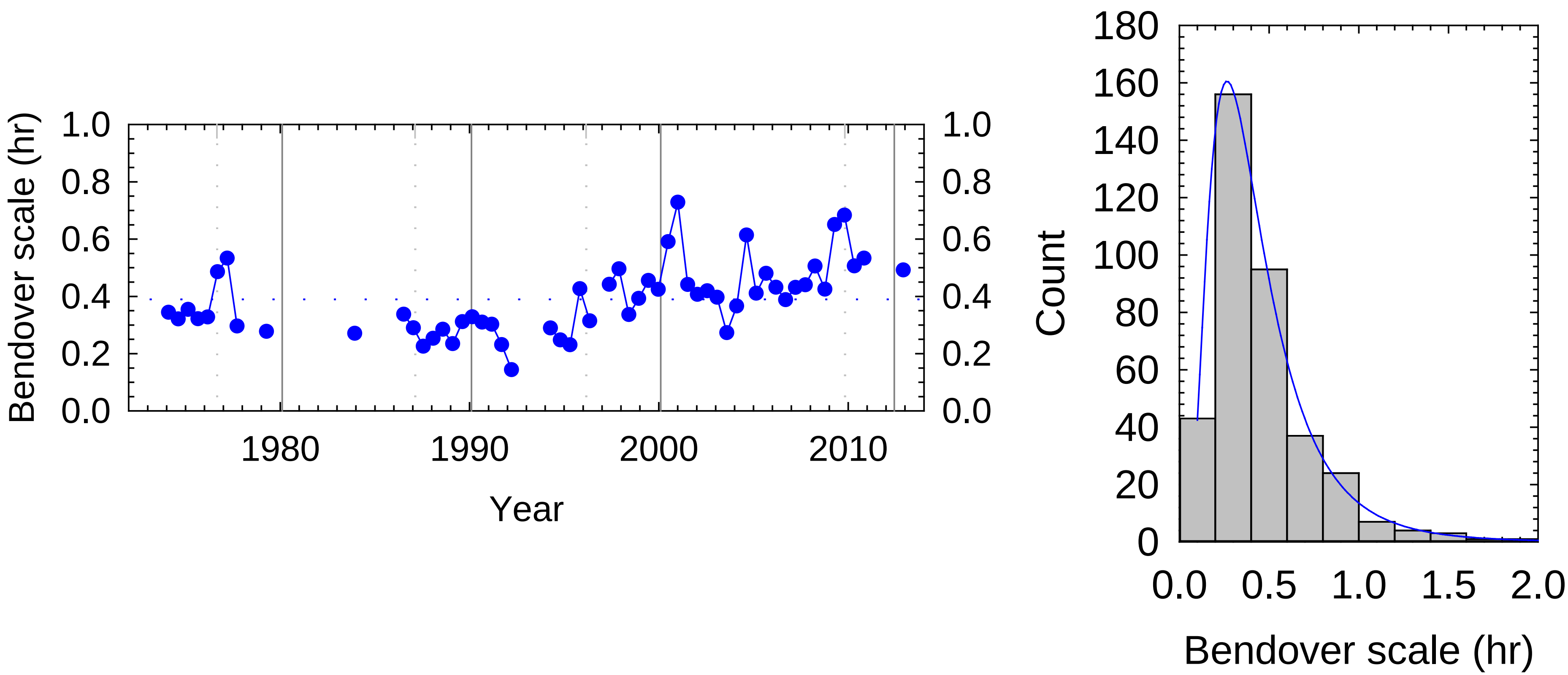


Fig. 9 189-d averages of the bendover scale (break between inertial- and energy range) show no significant periodicity consistent with results of Wicks et al. (2010, Solar Phys, 262) for 1974 – 2009 . Possible log-normal distribution (see Ruiz et al. 2014, Solar Phys, 289).

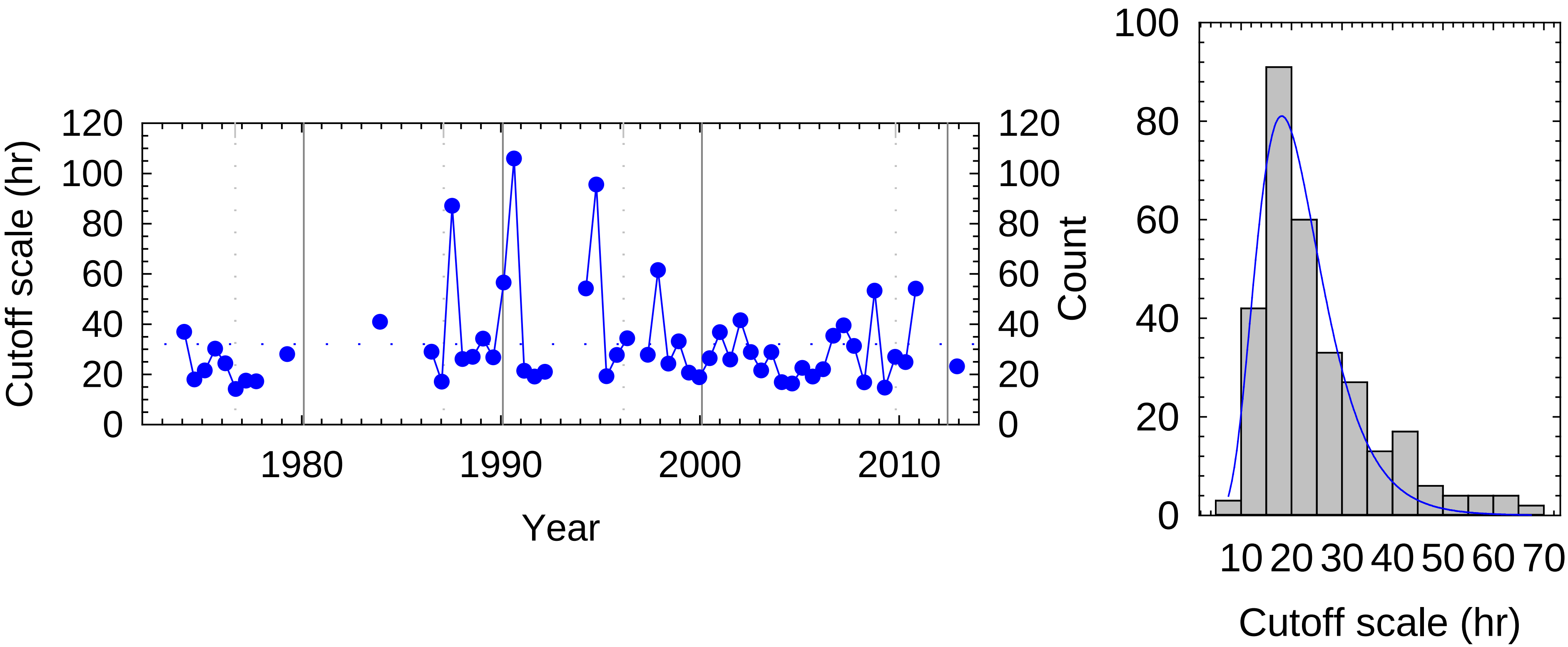


Fig. 10 189-d averages of the cutoff scale (break between energy- and low-frequency cutoff range) show no significant periodicity. Possible log-normal distribution.

4. Discussion

- Novel technique utilizing second-order structure function yields results in good to reasonable agreement with previous studies.
- Variance and spectrum level show most significant periodic changes over a solar-activity cycle.
- Average inertial range spectral index of -1.666 ± 0.002 (latter value standard error) in excellent agreement with Kolmogorov value of $-5/3$. No solar-cycle dependence.
- Average energy range index of -1.06 ± 0.19 (latter value standard deviation) consistent with value of -1.2 obtained by Bieber et al. (1993, JGR, 98) for the period 1965–1988, 11-yr periodicity.

- Average variance (from yearly averages with 640 hour lag) is 13.1 nT^2, in good agreement with 13.2 nT^2 reported by Bieber et al. (1994, ApJ, 420).
- Average bendover scale of approximately 0.4 hours is a lower limit by at least a factor of two. No solar-cycle dependence. Cutoff scale ~100 times the bendover scale but may simply be an artifact of current technique.
- *Results suggest that the dominant change in the spectrum of fluctuations of the N-component of the magnetic field over a solar cycle, for scales up to ~100 times the bendover scale, is the level, which is well correlated with the magnitude of the magnetic field.*

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