Turbulence conditions at the beginning of the space age: a preliminary analysis

C. P. Wolmarans

N. E. Engelbrecht

Centre for Space Research

North-West University

July 9, 2019

Contents

Introduction

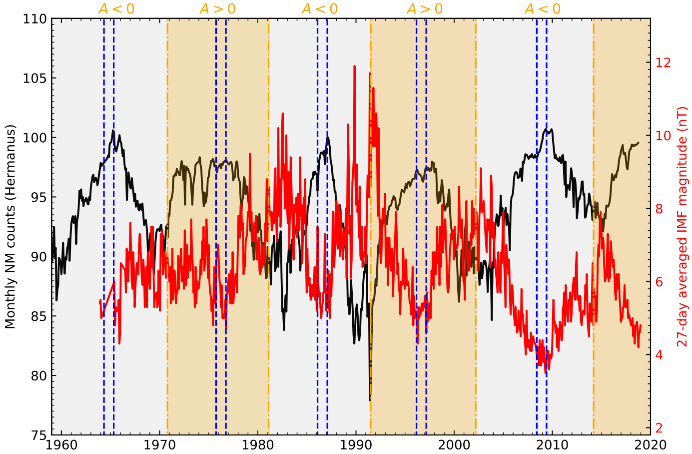


Figure 1: Monthly NM counts (Hermanus) and 27-day averaged magnetic field magnitudes (OMNI).

Introduction

- Interested in cosmic ray (CR) modulation during this period, with unexpected behavior in the relationship between CR intensity and the magnetic field magnitude.
- Turbulence quantities allow the study of diffusion and drift from scattering theories, which are important to understanding CR modulation (Engelbrecht & Burger, 2013).
- Early spacecraft had limited observational capabilities.
- Turbulence analysis in spite of low data resolution and omissions.
- Useful analysis techniques include constructing variances and determining correlation lengths from the N-component of the magnetic field.

Analysis techniques

- Magnetic variance as an indication of the underlying turbulence spectrum (Forsyth *et al.*, 1996), where i is a subinterval of length τ

$$\delta B^2(\tau) = \langle (B_N(t) - \langle B_N \rangle)^2 \rangle_i \tag{1}$$

- Second-order structure function (Burger & Engelbrecht, 2018),

$$S_2(\tau) = \langle |B_N(t+\tau) - B_N(t)|^2 \rangle \tag{2}$$

- Standard correlation function (Frisch, 1995),

$$R(\tau) = \langle B_N(t).B_N(t+\tau) \rangle \tag{3}$$

- Correlation function using second-order structure adapted from Huang *et al.* (2010),

$$R(\tau) = \delta B_N^2 - S_2(\tau)/2 \tag{4}$$

- Correlation scale where $R(\tau)$ is $1/e$ of its maximum (Zhao *et al.*, 2018).
- Synthetic data of known variance was used to test effect of resolution and gaps.

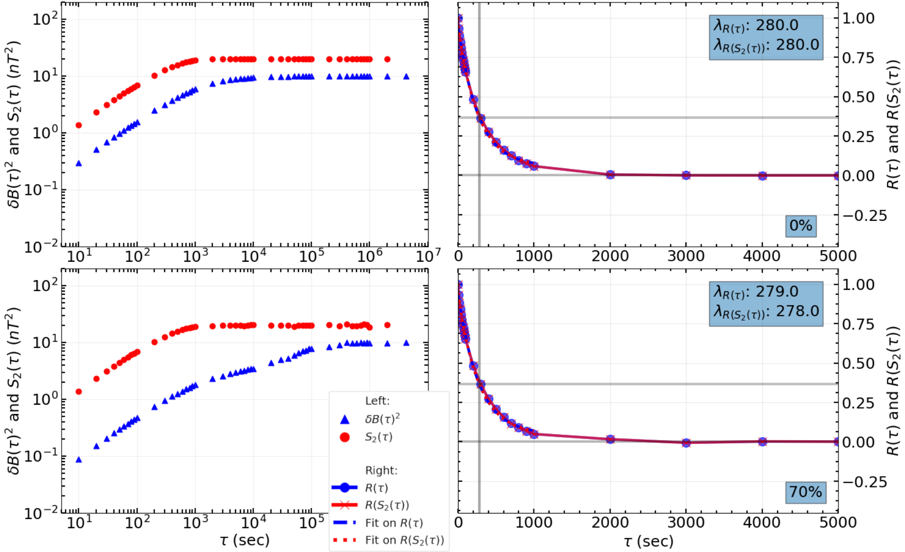


Figure 2: Synthetic data analysis at highest resolution for 0% and 70% omissions.

Analysis techniques

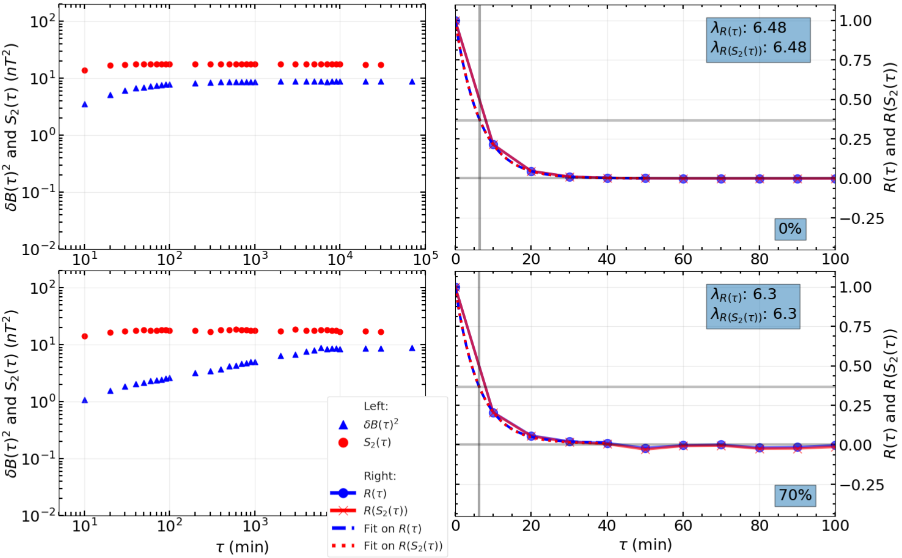


Figure 3: Synthetic data analysis with 1 minute resolution.

Analysis techniques

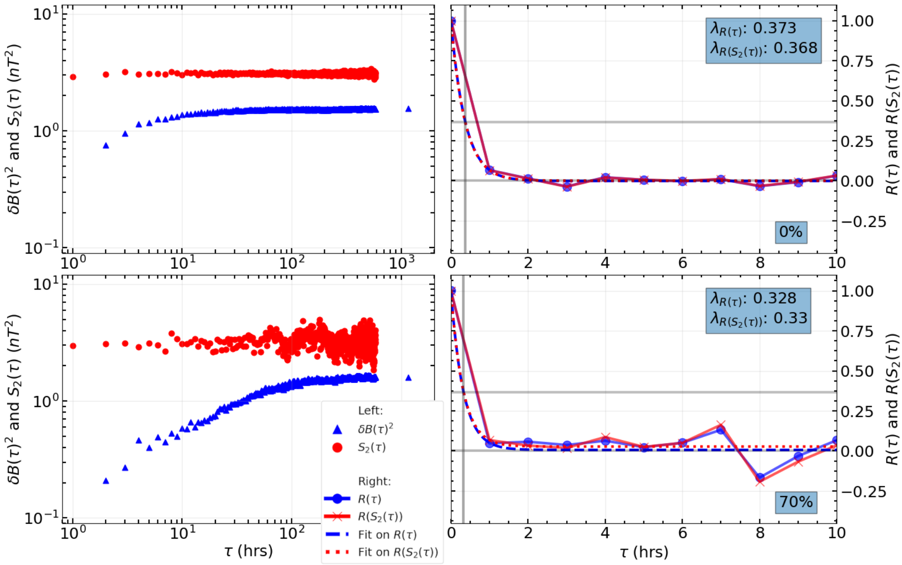


Figure 4: Synthetic data analysis with 1 hour resolution.

Solar cycle depedence of turbulence quantities

- Nel (2015), Burger and Engelbrecht (2018), Moloto *et al.* (2018) and Zhao *et al.* (2018) considered solar cycle dependence of turbulence quantities.
- Nel (2015) and Burger and Engelbrecht (2018) show the possibility of an approximate 11 year periodicity in magnetic variance and magnetic field magnitude, which increases from solar minimum to maximum.
- Burger and Engelbrecht (2018) reported a similar periodicity and increase toward solar maximum in correlation lengths calculated over 43 years worth of data.
- The expectation exists that turbulence quantities determined by partial variances and the correlation function on low resolution data, should also yield lower values during minimum conditions and higher during maxima.

- Total variances and correlation functions calculated for 13-day intervals and averaged over each year, to show variations in minimum and maximum.

Year	$\delta B_N{}^2 (nT^2)$	$\lambda_c (10^6 km)$
1964	5.43	2.376
1970	10.27	6.264
1976	5.51	3.355
1980	12.67	6.451
1986	6.87	4.838
1989	14.02	5.469
1996	4.45	3.514
2001	13.47	6.213
2009	3.06	2.750
2014	9.38	6.638

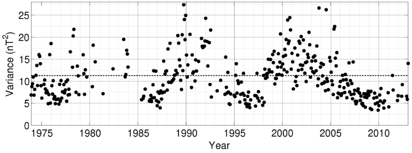


Figure 5: 27-day magnetic variances, Nel (2015).

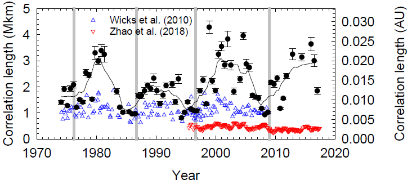
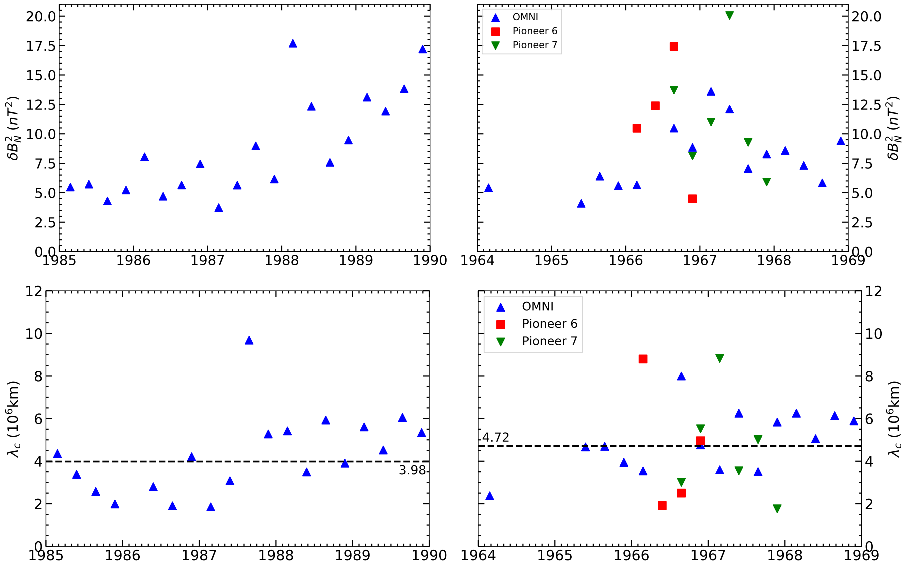
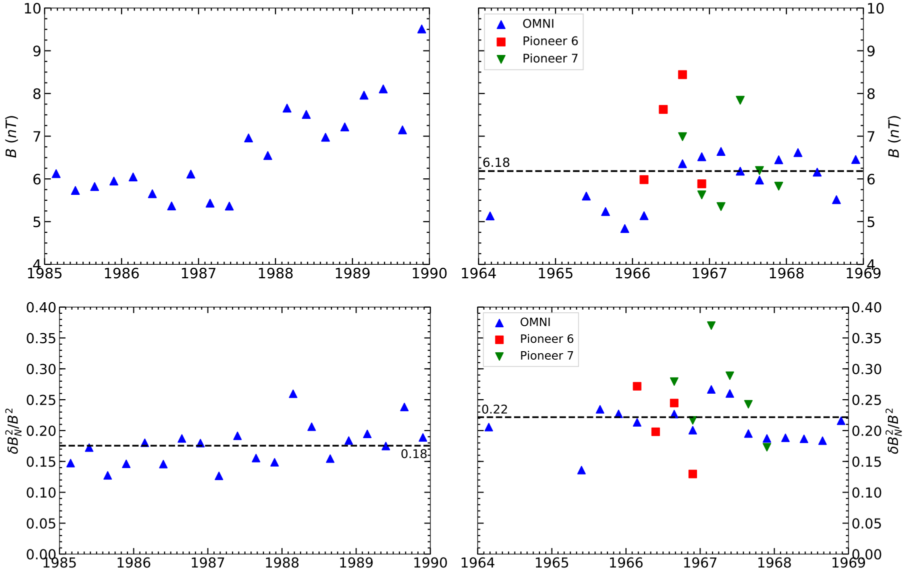


Figure 6: Correlation lengths obtained from 1 minute resolution OMNI IMP and ACE data (Burger & Engelbrecht, 2018).

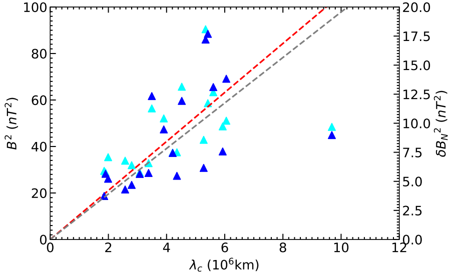
Analysis of early space age data

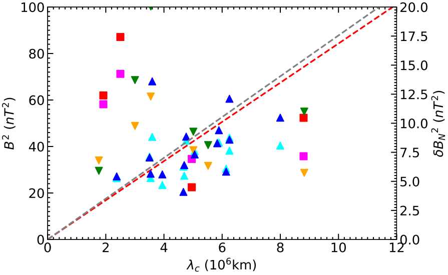


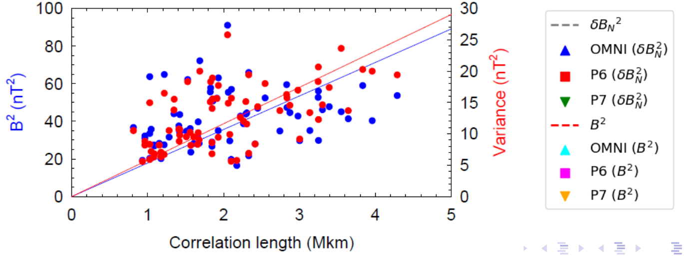
Analysis of early space age data



Analysis of early space age data







In summary

- Difference in the behaviour of variance and magnetic field magnitudes between 60s and 80s.
- Diffusion coefficients depend on $\sim \frac{\delta B_N^2}{B^2}$, or its inverse. During the 60s this ratio remains roughly constant and similar to that of the 80s. Implying normal diffusion behaviour during this time.
- λ_c is relatively flat, but they are expected to be off due to systematic errors from low data resolution.
- It remains to be seen what these turbulence quantities would yield in terms of CR modulation studies.
- However, the charge sign dependence is usual as seen in figure 1 indicating current sheet drift
- Lower magnetic field magnitude in the approach to the 60s maximum in conjunction with the constant ratio may imply improved drift effects.
- Archival spacecraft data may still provide useful insight in CR modulation. Future work may include studying the solar storm in May of 1967 using *Pioneer* 6 & 7 data.