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Understanding the shape of sunspot cycles by principal component analysis

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We study the shape of the sunspot cycle using and the principal component analysis (PCA) for sunspot number (SSN) and group sunspot number (GSN) indices for solar cycles 1-23. The first two principal components of sunspot cycle shape explain 84.0% and 81.9% of the total variance of SSN and GSN, respectively. The first principal component (PC1) describes the average shape of the solar cycle, and the second component (PC2) represents the leading differences between the cycles. The sunspot cycles 5, 10, 12, 15, 19 and 20 are defined almost solely by PC1. We compare the original SSN and GSN time series and their PC1+PC2 proxies for cycles 1-23. The correlation coefficient between original and proxy time series is 0.940 for SSN1 and 0.938 for GSN.

We calculate the PCA proxy of the cycles separately for the 18th, 19th and 20th century sub-periods of SSN and GSN, and study their properties. The PC1 explains 69.1%, 73.5% and 85.2% of the total variance of cycles in the three sub-periods of SSN, respectively. It seems that the solar cycle 14 is a "model" cycle, which has an average shape for both 19th and 20th century sub-periods. PC1 explains 56.6%, 70.8% and 86.7% of the total variance of cycles in the three sub-periods of GSN, respectively. SC 14 continues to be a model cycle in the 19th century, but not model cycle for the 20th century of GSN. This suggests that the shape of the model cycle is different for GSN in 19th and 20th century. Percentage explained by the PC1 is much lower during the 18th century for GSN than SSN due to data gaps, but are roughly the same during 19th and 20th century.

We test the validity of the two Waldmeier rules, i.e. the anti-correlation between cycle height and length of the ascending phase of the cycle and anti-correlation between cycle height and length of the preceding cycle, in the original and PC1+PC2 proxy cycles. Waldmeier rules are valid for the whole sequence of cycles 1-23, but somewhat stronger for SSN than GSN cycles. When calculated separately for 18th, 19th and 20th century sub-periods, we find that these rules are valid for the 18th SSN, but are statistically insignificant for 18th century GSN and 19th and 20th century SSN and GSN.
Our study also shows that the Gnevyshev gap divides the sunspot cycle in to two disparate parts: the ascending phase/maximum and the declining phase, and is seen as a zero point of the PC2 curve of SSN and GSN.