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The Empirical Mode Decomposition to study the sunspot number variability

M. Laurenza[1], A. Vecchio[2], M. Storini[1], V. Carbone[2]

[1]IAPS-INAF, Rome, Italy
[2]Università della Calabria, Cosenza, Italy

Outline

- Introduction
- The Empirical Mode Decomposition technique
- Results for the time variability of Rz and Rg
- Comparison with the sunspot area data
- Conclusions

Introduction

- Solar activity is variable on a wide range of temporal scales.

- Apart from the 11-yr cycle, a secular variation (Gleissberg cycle) was reported in a broad variety of solar-terrestrial phenomena (e.g., Eddy, 1976; Friis-Christensen and Lassen, 1991; Usoskin and Mursula, 2003; Feynman and Ruzmaikin, 2011); important for solar dynamo theories and climate studies.

- No consensus on the long-term variability (trends, modern grand maximum; Usoskin et al., 2007; Lockwood et al., 2009, Vieira and Solanki, 2010).

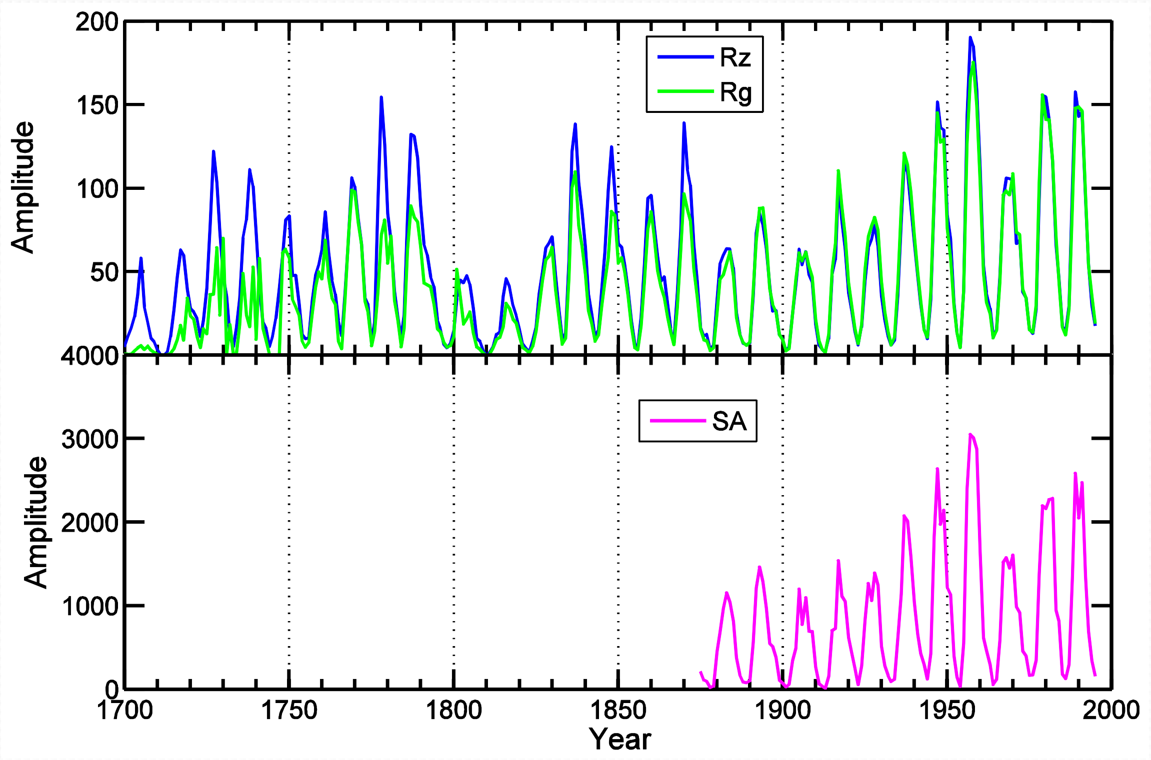
- A preliminary study is presented where the Empirical Mode Decomposition (EMD) analysis has been performed on time series of the sunspot number (Rz), groups (Rg) and area (SA) in order to determine their basic modes of variability.

- Similarities and discrepancies among the different indices (scale dependent) at separated time scales can also be obtained.

Data used

- Yearly averages of the Group sunspot numbers (Rg) and the Wolf sunspot numbers (Rz) for the period 1700-1995.

- Yearly averages of the sunspot area (SA) for the period 1875-1995.



Empirical Mode Decomposition (EMD)

- The EMD identifies timescales associated with non stationary data (Huang et al., 1998).

•In the EMD framework, a time series X(t) is decomposed into a finite number m of oscillating Intrinsic Mode Functions (IMFs) as:

$$X(t_n) = \sum_{j=0}^{m} C_j(t_n) + r_m(t_n)$$

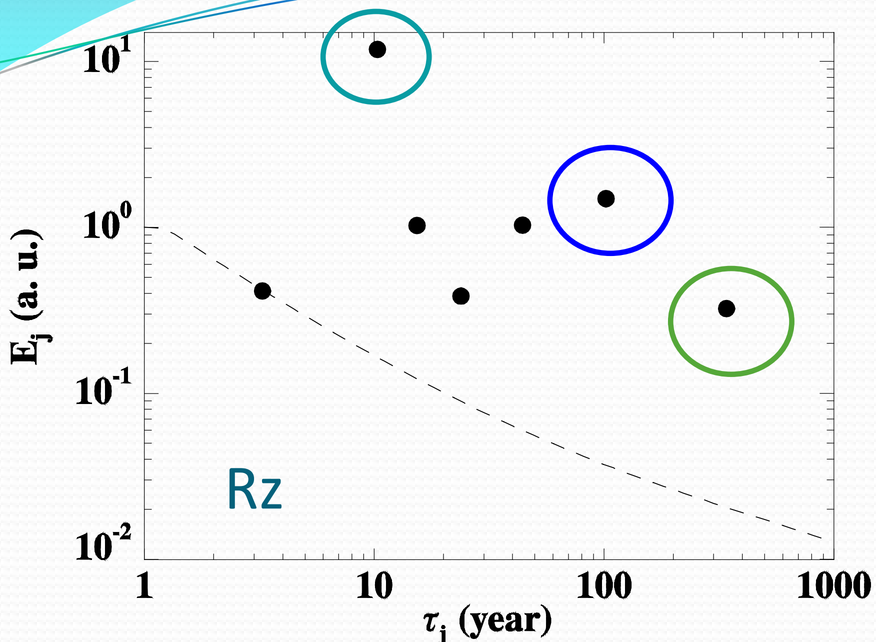
- The IMFs C_j are not given a priori since they can be extracted from the data set under analysis.

- EMD modes represent zero mean oscillations with characteristic timescale τ_j.

•One mode associated with the trend r_m (if actually present) is naturally obtained from this analysis.

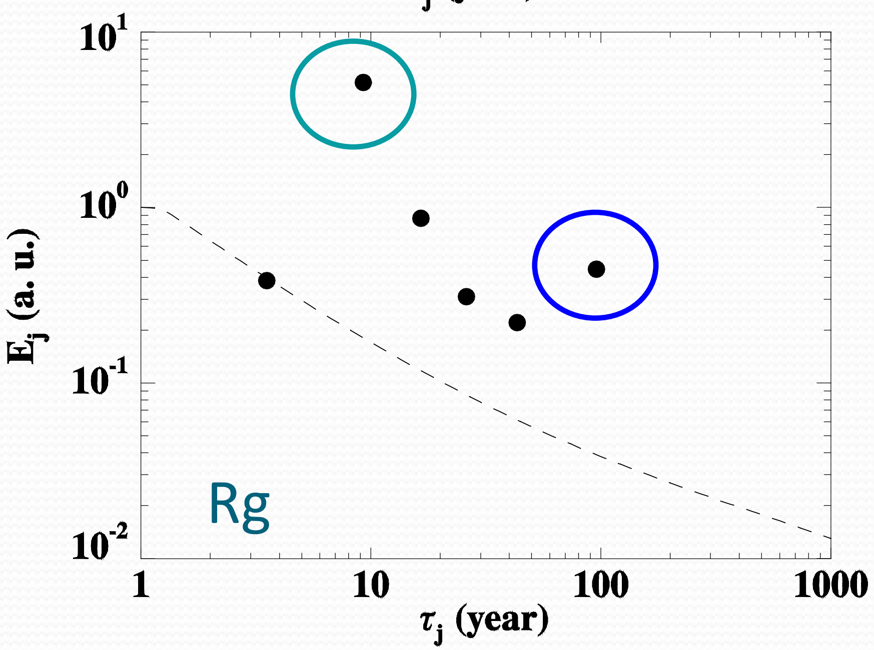
•This kind of decomposition is local, complete, and orthogonal.

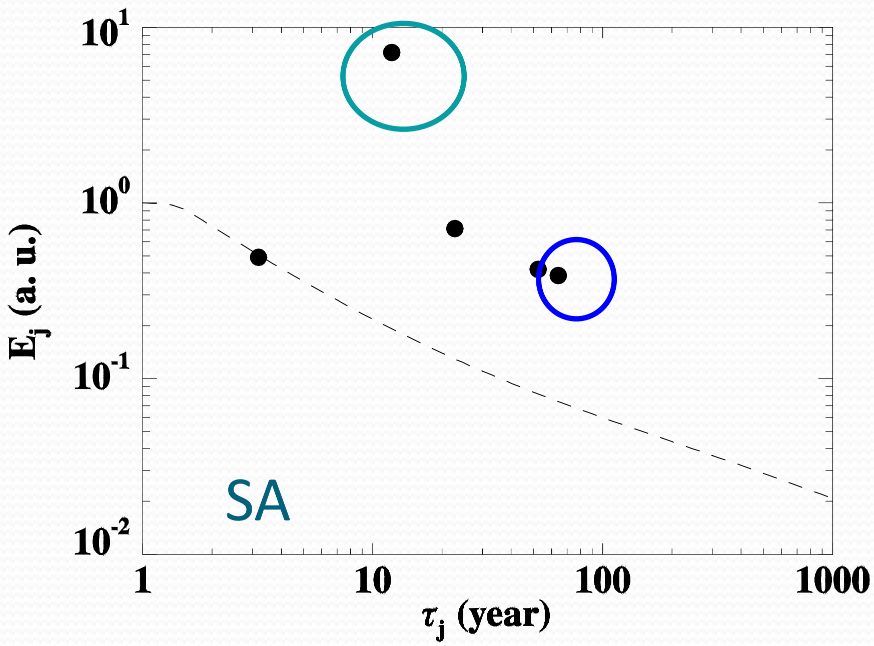
Amplitude – period diagram



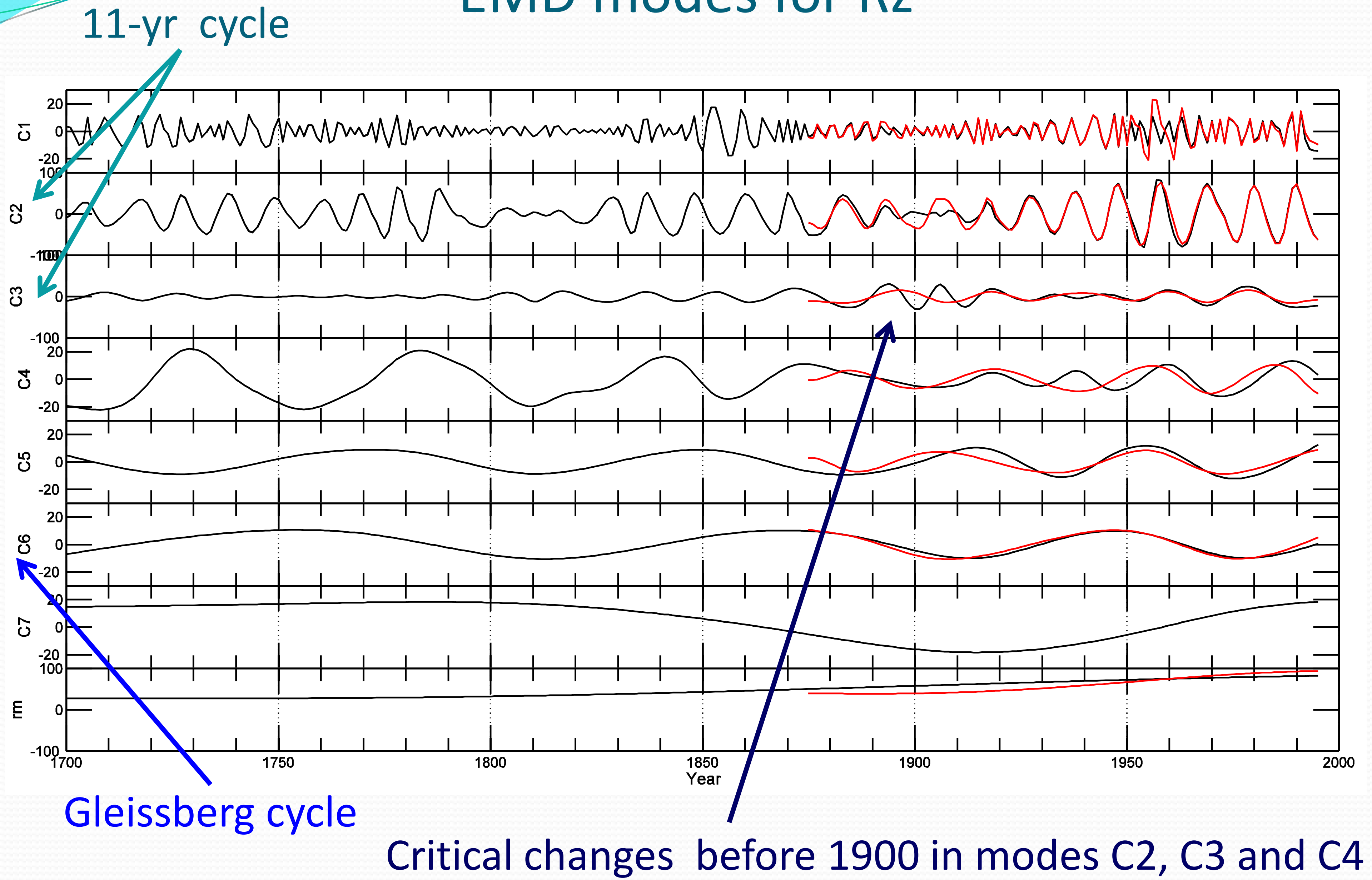
- The dominant modes for Rz and Rg are associated with periods close to the 11 yr cycle and the Gleissberg cycle. Rz shows one more mode than Rg.

- The dominant mode for SA is associated with the period close to the 11 yr cycle.

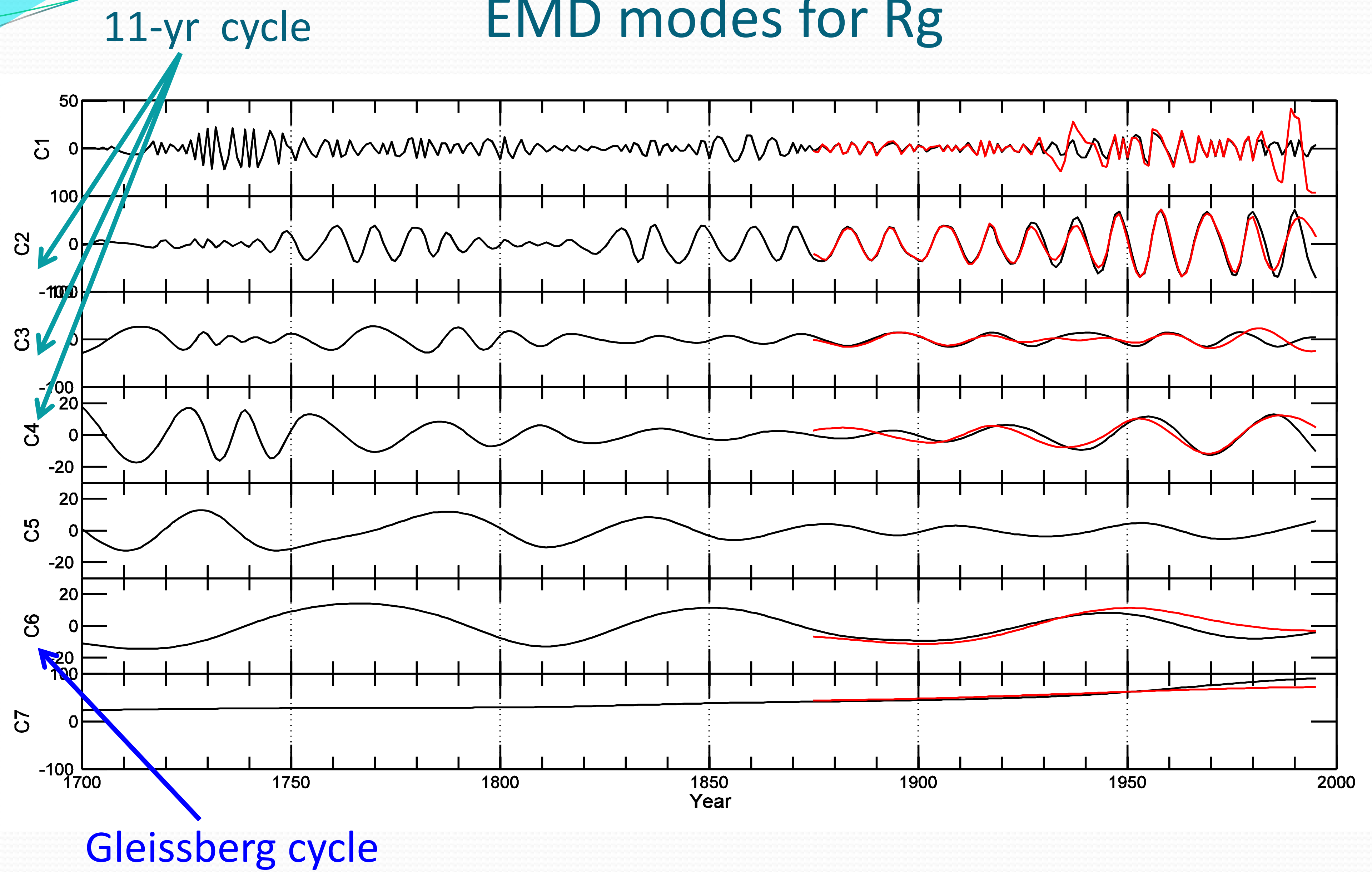




EMD modes for Rz

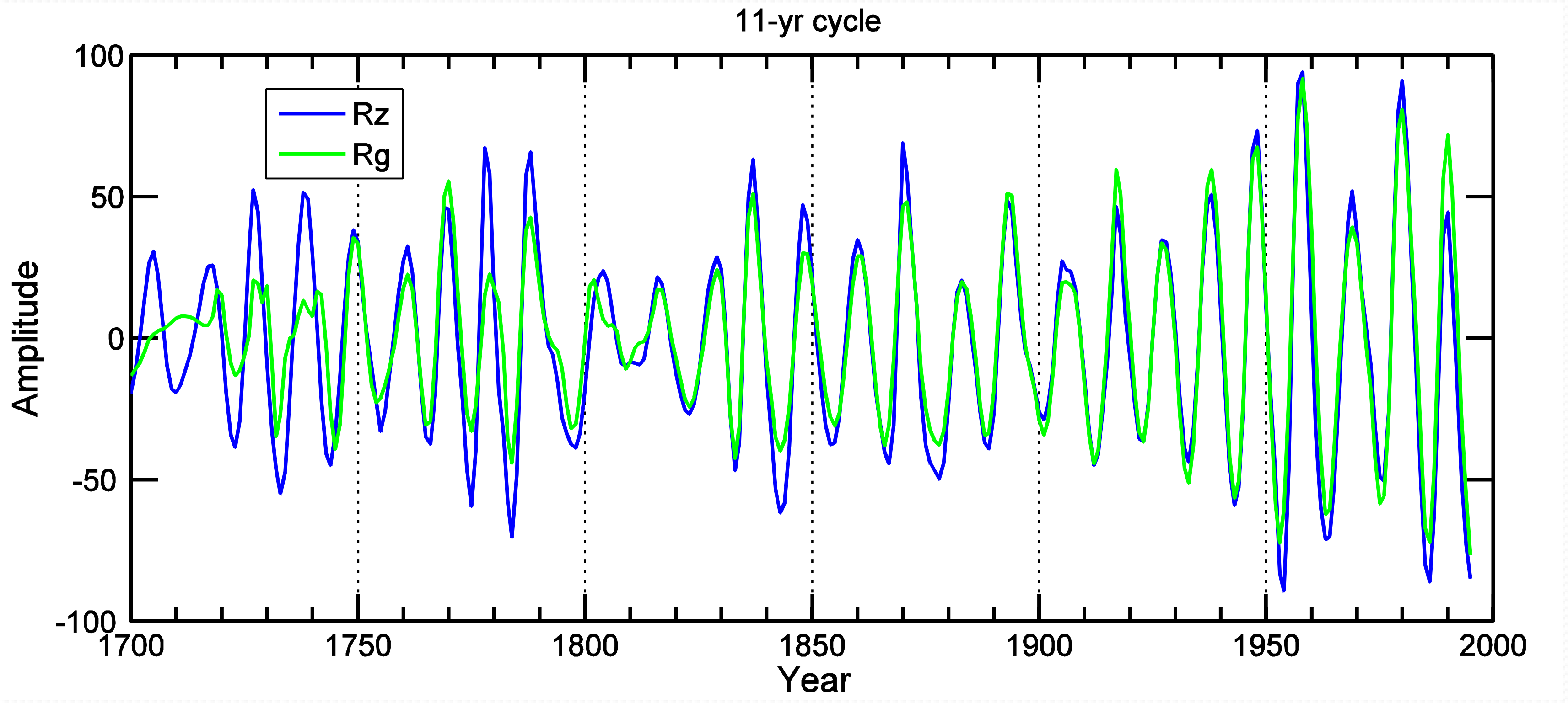


EMD modes for Rg



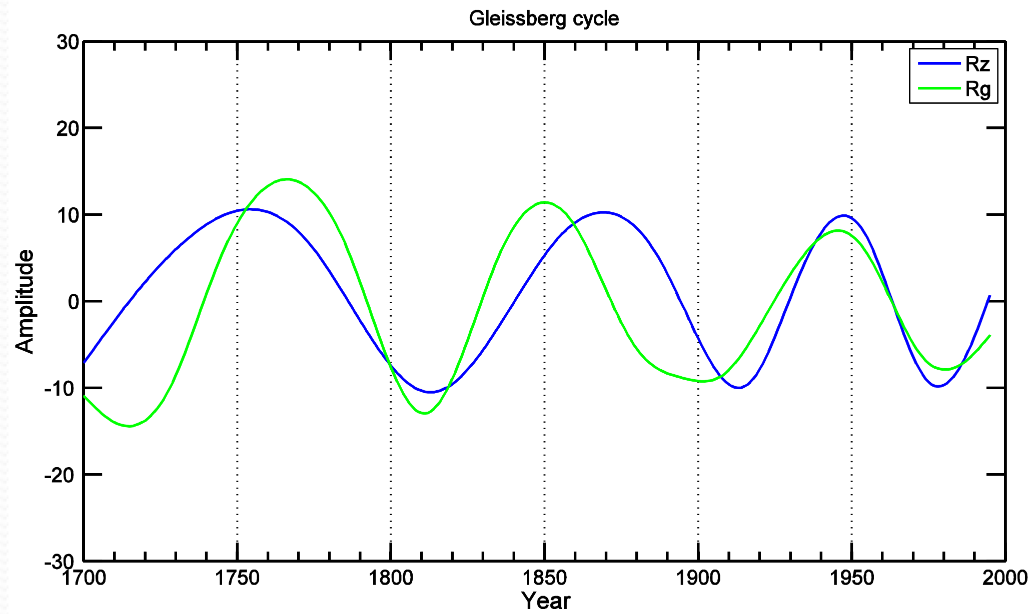
Reconstruction of the 11-yr cycle

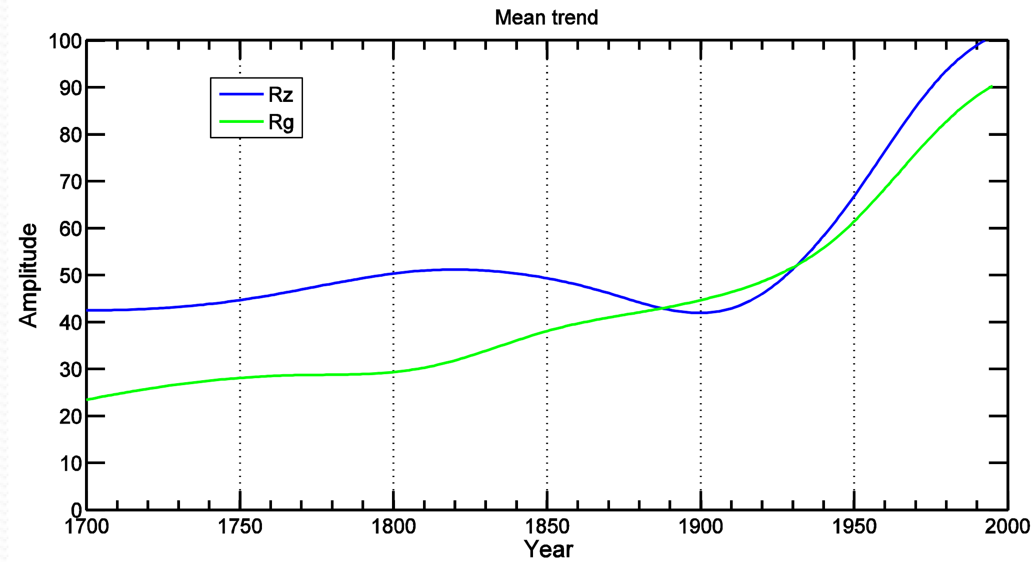
- Phase coherence.
- The 11-yr cycle amplitude is particularly low for Rg from 1700 to 1745.
- Different amplitude for all solar cycles up to 1880.



Long term variability

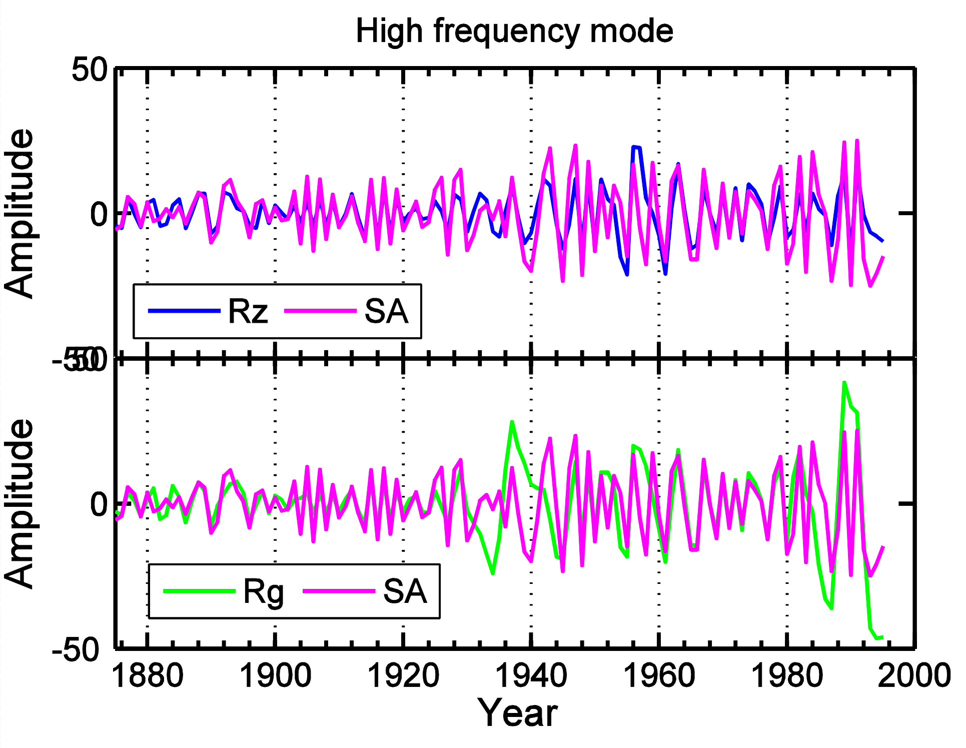
- No good agreement between Rz and Rg on long time-scales: phase shift for the Gleissberg cycle.
- These differences might be due to the limited time coverage, not long enough to properly describe these oscillations.
- The mean trend for Rz shows a minimum around 1900, whereas the Rg one is monotonically increasing.
- Their amplitude ratio is about 2 up to 1850.

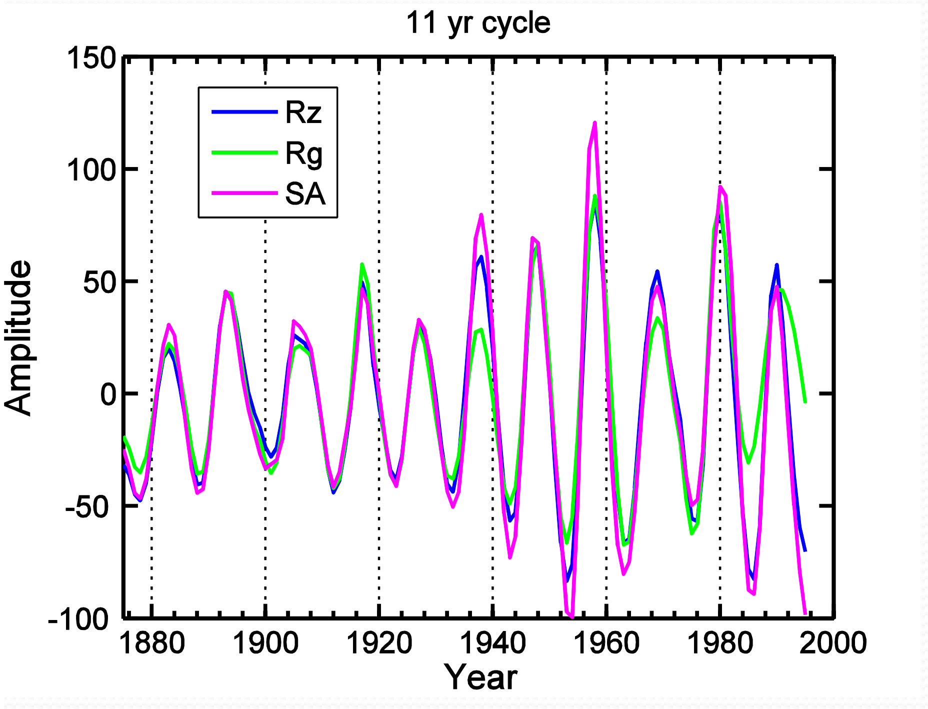




Comparison with the sunspot area

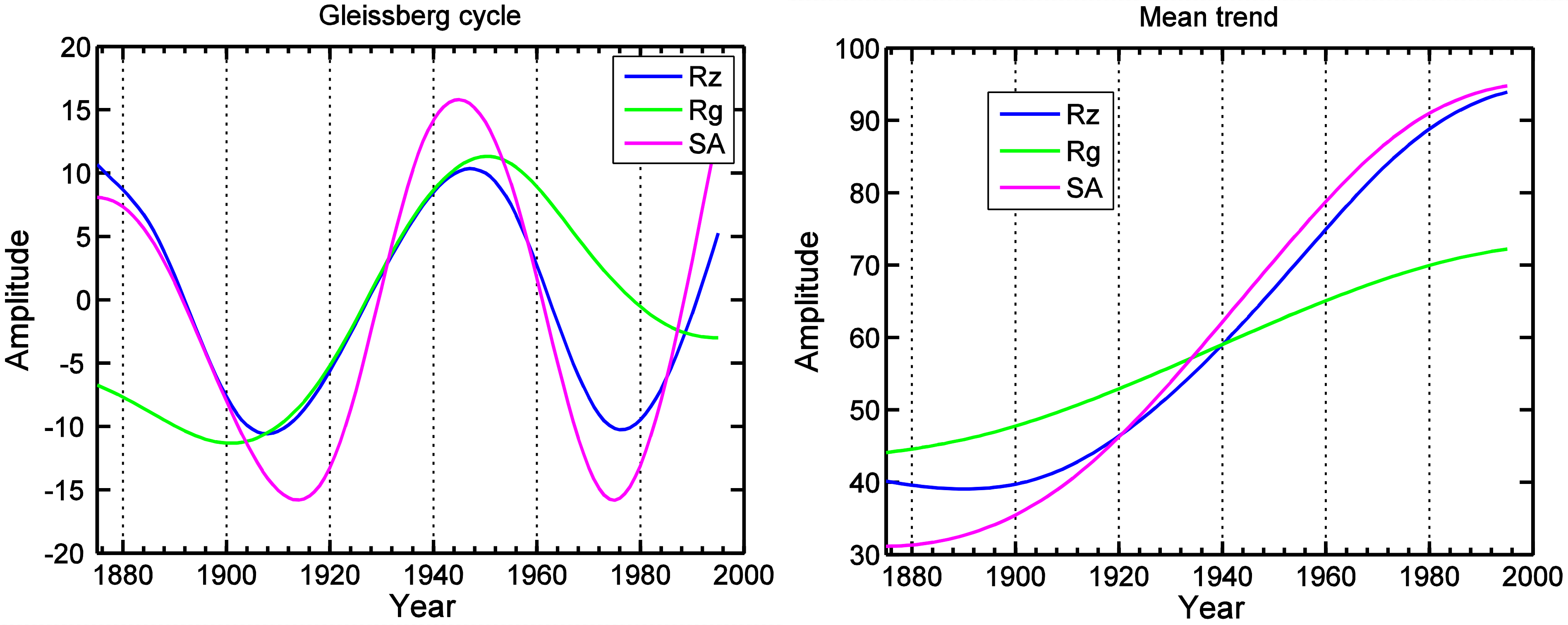
- Differences in the high frequency modes in the periods 1880-1888, 1930-1948 and 1956-1960; monthly data needed for a careful comparison.
- General agreement between Rz and Sa for the 11-yr cycle.





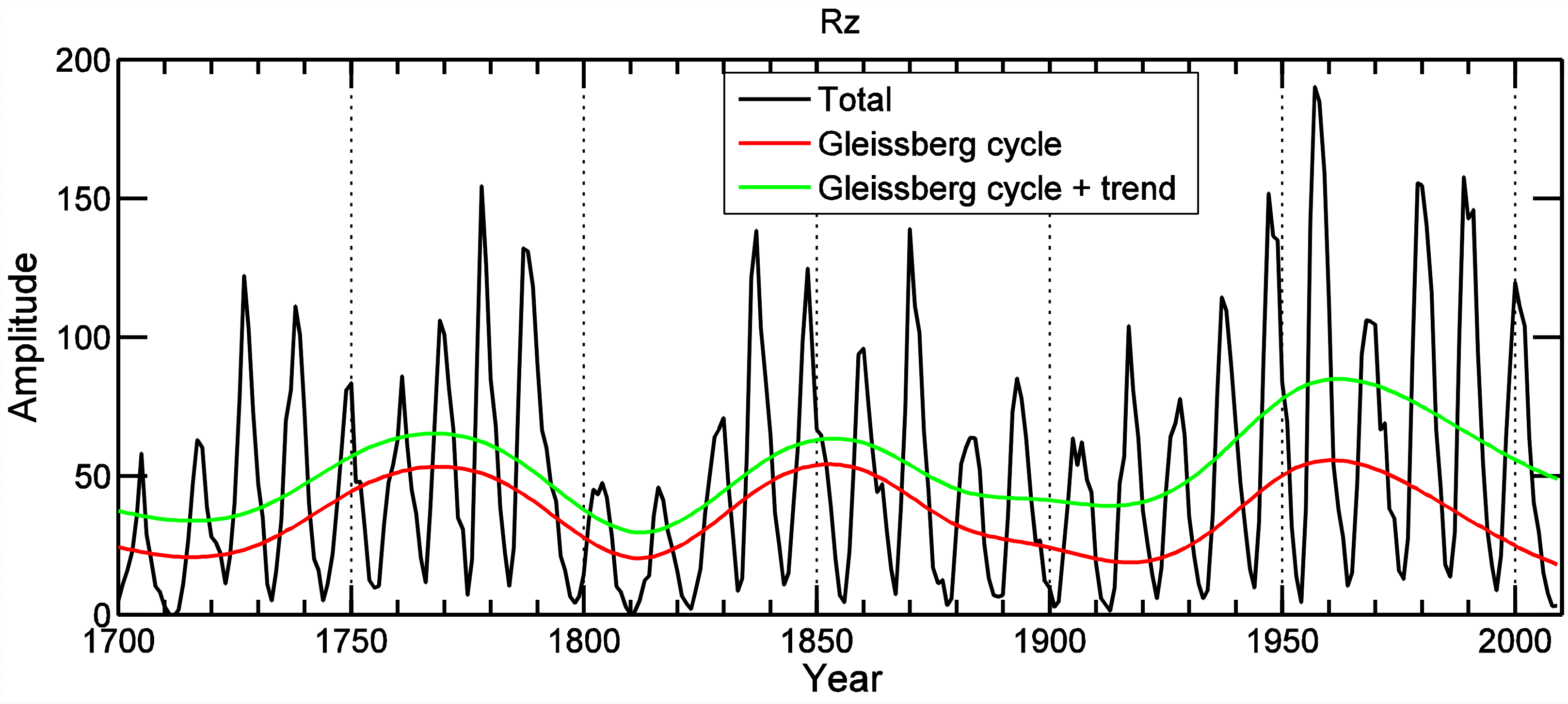
Comparison with the sunspot area

- Consistency between Rz and SA on long time-scales.
- Rg has a different behavior.



- When considering a longer time period (1700-2010) the Gleissberg cycle shows a maximum around 1960, which slowly declines afterwards (consistently with results of Feynman and Razmaikin, 2011) .

- The mean trend produces an increase of activity with respect to the Gleissberg cycle after 1900.



Conclusions

- Noticeable changes in Rz around 1900, possibly responsible for a frequency shift of the 11-yr cycle in this period (coincinding with a Gleissberg minimum).
- The 11-yr cycle amplitude is much lower in Rg than Rz from 1700 to 1850. The 11-yr cycle phase is always coherent for Rz, Rg and SA. Good agreement for Rz and SA amplitude.
- The long term variability is better obtained from Rz than Rg, from 1880 to present.
- A systematic long term drift was found in Rz, Rg and SA.
- Rz has an additional mode compared with Rg over the period 1700-1995, associated with a different behavior before and after 1850.
- The so-called modern grand maximum results from the superposition of the long term trend to the Gleissberg cycle.

Aknowledgements

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