Decomposing the geomagnetic field: oscillation modes and characteristics

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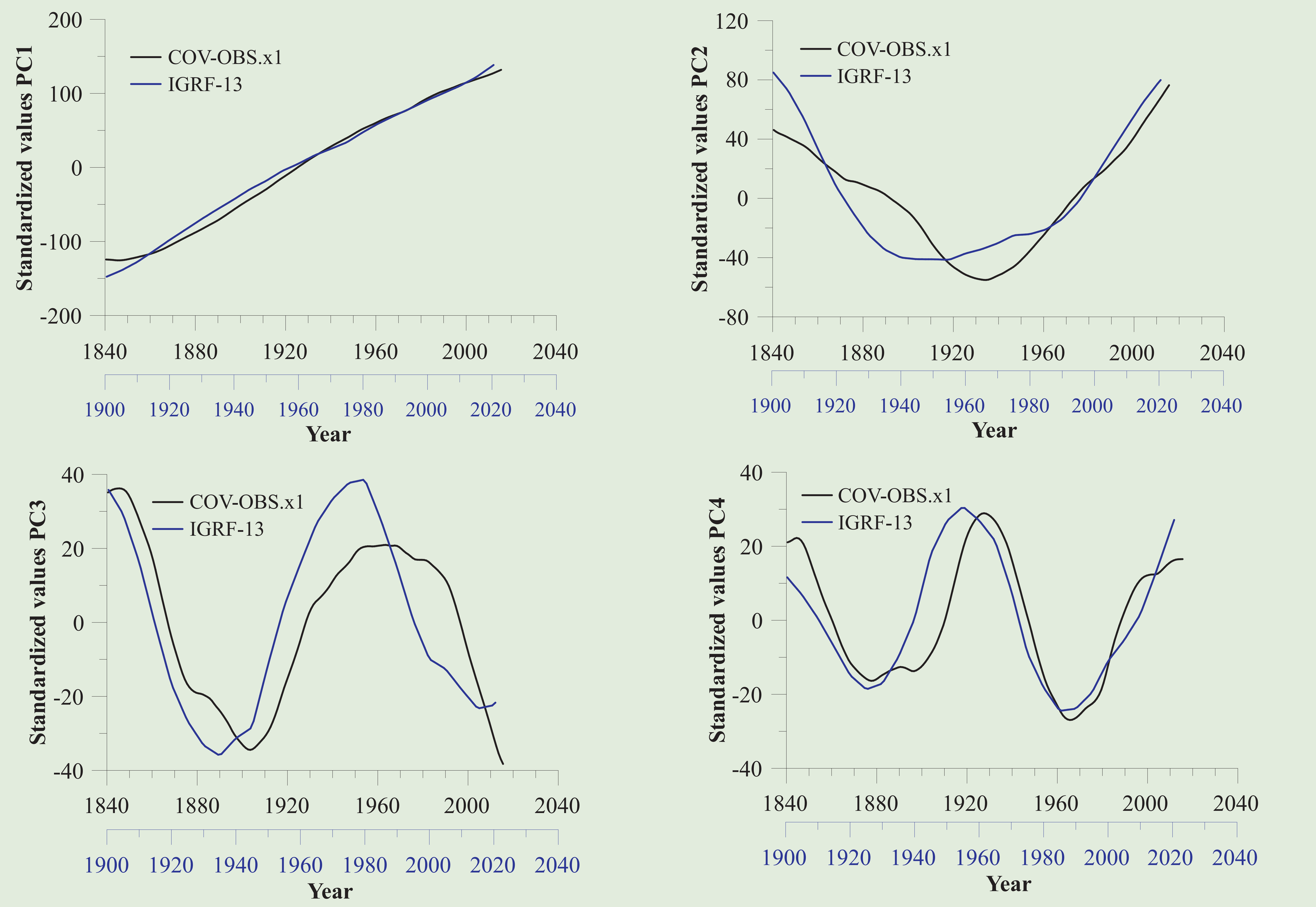
Highlights

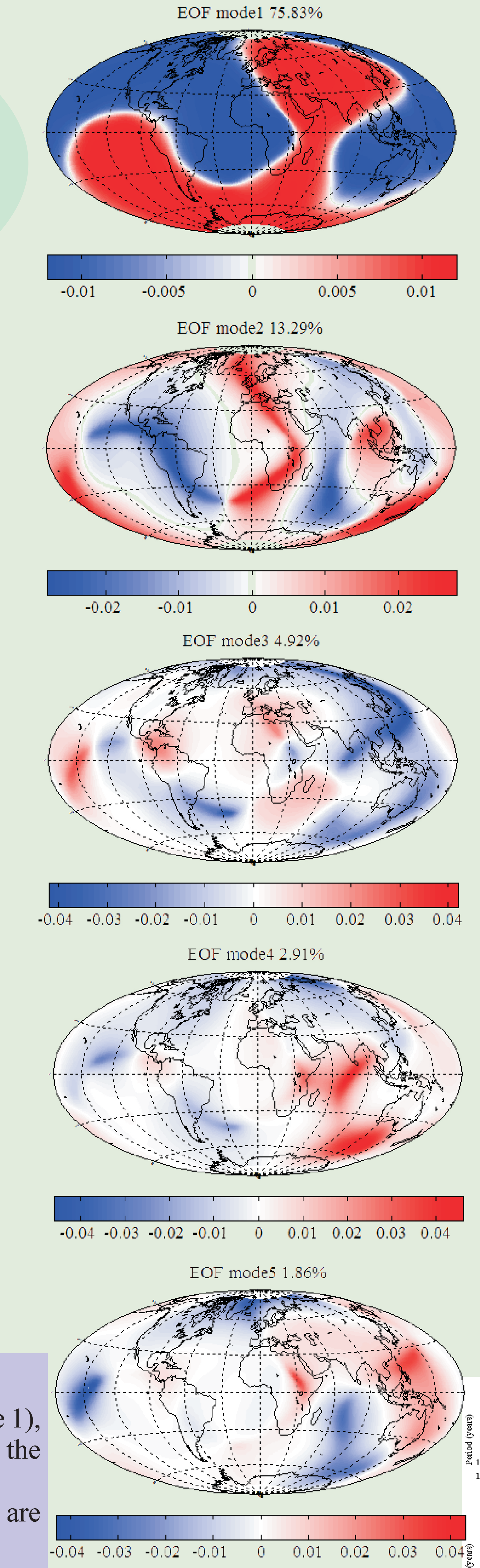
- COV-OBS.x1 (Gillet et al., 2015) and IGRF-13 models were used to decompose the Earth's surface geomagnetic field, namely the vertical component, into various oscillations;
- Two different approaches were applied in our study; on one hand, Empirical orthogonal functions (EOF) and, on the other, HP (Hodrick and Prescott, 1997) and Butterworth (Butterworth, 1930) filtering;
- Both methods show oscillations of >100 years as well as 60-90 years;
- Comparisons of the two used approaches are illustrated here for the vertical component of the COV-OBS.x1 model as it covers a wider time interval than the IGRF-13 model.

Principal component (PC) comparisons

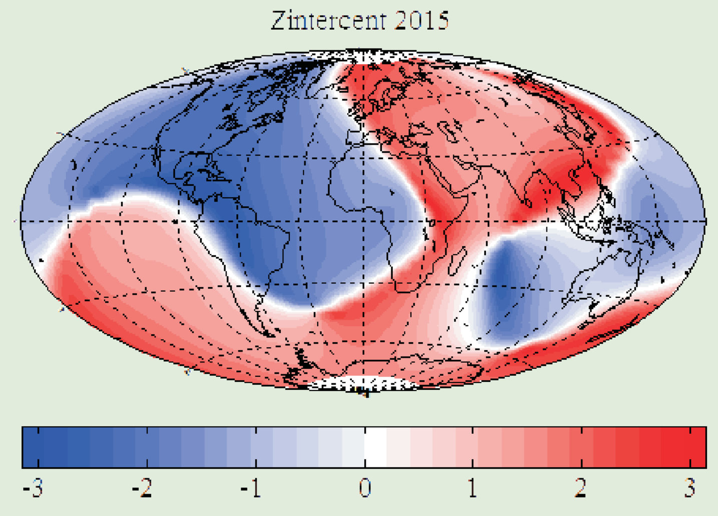


The general aspect of the EOF modes as well as the PCs obtained using COV-OBS.x1 and IGRF-13 models are in good agreement, slightly different periodicities in the principal component time series are due to different time spans covered by the models.

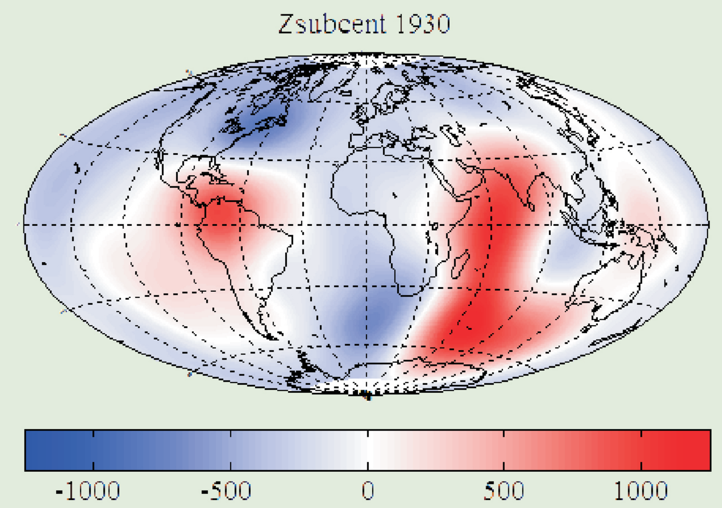
EOF modes



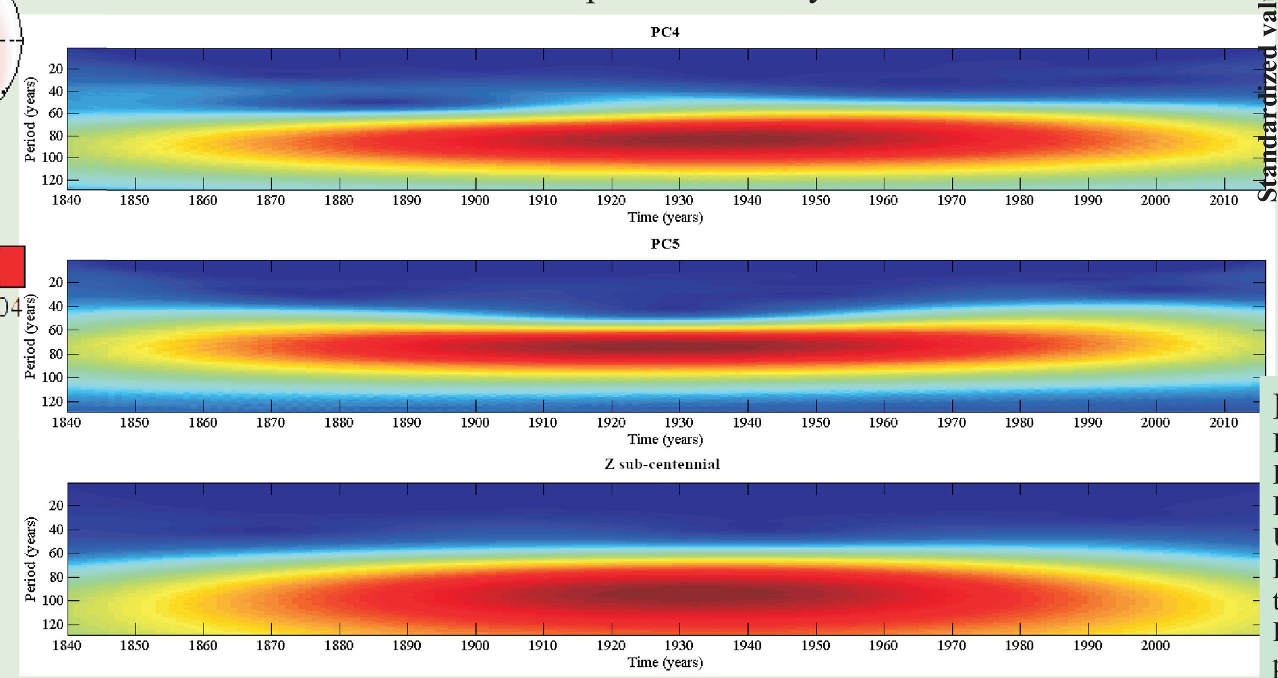
HP and Butterworth filtering



Standardized values of the inter-centennial component for the year 2015

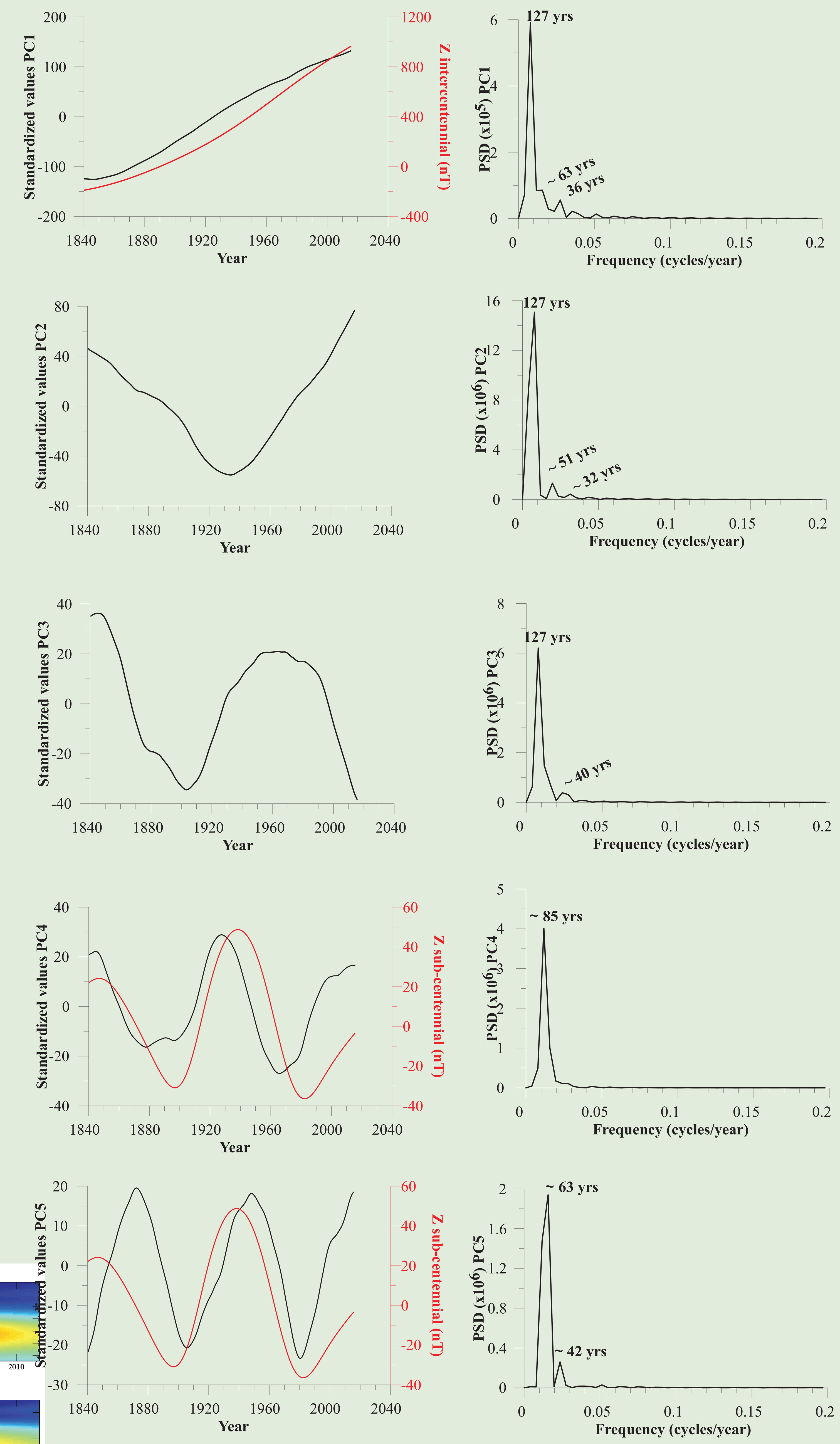


Sub-centennial component for the year 1930



Wavelet comparison between PC4 and PC5 of the EOF analysis and the sub-centennial component obtained by means of HP and Butterworth filtering methods showing that the two PCs can be explained by the sub-centennial component

Principal component (black) and HP and Butterworth filtering (red)



Conclusions

- The first three oscillation modes have periodicities of >100 years and describe 75.83% (mode 1), 13.29% (mode 2), respectively 4.92% (mode 3) of the vertical component characteristics at the Earth's surface;
- EOF modes 4 and 5 are characterized by dominant periodicities of 60-90 year. These modes are responsible for 2.91% (mode 4) and 1.86% (mode 5) of the vertical component characteristics;
- Although the variance of the modes 4 and 5 is rather small compared to that of the first three modes, these two modes are responsible for the detailed structure of the geomagnetic field;
- **The results of the EOF analysis endorse our previous studies (Demetrescu&Dobrica, 2014; Stefan et al., 2017; Dobrica et al., 2018) according of which the geomagnetic field consists of oscillations at inter-centennial (> 100 years) and sub-centennial time scales (60-90 years); with the inter-centennial oscillation bearing the largest part of the field while the sub-centennial oscillation is responsible for the detailed structure of the geomagnetic field.**

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Additional information regarding the poster "Decomposing the geomagnetic field: oscillation modes and characteristics", authors C. Stefan, V. Dobrica, C. Demetrescu

Data and method

The COV-OBS.x1 (Gillet et al., 2015) and IGRF-13 main geomagnetic field models, covering the time span 1840–2020, respectively 1900-2020, were used to obtain time series of the vertical component (Z) at the Earth's surface in a 2.5° × 2.5° latitude/longitude grid. The codes and coefficients of the models are available online at http://www.spacecenter.dk/files/magnetic-models/COV-OBSx1/ and at https://www.ngdc.noaa.gov/IAGA/vmod/igrf.html, respectively.

Two different approaches were applied in order to decompose the geomagnetic field, on one hand, the empirical orthogonal functions (EOF), and, on the other hand, Hodrick–Prescott (HP) (Hodrick and Prescott, 1997) and Butterworth (Butterworth, 1930) filtering. Briefly, EOF allows defining the spatial distribution of the oscillation modes/variability modes of a physical field, their temporal variation as well as their relevance in terms of variance (Bjornsson and Venegas, 1997). Bjornsson and Venegas (1997) proposed that the term EOF to be used to describe the spatial distribution of the variability modes and the principal component (PC) term to be used for the temporal variation of the variability modes as there was confusion in the literature as both terms were used to describe the same method. In our study the terms EOF and PC are used according to Bjornsson and Venegas (1997). The principle of the HP filter is that a time series is the sum of a long term component (trend) and a cyclic component. The determination of the long term component is equivalent to a cubic spline smoother.

Results and discussion

The vertical component time series of the geomagnetic field, in a 2.5° × 2.5° latitude/longitude global grid, obtained using the COV-OBS.x1 and IGRF-13 models were decomposed in oscillation modes using the EOF method as well into a long term and a cyclic component by means of HP filtering. The long term component resulted using the HP filter, with amplitudes reaching 7000 nT, is associated to the internal field while the cyclic component, with much smaller amplitudes, could correspond to the external field. Further the long term component is filtered by means of a Butterworth filter (1930) with different cut-off periods in order to obtain oscillation at inter-centennial (> 100 years) and sub-centennial (60-90 years) time scales.

The results of the EOF analysis shows that the first three oscillation modes are characterized by periodicities of >100 years and describe 75.83% (mode 1), 13.29% (mode 2) and 4.92% (mode 3) of the characteristics of the geomagnetic field at Earth's surface. Modes 4 and 5 are characterized by dominant periodicities of 60-90 year. These modes are responsible for 2.91% (mode 4), respectively 1.86% (mode 5) of the vertical component characteristics. Although the variance of the modes 4 and 5 is rather small compared to that of the first three modes, these two modes are responsible for the detailed structure of the geomagnetic field. Modes 6-10 that have a total variance of 1.18% also lend to the detailed structure of the geomagnetic field.

We consider that the inter-centennial component (> 100 years) obtained by means of HP and Butterworth filtering explains the first EOF mode as it bears the largest part of the geomagnetic field at the Earth's surface. EOF modes 4 and 5 can be attributed to the sub-centennial component (60-90 years) that reveals the detailed structure of the geomagnetic field.

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