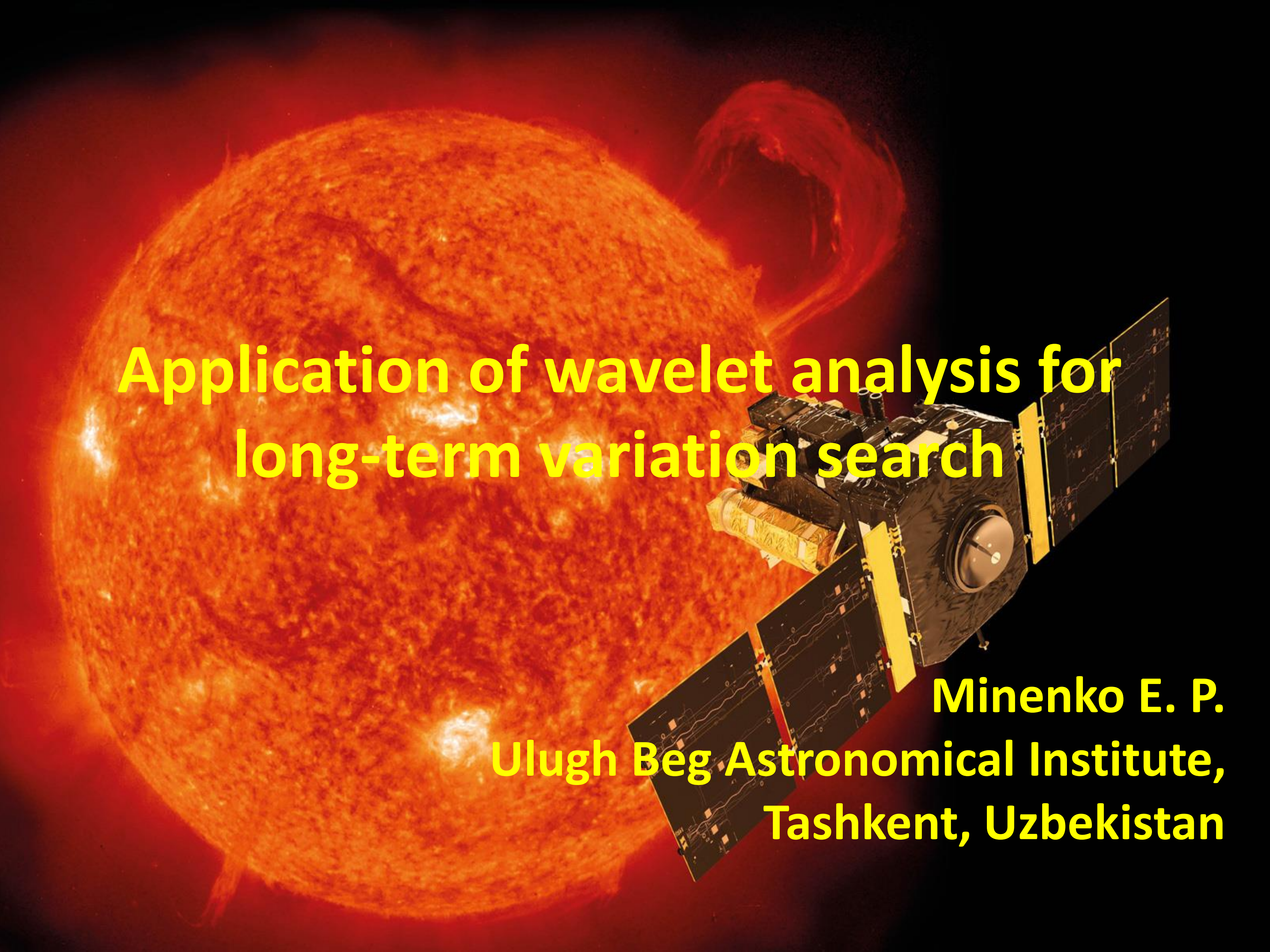

# Application of wavelet analysis for long-term variation search


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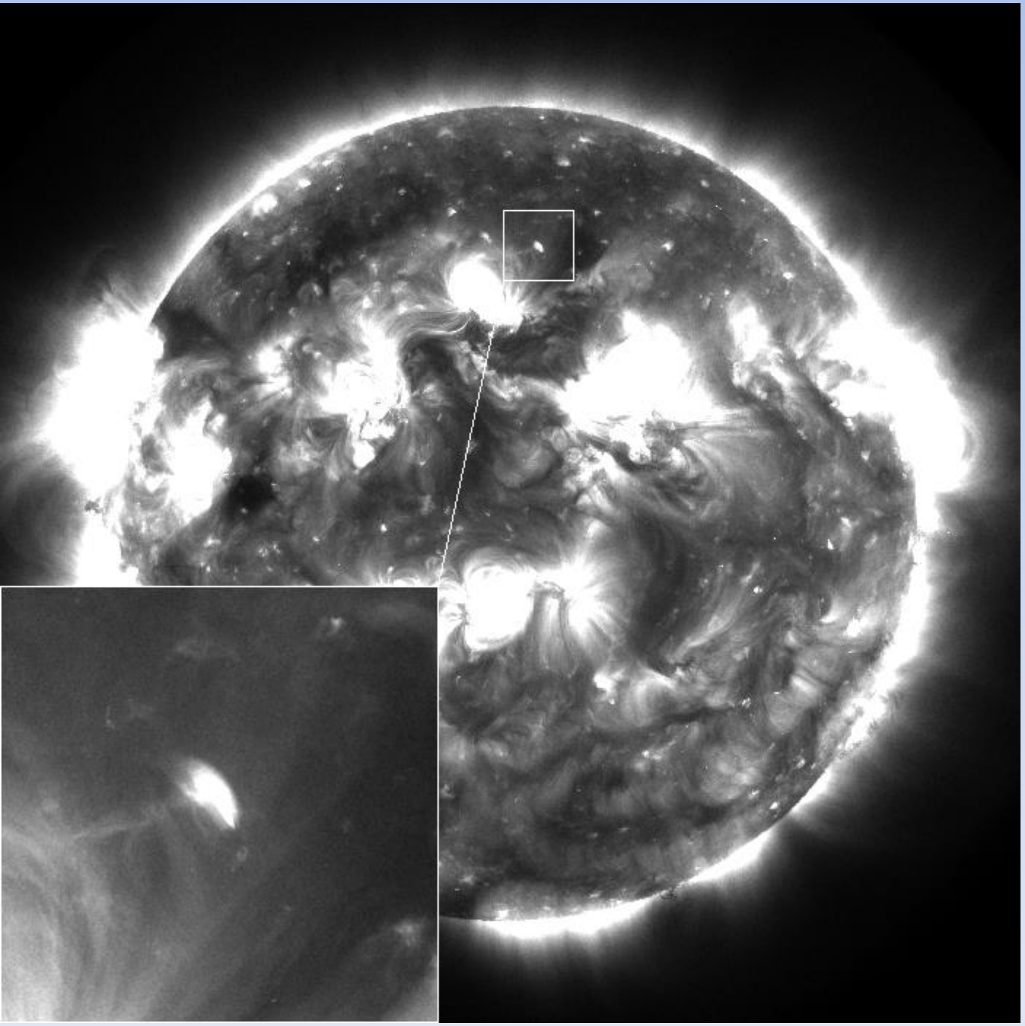
# Introduction

An increase of observational data from Maidanak observatory requires the development and application of modern methods of processing and analysis of digital images.

Today I want to present an example of application of wavelet analysis for digital images from the SOHO space observatory. Wavelet analysis is used in many fields of physics that involve the study of (nonstationary) time series like astronomy, geophysics, acoustics et cetera.

The methods and technique could be used not only for solar data analysis but also for data from Maidanak.

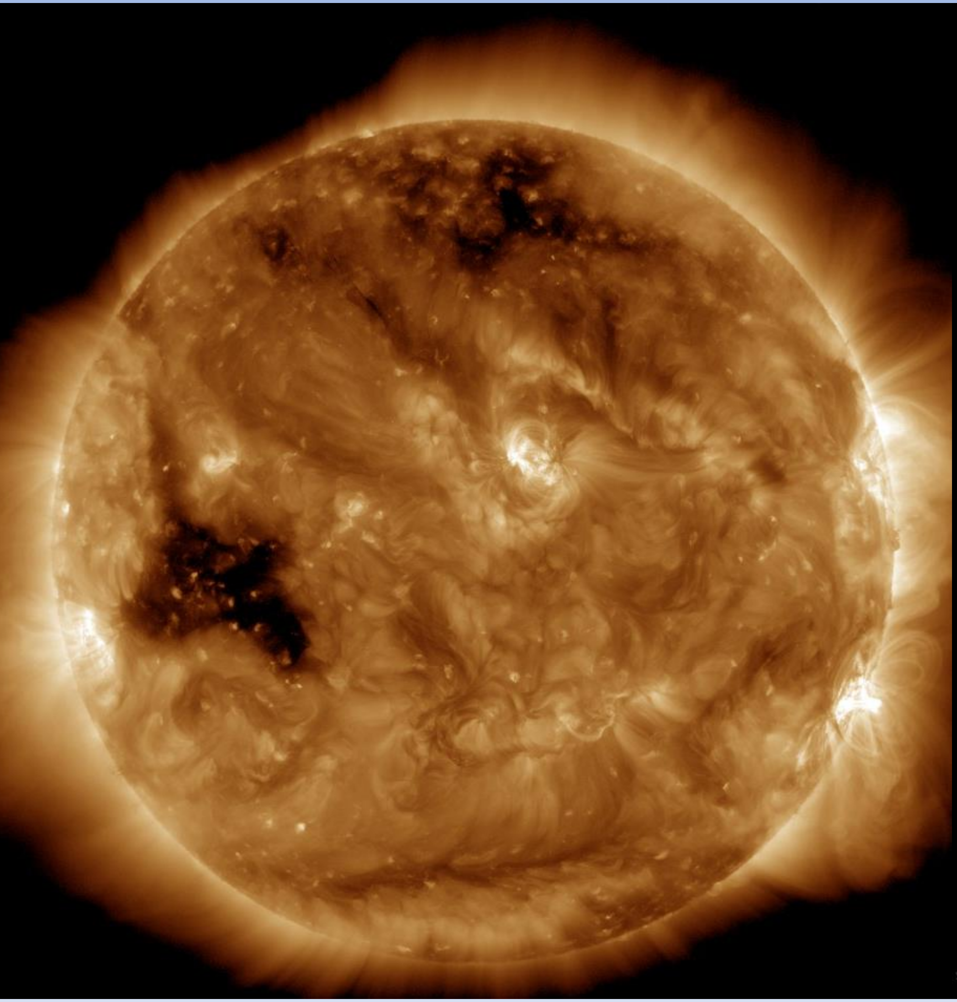
# Coronal Bright Points (CBPs)



CBPs are short-lived (<2 days) point like features (size from 4,000 to 40,000 km) with enhanced emission, located in the transition zone and the solar corona, where the temperature rises sharply from several tens of thousands to a million degrees.

# EIT/SOHO 195 Å

# MDI/SOHO



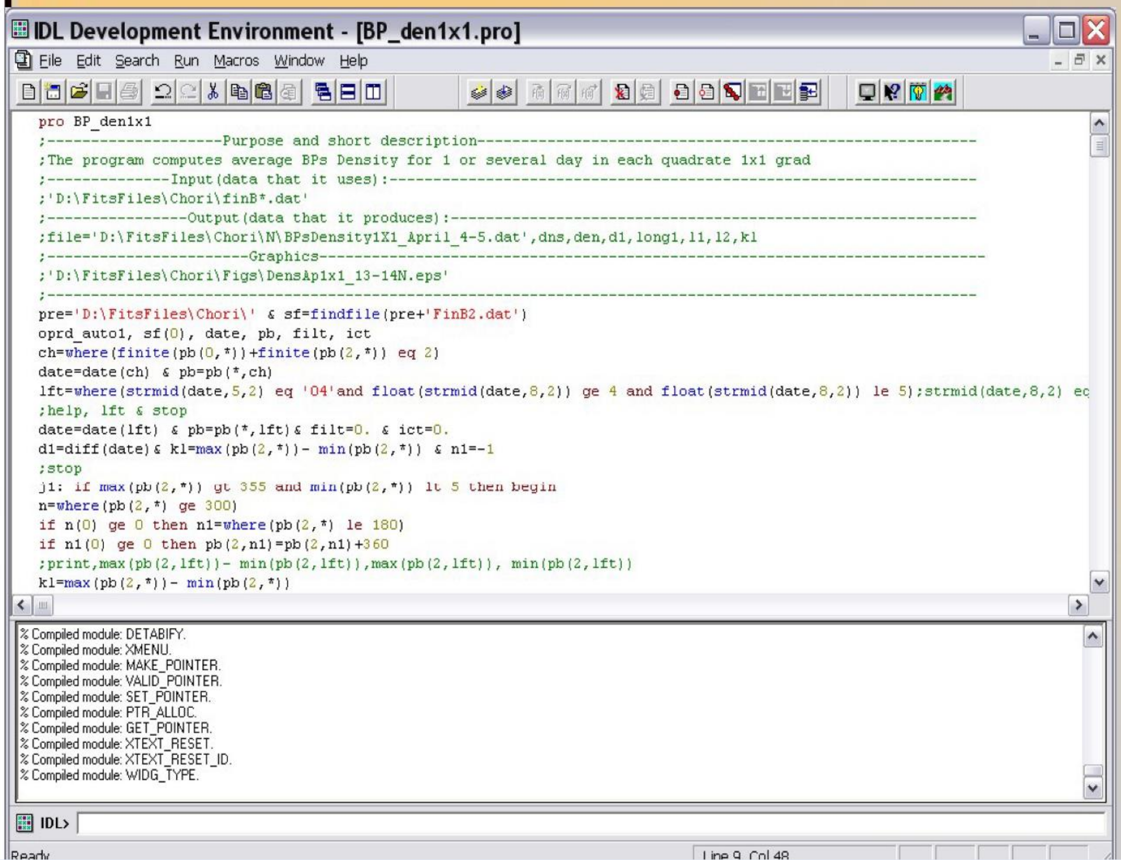

CBPs are usually associated with bipolar magnetic structures and are very similar to active regions on the Sun only small- scale.

# Data

- We use series of monthly mean values of both the total number of CBPs and their distribution at various latitudinal intervals over the solar disk obtained with a frequency of one image per day.
- The data cover an interval of ~25 years (from January 1, 1996, to April 2020) which corresponds to two complete Solar cycles: 23 and 24.
- The analyzed data were obtained from EIT (**E**xtreme ultraviolet **I**maging **T**elescope) instrument at wavelength of 195 Å onboard SOHO space observatory.

# For analysis we use IDL programming language

## Interactive Data Language (IDL )




IDL is the most commonly used language for solar researches. The latest version is IDL 8.6, but we use IDL 5.2 which was granted by our French colleagues in 2001. Many features are not available in the old vertions, e.g. the IDL SolarSoft VSO client (vso_search and vso_get) software require IDL 8.4 and later.

# What we have done

- CBPs were separated into two types according to their intensity : “dim” and “bright”. The first type of CBPs  is observed through out the entire solar disk, while the second is mainly observed in the active region formation zone.
- The latitudinal-temporal changes in the frequency spectra for the CBPs number were studied based on the wavelet transform.
- For the analysis of time series, the sixth-order Morlet wavelet was selected, and a 99% significance level was established as a criterion.

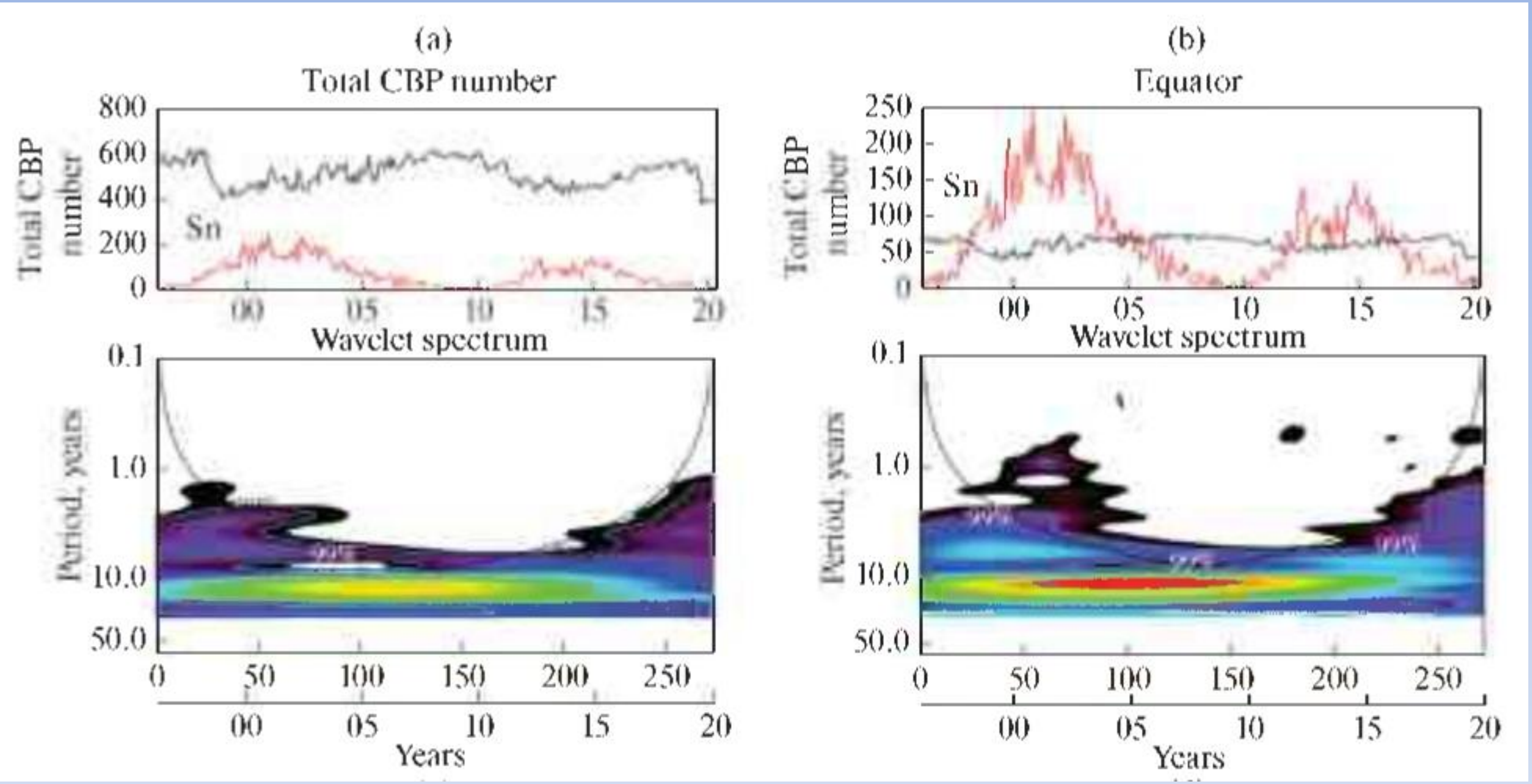
# Results

**Table 1.** Pearson correlation coefficient (for data for 1996 to early 2020)

| Comparable parameters | Correlation coefficient value |
|---|---|
| Number of CBPs of two types and Sn | −0.555066 |
| Number of CBPs of both types at the equator and Sn | −0.375557 |
| Number of CBPs of both types in the active formation zone and Sn | −0.543185 |
| Number of CBPs of both types in the high-latitude zone and Sn | 0.747762 |
| Number of type-I CBPs (dim) and Sn | 0.874308 |
| Number of type-I CBPs at the equator and Sn | 0.852492 |
| Number of type-I CBPs in the active formation zone and Sn | −0.543185 |
| Number of type-I CBPs in the high-latitude zone and Sn | −0.823839 |
| Number of type-II CBPs (bright) and Sn | 0.864622 |
| Number of type-II CBPs at the equator and Sn | 0.748934 |
| Number of type-II CBPs in the zone of active formations and Sn | 0.751351 |
| Number of type-II CBPs in the high-latitude zone and Sn | 0.517597 |

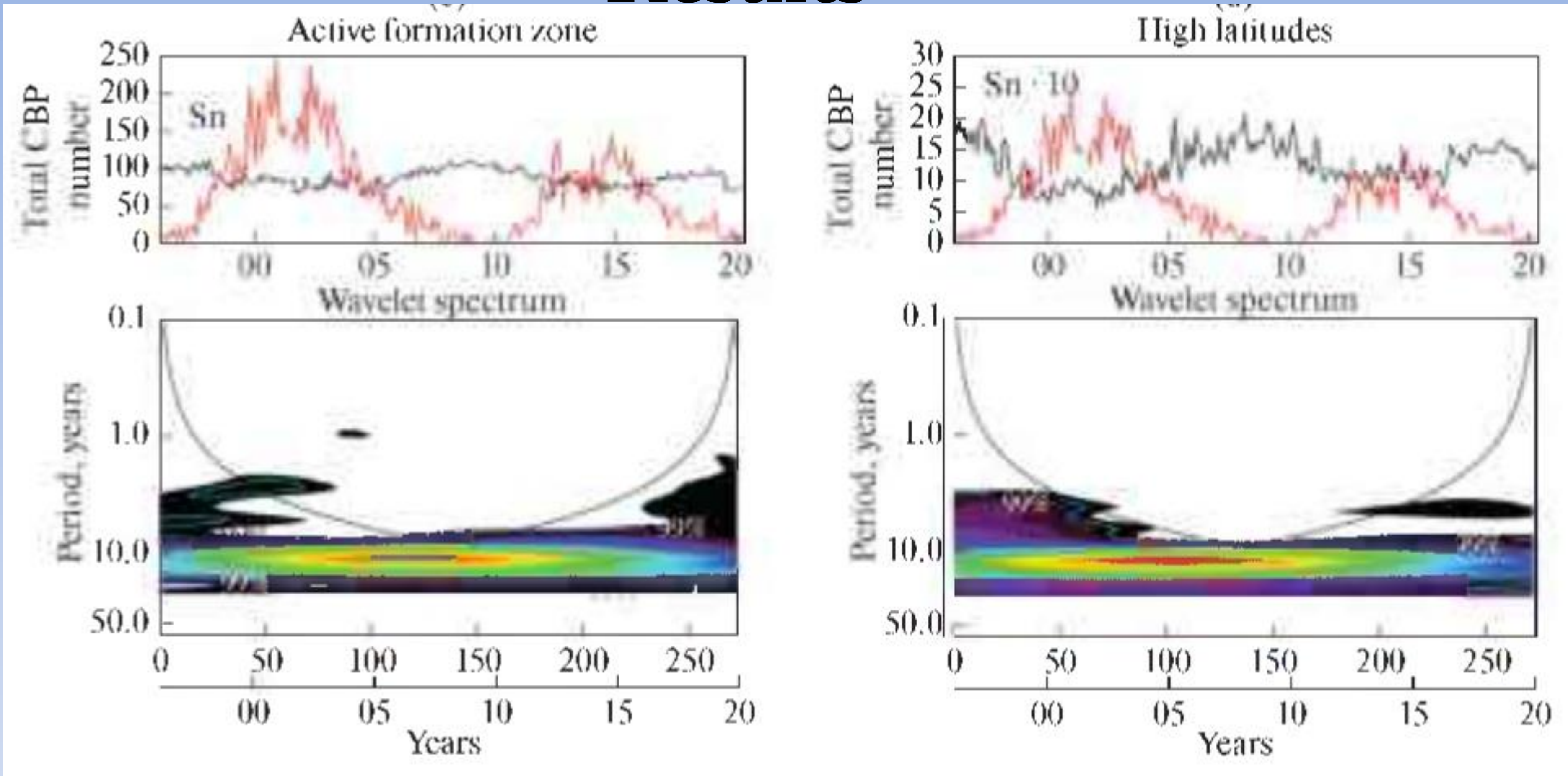
The table presents values of the Pearson correlation coefficient between CBPs number and the Sunspot number Index from World Data Center of Royal Observatory of Belgium, Brussels (SIDC, SILSO). The coefficient values show no dependency of total CBPs number on solar cycle.

# Results



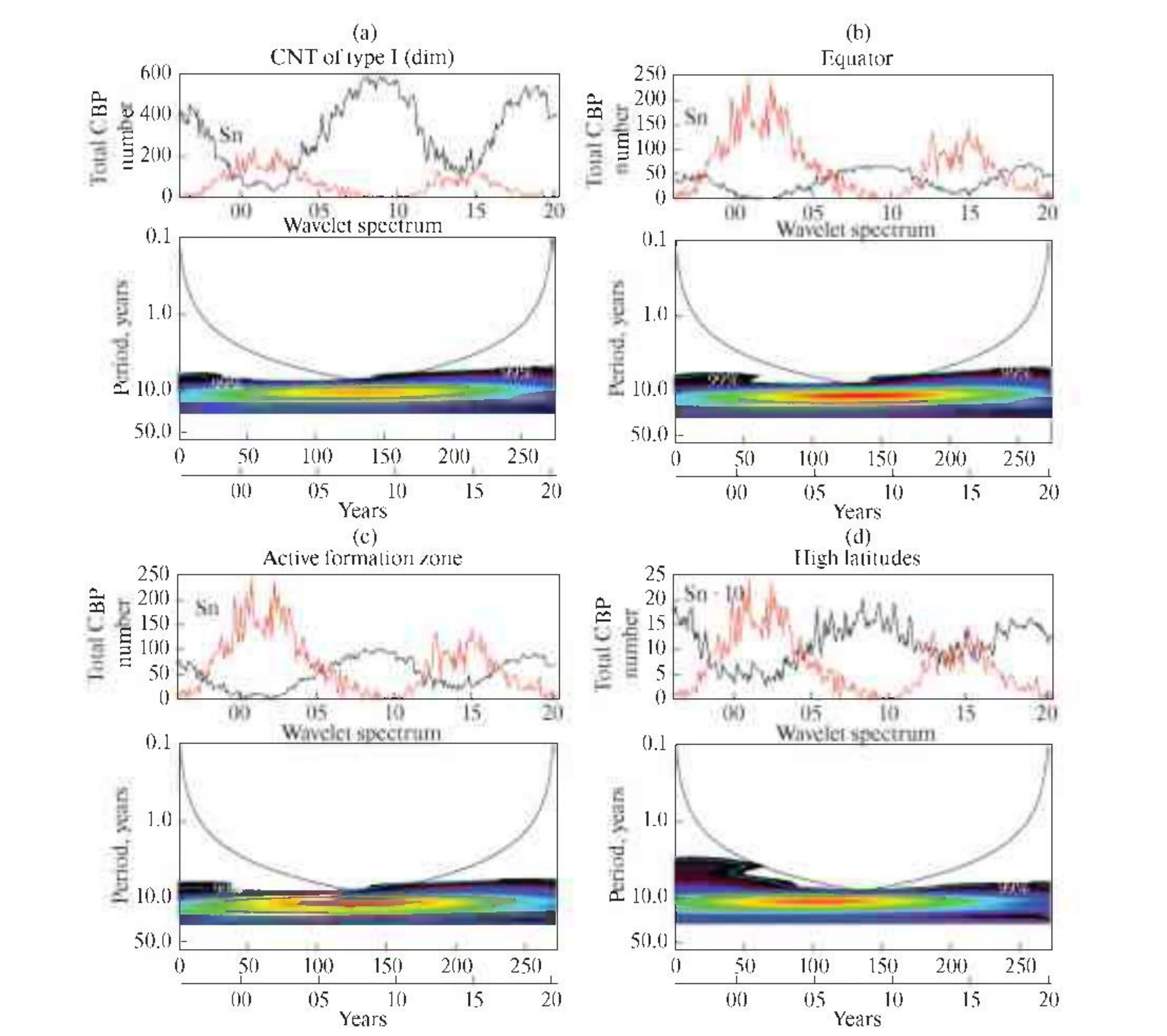

Changes in the monthly mean values of the CBPs number (top) and the corresponding wavelet spectrum of the time profile of the CBPs number (a) in all latitudes and (b) equatorial zone. Change of the monthly average values of Sunspot numbers is red.

# Results

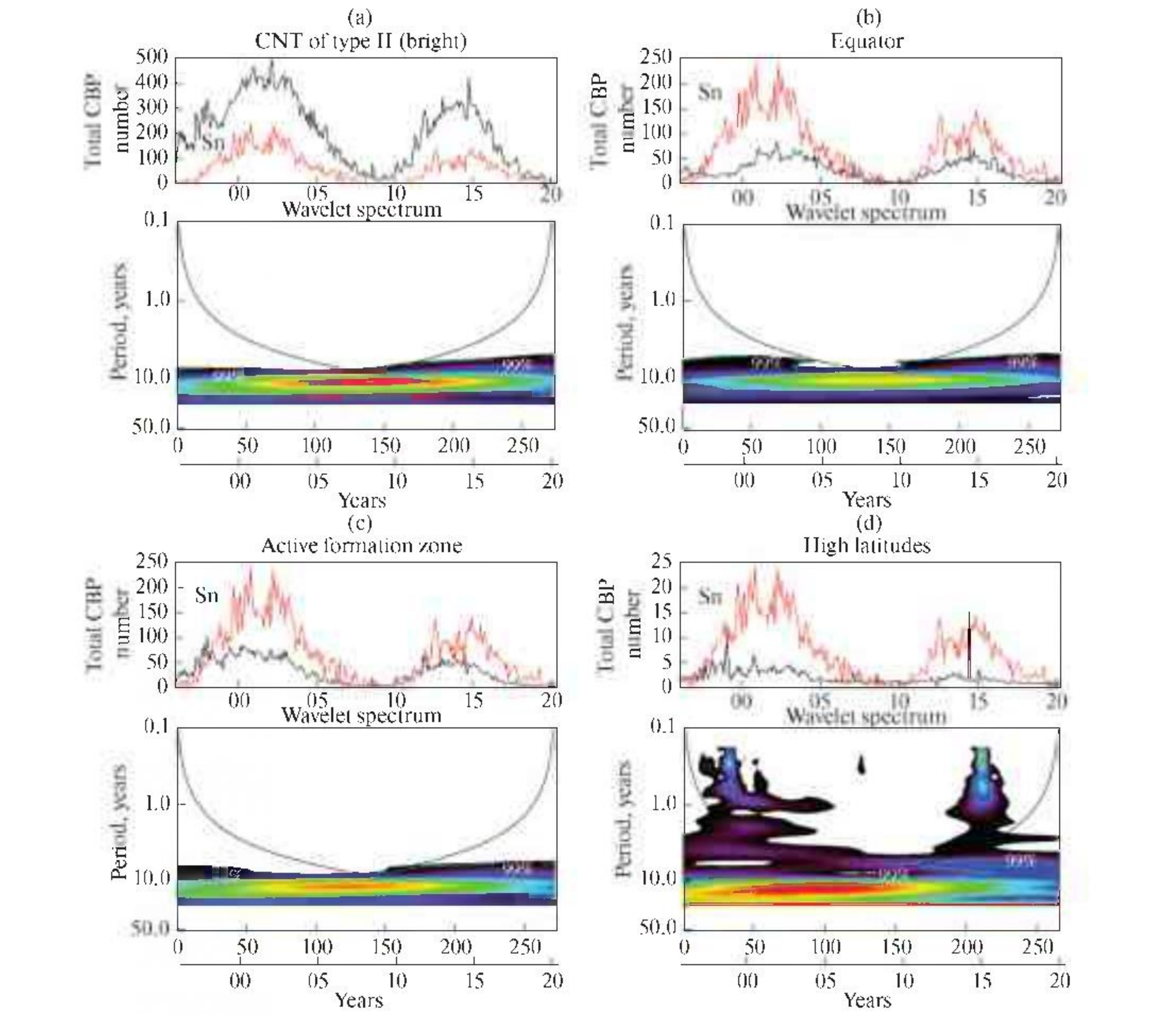



Changes in the monthly mean values of the CBPs number and the corresponding wavelet spectrum of the time profile of the CBPs number in active regions zone and high latitudes. Change of the monthly average values of Sunspot numbers is red.

# First type of CBPs (dim)



# Second type of CBPs (bright)



# Conclusions

- The application of wavelet analysis made it possible to detect the presence of 11-year variations in all the cases considered, which was not revealed by other methods.
- At high latitudes, two other periods - of 12.5 and 22 years are found in the case of bright CBPs (the second type).
- Wavelet analysis could be successfully used for researches of long-term variations of different indexes.