EFFECTS OF THE SOLAR VARIABILITY ON THE NORTH TEMPERATE CLIMATE

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Possible climatic effects related to solar variability have been investigated by means of long-term statistical correlations between surface air temperature and solar/geomagnetic indices. The data from NCEP/NCAR reanalysis database for the north temperate zone (Europe, North America and northern Asia) have been used followed by a discussion of the differences between observed and reanalyzed data. Power spectral analysis of surface air temperature indicates the occurrence of periodicities between 2 and 7 years, associated to atmospheric phenomena, and periodicities around 11 and 22 years, normally associated to solar variability. The 11- and 22-year signals in temperature data were derived by applying simple filtering procedures. Various features of these signals are discussed on different spatial scales of the Northern Hemisphere.

Key words: solar/geomagnetic activity, NCEP/NCAR reanalyzed temperature, cross-correlation analysis.

1. INTRODUCTION

The climate system is driven by the energy coming from the Sun. However, it became certain that a combination of both natural and human induced forcing is driving the present observed climate change.

As regards the solar forcing, there are still controversies related to the mechanisms controlling the climate variability given by it. The solar activity, as a natural forcing of the Earth's climate, could influence the terrestrial climate in various ways and at various time-scales, both directly, by long-term modifications of the solar radiative emission affecting the energy balance of the Earth's surface, and indirectly, by effects of the solar wind on magnetosphere and ionosphere (geomagnetic activity) and by the modulation of cosmic ray flux through combined effects of the heliospheric and terrestrial magnetic fields (Haigh, 2007; Gray *et al.*, 2010). The solar influence on climate cannot be directly measured, but correlations between the solar activity and climate parameters were found, such as the well-known correlation between the mean temperature of the Northern Hemisphere and the length of the solar cycles, published by Friis-Christensen and Lassen (1991).

Recently, many studies focused on the Sun – Earth's climate relationship, providing statistically significant signatures of solar activity changes on climate at the 11-year solar cycle timescales (Bucha, Bucha Jr., 1998; Cliver *et al.*, 1998; Bucha, Bucha Jr., 2002; Le Mouël *et al.*, 2005; El-Borie, Al-Thoyaib, 2006; Valev, 2006; Courtillot *et al.*, 2007; Le Mouël *et al.*, 2008; Le Mouël *et al.*, 2009; Dobrică *et al.*, 2009; Courtillot *et al.*, 2010; Dobrică *et al.*, 2010; Yiou *et al.*, 2010). A review by Lockwood (2012) concerning solar influence on global and regional terrestrial climate advised that solar influence could be stronger at local or regional scale than at the global one.

In this study we have identified possible effects of solar variability on the most important three continental areas (Europe, North America and northern Asia) from the northern temperate climate zone. After a short introduction, the paper describes the data that have been used, namely the reanalyzed data from the NCEP/NCAR database, and the way in which those data have been processed. The results section comprises the discussion of obtained results based on both long-term variations of temperature and statistical correlations between surface air temperature and solar/geomagnetic indices. The paper ends with several conclusions.

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2. DATA AND PROCESSING

2.1. DATA

Assessing the climate variability depends on the existence and accuracy of records of climatic parameters, such as air temperature or precipitation. The longest homogeneous instrumental temperature series in the world is the Central England temperature record dating back to 1659. In Europe, other similar temperature records dating back to the middle of the 18th century are available for Hohenpeissenberg (Germany), Vienna (Austria) and Prague (Czech Republic). For the 20th century, a robust and reliable data set of long instrumental records of air temperature is available at http://www.ecad.eu from European Climate Assessment & Dataset (ECA&D) (Klein Tank *et al.*, 2002). Unfortunately, the instrumental records from meteorological stations suffer from limitations, such as lack of spatial coverage over areas of interest, especially in mountains and high latitude regions, and time intervals with missing information. In such cases, gridded databases, such as global reanalysis data (Trenberth, 2007), could be used to avoid the problems with missing data or with unevenly spatial coverage.

The monthly data from NCEP/NCAR reanalysis database for the north temperate zone (Europe, North America and northern Asia) have been used in this study (http://www.esrl.noaa.gov/psd/) (Kalnay *et al.*, 1996).

The NCEP/NCAR database is a result of a cooperation project between the National Centers for Environment Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) in USA, called the Reanalysis Project NCEP/NCAR. The aim of this project was to produce a data bank with atmospheric fields for a 51-year interval starting 1948, which is continuing at present by collecting a large volume of terrestrial, marine, atmospheric soundings, satellite data etc. and by control and assimilation of these data with an assimilation system (CDAS), the same for the entire analyzed period. The reanalysis of data produced information on distribution of parameters that describe the atmospheric fields in a network with a resolution of 2.5x2.5° latitude and longitude. The model has a temporal coverage with four values a day, daily, and monthly values, beginning with 01/01/1948.

As an example of using the database (the reanalysis model 1, 1948–present), both the spatial distribution of the Earth's surface air temperature for the year 1995 and the temporal evolution at grid points, for the time interval 1948–2012, in case of Europe are presented in Fig. 1.

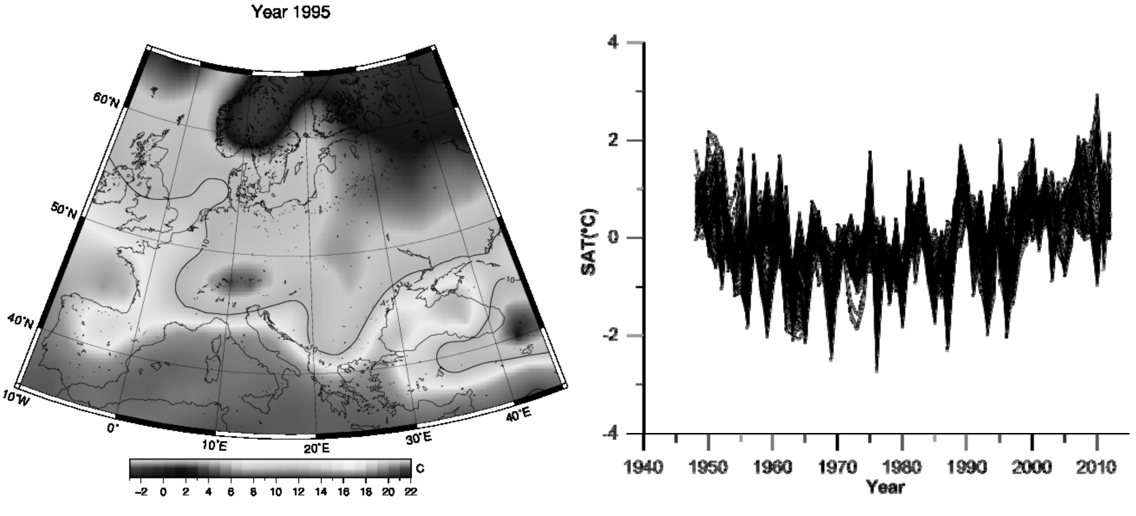

Fig. 1 – The geographical distribution of mean surface temperature distribution in 1995 (left) and the temporal evolution of surface air temperature at the 92 grid points over Europe, as given by the NCEP/NCAR database.

2.1.1. Comparison with observed data

In order to see how well the reanalyzed data fit the observed ones we have made several comparisons between reanalyzed and observed surface temperatures for specific locations. The temporal evolution of temperatures for these locations shows that there are general level differences between observed and reanalyzed data of up to ~2–3°C, but the overall trend and variability is the same for both types of data, as was shown by Pîrloagă and Dobrică (2014).

2.2. PROCESSING

To find tendencies and periodicities in data, standard spectral analysis techniques were used, such as the Fast Fourier Transform (FFT) or the Multi-Taper Method (MTM). In the following we present, as an example, results obtained by means of FFT and MTM in case of one of the longest record with instrumental data (1706–2011), station De Bilt, Netherlands (Fig. 2). The shorter, reanalysis data series would not bring out the longest periods in data and, consequently, the corresponding spectra are not shown.

The spectral analysis of the time series indicates the presence of short period variations (2–7 years, 84–92 % significance), associated to atmospheric phenomena, variations with a period of ~11 years (90 % significance), as well as longer periods, of 22–30 years (95 % significance), or even longer, of ~80 years, normally associated to solar variability, which superpose in the analyzed signal.

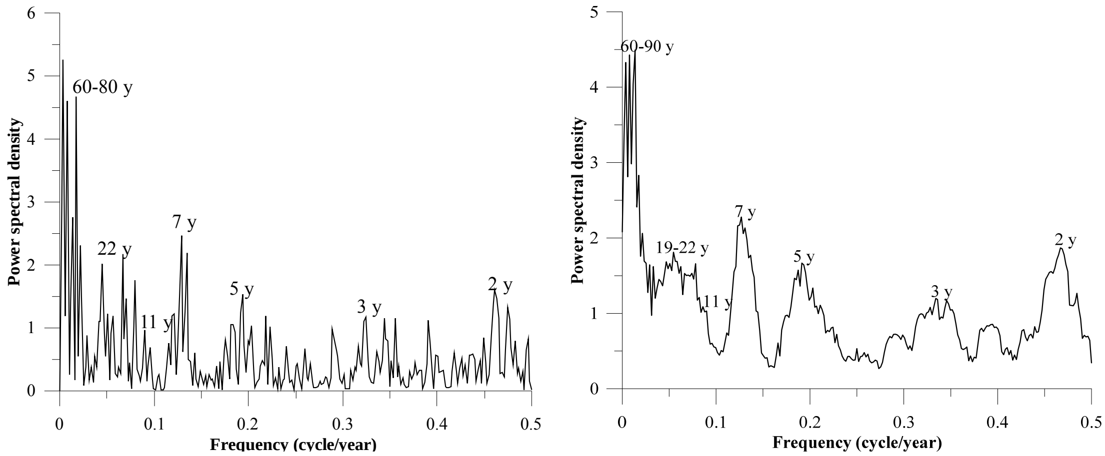

Fig. 2 – Spectral analysis on De Bilt data: FFT (left), MTM (right).

We can get 11- and 22-year signals in temperature data by applying simple filtering procedures. First of all, the time series have been filtered with a low pass moving average filter with a window of 4 years in order to filter out the short periodicities. Afterwards, the time series have been filtered successively by means of 11- and 22-year running averages, obtaining the so-called interdecadal trend and, respectively, the centennial trend. The corresponding 11- and 22-year signals have been computed as differences between the successive filtered time series (Dobrică *et al.*, 2009; Dobrică *et al.*, 2010). The illustration of these processing steps is given in Fig. 3. The existence of a decadal variation with an amplitude (peak to through) of about 1°C and of an inderdecadal variation with an amplitude of 0.4°C can be noticed (the lower plot in Fig. 3).

3. RESULTS

3.1. LONG-TERM VARIATIONS IN REANALYZED TEMPERATURES

The long-term surface air temperature variations for the European continent are plotted in Fig. 1. We superimposed time series from all analyzed grid points of the network, 10°W-45°E, 45-52.5°N (92 points), to show the similar temporal behavior of grid points temperature. The main characteristics of the evolutions shown are the coherence of the variation at all points and the existence of decadal, interdecadal and longer variations. In spite of the regional climatic differences on the continental scale, the variations are similar at all grid points, thus justifying a further analysis on the mean values over that continental area.

We also worked out the NCEP/NCAR database temperatures from the other continental areas characterized by a temperate climate, namely North America, 90–120°W, 45–52.5°N (52 points), and northern Asia, 90–120°E, 45–52.5°N (52 points), showing the same coherence as the European data. In the following we will use the average temperature for each of the three continental areas (Fig. 4). In the same figure the interdecadal and centennial trends, together with the corresponding 11- and 22-year signals are presented.

A similar long-term temporal behaviour of average surface air temperature for the three continental areas, with a minimum around ~1975 followed by a general increase in the last decades, can be observed. Strong and coherent signals at the decadal (11 years) and interdecadal (22 years) timescales, in the averages of reanalyzed surface air temperature data over the considered continental areas, have been identified, with amplitudes from peak to trough of about 1–2°C and, respectively, 0.8°C.

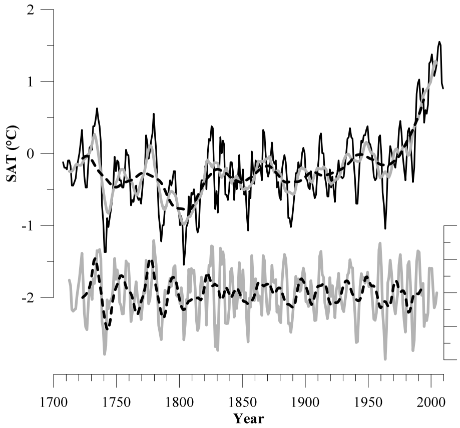

Fig. 3 – Example of data treatment, on the time series from De Bilt. Upper plots: the time series (black), referred to the average value for the entire time interval, the interdecadal (gray), and the centennial (dashed) trends. Lower plots: the 11-year (gray) and the 22-year (dashed) signals.

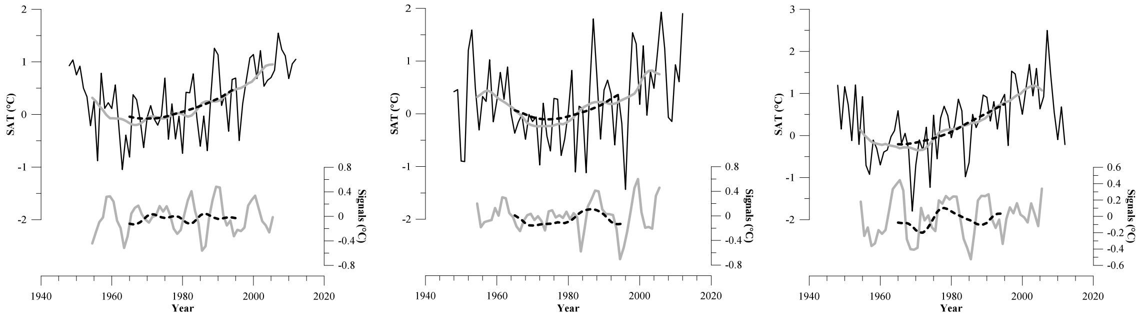

Fig. 4 – Average time-series referred to the mean value for the time interval considered, trends and signals in reanalyzed temperatures (left – Europe, middle – North America, right – Asia). Upper plots: average temperature for the three continental areas of the present study (black) and the interdecadal (gray) and centennial (dashed) trends. Lower plots: the 11-year (gray) and the 22-year (dashed) signals.

3.2. SOLAR VARIABILITY EFFECTS IN NORTH TEMPERATE CLIMATE

In order to discuss solar variability effects on temperature, we compare the temperature trends and signals at the two time-scales (11- and 22-year) with the corresponding components of the solar and geomagnetic activity. This is done in Fig. 5 for trends and in Fig. 6 for signals. As a proxy for the solar activity the standard sunspot time series, R, available at http://www. ngdc. noaa.gov/stp/space-weather/solar-data/ solar-indices/sunspot-numbers/ international/tables/, was used. The global geomagnetic activity at mid latitudes is described by the *aa* index (Mayaud, 1972, 1980), obtained from records of two antipodal geomagnetic observatories (Hartland, Great Britain, and Canberra, Australia), available at http://isgi.latmos.ipsl.fr/ source/ indices/aa/.

First, we compare trends in data for the three areas under study and conclude they are similar, in spite of slight differences among them. But when we compare temperature trends with the interdecadal and centennial trends in the solar and geomagnetic activity, a marked discrepancy after 1980–1990 becomes visible. According to Le Mouël *et al.* (2005) and Dobrică *et al.* (2009) it is the possible emergence of the effect of anthropogenic greenhouse gases, which prevails on the natural forcing after 1980–1990. We also note the shorter by 21 years of the 22-year curves, as a result of way we processed the data.

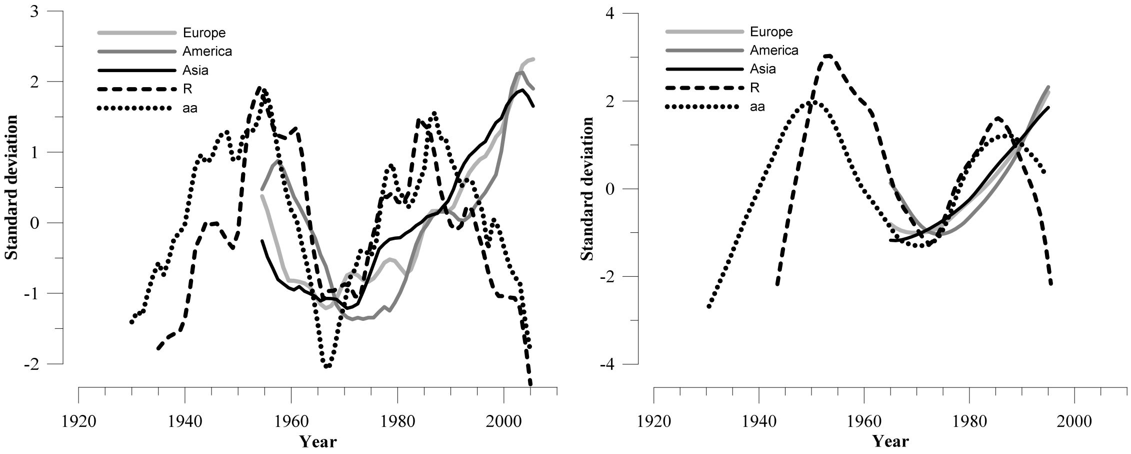

Fig. 5 – A comparison of interdecadal (left) and centennial (right) trends in surface air temperature with the solar and geomagnetic activity.

As regards the solar/geomagnetic related signals at the two time scales, of 11 and 22-years, a direct comparison might not be relevant because wiggles at a ~5-year time scale are present in geomagnetic data (the *aa* index) as a result of the well-known second maximum of activity during the descending phase of the solar cycle, which temperature seems not following. Also, in the 22-year signal reminiscent 11-year wiggles are still present. After removing those components in the geomagnetic activity, correlations with the signal in temperature should be improved.

The cross-correlation analysis between the 11-year signal in temperature and the corresponding ones in the solar and geomagnetic activity is shown in Fig. 7. The correlation coefficient between the 11-year signal in temperature and the corresponding one in the sunspot number is shown in the left hand side of the figure, while the cross-correlation of the same temperature signal with the *aa* time series is shown in the right hand side. The correlation coefficients are significant at the 95 % level, both with R and *aa*, higher in case of Europe (0.62 and respectively 0.61) as compared to Asia (0.29 and 0.25) and America (0.32 and 0.37). As regards the time lag between the compared time series, two comments are worth mentioning, namely: (a) this is larger by 1 year in case of the temperature/geomagnetic activity than in case of temperature/solar activity, which is to be expected having in view that the geomagnetic activity is a result of the solar activity and its action on climate is not as straightforward as the direct solar action, and (b) the time lag is different for the three continental areas (compare 0 and, respectively, 1 year for Europe with 2–3, respectively, 4 years for North America, and 2–3, respectively, 3 years for Asia).

Also, a lagged response of the 11-year solar cycle on Atlantic/European weather patterns was recently discussed by Gray *et al.* (2013) on sea level pressure and sea surface temperature data. They found statistically significant solar signal at 11-year timescale lagged by a few years from data.

At the moment of the writing we do not have a straight physical explanation for that, but our finding is in line with the opinion that the dependence of climate on the solar input is a regional rather than a global effect (Lockwood, 2012). The 22-year signal is too short to allow any definite conclusion to be drawn, and the cross-correlation analysis is not shown.

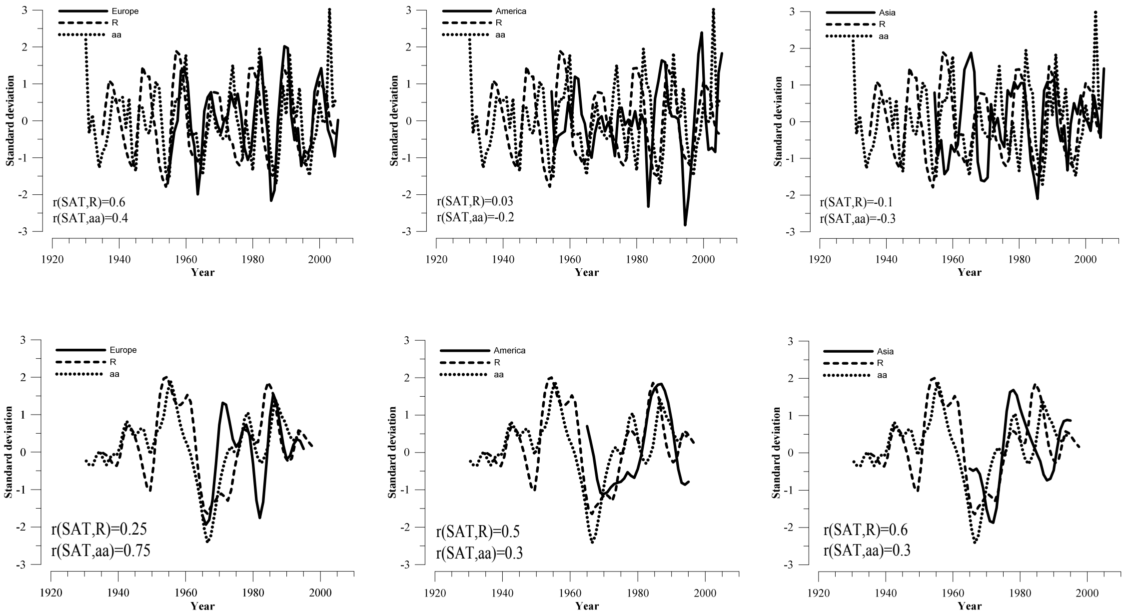

Fig. 6 – Comparison of the 11-year signal (upper row) and of the 22-year signal (lower row) in temperature data with corresponding signals in solar/geomagnetic activity. Left – Europe, middle – North America, right – Asia.

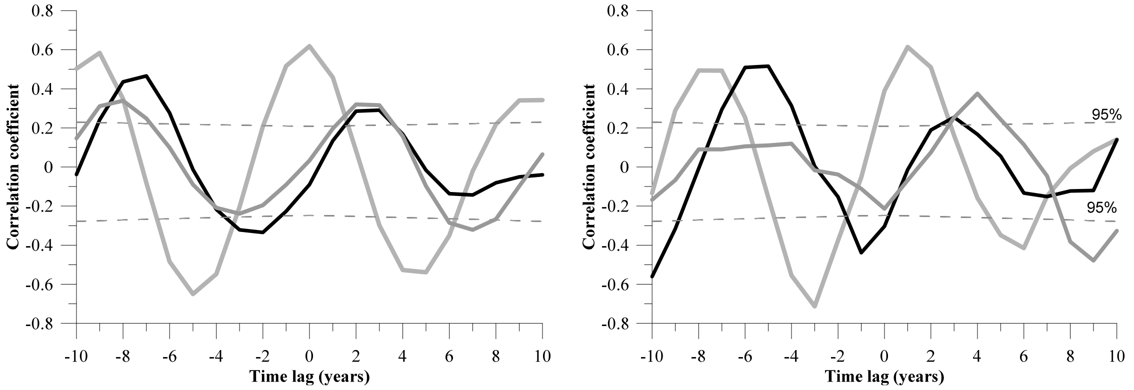

Fig. 7 – Cross-correlation analysis for SAT/R (left) and SAT/aa (right) for the 11-year signal in case of Europe (light gray), North America (dark gray) and Asia (black). The 95% significance level is indicated.

4. CONCLUSIONS

Temperature data from three continental areas of the north temperate climate zone, in the latitudinal band 45–52.5°N, in the NCEP/NCAR database have been used in the present study, with an aim to identify solar/geomagnetic signals in the temperature time series. The main conclusions are:

– There are general differences between observed and reanalyzed data of up to ~2–3°C, the observed temperature being over or underestimated by the reanalyzed ones. However, the variability in the time series is similar in the two data sets as shown by correlation coefficients of the order of 0.8;

– Similar temporal behaviour of temperature at all analyzed grid points of the network over different climate zones, with a minimum at around ~1975 followed by a general increase in the last decades is observed. The investigation on solar/geomagnetic signals proceeded on averages concerning the continental area considered;

– Slightly, nonsignificantly different temperature trends at the interdecadal and centennial time scales characterize the three studied continental areas;

– 11- and 22-year signals in temperature have been identified, with amplitudes from peak to through of about 2°C and, respectively, 0.8°C;

– Correlation coefficients between temperature and solar/geomagnetic indices, at Schwabe and Hale solar cycle timescales, show well defined solar activity signals in temperature of the north temperate zone at local or regional scale rather than at the global one.

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