ON THE AMPLITUDE OF LONG-TERM VARIATIONS OF THE TOTAL SOLAR IRRADIANCE IN THE PAST

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К ВОПРОСУ ОБ АМПЛИТУДЕ ДОЛГОВРЕМЕННЫХ КОЛЕБАНИЙ СУММАРНОЙ СОЛНЕЧНОЙ РАДИАЦИИ В ПРОШЛОМ

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Проведена оценка того, насколько надежно и точно современные реконструкции полной солнечной радиации (TSI) восстанавливают вековые вариации этой величины в прошлом. Прогноз долгосрочных изменений TSI в 1978–2015 гг. произведен на основе семи палеореконструкций, охватывающих последние 12–13 веков и закончившихся в 1978 г. Используемые реконструкции описывают долговременные вариации с амплитудой от 0,22 Вт×м$^{-2}$ (малоизменчивость серия) до 2,36 Вт×м$^{-2}$ (серия с высокой изменчивостью). Был использован нелинейный аналоговый метод прогнозирования, и результаты прогноза сравнивались с фактическими наблюдаемыми значениями. Было показано, что, хотя в целом наблюдаемые записи TSI лучше предсказываются реконструкциями с низкой изменчивостью, нельзя также исключать возможность того, что солнечная радиация испытывала значительные колебания в прошлом.

Introduction

Long-term changes in the total solar radiation – a factor that potentially affects the Earth's climate – are practically unknown. Instrumental measurements of this value began only in 1978. Reconstructions obtained by indirect methods vary greatly and show very different amplitudes of secular variations. They can be divided into low-variability (LV) and high-variability (HV) records (Connolly et al., 2021). But the question of which type of reconstruction – LV or HV – describes the long-term variations of TSI in the past more accurately remains open. Actually, how accurate are the estimates of TSI in the past? A major weakness of all such estimates is that their quality hardly can be assessed through their direct comparison to the observations. In present work it was performed examination of which type of TSI reconstructions is preferable – low-variability or high-variability. To solve this problem, the following algorithm was applied: (a) forecasts of TSI changes in 1979–2015 were made using various types of reconstructions as an information bank (see Ogurtsov (2009)); (b) results of the forecasts were compared with the real, instrumentally measured TSI; (c) evaluation of which type of reconstructions predicts the real TSI more accurately and reliably was performed. In the present work it were used the seven TSI proxy records – the time series of [1–7]. The amplitude of the secular variation ΔTSI was taken as the standard deviation of the corresponding series. Reconstructions with ΔTSI<1.0 W×m^{-2} [2, 4, 6, 7] were considered as LV series and records with ΔTSI>1.0 W×m^{-2} [1, 3, 5] were considered as HV series.

Results

The two most up-to-date composite series of experimentally measured TSI was obtained by Dudok de Wit et al. [8]. This composite data set has two versions – the first version was based on the original TSI records (TSIU) and the second includes some instrumental corrections (TSIC). Both these composites are shown in Figure 1.

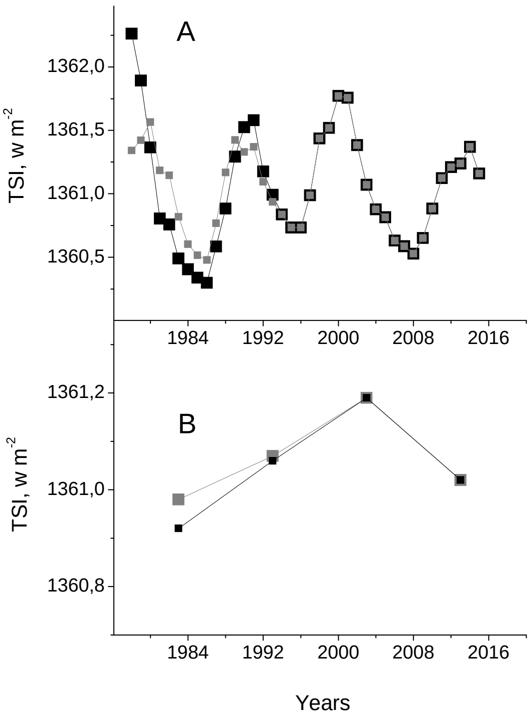

Fig. 1. A – annually interpolated TSI composites [8]. Black line – uncorrected version (TSIU); gray line – corrected version (TSIC); B – ten year averages of TSI. Black line – TSIU, gray line – TSIC.

Figure 1A shows yearly averages and Figure 1B shows ten year averages (mean values over 1978–1987, 1988–1997, 1997–2007, 2007–2015). All TSI reconstructions were normalized so that their value at the end point (1978) coincided with the corresponding value of the observed TSI averaged over decades. Thus, TSI reconstructions consisting of 115–129 points and instrumental data consisting of four points (1983, 1993, 2003, 2013) were used in analysis. Forecast of long-term changes in TSI in 1978–2015 (4 points) was produced using seven paleoreconstructions covering the last 12–13 centuries (115–129 points). The nonlinear forecasts were made using the method of analogs, suggested by Sugihara and May [9] and based on the reconstruction of the trajectory of the dynamic system of the predicted series in a pseudo-phase space. All forecasts were made using the attractor dimension d=3 and seven nearest neighbors. For each prediction the forecast error was estimated as a standard deviation between the predicted and observed records. It were performed a number of simulations in each of which the surrogate series was constructed by adding a random value to each point in the forecasted record (1983–2013). Each random value was generated by Gaussian white noise with a standard deviation equal to the corresponding value of the prediction uncertainty. Then, the probability *P* of such surrogate series describe the experimental record i.e. that (a) the 1978–2015 mean value of the expected series will have a deviation from the mean experimental series of no more than 1 W×m^{-2} and (b) the predicted series will describe a trend similar to the observed one ($TSI_{forc}(1983)<TSI_{forc}(1993)<TSI_{forc}(2003)>TSI_{forc}(2013)$) was estimated. The results obtained are shown in Fig. 2.

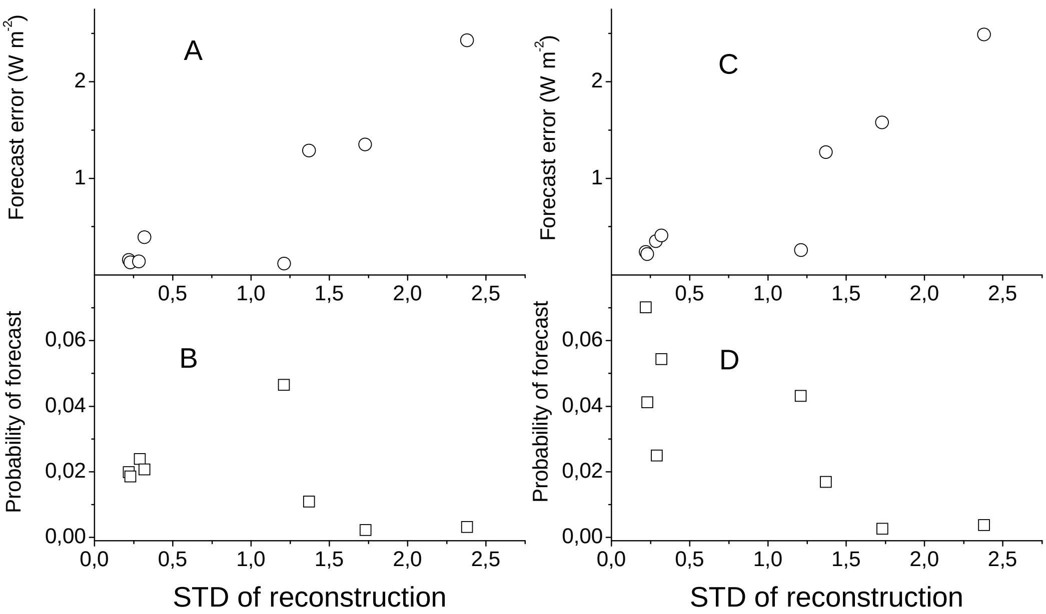

Fig. 2. Dependence of the quality of nonlinear predictions on STD of reconstructions. A – error of forecast made for TSIC; B – probability of forecast made for TSIC; C – error of forecast made for TSIU; D – probability of forecast made for TSIU.

Conclusion

The performed analysis, based on non-linear prediction, showed that:

(a) In general, the observed TSI records are better predicted by low variability reconstructions.

(b) On the other hand, the fairly reliable prediction was obtained for the TSIC record using HV reconstruction of Bard et al. (2000), which show rise of TSI by 3.6 W×m^{-2} after the Maunder minimum.

(c) All predictions obtained give a decreasing trend over the entire 40 years, which is in better agreement with the PMOD version of TSI.

However, the possibility that TSI has experienced more significant fluctuations in the past with amplitude of 1.2 W×m^{-2} (rise by 2.5 W×m^{-2} since the end of the Maunder minimum) cannot be ruled out either.

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