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Spatial and temporal variability of convective instability in the south of Western Siberia, determined on the basis of the Total Totals index (ERA5 reanalysis)

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ABSTRACT

The spatial and temporal variability of convective instability in the south of Western Siberia during the summer months of 1990–2019 was analyzed using Total Totals index values computed from ERA5 (ECMWF) data. For a 30-year period and specific decades, the spatial variability of the mean Total Totals values calculated for high atmospheric instability (by values above the 75th percentile) has been estimated. Centers with maximum values of the Total Totals index were localized for the 6, 9, and 12 UTC that approximately correspond to the beginning, maximum, and end of active convection under intra-mass conditions. The intra-decadal variability of the atmospheric convective potential was evaluated based on the Total Totals index over Western Siberia. Under changing climate conditions, the areas with the greatest changes in convective potential were identified.

Key words: convection, instability index, reanalysis, hazardous phenomena.

1. INTRODUCTION

Convective activity is known to trigger adverse and hazardous events each year such as thunderstorms, intense heavy rainfall, hail, squalls, microbursts, tornadoes, etc.[1-12]. The occurrence of such events in Western Siberia has risen considerably since the beginning of the XXI century[13-15]. There have been a number of instability indices developed to assess the risk of thunderstorm clouds and related convective hazards[15,16]. These indices provide both a qualitative and quantitative assessment of atmospheric instability.

For the south of Western Siberia, estimates of the variability of the K index had previously been obtained. In the context of global climatic changes, there has been a major rise in the degree of atmospheric instability[17]. At the same time, the Total Totals index, according to[18], has the most significant agreement with real-case thunderstorm scenarios.

The degree of instability and potential formation of convective hazards depend on the thickness of the unstable moist layer in atmosphere, which are evaluated by Total Totals index (*TT*)[19]:

$$TT = T_{850} + TD_{850} - 2T_{500},$$

where T represents temperature at the indicated level (ºC) and TD represents dew point temperature (°C).

The focus in this paper is on the analysis of the spatial and temporal variability of convective instability in the south of Western Siberia for which we have the Total Totals index during the summer months of 1990–2019 obtained from the ERA5 reanalysis.

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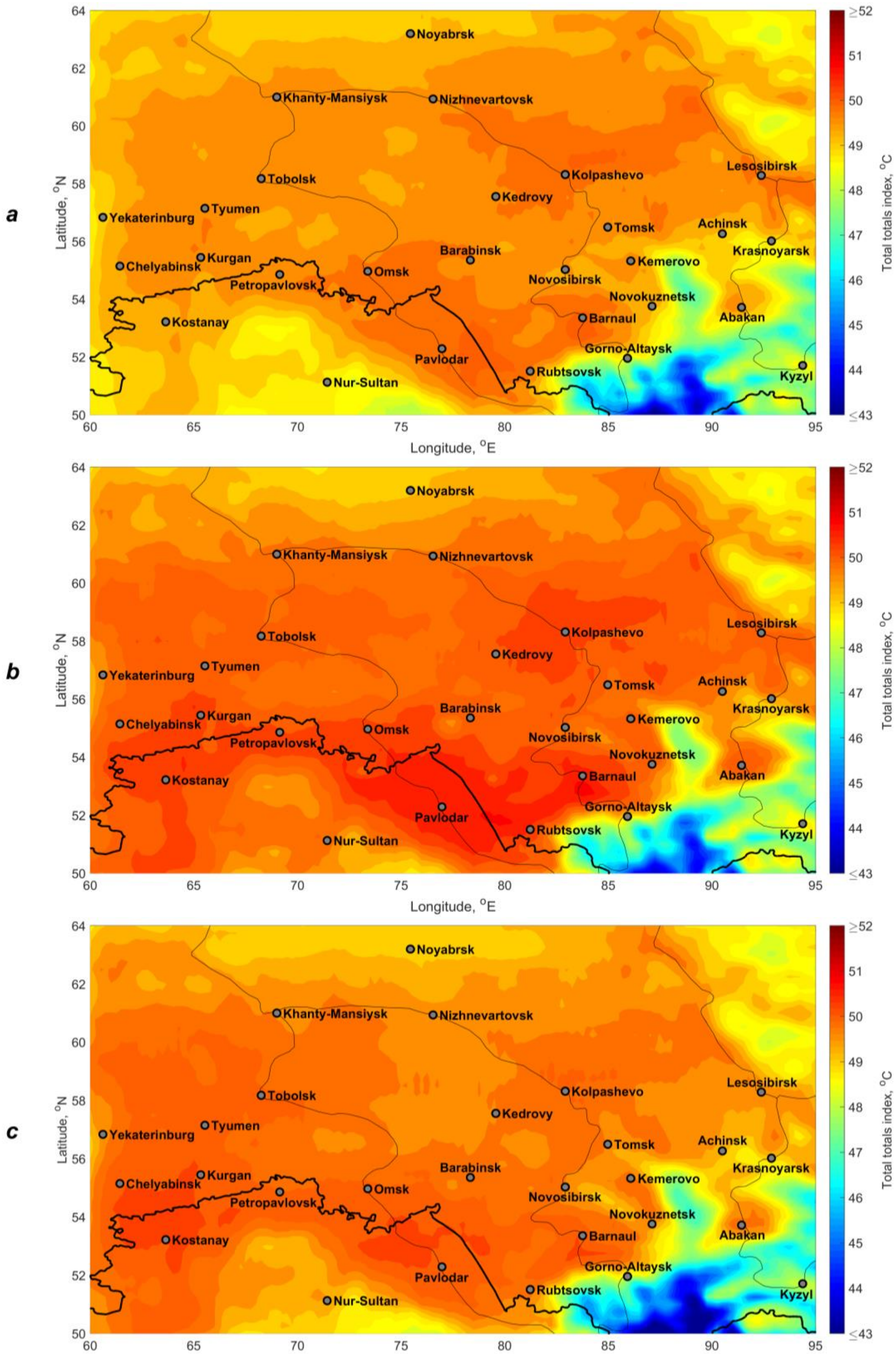

Figure 1. Spatial distribution of the mean TT values (based on ≥ 75 percentile values) for the summer months 1990–2019 at 6 (a), 9 (b), and 12 (c) UTC.

2. USED DATA AND ITS PROCESSING

ERA5 is the fifth-generation reanalysis produced by ECMWF (European Center for Medium-Range Forecasts), providing global data on many atmospheric, land-surface and sea-state climate variables. The ERA5 has a number of advantages, including a continuous series of reliable data for more than 40 years (from 1979 onward), high spatial (0.25×0.25°), and temporal resolution (1 hour)[20]. We used the Total Totals (*TT*) index from the ERA5 reanalysis, downloaded from the Copernicus Climate Change Service server[21].

Using *TT* values greater than or equal to the 75th percentile, the average values of the Total Totals index during the summer months at 6, 9, and 12 UTC has been calculated. This approach is applicable for obtaining estimates of mean *TT* values not for all synoptic conditions, namely for high atmospheric instability, under which powerful convective clouds and phenomena of convective origin are formed. The hours at 6, 9, and 12 UTC approximately correspond to the beginning, maximum, and end of active intra-mass convective activity. The computation was performed both for a 30-year period (1990–2019) and for specific decades within this period.

3. MAIN RESULTS

Figure 1 represents the spatial distribution of the mean TT values calculated using the approach described above. Determined by the vertical profiles of *TT* has a heterogeneous pattern of horizontal distribution of areas with high values, ranging from 44 to 51 °C. In the daytime, the primary area of convective instability is detected over the plain region of the upper reaches of the Irtysh and Ob Rivers along the Russian-Kazakh border, as shown in Figure 1. This center persisted during all diurnal periods. In addition to it, two more large centers can also be distinguished, located over the central part of the Tomsk Oblast and the southeastern periphery of the Urals, respectively. Between 6 and 12 UTC, the intensity of these two centers varies. Thus, the first center is more active around midday, while the second in the evening. Smaller spots with high *TT* values may be found above the Minusinsk Basin and the middle course of Yenisei River. The central parts of the Altai Mountains and the mountain ranges of the Western Sayan were marked with minimum *TT* values.

The identified positions of instability centers mapped from the ERA5 reanalysis data are in qualitative agreement with the lightning discharge density map plotted for 2016–2020 according to the WWLLN database (see Fig. 2).

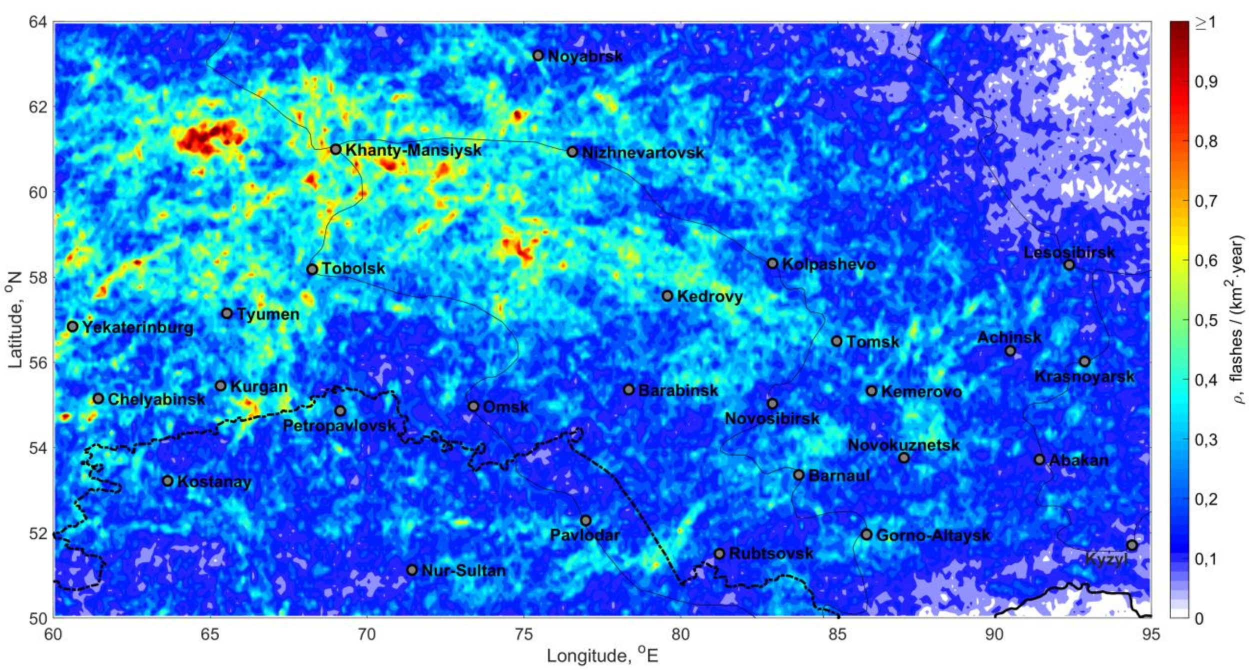

Figure 2. Spatial distribution of lightning discharge density values over the southern parts of the Urals and Western Siberia for 2016–2020.

Due to the combination of physiographic conditions and atmospheric circulation in the areas of the boggy Kondinskaya lowland and the Great Vasyugan bog, a high frequency of thunderstorms is found. The rarefied water system contributes to increasing temperature contrasts favorable for active local cyclogenesis and frontal intensification, against which deep convection with latent condensation heat release and rapid formation of mesoscale convective cloudiness and hazardous phenomena occur.

A comparative analysis of the *TT* fields for individual decades showed significant interdecadal variability of the convective potential of the atmosphere over the study area. The maximum *TT* values, as well as the maximum area with *TT* values ≥ 50 °C, calculated on the basis of the chosen approach, were observed in the period from 2000 to 2009 (see Fig. 3).

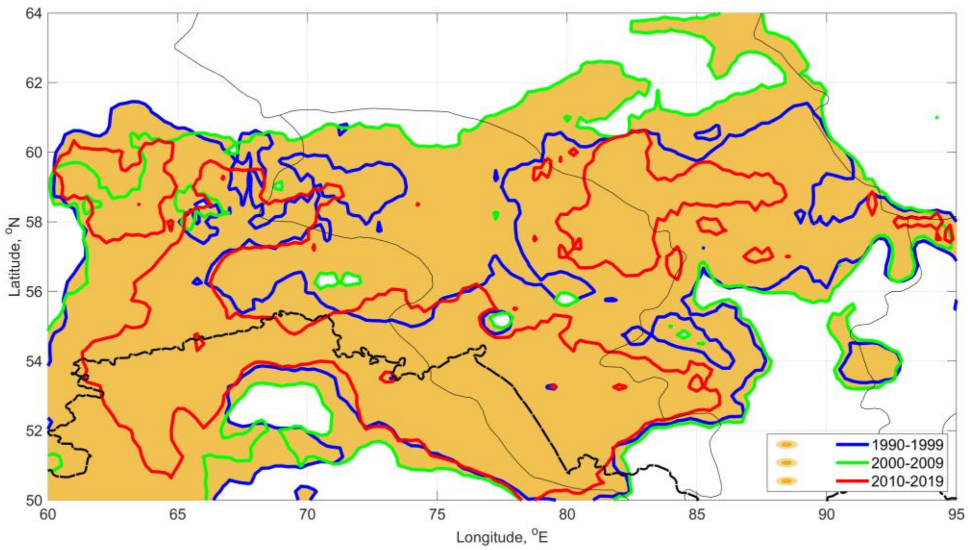

Figure 3. Location of the averaged *TT* index line ≥ 50 °C at 9 UTC for the periods.

CONCLUSION

At present time parametrization of lightning activity which connects frequency of lightning flashes with characteristics of convective cloudiness and hazardous phenomena produced by it is being introduced into climatic models, results of the presented work may be interesting and relevant in this aspect.

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