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The long-term 20th century re-analysis features over the North Atlantic-Eurasia region

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The currently available long-term 20th century re-analysis (20CR) was applied to studying particular features of the intra-seasonal and multi-annual climate variability over the Atlantic-Eurasian domain. This re-analysis shows a good consistency with observations and appears to be the sufficient tool to study surface air temperature (SAT) and geopotential height on daily to seasonal scales over Eurasia. However, a disagreement was found in the mean daily values: an underestimation in spring and overestimation in summer. The cold period of the year is characterized by the least discrepancy between reanalysis and observations. The appropriate quality of 20CR seems to be reliable before 1950 and after 1950, and it is based on the comparison analysis of the blocking events and the mean annual integral meridional drift transport. The resulting linear trends of 20CR for 140 years show a significant positive tendency over the globe, except of large parts of Europe and northeastern Pacific/North Atlantic, where a natural climate variability is prominent.

Introduction

The long-term data set called "Twentieth Century reanalysis project" (20CR) was completed within the last decade (Compo *et al*. 2011). It spreads over more than a century (1871–2012) and makes it possible to analyse the variability of hydrometeorological fields on daily-to-interdecadal time scales (Ghil *et al.* 2002, Alvarez-Garcia *et al*. 2011, Häkkinen *et al*. 2011), or to verify climate models over large historical periods (Cattiaux *et al.* 2013, Basharin *et al.* 2016).

Unlike other reanalyses, this comprehensive reanalysis is famous for a very few types of assimilated observations: only daily surface pressure, monthly sea surface temperature (SST) and sea ice extension data. Meanwhile, other reanalyses include the huge amount of assimilated satellite observations since the last decades of 20th century. Besides the objectives and strategy stated, the accuracy of 20CR data were preliminary analysed and the results were summarized in the basic research paper of 20CR (Compo *et al.* 2011), which argues that this data set is a useful resource for climate diagnostic studies as well as for model validations (Häkkinen *et al*. 2011, Bett *et al*. 2013, Msadek *et al*. 2013, Polonsky *et al*. 2017). The inconsistencies of linear trends of the surface air temperature between the observations and 20CR for the period 1979–2012 were found in the polar regions of the northern hemisphere (Polonsky

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and Basharin 2012, Parker 2011, Wang *et al.* 2013).

There are still doubts that 20CR is reliable enough before 1950 (Kruger 2012, Polonsky and Basharin 2012), when a relatively small amount of observations were assimilated. The 20CR data seem to be sufficiently accurate to reproduce the intensity of extratropical cyclones before 1950 (Thorne and Vose 2010, Wang *et al.* 2013). Thus, the previous research results indicate that 20CR reanalysis can be used for the analysis of low-frequency climate variability, with the exception of the polar regions of the northern hemisphere (Polonsky and Basharin 2012, Parker 2011). However, in the last decade there was still not enough scientific papers evidencing the quality of 20CR data on daily to seasonal scales (Allan *et al*. 2014). Therefore, recent studies focused on the comparison of 20CR with other databases, reanalyses, and observations (Stickler *et al.* 2015, Poli *et al.* 2016, Polonsky *et al*. 2017).

Among all the available variables in 20CR, the surface air temperature (SAT) has been most often discussed for different regions around the globe (Polonsky and Basharin 2012, Allan *et al.* 2014, Stickler *et al.* 2015). Their results endorse the robustness of global warming (Pachauri *et al.* 2014). Yu *et al.* (2014) focused on decadal modulations of wintertime land-surface air temperature and atmospheric circulation in the Northern Hemisphere. The patterns found appear to be broadly similar to the leading modes of the decadal climate variability, although the 20CR simulated patterns are generally smoother spatially and weaker in intensity compared with those in the NCEP reanalysis.

The variability of the wind speed across Europe was discussed from the point of view of European storminess over the past 140 years by Bett *et al.* (2013). It states that there is no evidence on well-defined long-term trends in the 20CR wind speed over Europe, and its variability was found to be quite large between different decades. Later, the same authors examined the applicability of their research results for a wind industry in Europe (Bett *et al.* 2014). The performance of 20CR in reproducing observed monthly precipitation rate over the globe is very high (Lee and Biasutti 2014) in comparison to that of comprehensive reanalyses that also assimilate upper air and satellite observations (like ERA and NCEP/NCAR).

The geopotential height and sea level pressure are very common variables in the diagnosis of cyclone/anticyclone activity, being the main parameters used in representing the atmospheric circulation within extratropical latitudes in 20CR. For example, these fields are associated with various indices reflecting the changes of atmospheric circulation: the position and intensity of the centers of action, the storm track activity, etc. These changes play a key role in the water vapor transport in mid-latitudes (Barnston and Livezey 1987, Sutton and Hodson 2005, Stankunavicius *et al.* 2012, Rudeva *et al*. 2014). In particular, blocking events detected by latitudinal differences in the geopotential height at the 500-mb level (Z500) are under considerable interest because of their association with long-lived weather and also climate anomalies (Stankūnavičius *et al.* 2017, Häkkinen *et al.* 2011). Such blocking events lead to extremely cold winters (such as in 1962/1963 or 2009/2010) or hot and dry summers (e.g. 2003), accompanying a loss of life and substantial negative economic impact attracting attention of climate scientists, meteorologists and policy makers (Häkkinen *et al.* 2011, Pachauri *et al.* 2014).

The oceanic meridional heat/mass transport and its variability in North Atlantic is an important part of climate change studies (Knight *et al.* 2005, Msadek *et al.* 2013, Polonsky *et al.* 2017). The integral meridional drift transport (IMDT) obtained according to the Ekman relations plays a key role in oceanic transport in the Atlantic (Polonsky and Krasheninikova 2011). The IMDT variability has an impact on basin-wide SST anomalies and is therefore able to alter the position and depth of atmospheric centers of action as well as the main characteristics of storm tracks over the North Atlantic (Sutton and Hodson 2005, Häkkinen *et al.* 2011, Stankūnavičius *et al.* 2017). Hence the annual heat/mass IMDT surely influences the low-frequency climate variability superimposed by anthropogenic warming around the globe (Pachauri *et al.* 2014). Accurate and more realistic IMDT values are some of the ways in assessing the performance of coupled ocean–atmosphere models (Msadek *et al.* 2013).

A number of studies use 20CR for assessing the climate variability during the reanalysis record time and its link to the improved risk assessment, climate projections and environmental protection. Therefore, the main motivation of our study was to: (1) to examine the intra-monthly statistics and differences between the daily 20CR and observations (SAT and 500-mb geopotential height) over the Eurasian domain, (2) to trace the consistency in long-term atmosphere-ocean characteristics, such as the mean integral meridional drift transport and blocking frequency before and after 1950, and (3) to assess the global linear trends based on 20CR for 140 years. These three items are dealt within the "results and analysis" section. The "data and methods" section describes the data and methods used in this study. The discussion and conclusions are provided in the final section of the paper.

Data and methods

The Twentieth Century Reanalysis version 2 (20CRv2) data used in this study were retrieved from the 20CRv2 project website. This data set is available for daily and monthly temporal scales and for two-degree longitude-latitude horizontal resolution at 28 vertical levels for the period 1871–2012. In the 20CR data set, only the surface pressure, monthly SSTs and sea ice distribution were assimilated and assumed as boundary conditions. It is worth mentioning that a 56-member ensemble was used to estimate the uncertainty in the 20CR data set (Compo *et al.* 2011). The 20th Century Reanalysis data were provided by NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their web site at http://www.esrl.noaa.gov/psd/. Support for the Twentieth Century Reanalysis Project data set is provided by the U.S. Department of Energy and by the National Oceanic and Atmospheric Administration.

The surface data for verification taken from the conventional observations network were compared with neighboring gridded 20CR data over the Eurasia region. The SAT data for the selected stations of the observational network were downloaded from the KNMI Climate Explorer (http://eca.knmi.nl): Kiev, Vilnius, Berlin, Milan, Kazan, Blagoveschensk, Tomsk, Borzja, Paris, Yakutsk, Odessa and Chita (Table 1). These stations have the longest records comparable to the 20CR data set length, and that is why they were chosen for the analysis. All the selected stations represent different natural zones in midlatitudes: from different types of taiga (Yakutsk, Tomsk) and steppes (Chita, Kazan, Odessa) to temperate broadleaf (Paris, Berlin, Milan) and mixed (Kiev, Vilnius) forests. In general, the database was described in detail in Tank *et al*. (2002).

Table 1. List of the used meteorological stations, their locations with 20CR grid points analogous and their dependence to particular Eurasian domains.

Domain	Station name	Location of stations	Nearest 20CR grid point
Western Eurasia			
	Kiev	50.4°N, 30.5°W	50°N, 30°W
	Paris	48.9°N, 2.4°W	48°N, 2°W
	Berlin	52.4°N, 13.3°E	52°N, 14°W
	Vilnius	54.7°N, 25.2°E	54°N, 26°W
Eastern Eurasia			
	Borza	50.2°N,116.3°E	50°N, 116°E
	Yakutsk	62.0°N,129.4°E	62°N, 130°E
	Tomsk	56.3°N, 84.5°E	56°N, 84°E
	Blagoveschensk	50.1°N, 127.3°E	50°N, 128°E
	Kazan	55.4°N, 49.1°E	56°N, 50°E
	Chita	52.0°N,113.3°E	52°N, 114°E
Stations not included the domains listed above	Milan	45.3°N, 9.11°E	46°N, 10°E
	Odessa	46.3°N, 30.3°E	46°N, 30°E

Integrated Global Radiosonde Archive (IGRA) consists of radiosonde and pilot balloon observations at many stations around the world with varying periods of record, many of which are extended from the middle of the 20th century to the present. They are at the standard and significant levels, as well as at the surface and tropopause. The IGRA data set combines as many reliable data sources as possible into one archive, applies quality assurance algorithms that remove gross errors in the data, and puts into place an automatic system for updating the resulting archive on a daily basis. In its final form, IGRA is the largest and most comprehensive data set of quality-assured radiosonde observations that is freely available (Durre *et al.* 2006). The IGRA data were used for the comparison of analysis with the 20CR Z500 data.

The following meteorological stations have been selected for the Z500 comparison between two data sets, 20CR *vs*. IGRA: Kiev, Berlin, Kazan, and Chita (Table 1). These stations have the longest records since the middle of 20th century and the least amount of gaps, which is why they were chosen for the analysis. In general, for each station the mean daily difference between the SAT and Z500 were defined to estimate the possible bias between the upper air and surface observations and 20CR data set for the Twentieth Century and beyond. This mean discrepancy between observations and 20CR data set is associated with the mean daily error in the reanalysis and can contribute to the conclusions of the risk assessment and environmental protection. The standard statistical characteristics for 20CR and observations, namely mean, standard deviation and their correlations were defined in this study. The stations were also grouped into two domains: Western and Eastern Eurasia, responding to the results of their similarities in climate characteristics and correlations.

The largest disagreement of the SAT was found for the Odessa and Milan stations, which is why they were analysed separately and not included into the Western/Eastern domains (Table 1). It seems that this disagreement arose mainly from the orography and sea-land gradient differences in the atmosphere on regional scales. Moreover, the maximum distance between the hydrometeorological stations and the nearest grid points of reanalysis is less than 50 km, which is not negligible for these stations.

Two periods before and after the middle of the 20th century were characterized by very different number of assimilated data (Compo 2011, Feuchter *et al.* 2013, Allan *et al.* 2014, Stickler *et al.* 2015). Therefore, differences in the seasonal blocking and mean annual IMDT climatology in the North Atlantic are worth to be determined between above mentioned periods. These climatic parameters have a great impact on the North Atlantic-Eurasia climate variability (Häkkinen *et al.* 2011, Knight *et al.* 2005). The blocking frequency was defined according to the blocking index calculation methodology described in detail by Tibaldi and Molteni (1990), which is based on the daily values of the meridional gradients of Z500.

The mean annual IMDT is associated with the time-varying Ekman transport at each latitude in the North Atlantic region (Boning *et al.* 2001). It was detected over the larger North Atlantic region extending from 6°N to 60°N using monthly sea level pressure data. We defined the mean annual IMDT by integrating mass transport values in each grid point between America and Africa/Europe coastlines' shape according to the calculation procedure described in detail in Polonsky and Krasheninnikova (2011). The estimates of IMDT differ among different authors due to the chosen method of experimental data assimilation in reanalysis, the tangential wind stress calculation techniques that forces the ocean circulation, and the space-time smoothing of the used data (Hall and Bryden 1982, Harrison *et al.* 1989, Fillenbaum *et al.* 1997, Josey *et al.* 2002, Polonsky and Krasheninnikova 2011, Polonsky *et al.* 2017).

The linear SAT trends were calculated using the 20CR data set. Their latitudinal averages for the late 20th century were considered to be far from the truth, particularly for the polar regions (Rayner *et al.* 2003, Parker 2011). Therefore, the area of trend calculation was done between the latitudes 70°N and 70°S. The decision about significance of all defined statistical values in this study was made at the 95% confidence level, according to Student's *t*-test. Therefore, only significant changes estimated with $p > 0.95$ were highlighted. All the statistical characteristics and indices were performed using standard algorithms.

Results and analysis

Variability on intra-monthly scale

Permanent efforts to ensure the right representation of the broad scale of variability and statistical momentums of 20CR recently were performed in Allan *et al.* (2014), Basharin *et al.* (2014), Stickler *et al.* (2015). The daily SAT and Z500 for the selected stations of the observation network (listed in Table 1) were compared over months with neighboring re-analysis grid points over the Eurasian region. We studied the statistical momentums (mean, standard deviation, correlations between 20CR and observations) for the western and eastern parts of Eurasia separately.

Correlations between SAT data in 20CR and observations found to be very high and statistically significant: 0.9 and higher for both western and eastern parts of Eurasia. This confirms the results of Allan *et al.* (2014). As for the Z500 field, the correlations found appear to be different for the western and eastern parts of Eurasia (Table 2). In the western part they exceed 0.9 year round, while over the eastern part the correlations vary between 0.65 and 0.9. The standard deviation (between SAT/Z500 and station observations) remains, in general, stable in each month of the year. It lies within an interval of 6–13 °C for SAT and 50–150 geopotential meters (gpm) for Z500 over both parts of Eurasia.

The mean daily difference of SAT for the selected stations (Table 1) was less than 1–2 °C during October-March, and more than two times this value during the other months (Fig. 1). In spring, a good coincidence was found between the daily values of 20CR and observations in the western part of Eurasia, but poor in the eastern part. The largest SAT disagreement was found for the Odessa and Milan stations. Their mean daily difference reached up to 8–12 °C during April-July and originated probably from orography and sea-land differences. Therefore, these two stations were analysed separately and were not included into the Western/Eastern Eurasia domains. It is worth mentioning that the large mean daily difference in Z500 was also found during the spring and summer time.

The mean daily difference of Z500 for the other stations was about 10–25 gpm during October–March, while it usually exceeded 30 gpm in spring and following summer period (Fig. 1). The Eastern Eurasia was also characterized by a high mean daily difference in Z500 and SAT during the spring-summer time.

It is worth noting that the daily values of SAT/Z500 for 20CR were underestimated by up to 3 °C/ 30 gpm on average in spring, while they are overestimated during the summer time. The cold period of the year was characterized by the

Table 2. Monthly mean correlations between daily means of Z500 in 20CR and observations and their standard deviations (STD: STD_20CR for 20CR and STD_Obs for observations) in Western and Eastern Eurasia regions.

Months	Western Eurasia			Eastern Eurasia		
	Correlation	STD_20CR	STD_Obs	Correlation	STD_20CR	STD_Obs
1	0.935	78.925	131.549	0.855	100.254	102.382
2	0.950	68.220	95.597	0.762	130.733	153.966
3	0.967	56.754	110.174	0.886	123.956	122.970
4	0.942	51.419	142.963	0.680	80.163	93.288
5	0.833	64.521	105.753	0.821	60.854	75.194
6	0.931	59.081	62.439	0.652	61.382	74.383
7	0.868	50.270	50.188	0.764	47.329	55.887
8	0.984	45.246	63.476	0.790	104.358	105.029
9	0.974	52.160	85.374	0.838	133.640	139.881
10	0.972	41.304	64.255	0.833	92.800	104.781
11	0.976	64.145	123.518	0.901	128.893	134.752
12	0.989	69.568	118.406	0.865	156.240	181.385

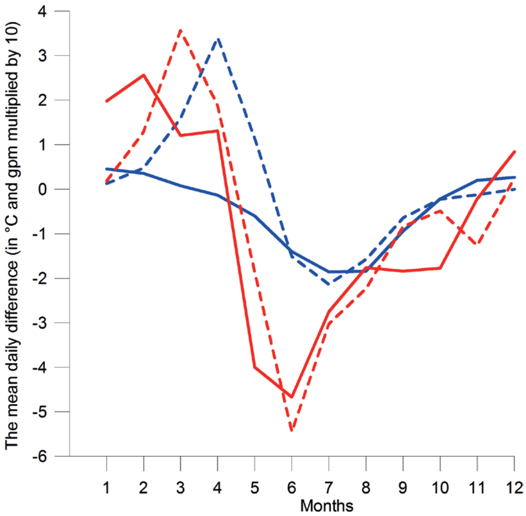

Fig. 1. The mean daily difference (in °C and gpm multiplied by 10) of surface air temperature (blue lines) and Z500 (red lines) for each month (January "1", February "2" and so on) of a year over the Western (solid lines) and Eastern (dashed lines) Eurasian regions (*see* also Table 1).

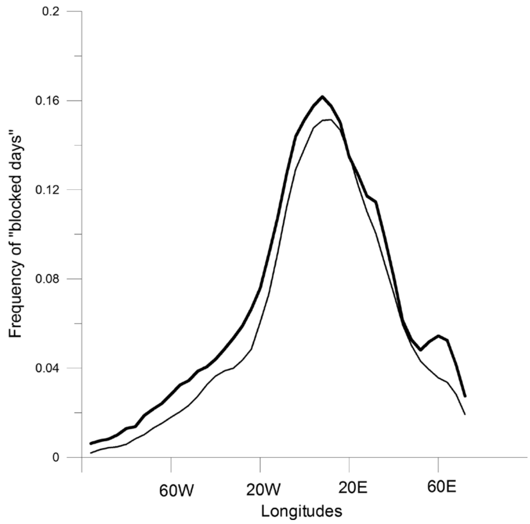

Fig. 2. The mean blocking frequency per cold season over the North Atlantic-European domain before 1950 (thin line) and after 1950 (thick line). There are no significant differences at any particular longitude (at the 0.05% level).

least difference in the SAT/Z500 daily values between the reanalysis and observations.

Comparison of blocking frequency and IMDT before and after 1950

The blocking frequency is sufficiently well reproduced in the North Atlantic–European region according to 20CR data since 1950 (Häkkinen *et al.* 2011). However, there still are doubts that 20CR is reliable enough before 1950 (Kruger 2012). This period is represented by the limited number of assimilated observations in 20CR and it leaves the dispute how reliable is the reproduced blocking frequency (Wang *et al*. 2014, Basharin *et al.* 2014). Contradictions between these two periods can become evident when analysing the frequency of the blocking events before and after 1950 for the North Atlantic–European region. The curves for the mean blocking frequency for different longitudinal belts during the periods 1871–1949 and 1950–2012 hardly differ from each other (Fig. 2), the difference being not statistically significant at the 0.05 level. The largest differences in the curves is seen in the longitudes over the middle North Atlantic and in the easternmost European longitudinal band (50°–60°E). The curve representing the 1871–1950 period is characterized by a smoother shape in the Atlantic-European region, probably because of the paucity of assimilated data for this period.

The other example of the 20CR permanent signal representation before and after 1950 is the mean annual IMDT and its latitudinal variation over the North Atlantic (6°–60°N) (Fig. 3). The local IMDT minimum was found over the intertropical convergence zone (8 Sv) and its maximum at 14°N (16 Sv) where the north-east trade winds prevail. The mean annual IMDT monotonically decreased further north and the second minimum (4 Sv) was situated at the latitudinal belt of around 40°N where the western transfer zone starts to dominate. The difference between curves before and after 1950 is statistically insignificant and the detected variability of the mean annual IMDT (Fig. 3) coincides with the IMDT values defined using NCEP reanalysis (Polonsky *et al.* 2017).

Global linear trends for 1871–2012

The linear SAT trends based on 20CR data set

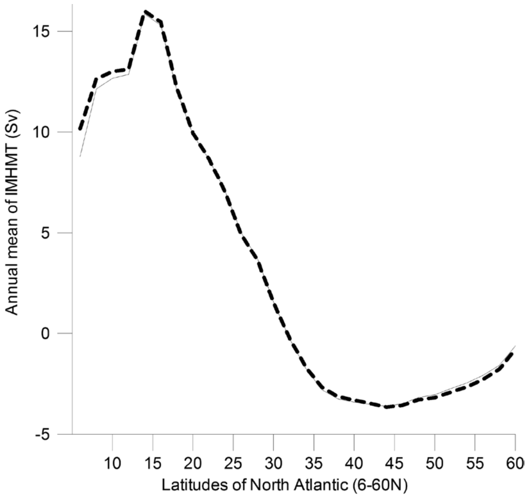

Fig. 3. Mean annual integral meridional mass transport (Sv) for the North Atlantic (6°N–60°N) before 1950 (thin line) and after 1950 (dashed line). There are no significant differences at any latitude (at the 0.05% level)

were widely analysed over particular regions for the past centuries (e.g. Polonsky and Basharin 2012). In the greater part of the globe (Fig. 4) between latitudes 70°N and 70°S, the typical values of the trends were in the range from zero to 2 °C/century during the summer and winter seasons. The linear trend exceeded 7–8 °C/century over the high (north and south) latitudes. The maximum 20CR SAT trends were detected in the polar regions (12 °C/century) (Fig. 4).

During the winter season, there were no negative SAT linear trends over the globe. The maximum value of the trend exceeded 3–4 °C/century in the northwestern part of North America and 2–3 °C/century in the central part of Eurasia. During the summertime the negative linear trends were found in few regions: over Eurasia, North/South America and northeastern parts of North Pacific and North Atlantic. Their typical values varied from –1 °C to 0 °C per century, however they were statistically insignificant. The prevailing global-scale SAT trend was small but preliminary positive (Fig. 4). In total, the observed variations in the linear SAT 20CR trends confirm the results of the report of the Intergovernmental Panel on Climate Change (Pachauri *et al.* 2014), where much faster rate of the warming in the high latitudes is reported.

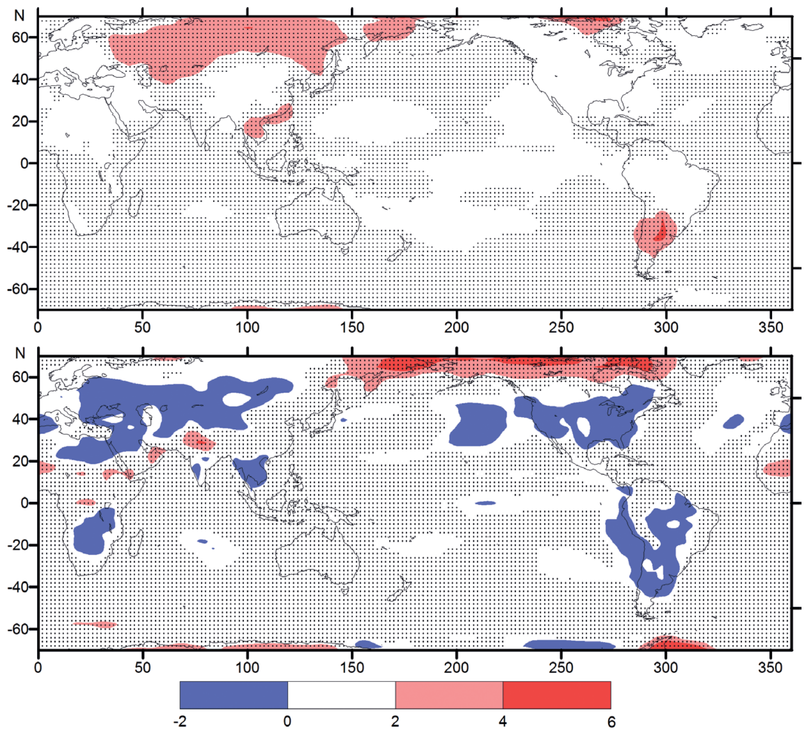

Fig. 4. 20CR linear surface air temperature trends (°C/century) in winter (top) and summer (bottom) for 1871–2012. Dotted area corresponds to the trends that are significant at the 0.05% level.

Discussion and conclusions

The following features of the 20CR were found in this study over North Atlantic-Eurasia region: high correlation coefficients (0.7–0.99) of the SAT/geopotential heights between 20CR and observations at selected points on daily to seasonal scales suggest appropriate quality of 20CR in mid-latitudes over Eurasia. The high correlations however confirm only the good agreement in phase but not in magnitude. The daily values of the SAT/geopotential height of 20CR were found to be underestimated by a factor of up to 2–3 during the spring season. At the same time, they seem to be overestimated in the summertime. The cold period of the year was characterized by the least mismatch of daily values between reanalysis and observations. Similar findings were also traced in Feuchter *et al.* (2013) and Allan *et al.* (2014).

Our study confirms the already well-documented large differences in the daily data between reanalysis and observations for the spring-summer period for the surface as well as for the upper-air variables. Arguably, this tendency can be associated with a poor representation of the convective precipitation, or with the poor land sub-model for a warm period (Efimov *et al.* 2015, Rybka and Tost 2014). The 20CR performance in reproducing the observed total precipitation rate is quite high (Lee and Biasutti 2014) in comparison with the more comprehensive re-analyses, like ERA and NCEP/NCAR. Therefore, the careful considerations needed to be done when using the daily SAT/Z500 data for the spring-summer period.

The stations that belong to the western part of Eurasia showed better agreements with the 20CR daily data than those in the Eastern Eurasia. Such a result is likely due to the greater amount of assimilated data in the western part than in the eastern part of Eurasia.

The presented analysis and other research results (Häkkinen *et al.* 2011, Stankūnavičius *et al*. 2017, Polonsky *et al.* 2017) show the proper blocking and IMDT climatology in 20CR data for the periods both before and after 1950. In particular, the annual mean of the IMDT based on NCEP/NCAR is also characterized by a local minimum over the ITCZ, maximum (18 Sv/1.6 PW at 12°N) in the area of the northeast trade winds, and a monotonic decrease up to the other minimum (approximately at 40°N) on the western transfer zone (–2.3 Sv/–0.12 PW) (Polonsky *et al.* 2017). However, this paper also shows that there are some differences of the 20CR and NCEP/NCAR IMDT curves over ITCZ zones. The results of this study suggest the lower quality of the 20CR data set (and also ERA-20C) in the low latitudes of the World Ocean. The reason for such data set quality is an insufficient number of assimilated observations (in comparison with mid-latitudes) into reanalysis and the sensitivity of assimilation procedures to the surface pressure observations errors (Tank *et al.* 2002, Allan *et al.* 2014, Stickler *et al.* 2015). It should also be noted that the IMDT variability in low latitudes based on the NCEP reanalysis seems to be larger than that of 20CR reanalysis (Polonsky *et al.* 2017).

Significant differences noted between the SAT trends north of 70°N and south of 70°S suggest careful 20CR data use over the poles for climate diagnostic studies. The insufficient observation data assimilated into reanalysis was found to be the main reason of such discrepancy (Rayner *et al.* 2003, Parker 2011, Polonsky and Basharin 2012). In other geographical areas, the 20CR data can be surely used for related climate studies. Over larger part of Europe, Pacific and North Atlantic, the 20CR linear trends were found to be statistically insignificant. These regions partly coincide with the tracks of the intense natural cyclone activity.

The linear trends and correlations for the Eastern European region in terms of comparison between observations and 20CR were already discussed in Polonsky and Basharin (2012). This paper states that the difference between observation and 20CR can be treated as negligible. Correlation coefficients of SAT between the observations at meteorological stations and 20CR exceeded 0.9. However, particular disagreements were also found between data sets in mountainous and coastal areas during the winter season over Carpathians and Black Sea coast, respectively. The linear SAT trends in these regions differed also from each other (0.2315 °C/century in observations and 2.1507 °C/century in 20CR). Such results on local and regional scales could be influenced by the orography and sea-land differences, and 20CR is unable to capture the observed regional climate variability. In total, the prevailing linear trends (Fig. 4) on regional and global scales were preliminary positive and statistically significant over a large part of the globe, demonstrating the robustness of global warming (Pachauri *et al.* 2013, Rudeva *et al*. 2014).

In this paper, the definite features of 20CR were delineated and discussed preliminary for the North Atlantic-Eurasia region. The 20CR data set and daily observations do not substantially diverge during a cold period of the year, while significant disagreements were found during the spring-summer period. The analysis of the selected climate characteristics (blocking and IMDT climatology) revealed that the observed differences are statistically insignificant both before 1950 and after 1950. It supports the results by different authors (Allan *et al.* 2014, Yu *et al.* 2014, Stickler *et al.* 2015), arguing that the 20CR surface and upper air data are consistent with the other re-analyses and observations at the major time scales. As a whole, the presented analysis and related studies revealed that 20CRv2 is a comprehensive data set with a new approach in contemporary reanalyses (Compo *et al.* 2011) that leads to good results over the past centuries (Häkkinen *et al.* 2011, Feuchter *et al.* 2013, Allan *et al.* 2014, Polonsky *et al*. 2017).

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