We would like to thank the reviewers for the thorough reviews and detailed comments. Here we provide answers to the questions raised in the reviews.
Comments of the reviewers are in blue, our answers are in green, and corrections in the paper text are in black.

Reviewer 1.

I urge the authors to carefully read section 3.3 in Vinther et al., 2010 and adopt a similar line of thinking – if not adopting a similar approach to dividing the seasons.

We changed the method for the seasons dividing following the recommended paper. The results of the new records analysis are discussed below at the answers to the reviewer 2.

I can't find any references of which data is used for NAO, AO and AMO. Please make sure to check all data for references and describe the climate indices in the data section, including definitions and data sources.

References for all the data sources had been presented in the table 1 in all the versions of the paper. We broadened the data section with the description of the indices. AMO index was excluded from the paper following the suggestion of the reviewer 2.

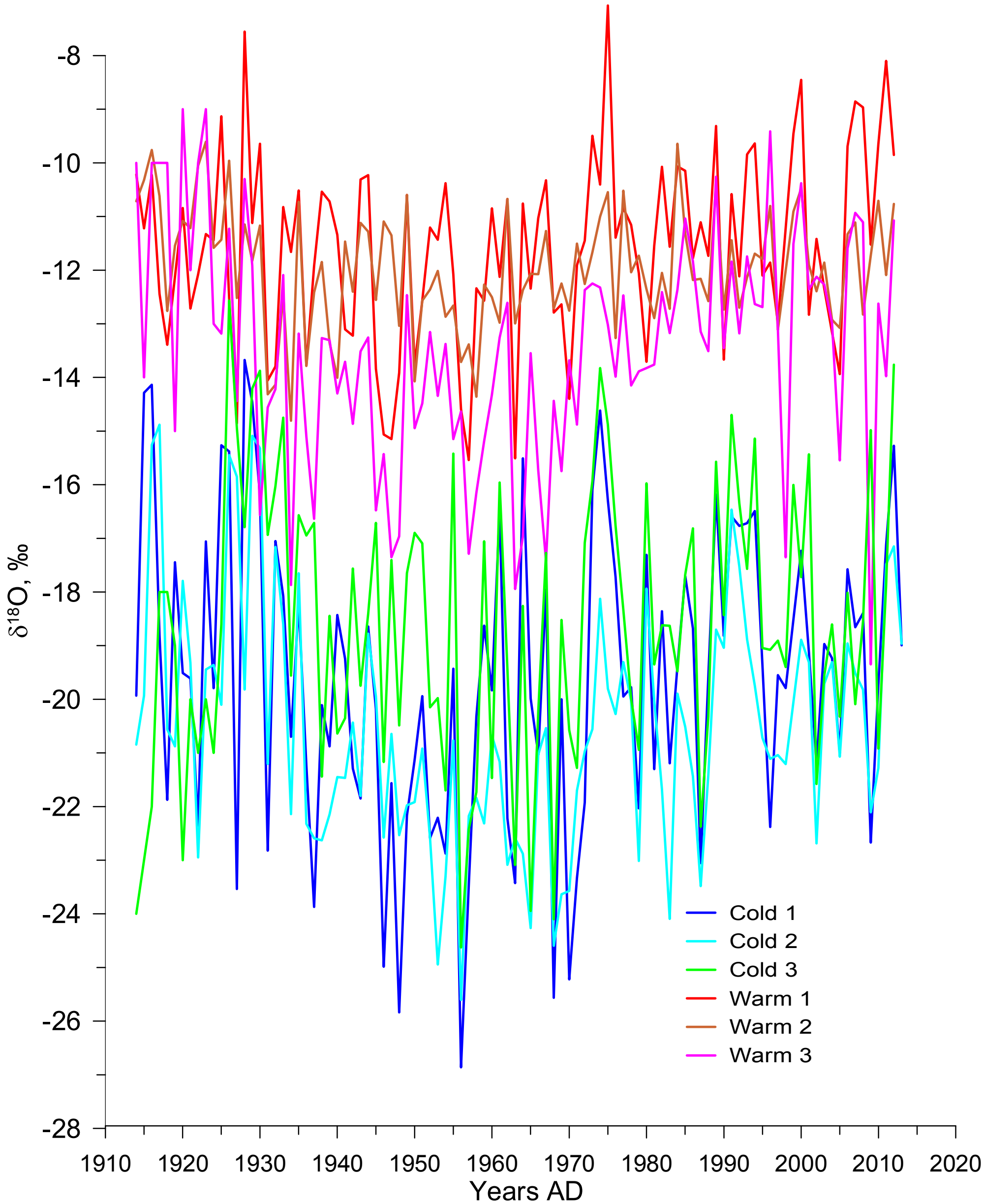
Circulation of the atmosphere influence sufficiently isotopic composition of the ice cores (Casado et al., 2013 and references therein). Atmospheric circulation quantitatively characterized by circulation indices. In this research we used three indices: NAO, AO, NCP that are widely used to characterize European climate (Jones et al., 2003, Thompson and Wallace, 2001, Brunetti et al., 2011 and references therein). Time span and references for the indices are presented in table 1.
NAO (North-Atlantic Oscillation) characterizes type of circulation in Europe, strength of Azores maximum and Icelandic minimum. Positive values of NAO index correspond to lower than usual value of atmospheric pressure in Iceland and higher that usual value of atmospheric pressure at Azores. Negative index correspond to less prominent centers of action in the Norrthern Hemisphere. Usually this index is calculated as difference of atmospheric pressure measured at Reykjavik and Lisbon, Ponta Delgada or Gibraltar. Here we used data from (Vinther et al., 2003 and https:\\crudata.uea.ac.uk\~timo\datapages\naoi.htm) that were calculated using data from Gibraltar station. Negative NAO leads to increase of precipitation rate in Southern Europe, positive NAO leads to increase of precipitation rate in Northern Europe (Hurrel, 1995, Jones et al., 2003, Vinther et al., 2003).
Arctic Oscillation index (AO) also is a characteristic of the Northern Hemisphere circulation. It is used to analyze climatic variability with periods longer that 10 years. It is calculated as EOF of 500 hPa surface. Negative valued correspond to high pressure at the Pole and cooling of Europe, while positive values correspond to low pressure at the Pole and drying of Mediterranean (Thompson and Wallace, 2001). We used AO data from NOAA (http:\\www.cpc.ncep.noaa.gov\products\precip\CWlink\).
NCP (North-Sea Caspian Pattern) index is less widely used, though it was proved that it is convenient to use it in Mediterranean climate studies (Kutiel et al., 1997; Brunetti et al., 2011). The index is

calculated as normalized difference of geopotential heights between Caspian and Northern seas. Positive values correspond to stronger meridional circulation in Europe and lower summer temperatures, Negative values reflect strengthening of zonal circulation and higher summer temperatures in Europe (Brunetti et al., 2011). We used NCP data from NOAA (http:\\www.cpc.ncep.noaa.gov\products\precip\CWlink\).

Reviewer 2.

Separation into seasonal data: Main point of concern.
Only once this issue is properly solved, the points discussed later on should be addressed because some of the current results/values might change significantly (not necessarily though).

We tried three seasons' separation methodologies: using the fixed value as it was in the previous version of the paper, method used by Mariani et al., 2014 and by Vinther et al., 2010. The method of Vinther et al was slightly changed in order to avoid ascribing minima to the warm season and maxima to the cold season. But we stacked to having the minima and maxima in the middle of the corresponding season as it is in accordance with meteorological data showing minimum temperatures in Jan-Feb and maximum temperatures in Jul-Aug. Here we compare three versions of warm and cold seasons interannual variations of δ18O and accumulation rate. Though the differences are sufficient (fig. A1 and A2), none of the methods led to finding persistent correlation between δ18O and air temperature.



δ18O, ‰
-8
-10
-12
-14
-16
-18
-20
-22
-24
-26
-28
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Years AD
Cold 1
Cold 2
Cold 3
Warm 1
Warm 2
Warm 3

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Fig. A1. Interannual variations of δ18O in cold and warm seasons using different dividing methods. Number in the legend refer to the different dividing methods: 1 – method of Vinther et al., 2010; 2 – method of the fixed threshold; 3 – method of Mariani et al., 2014.

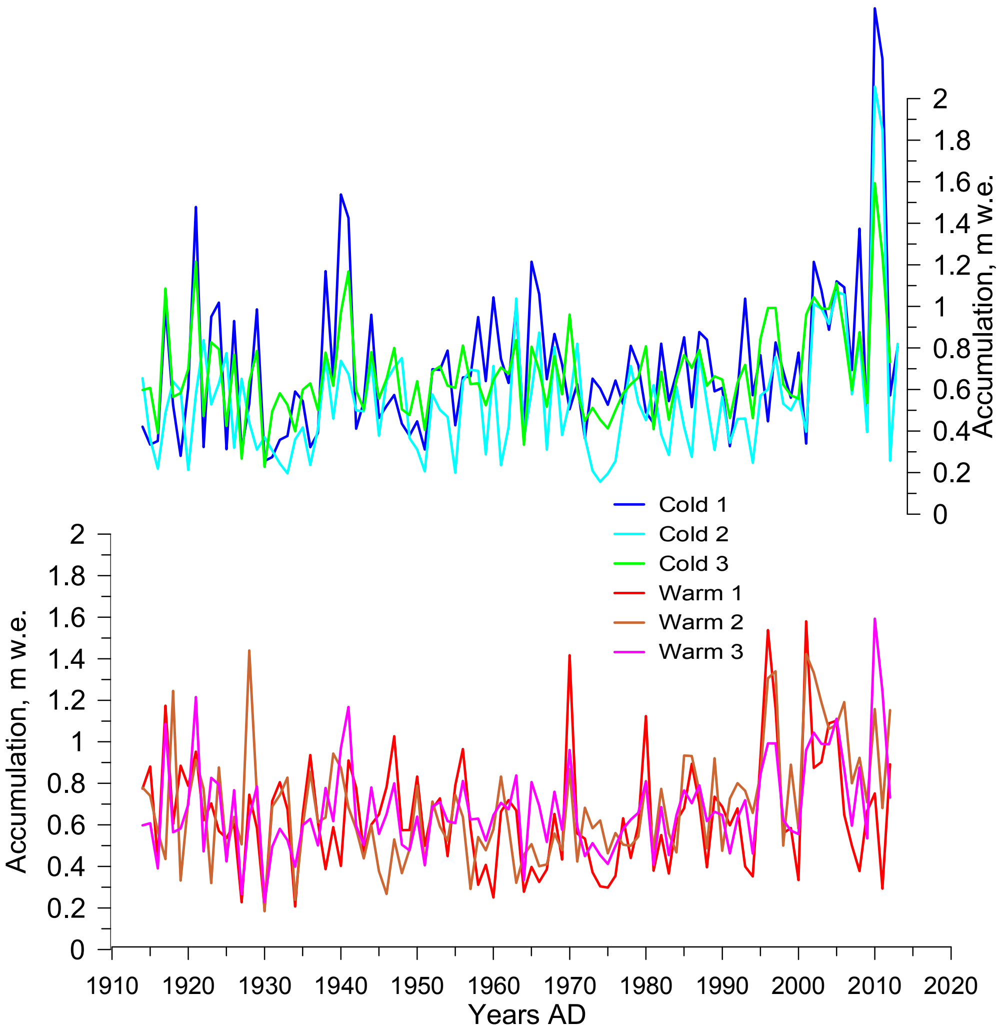

Fig. 2A. The same as fig. 1A but for the accumulation rate.

In the current version of the paper we changed the separation method following the Vinther et al., 2010, also using the ammonium data as an independent marker according to criteria described in (Mikhalenko et al., 2015).
We added this point to the dating section. The fig. 3 was also changed.

2.1.4 Dating

The chronology is based on the identification of annual layers. These are prominent in δ18O with the average seasonal amplitude of 20 ‰. For annual mean values we calculated averages of δ18O from one minimum of this parameter to another one as well as from one maximum to another. As we found no significant differences between the records obtained with two ways of year allocation we use minimum to minimum dating as more common one. We compared annual layers counting performed independently using the seasonal cycles in the isotopic composition and the ammonium concentration. The discrepancy between two independent chronologies is 2 years at a depth of 126 m. We used the dating based on the isotopic composition data in this paper. This dating is also best fit for the correlation analysis with the meteorological data. Hereafter, we focus our analysis on one century, from 1914 till 2013, which corresponds to the upper 126 m of the core. This period has been chosen because of relatively small dating uncertainty and the availability of other records such as local meteorological observations. At the bottom part of the core the isotopic composition cycles are less prominent and cannot be used for dating, consequently the dating uncertainty is sufficiently higher. The isotopic composition of that part of the core will be discussed elsewhere. In meteorological data we used average values from January to December of each year for the comparison with annual means of ice cores parameter.
For warm and cold seasons allocation we used slightly adapted method from (Vinther et al., 2010). The original method requires ascribing of equal accumulation rate for warm and cold season of each year. We changed the borders between the seasons when needed in order to avoid ascribing minimum of δ18O to the warm season and maximum to the cold season. We stacked to keeping the extreme values in the middle of the season as this is in coherence with meteorological data. We also used ammonium concentration as an independent marker, using criteria described on (Mikhalenko et al., 2015). For equivocal situations, we also used additional data: melt layers and dust layers (used to identify the warm season) (Kutuzov et al., 2013) as well as succinic acid concentration data that also have seasonal variations (Mikhalenko et al., 2015).
Figure 3 illustrates the identification of seasons using the isotopic composition seasonal cycle. In meteorological data we used period from November to April for the cold season and period from May to October for the warm season.

Following the suggestion of the reviewer we added annual mean data to all the sections in the paper. When studying the annual means we also tried two versions of the dating. We calculated mean values from minimum to minimum in the ice core data and from Jan to Dec in meteodata. And we did the same from maximum to maximum and from Jul to Jun. As we didn't find any difference in using these records we present the dataset obtained by the min-min dating as more commonly used one.

Other major comments:

Seasons and summer winter definition:

The terms summer and winter are used for the ice core data separated into two seasons (e.g. in the Abstract line 404). Since the year is thereby divided in two seasons only this can certainly not be correct. The authors do give a definition of summer (May-Oct) and winter (Nov-Apr) rather late in the manuscript. Nevertheless, this definition is very uncommon and certainly extremely confusing. I suggest sticking entirely to the term warm/cold season with this term being defined in the very beginning of the manuscript (indicate months belonging to the respective seasons).

We changed the terms summer/winter to the warm/cold seasons respectively. The definition of these seasons is now given in the section 2.1.4.

Figure 3 illustrates the identification of seasons using the isotopic composition seasonal cycle. In meteorological data we used period from November to April for the cold season and period from May to October for the warm season.

Correlation:

Throughout the manuscript it is difficult to keep track in what resolution the correlation analysis were performed (annual, seasonal, multiannual/smoothed data?). With at least the numbers of years included in the Tables this has already been slightly improved in the new version. Still it is unclear. I thus suggest to include the time period (19xy – 20zx?) and number data points (n=?) instead. This information should also be given in the text.

We added the time period and the number of data points to the tables 2 and 4. This is also clarified in the text. We removed the discussion of smoothed datasets from the paper as well as chapter 2.3 statistical methods.

Table 2: Correlation coefficients between meteorological data and indices of large-scale modes of variability (statistically significant coefficients at $p < 0.05$ are highlighted in bold). The period of calculation and number of data points (n) for each coefficient are shown in brackets.

Annual mean	Temperature	P south*	P north*
NAO	-0.24 (1914-2013, n=100)	-0.24 (1966-2013, n=48)	-0.03 (1966-2013, n=48)
AO	-0.34 (1950-2013, n=64)	-0.06 (1966-2013, n=48)	0.02 (1966-2013, n=48)

NCP	-0.55 (1948-2013, n=66)	0.26 (1966-2013, n=48)	0.26 (1966-2013, n=48)
Warm season			
NAO	-0.47 (1914-2013, n=100)	0.23 (1966-2013, n=48)	0.03 (1966-2013, n=48)
AO	-0.11 (1950-2013, n=64)	0.08 (1966-2013, n=48)	0.14 (1966-2013, n=48)
NCP	-0.50 (1948-2013, n=66)	0.34 (1966-2013, n=48)	0.34 (1966-2013, n=48)
Cold season			
NAO	-0.41 (1914-2013, n=100)	0.04 (1966-2013, n=48)	0.26 (1966-2013, n=48)
AO	-0.40 (1950-2013, n=64)	0.14 (1966-2013, n=48)	0.37 (1966-2013, n=48)
NCP	-0.77 (1948-2013, n=66)	0.25 (1966-2013, n=48)	0.33 (1966-2013, n=48)

Table 4. Correlation coefficients between ice core data, meteorological data and indices of large-scale modes of variability (statistically significant coefficients at $p < 0.05$ are highlighted in bold). The period of calculation and number of data points (n) for each coefficient is shown in brackets.

Annual means	$\delta^{18}O$	Accumulation	*d*	NAO	AO	NCP
T. °C	-0.01 (1914-2013, n=100)	0.16 (1914-2013, n=100)	0.00 (1914-2013, n=100)	-0.24 (1914-2013, n=100)	-0.34 (1950-2013, n=64)	-0.55 (1948-2013, n=66)
P north*	-0.30 (1966-2013, n=48)	0.36 (1966-2013, n=48)	0.17 (1966-2013, n=48)	-0.03 (1966-2013, n=48)	-0.03 (1966-2013, n=48)	0.27 (1966-2013, n=48)
P south*	0.06 (1966-2013, n=48)	0.52 (1966-2013, n=48)	0.07 (1966-2013, n=48)	-0.24 (1966-2013, n=48)	-0.06 (1966-2013, n=48)	0.18 (1966-2013, n=48)
$\delta^{18}O$		-0.20 (1914-2013, n=100)	-0.06 (1914-2013, n=100)	0.07 (1914-2013, n=100)	0.41 (1950-2013, n=64)	0.11 (1948-2013, n=66)
Accumulation			0.21 06 (1914-2013, n=100)	-0.29 (1914-2013, n=100)	-0.29 (1950-2013, n=64)	-0.03 (1948-2013, n=66)

d				-0.08 (1914-2013, n=100)	-0.26 (1950-2013, n=64)	-0.14 (1948-2013, n=66)
Warm season	$\delta^{18}O$	Accumulation	*d*	NAO	AO	NCP
T. °C	0.13 (1914-2013, n=100)	-0.04 (1914-2013, n=100)	0.20 (1914-2013, n=100)	-0.02 (1914-2013, n=100)	-0.10 (1950-2013, n=64)	-0.51 (1948-2013, n=66)
P north*	0.01 (1966-2013, n=48)	0.16 (1966-2013, n=48)	0.09 (1966-2013, n=48)	0.13 (1966-2013, n=48)	-0.14 (1966-2013, n=48)	0.18 (1966-2013, n=48)
P south*	-0.27 (1966-2013, n=48)	0.49 (1966-2013, n=48)	-0.02 (1966-2013, n=48)	-0.01 (1966-2013, n=48)	0.07 (1966-2013, n=48)	0.34 (1966-2013, n=48)
$\delta^{18}O$		-0.42 (1914-2013, n=100)	-0.05 (1914-2013, n=100)	-0.08 (1914-2013, n=100)	0.16 (1950-2013, n=64)	0.00 (1948-2013, n=66)
Accumulation			0.31 06 (1914-2013, n=100)	0.00 (1914-2013, n=100)	0.09 (1950-2013, n=64)	0.00 (1948-2013, n=66)
d				0.00 (1914-2013, n=100)	-0.01 (1950-2013, n=64)	-0.14 (1948-2013, n=66)
Cold season	$\delta^{18}O$	Accumulation	*d*	NAO	AO	NCP
T. °C	-0.09 (1914-2013, n=100)	0.11 (1914-2013, n=100)	-0.15 (1914-2013, n=100)	-0.30 (1914-2013, n=100)	-0.45 (1950-2013, n=64)	-0.79 (1948-2013, n=66)
P north*	0.20 (1966-2013, n=48)	0.21 (1966-2013, n=48)	-0.12 (1966-2013, n=48)	0.51 (1966-2013, n=48)	0.37 (1966-2013, n=48)	0.23 (1966-2013, n=48)
P south*	-0.30(1966-2013, n=48)	0.37 (1966-2013, n=48)	-0.13 (1966-2013, n=48)	0.26 (1966-2013, n=48)	0.14 (1966-2013, n=48)	0.25 (1966-2013, n=48)
$\delta^{18}O$		0.05 (1914-2013, n=100)	0.02 (1914-2013, n=100)	0.41 (1914-2013, n=100)	0.41 (1950-2013, n=64)	0.19 (1948-2013, n=66)
Accumulation			0.07(1914-2013, n=100)	-0.18 (1914-2013, n=100)	-0.15 (1950-2013, n=64)	0.18 (1948-2013, n=66)
d				-0.06 (1914-2013, n=100)	-0.01 (1950-2013, n=64)	0.11 (1948-2013, n=66)

*P south – precipitation rate at the weather stations to the South from the Caucasus, P north – precipitation rate at the weather stations to the North from the Caucasus.

As a consequence the significance levels of all correlations using smoothed data have to be reconsidered. Considering this, also the newly added panel in Fig. 11 does not make any sense as in the sliding window the number of data points is even further reduced. It should thus be removed as it does not contain any useful information.

We thank the reviewer for providing the comprehensive explanation of the calculations. We removed all the discussion of smoothed datasets, including fig.11.

2.1.5 Diffusion of stable isotopes
Line 565-566: "Moreover we would find a positive correlation between accumulation rate and seasonal amplitude of δ18O."
I do not see why you would expect this to be correlated under this assumption. I think what is meant is the actual layer thickness and not the accumulation rate?

Agree. We tried both: accumulation and actual layer thickness. In both cases no significant correlation was found.

Moreover we would find a positive correlation between layer thickness and seasonal amplitude of $\delta^{18}O$.

The way it is written here the choice is not very convincing. Reading further on in the manuscript I agree that this seems to be the best choice. But this should become clear at this point already. Also, in the new Fig.1 this station seems to be S of the main ridge? You are in the fortunate position to have station data both from the north (2-5) and the south (most relevant probably 9 and 10, maybe also 1) as well as high elevation station data for both sides (N: 6,8 and S; 7). As a further plus, the later 3 are in very close proximity to the drill site.
I suggest to show the precipitation distribution for all station data (at least in the supplement) and to discuss the patterns according to the groups (N, S, high elevation with N and S indicated) with the final conclusion why this station was chosen.

Kukhorsky Pereval station is situated S from the Elbrus but N from the Main Caucasus ridge. The detailed map is shown in Mikhalenko et al., 2015 (fig. 1 b). But in terms of precipitation annual cycle it belongs to the southern group. The brown line on fig. 1 shows the border between two types of precipitation cycle.
We do not find it useful to discuss the seasonal cycles at all the stations as it has already been performed by (Mikhalenko et al., 2015), we added the link to the text. We have chosen two stations for the calculations: Mineralnye Vody for the N stations and Klukhorskiy Pereval for the S stations because of their close position to the drilling site and because of uninterrupted record for the period of precipitation data availability (1966-2013)

Presentation of
a) Accumulation:

All this information is almost entirely lost in the way Fig. S4 is presented.
1) It is not indicated to which stations the purple lines belong.
2) Because being normalized the absolute values are not visible.
3) The effect of altitude and distance from the sea is not visible since only the stacked record is shown and shown as normalized values.
I suggest following the example in Fig. 8 of Mariani et al. 2014, including all station data on the absolute scale and the altitude indicated behind the station name (one could even think of an additional scatter plot to show the effect of altitude and distance from the sea, respectively). By doing so, the reader is immediately able to visually see all statements made with the additional information about the amplitude of the variations and correlation (visual) between the stations. Since you also discuss seasonal data it would make sense to do provide figures for annual and seasonal values (if the fig does not get too complex, maybe they can be combined).

We changed the records of precipitation in the paper from normalized values to absolute ones. The records for many of the stations are presented in Shahgedanova et al., 2014 and Tielidze et al., 2016. We added these references to the text.

b) Temperature:
The above generally also applies to the temperature data sets and its presentation in your Fig. 8 (show all stations, not normalized). Again, in annual and seasonal resolution. Considering my previous comments highlighting the importance of discussing annual values first a panel should be added to Fig. 5 for annual resolution.

We changed the presentation of the temperature records to absolute values at the drilling site calculated using the lapse rate.

Discussion of
a) Temperature:

In the manuscript the stacked record is then used for further discussion. This assumes that all stations show very similar patterns for the respective region (N or S). Indicated by the standard deviation in Fig. 8, this assumption seems reasonable for the temperature. But also here valuable information is lost by doing so. For example, by using normalized values in Fig. 11, the information of the slope is lost, which is an important value as it is indicative for the relation between d18O and °C. The slope should be around 0.6 (or in the range of maybe 0.4-0.8). Currently a negative slope is found which is however another issue (see comment later).
I suggest to use the high elevation stations only (one of them should be enough) and correct the T for the laps rate to the altitude of the drill site in order to get the most reliable d18O/T relationship (i.e. slope).

We changed the presentation of the temperature records to absolute values at the drilling site calculated using the lapse rate.

b) Precipitation:

For precipitation the variation between the different stations might be larger. Currently this cannot be assessed with the information provided but will become visible with the suggested changes for presentation of the data.

The information lost if using the stacked and normalized data is the amplitude of variability (both inter-annual and seasonal). Also, the elevation effect in total precipitation should be visible between station and ice core data. If not, it should be discussed.

I suggest to also here using the high elevation stations only instead of the stacked record which in fact likely is not representative for the drill site (too much weight is given to the low elevation stations and the N stations). As pointed out in the manuscript Klukhorski Pereval station (based on the current evaluation with $r = 0.65$ for both seasons) seems to be the best choice (at least for the current evaluation).

Correlation coefficients for annual resolution should be included in Table 4.

We changed the presentation to the absolute values from two stations: Klukhorskiy Pereval (representative of the S stations) and Mineralnye Vody (representative of the N stations).

Line 652-654: "As an example we show the seasonal cycle of δ18O and d for Bakuriani station in 2009 (fig. 7). This station is the only one in the region for which the whole uninterrupted dataset for one annual cycle is available. The seasonal amplitude of δ18O is about 10 ‰."

In the revised version the T profile is added to Fig. 7. A quick and dirty calculation based on indicated y-axis-range for d18O (-2 to -18) and T (25 to -5) results in a slope of around 0.6 indicative for the d18O/T dependence. This value is as expected. Please re-calculate more carefully based on the data. How does the dependence change if precipitation weighted T is used instead (if available use daily T and p data for the weighting)? The correlation should improve since d18O can only be recorded if precipitation occurs.

We recalculated the slope using the data. The slope is 0.32 ‰/°C. Unfortunately, daily data are not available for this station as well as for the other GNIP stations in the region.

The seasonal amplitude of δ^{18}O is about 17 ‰. The slope between δ18O and temperature is 0.32 ‰/°C.

3.2 Ice core records

Line 681-684: "Different patterns of inter-annual to multi-decadal variations appear in the instrumental temperature data (see section 3.1) and ice core δ18O records (Fig 5) emerge for winter versus summer. Consequently, we do not investigate annual mean results, and focus on each season."

I do not understand the statement in the first sentence probably because of language. In any case, the motivation to not use annual data is not convincing at all based on the presented data and for several reasons explained earlier. Based on what assumption can you assume that annual data cannot be compared to meteorological data but seasonal data can? It might be that this will be the outcome of the evaluation of the annual data I proposed earlier but until this is discussed and shown properly such an assumption is pure speculation. The current splitting of the ice core data contains a large uncertainty by itself. Any finding might thus just be a coincidence. By using the annual data first this additional uncertainty is removed which opposite to the authors argumentation above strongly suggests to investigate the annual results first.

In any case, as suggested before, please add results for the annual resolved data to Table 4 and a panel with annual resolution d18O data to Figure 5. In the current version, the annual data in Fig. 8 cannot be compared anywhere with the annual ice core data.

We added the annual data as well

3.3 Comparison of ice core records with regional meteorological data

Line 714-717: “We found no significant correlation between the ice core δ18O record and regional temperature, neither with the reanalysis data, nor with the observation data, when using the whole period. A significant correlation ($r = 0.52$, $p<0.05$) emerges for summer data, when calculated for the period since 1984. The slope for this period is 0.25 per mille per °C. We also repeated our linear correlation analysis using precipitation weighted temperature, and obtained the same results.”

The value of 0.25 per mil /°C is very surprising regarding the fact that reasonable correlation was found. It is also a little bit surprising that precipitation weighting did not change the slope (although if no seasonal pattern in p exists this seems not unreasonable).

What data resolution has been used for the precipitation weighting of the temperature? Daily, weekly or monthly data (annual data would make no sense)?

Considering the fact no change was observed, I assume the seasonal distribution of p used for weighting was the one derived for the southern stations? From which station (I suggest to use Klukhorski Pereval station only because it shows highest correlation, see comments before)?

How does the correlation and slope look like if the one from the N stations is used instead?

How do the correlations and slope look like in this case for the annual and winter d18O record? Please redo the analysis accordingly for the entire period and for the 1984-2013 period.

Since precipitation data is shown only from 1966 I assume the precipitation weighting was only performed for this period? Or did you use the monthly distribution derived for the 1966-2013 period also for the period before, assuming it did not change much (if not done already this might be worth trying)? In any case, the information of what has been done is missing now. Please add.

As the seasonal averages of δ18O were changed, the new correlation coefficient is 0.13 for the 100-years period for the warm season. Again, the correlation is much higher ($r=0.44$, $p<0.05$) if we take the period from 1984 till 2013. The slope is 0.6 ‰/°C. No correlation found for the cold season or for the annual means.

Calculation of precipitation weighted temperatures using precipitation didn’t give any additional correlation. For the precipitation weighting we used daily values of meteodata. We calculated this parameter for two stations: Klukhorsky Pereval (representative of the S stations) and Mineral’nye Vody (representative of N stations). The main period of calculation is 1966-2013 as reliable precipitation data is available for this period only. We also tried calculation for the longer period using "unreliable" data that led to the same result.

We found no significant correlation between the ice core $\delta^{18}O$ record and regional temperature, neither with the reanalysis data, nor with the observation data, when using the whole period. A significant correlation ($r = 0.44$, $p<0.05$) emerges for warm season data, when calculated for the period since 1984. The slope for this period is 0.6 per mille per °C. We also repeated our linear correlation analysis using precipitation weighted temperature, and obtained the same results. The precipitation weighted temperature was calculated using daily meteorological data. We used data from two stations: Klukhorskiy Pereval (as a representative of southern stations) and Mineralnye Vody (as a representative of the northern stations). We didn't find any statistically significant correlations when compared 3-, 5-, 7-years running means of these parameters.

Line 721-723: "Our results are comparable to those obtained in the Alps by Mariani et al. (2014): again, while the seasonal cycle of ice core δ18O appears related to that of temperature, this is not the case for inter-annual variations, driven by other factors such as changes in moisture sources."
It does not seem that the current results are comparable. See conclusion in the cited paper:
"1. The seasonal cycle of temperature is well-captured in both the Alpine ice cores. On a seasonal scale δ18O is thus a valid temperature proxy explaining ~60% of the signal.
2. On an annual scale the high variability of precipitation, especially at high-altitude sites, might considerably bias the isotopic signal. For the glacier site with homogeneous distribution of precipitation throughout the year the mean temperature signal is still partly preserved also on an annual scale. In the other case with strong intraseasonal precipitation variability, the annual mean of δ18O was representative only for temperature during precipitation and not for annual mean temperature."

We agree, that in (Mariani et al., 2014) the authors found strong link between temperature and δ18O on seasonal cycle scale. While on annual scale the signal is biased by other factors. Though they report correlation between δ18O and precipitation weighted temperature, this result is not useful for palaeoclimatology. Citation: "For such a glacier site, a paleotemperature reconstruction is not feasible." We added that this finding is a feature of annual variability of δ18O.

We found no persistent link between ice cores δ18O and temperature on interannual scale

Line 733-735: "The regression analysis showed significant negative correlation between the two parameters. The regression equation for 11-year running means in the 1914-1928 and 1994-2013 differs from the same for the 1929-1993 (see fig. 11 for the correlation plot and regression equations as well as for the sliding window correlation plot).
Based on what criteria can these 2 periods (1914-1928/1994-2013 and 1929-1993) be separated? This seems rather subjective. If looking at the entire period, the correlation would be much worse and the negative slope would not be observed (i.e. both correlation and accordingly the negative slope would not be significant; which is actually also not the case now considering the issue with the correlation

analysis of smoothed data pointed out before). Using p weighted data and a different approach for seasonal separation of the d18O (both discussed before) might lead to completely different results anyhow. So please reconsider once the reevaluation is done.

We entirely removed this paragraph as well as fig.11

Line 735-737: "The 10-years sliding window correlation…"
Remove (see discussion of correlation analysis).

Removed

Line 943 - New (and old) Fig. 3: Why is there a winter and a summer missing around 31 m? Or should the winter around 33 m cover this entire section from around 31-34?

There was a piece of the core lost during the drilling operations. This part is covered by the bottom part of the 2004 core where the sampling resolution was 50 cm. It is evident that two seasons (one warm and one cold) are missing but we removed these values from the correlation analysis because of large uncertainty of the seasonal values calculations in this case.

The drilling problems are described in (Mikhalenko et al., 2015). The biggest gap appears at the depth 31.3 and 32.1 m. There was a piece of the core lost during the drilling operations. This part is covered by the bottom part of the 2004 core where the sampling resolution was 50 cm. It is evident that two seasons (one warm and one cold) are partially missing. We didn't use these values for the correlation analysis because of large uncertainty of the seasonal values calculations in this case.

Abstract - line 403 ff: "In the summer season the isotopic composition depends on the local temperature..."
..and conclusion line 802 ff: "This may explain the significant albeit non persistent correlation of summer δ18O and temperature."
According to the main text this is only true for a certain period (1984-2013)? Please be precise or reconsider the statement.

Reformulated according to the newer calculations.

In the warm season the isotopic composition depends on the local temperature but the correlation is not persistent in time.

Line 524-525 (& Fig. S2):
The overlap between the different cores does indeed look very good. Except for the lowermost 2-3 m of the 2013 core with the 2009 core (around 3-7 m depth in Fig. S2). Please comment.

We explain this with the different sampling resolution (5 cm for 2013 core and 15 cm for 2009 core), this explanation is in the text.

Line 612-613: "The average regional lapse rate was calculated using the available meteorological data. It is minimum (replace with "lowest") in winter (2.3°C per 1000 m) and maximum (replace with "highest") (5.2 °C per 1000 m) in summer (Fig. S3)."
Is this similar for N and S? Are these numbers and Fig S3 for N and S combined or only for one of the 2 regions (or only one station?)?

Comments added

The average regional lapse rate was calculated using the available meteorological data, we used the data from all of the stations for the calculation. The lapse rate is lowest in winter (2.3°C per 1000 m) and highest (5.2 °C per 1000 m) in summer (Fig. S3).

Line 678-680: "We note that the shallow ice core from the Maili plateau of Kazbek shows the same mean values of δ18O as the Elbrus ice cores during their overlap period. This is a surprise, given the difference in elevation (500 m) and continentality (200 km distance)."
Is this really that much of a surprise? The continentally should make the d18O at Kazbek more negative whereas the lower elevation should make it more positive. In the sum, the two factors seem to cancel out. Can you give some estimates about the size of those two effects and if a 0 sum is reasonable? For the altitude effect, see e.g. Mariani et al., 2014 and references therein.

We calculated continental gradient and lapse rate for δ18O using the data from the GNIP stations in the region that are situated at the lower elevations and in our opinion one should be very cautious when using this data for the high elevations ice cores study. The lapse rate is -0.25 ‰/100 m and continental gradient is -0.85 ‰ /100 km. The mean value of δ18O for Kazbek ice core should be 1.25‰ more positive because of elevation difference and 1.7‰ more negative due to continentality factor. We removed the surprise from the text.

This is a result of a mutual compensation of δ18O increase due to lower elevation position (Kazbek drilling site is 500 m lower) and of δ18O decrease because of continentality effect (Kazbek is 200 km further from the sea).

Line 774-777: "In order to explore the relationships of the Elbrus ice core datasets with the AMO, we used 20-year smoothed data."
I suggest removing this paragraph about AMO entirely. You do show it in Fig 9 and 10 and in some of the tables for comparison with the meteorological data. At this point it does not add anything but takes away from the main focus. Also, by using a 20 yr smoothed record the df is very low for the correlation analysis (<10, see earlier comment) and the result likely not significant anyhow.

Removed

Conclusion - Line 789-790: “We found no persistent link between ice cores δ18O and temperature, common feature emerging from non-polar ice cores (e.g. Mariani et al., 2014).”
This is not consistent whit what has been found in the Mariani et al, 2014 paper: See conclusion therein: “1. The seasonal cycle of temperature is well-captured in both the Alpine ice cores. On a seasonal scale δ18O is thus a valid temperature proxy explaining ~60% of the signal.
2. On an annual scale the high variability of precipitation, especially at high-altitude sites, might considerably bias the isotopic signal. For the glacier site with homogeneous distribution of precipitation throughout the year the mean temperature signal is still partly preserved also on an annual scale. In the other case with strong intraseasonal precipitation variability, the annual mean of δ18O was representative only for temperature during precipitation and not for annual mean temperature.”

We agree, that in (Mariani et al., 2014) the authors found strong link between temperature and δ18O on seasonal cycle scale. While on annual scale the signal is biased by other factors. Though they report correlation between δ18O and precipitation weighted temperature, this result is not useful for palaeoclimatology. Citation: “For such a glacier site, a paleotemperature reconstruction is not feasible.” We added that this finding is a feature of annual variability of δ18O.

We found no persistent link between ice cores δ18O and temperature on interannual scale

Line 808-810: “The accumulation rate at the drilling site is highly correlated with the precipitation rate and gives information about precipitation variability before the beginning of meteorological observations.”
In the current manuscript, the correlation is rather weak and should be changed to “…is significantly correlated…”. However, with the current issues this result might change.

Changed

…drilling site is significantly correlated with the precipitation …

Language:
…needs to be improved in general and the writing has to be more precise.

The language of the corrected version has been checked by a native-speaker

Find some (rather randomly chosen) examples below.
Abstract - Line 396-397: Here, we report on the results of the water stable isotope composition from this ice core in comparison with results from shallow ice cores. The report is not about the comparison between the ice core and the shallow cores (although the measurements at different labs and with different methods have been compared and the cores have been overlapped). The important part is that

these datasets are combined and then the results are compared with the meteorological data etc (see line 25-27). Please reconsider this statement and/or reformulate.

Reformulated

Here, we report on the results of the water stable isotope composition from this ice core with additional data from the shallow cores.

Line 398-399: Dating has been performed for the upper 126 m of the deep core combined with shallow cores data.
Also here this is unclear. The records from the deep and shallow cores were combined and dating then performed on this combined dataset down to the ice core depth of 126 m (i.e. combined depth 126 m + xy m from the shallow cores).

Reformulated

combined with 20 m from the shallow cores.

Line 399:
The record covers 100 years but two centuries (21st and 20th century).

Reformulated

The record covers 100 years from 2013 back to 1914

Introduction - Line 431 ff: "The authors explored the links between the ice cores isotopic composition, local climate and large-scale circulation patterns. They found that in mountain regions isotopic composition of the ice cores governed both by the local meteorological conditions and by the regional and global factors. However, ice core records are complex. For instance, even in areas without any seasonal melt, accumulation is the net effect of precipitation, sublimation, and wind erosion processes, and may significantly differ from precipitation."
The "However" in the 3rd sentence is misleading because what follows is what has been observed and discussed in these papers.
I suggest e.g.: "...global factors. These studies discussed the complexity of interpreting ice core records from high-altitude glaciers due to the potential bias from post-depositional processes and frequent changes in the origin of moisture sources. For instance, even in areas without any seasonal melt, accumulation is the net effect of precipitation, sublimation, and wind erosion processes, and may significantly differ from precipitation."

Reformulated

These studies discussed the complexity of interpreting ice core records from high-altitude glaciers due to the potential bias from post-depositional processes and frequent changes in the origin of moisture sources.

Отформатировано: По левому краю

Отформатировано: Английский (США)

Large-scale drivers of Caucasus climate variability in meteorological records and Mt Elbrus ice cores

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Abstract

A 181.8 m ice core was recovered from a borehole drilled into bedrock on the western plateau of Mt. Elbrus (43°20'53.9'' N, 42◦25'36.0'' E; 5115 m a.s.l.) in the Caucasus, Russia, in 2009 (Mikhalenko et al., 2015). Here, we report on the results of the water stable isotope composition from this ice core with additional data from the shallow cores.~~Here, we report on the results of the water stable isotope composition from this ice core in comparison with results from shallow ice cores~~. There is a distinct seasonal cycle of the isotopic composition which allowed dating by annual layer counting. Dating has been performed for the upper 126 m of the deep core combined with 20 m from the shallow cores.~~combined with shallow cores data~~. The whole record covers ~~one century~~100 years from 2013 back to 1914. Due to the high accumulation rate (1380 mm w.e. per year) and limited melting we obtained the isotopic composition and accumulation rate records with seasonal resolution. These values were compared with available meteorological data from 13 weather stations in the region, and also with atmosphere circulation indices, back-trajectories calculations and GNIP data in order to decipher the drivers of accumulation and ice core isotopic composition in the Caucasus region. In the ~~summer~~ warm season (May - October) the isotopic composition depends on the local temperature, but the correlation is not persistent in time, while in ~~winter~~cold season (November – April), the atmospheric circulation is the predominant driver of the ice core isotopic composition. The snow accumulation rate correlates well with the precipitation rate in the region all year round, this made it possible to reconstruct and expand the precipitation record at the Caucasus highlands from 1914 till 1966 when the reliable meteorological observations of precipitation at high elevation began.

1 Introduction

Large scale modes of variability such as the NAO (North Atlantic Oscillation) ~~and AMO (Atlantic Multidecadal Oscillation)~~ are known to influence European climate variability (see review in Panagiotopulos et al., 2002). However, most studies of large-scale drivers of European climate change have been focused on low elevation instrumental records from weather stations, and there is very limited information about climate variability at high altitudes, and about differences in climate variability and trends at different elevations (EDW research group, 2015). Such differences were calculated in many mountain regions (EDW research group, 2015), except for the Caucasus, due to the lack of high elevation instrumental observations in this region.

The Caucasus is located southwards of the East European Plain. It is a high mountain region, with typical elevations of 3200-3500 m a.s.l., and with the highest point reaching 5642 m for Elbrus. The Main Caucasus Ridge acts as a barrier between subtropical and temperate mid-latitude climates, as observed for other high mountain regions such as the Himalaya. As in other mountain regions, there is a lack of high elevation meteorological records in the Caucasus. Moreover, existing records are relatively short: for example, reliable Caucasus precipitation measurements started only in 1966. An improved spatio-temporal coverage is required to investigate internal variability, to explore trends and spatial differences, and to evaluate the skills of atmospheric models providing atmospheric analysis products where no meteorological data are assimilated.

Measurements of the stable isotope composition of water, and annual accumulation rates in mid to high latitude ice cores are widely used proxies to estimate past temperature and precipitation rate changes. In many high mountain regions such as the Caucasus, and for elevations situated above the tree line, ice core data provides the only source of detailed information to document past climate changes, complementing punctual information retrieved from changes in glacier extent and recent glacier mass balance. For example study of the water stable isotope composition of several ice cores obtained in the Alps was recently conducted by Mariani et al. (2014) and the same research in Alaska was performed by Tsushima et al. (2015). The authors explored the links between the ice cores isotopic composition, local climate and large-scale circulation patterns. They found that in mountain regions isotopic composition of the ice cores governed both by the local meteorological conditions and by the regional and global factors. ~~However, ice core records are complex.~~ These studies discussed the complexity of interpreting ice core records from high-altitude glaciers due to the potential bias from post-depositional processes and frequent changes in the origin of moisture sources. For instance, even in areas without any seasonal melt, accumulation is the net effect of precipitation, sublimation, and wind erosion processes, and may significantly differ from precipitation. Water stable isotope records are in mid to high latitudes physically related to condensation temperature through distillation processes (Dansgaard, 1964), but the climate signal is archived through the snowfall deposition and post-deposition processes. One important artefact lies in the intermittency of precipitation, and the covariance between condensation temperature and precipitation, which may bias the climate record towards one season, or towards one particular weather regime, challenging an interpretation in terms of annual mean temperature (Persson et al., 2011). Moreover, water stable isotopes are integrated tracers of all phase changes occurring from evaporation to mountain condensation, and are also affected by non-local processes related to evaporation characteristics, or shifts in initial moisture sources. Such processes have the potential to alter the validity of an interpretation of the proxy record in terms of local, annual mean, or precipitation-

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weighted temperature. In some region, isotopic records are more related to hydrological cycles, recycling, rainout (Aemisegger et al., 2014). Finally, the condensation temperature may also strongly differ from surface air temperature; depending on elevation shifts in e.g. planetary boundary layer or convective activity (see Ekaykin and Lipenkov, 2009 for a review). While these processes make the interpretation of ice core records complex, they conversely open the possibility that the ice core proxy record may be in fact more sensitive to large-scale climate variability than punctual precipitation amounts. For instance, Casado et al (2014) have evidenced a strong fingerprint of the NAO in water stable isotope records from central Western Europe and Greenland, either in long instrumental records based on precipitation sampling, in seasonal ice core records, or in atmospheric models including water stable isotopes. Connection of Greenland ice cores isotopic composition with the atmospheric circulation patterns was studied by Vinther et al. (2003 and 2010). The strong influence of the NAO pattern on the Greenland ice cores isotopic composition has been discovered and the possibility to use the ice cores data for the past NAO changes reconstruction was proved (Vinther et al., 2003). The authors also revealed the importance of the seasonally resolved ice cores records study rather than annual records as there are different factors governing formation of the isotopic composition of precipitation in warm and in cold seasons (Vinther et al., 2010).

We will now briefly review earlier studies performed on climate variability in the Caucasus area, and which have already explored the relationships between regional climate, glacier expansion, and large-scale modes of variability: the NAO (North Atlantic Oscillation), AO (Arctic Oscillation), ~~AMO (Atlantic Meridional Oscillation)~~ and NCP (North Sea – Caspian Pattern). For example, Shahgedanova et al. (2005) monitored the mass balance of the Djankuat glacier, situated at an altitude between 2700 and 3900 m a.s.l. While no significant correlation was identified between accumulation rate and the winter NAO index, the years of high accumulation systematically occurred during winters with a very negative NAO index. Brunetti et al. (2011) explored the influence of the NCP mode on climate in Europe and around the Mediterranean region. They evidenced a negative correlation coefficient of -0.50 between temperature in the Caucasus and the NCP index. Baldini et al. (2008) investigated records of precipitation isotopic composition in Europe from the IAEA/GNIP stations, extrapolating a significant negative correlation between winter precipitation $\delta^{18}O$ in the Caucasus region and the NAO index (R = - 0.50). Casado et al (2013) studied the influence of precipitation intermittency on the relationships between precipitation $\delta^{18}O$, temperature, and the NAO. The influence of the NAO index on European climate and precipitation $\delta^{18}O$ appeared more prominent in winter than in summer (Comas-Bru et al., 2016).

Here, we take advantage of the new Elbrus deep ice cores (Mikhalenko et al., 2015), and produce the first analysis of water stable isotope and accumulation records. Section 2 introduces the data and methods, with a description of the ice core analyses and age scale, an overview of regional meteorological information, as well as the source of information for indices of modes of variability. Section 3 presents the results of the comparison and statistical analyses of the relationships between regional climate parameters (temperature and precipitation), Elbrus ice core records, and modes of variability. In section 4, we finally summarize our key findings and the next steps envisaged to strengthen the climatic interpretation of the Caucasus ice core records.

2 Data and methods

2.1 Ice core data

2.1.1 Drilling site and drilling campaigns

Here, we report on results from the new, deepest ice core from Mt Elbrus, in comparison with results from shallow ice cores. Deep drilling was performed on the Western Plateau (43°20'53.9" N, 42°25'36.0" E; 5115 m a.s.l.) of Mt Elbrus (fig. 1) in September 2009, allowing recovery of a 181.8 m long ice core, down to bedrock. The drilling site and the drilling operations are thoroughly described in Mikhalenko et al. (2015).

In order to update the ice core records towards the present-day, and enable a comparison of the measurements with local meteorological monitoring data, surface drilling operations were repeated at the same place in 2012 (11.5 m long) and in 2013 (20.5 m long). Results are also compared here with previously published isotopic composition data measured along the 22 m shallow ice core drilled at the same place in 2004 which covered the period from 1998 till 2004. (Mikhalenko et al, 2005).

In 2014, drilling operations were also successful at the Maili Plateau (Mt. Kazbek), at the altitude of 4500 m a.s.l. in 200 km eastwards from Elbrus (fig. 1), delivering a 20-m ice core. The Kazbek core is shown for the comparison only. Its detailed description will be published elsewhere.

2.1.2 Sampling process and sampling resolution

For the upper and the lower parts of the deep core (0-106 m and 158-181.8 m) and for the shallow firn cores drilled in 2012 and 2013, sampling was performed using classical cutting-melting procedures. For the other depth intervals, melted samples were extracted from the continuous flow analysis system of LGGE (Grenoble, France), automatically sub-sampled, frozen and stored in vials for subsequent isotopic analysis. The description of the CFA system will be published elsewhere.

The sampling resolution was 15 cm for the upper 16 m of the deep core (see the sketch of the sampling resolution in fig. 2c). It was then increased to 5 cm in order to achieve better resolution, from 16 to 70 m depth and in the bottom part of the core (158-182 m depth). To ensure 15-20 samples per year, the sampling resolution was increased to 4 cm in the depth range from 70 to 106 m, similar to the sampling resolution of the CFA system (3.7 cm).

Samples from the shallow cores drilled in 2012 and 2013 were cut with a resolution of 10 and 5 cm, respectively.

2.1.3 Isotopic measurements

The methods of the isotopic measurements have been partially discussed in (Mikhalenko et al., 2015). Water stable isotope ratios ($\delta^{18}O$ and δD) were measured at the Climate and Environmental Research Laboratory (CERL) of Arctic and Antarctic research Institute (St Petersburg, Russia), using a Picarro L2120-i analyzer. Each sample was measured once. Sequences of measurements included the injection of 5 samples, followed by the injection of an internal laboratory standard with an isotopic value close to that of the samples. We also repeated the measurements of about 10% of all the samples in order to calculate the analytical precision: 0.06‰ for $\delta^{18}O$ and 0.30‰ for δD. The depth profile of $\delta^{18}O$ (Mikhalenko et al., 2015; Kozachek et al., 2015) and of the deuterium excess ($d = \delta D - 8*\delta^{18}O$) are shown in fig. 2.

Moreover, 600 samples from the depth interval from 23 to 35 m were measured in the Laboratory of Isotope Hydrology of the IAEA (Vienna, Austria). The two records are highly correlated ($r=0.99$, $p < 0.05$) for both isotopes (Figure S2b) with a systematic offset of 0.2 ‰ for $\delta^{18}O$ and 1 ‰ for δD. The records of the second order parameter deuterium excess are also significantly correlated ($r=0.65$, $p < 0.05$) without any specific trend or systematic offset. This inter-laboratory comparison demonstrates the high quality of the isotopic measurements performed in CERL.

We also stress the close overlap of the upper part of the profiles of the water stable isotope records versus depth from the different cores drilled in 2009, 2012 and 2013 (Fig. S2a). Based on this close agreement within the different shallow firn cores, we decided to calculate a stack record for the period from 1914 till 2013 which is used hereafter for the dating.

In the depth interval from 100 to 106 m depth, we also have an overlap of samples obtained with classical cutting method and CFA method described above, without any significant difference (Fig. S2c), again allowing us to combine the two records into one stack record.

2.1.4 Dating

The chronology is based on the identification of annual layers. These are prominent in $\delta^{18}O$ with the average seasonal amplitude of 20 ‰. For annual mean values we calculated averages of δ18O from one minimum of this parameter to another one as well as from one maximum to another. As we found no significant differences between the records obtained with two ways of year allocation we use minimum to minimum dating as more common one. We compared annual layers counting performed independently using the seasonal cycles in the isotopic composition and the ammonium concentration. The discrepancy between two independent chronologies is 2 years at a depth of 126 m. We used the dating based on the isotopic composition data in this paper. This dating is also best fit for the correlation analysis with the meteorological data. Hereafter, we focus our analysis on one century, from 1914 till 2013, which corresponds to the upper 126 m of the core. This period has been chosen because of relatively small dating uncertainty and the availability of other records such as local meteorological observations. At the bottom part of the core the isotopic composition cycles are less prominent and cannot be used for dating, consequently the dating uncertainty is sufficiently higher. The isotopic composition of that part of the core will be discussed elsewhere. In meteorological data we used average values from January to December of each year for the comparison with annual means of ice cores parameter.

For warm and cold seasons allocation we used slightly adapted method from (Vinther et al., 2010). The original method requires ascribing of equal accumulation rate for warm and cold season of each year. We changed the borders between the seasons when needed in order to avoid ascribing minimum of δ18O to the warm season and maximum to the cold season. We stacked to keeping the extreme values in the middle of the season as this is in coherence with meteorological data. We also used ammonium concentration as an independent marker, using criteria described on (Mikhalenko et al., 2015). For equivocal situations, we also used additional data: melt layers and dust layers (used to identify the warm season) (Kutuzov et al., 2013) as well as succinic acid concentration data that also have seasonal variations (Mikhalenko et al., 2015).
As there is no trend in the $\delta^{18}O$ record. we used the mean value of the $\delta^{18}O$ of the whole dataset (-15.5 ‰) as a threshold to separate between the warm and cold seasons. For equivocal situations, we also used additional data: melt layers and dust layers (used to identify the warm season) (Kutuzov et al., 2013) as well as ammonium and succinic acid concentration data that also have seasonal variations (Mikhalenko et al., 2015). Layers with the high dust concentration have been precisely dated by Kutuzov et al. (2013) for the 2012 ice core. Their results show that the separation of the core into a warm and cold season part using the average value of $\delta^{18}O$ is appropriate for this drilling site at least for the period from 2009 till 2012 that was investigated by Kutuzov et al. (2013). We compared annual layers counting performed independently using the seasonal cycles in the isotopic composition and the ammonium concentration. The discrepancy between two independent chronologies is 2 years at a depth of 126 m. We used the dating based on the isotopic composition data in this paper. This dating is also best fit for the correlation analysis with the meteorological data. Hereafter, we focus our analysis on one century, from 1914 till 2013, which corresponds to the upper 126 m of the core. This period has been chosen because of relatively small dating uncertainty and the availability of other records such as local meteorological observations. At the bottom part of the core the isotopic composition cycles are less prominent and cannot be used for dating, consequently the dating uncertainty is sufficiently higher. The isotopic composition of that part of the core will be discussed elsewhere. Figure 3 illustrates the identification of years seasons using the isotopic composition seasonal cycle. In meteorological data we used period from November to April for the cold season and period from May to October for the warm season.

There some gaps in the isotopic composition data that came from the technical problems during the drilling operations and the analysis process. The drilling problems are described in (Mikhalenko et al., 2015). We used the values from the duplicate core obtained in 2004 for the gap between 31.3 and 32.1 m. The biggest gap appears at the depth 31.3 and 32.1 m. There was a piece of the core lost during the drilling operations. This part is covered by the bottom part of the 2004 core where the sampling resolution was 50 cm. It is evident that two seasons (one warm and one cold) are partially missing. We didn't use these values for the correlation analysis because of large uncertainty of the seasonal values calculations in this case. In case of one sample missing we considered its isotopic value to be the average between the two neighbor samples. For a detailed description of the raw isotopic data and annual layers allocation for the upper 106 m of the core, please refer to Mikhalenko et al. (2015). Mean annual and seasonal values of $\delta^{18}O$ and *d* obtained as a result of the dating are shown in fig. 5 and 6 respectively.

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The annual accumulation rate is calculated as the thickness of the seasonal layer, multiplied by the layer density using the density profile from Mikhalenko et al. (2015), and corrected for layer thinning using the Dansgaard-Johnsen model (Dansgaard and Johnsen, 1969), with the following parameters: accumulation rate 1.583 m of ice equivalent, pore close-off depth = 55 m (Mikhalenko et al., 2015).

2.1.5 Diffusion of stable isotopes

We calculated the potential influense of diffusion on the stable isotopes record according to (Johnsen, 2000) model. We used the following parameters for the calculation: Our calculation showed that the seasonal amplitude of $\delta^{18}O$ variations could be 10-20% less because of the diffusion (Mikhalenko et al., 2015). If it was the case we would observe a decreasing of $\delta^{18}O$ maxima and increasing of minima with depth. Moreover we would find a positive correlation between ~~accumulation rate~~layer thickness and seasonal amplitude of $\delta^{18}O$. These features have not been found in the ice core data. The correlation coefficient between seasonal amplitude and accumulation rate is -0.10 and is statistically insignificant. There is also no statistically significant trend in the seasonal amplitude; the seasonal amplitude varies stochastically from 10 to 25 ‰. The maximum value observed on 1984 and the minimum in 1925. We therefore consider that the diffusion does not influence sufficientely the isotopic composition record in the upper 126 m of the ice core. At the bottom part of the core (e.g. at a depth of 180 m) the annual cycle of $\delta^{18}O$ should have an amplitude of 4 ‰ which is detectable but the length of the cycle should be less then 1 cm. As the *d* annual cycle is not prominent we cannot used the method based on the discrepancy between the $\delta^{18}O$ and *d* cycles. Thus, for obtaining climatic information from the bottom part of the core very high sampling resolution is required.

2.2 Meteorological data

We used the daily meteorological data (precipitation rate and mean daily temperature) from several weather stations around the drilling site (see map in Fig. 1 and Table 1) for comparison with the ice core data. We also investigated records of precipitation isotopic composition based on monthly sampling, performed at three stations to the south of Caucasus within the WMO-IAEA Global Network of Isotopes in Precipitation (GNIP) program (Table 1).
For comparison we used the NCEP/NCAR reanalysis temperature data (Kalnay et al., 1996) for the 500 mbar level which corresponds to the drilling site altitude. Two different models were used to calculate back trajectories: FLEXPART (Forster et al., 2007, Stohl et al., 2009), HYSPLIT (Draxler, 1999, Stein et al., 2015, Rolph, 2016). The LMDZiso model was used to estimate the precipitation isotopic composition at the drilling site (Risi et al., 2010).

2.3. Circulation indices

Circulation of the atmosphere influence sufficiently isotopic composition of the ice cores (Casado et al., 2013 and references therein). Atmospheric circulation quantitatively characterized by circulation indices. In this research we used three indices: NAO, AO, NCP that are widely used to characterize European climate (Jones et al., 2003, Thompson and Wallace, 2001, Brunetti et al., 2011 and references therein). Time span and references for the indices are presented in table 1.

NAO (North-Atlantic Oscillation) characterizes type of circulation in Europe, strength of Azores maximum and Icelandic minimum. Positive values of NAO index correspond to lower than usual value of atmospheric pressure in Iceland and higher that usual value of atmospheric pressure at Azores. Negative index correspond to less prominent centers of action in the Norrthern Hemisphere. Usually this index is calculated as difference of atmospheric pressure measured at Reykjavik and Lisbon, Ponta Delgada or Gibraltar. Here we used data from (Vinther et al., 2003 and https:\\crudata.uea.ac.uk\~timo\datapages\naoi.htm) that were calculated using data from Gibraltar station. Negative NAO leads to increase of precipitation rate in Southern Europe, positive NAO leads to increase of precipitation rate in Northern Europe (Hurrel, 1995, Jones et al., 2003, Vinther et al., 2003).

Arctic Oscillation index (AO) also is a characteristic of the Northern Hemisphere circulation. It is used to analyze climatic variability with periods longer that 10 years. It is calculated as EOF of 500 hPa surface. Negative valued correspond to high pressure at the Pole and cooling of Europe, while positive values correspond to low pressure at the Pole and drying of Mediterranean (Thompson and Wallace, 2001). We used AO data from NOAA (http:\\www.cpc.ncep.noaa.gov\products\precip\CWlink\).

NCP (North-Sea Caspian Pattern) index is less widely used, though it was proved that it is convenient to use it in Mediterranean climate studies (Kutiel et al., 1997; Brunetti et al., 2011). The index is calculated as normalized difference of geopotential heights between Caspian and Northern seas. Positive values correspond to stronger meridional circulation in Europe and lower summer temperatures, Negative values reflect strengthening of zonal circulation and higher summer temperatures in Europe (Brunetti et al., 2011). We used NCP data from NOAA (http:\\www.cpc.ncep.noaa.gov\products\precip\CWlink\).

~~2.3 Statistical methods~~

~~For the correlation analysis we used Pearson correlation coefficient. Statistical significance was estimated with the Student significance test. When compared running means records we calculated the degrees of freedom as N – 2n – 2, where N is number of data points and n – smoothing period.~~

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Отформатировано: Абзац списка, Междустр.интервал: 1,5 строки

3 Results

3.1 Regional climate

The main peculiarity of the drilling site is its location on the border between subtropical and temperate climatic zones (Volodicheva, 2004). Back-trajectory calculations show that the drilling site is characterized by remarkable seasonal differences in moisture sources locations. In winter, the origin of air masses varies from the Mediterranean to the North Atlantic. In summer, local moisture sources from the surrounding continents or from the Black Sea are predominant (see fig. S1 for examples).

Meteorological data depict large regional variations in the seasonal cycle of precipitation. To the south of the Caucasus, there is no distinct seasonal cycle (Fig. 4a), showing the climatology for the Klukhorsky Pereval station. In fact, the Klukhorsky Pereval station is situated north of the Main ridge, but in terms of the seasonal cycle of precipitation it undoubtedly belongs to the southern group. But we are nevertheless using this station as an example because of the uninterrupted record of temperature and precipitation for the 1966-1990 period. By contrast, the north of the Caucasus is marked by a distinct seasonality in precipitation amounts, which are maximum in summer and minimum in winter (Fig. 4b), showing the climatology for the Mineralnye Vody station. More examples of the Caucasus weather stations climatologies are goven in (Mikhalenko et al., 2015). Moreover, the annual precipitation rate to the south of the Caucasus is much higher than to the north. For example, the typical annual precipitation rate to the north of the Caucasus at the altitude close to the sea level is 500 mm per year, while to the south of the Caucasus at the same altitude it is about 1500 mm. The amount of precipitation in the region is affected by the altitude and the distance from the sea shore.

The seasonal changes of temperature appear uniform all over the region surrounding Caucasus, with warmest conditions observed in summer and coldest conditions observed in winter. The seasonal amplitude depends on the distance from the sea and the mean annual temperature depends on the altitude. The average regional lapse rate was calculated using the available meteorological data, we used the data from all of the stations for the calculation. ~~It~~The lapse rate is ~~minimum~~ lowest in winter (2.3°C per 1000 m) and ~~maximum~~ highest (5.2 °C per 1000 m) in summer (Fig. S3).

Based on the ~~coherency of temperature variability at all the weather stations in this region, we calculated a regional stack temperature record. Normalized temperature time series were calculated for each station for each season or for the whole year, and results were then averaged~~lapse rate we calculated temperature at the drilling site (see Fig.8a for the annual mean temperature variations. and 8b~~a~~ and 8~~b~~c for seasonal ~~stack~~ records). For precipitation data, available in this region since 1966, we ~~considered two different stacks~~show all the data (fig. S4), while in the calculations we used data from Klukhorskiy Pereval station as an example of stations without a seasonal cycle and Mineralnye Vody station as an example of those with a prominent cycle. ~~separating the stations with a distinct seasonal cycle from those where no seasonal cycle was identified for precipitation rates. We coherently used the reference period from 1966 to 1990 for normalization for both precipitation rate and temperature.~~ More examples of annual variations of temperature and precipitation at the Caucasus meteorological stations can be found in (Shahgedanova et al., 2014) and (Tielidze, 2016).

At our drilling site, an automatic weather station (AWS) provided in situ measurements for the period from August 2007 till January 2008. The day to day variations of temperature at low elevation weather stations and at the AWS are coherent for the whole period of the AWS work (Mikhalenko et al., 2015).

We also compared the data from meteorological stations with the NCEP reanalysis (Kalnay et al., 1996) outputs (not shown) for the 500 mbar level. Despite difference in absolute values on the daily scale when compared with the AWS data (the difference is random and varies from -1 to 1 °C), the observed regional data and reanalysis data have the same month to month variability. The maximum daily mean temperature at the drilling site according to the reanalysis data was -1.3 °C for the whole dataset. The temperature in the glacier at 10m depth, which correspond to the annual mean temperature at the drilling altitude, is -17 °C (Mikhalenko et al., 2015), the annual mean temperature at the drilling altitude from the NCEP reanalysis is -14 °C, and the same value calculated from meteorological observations and corrected for the lapse rate is -11 °C.

~~Hereafter in the meteorological data, we considered the cold season or winter of a given year to range from November of the previous year till April of the current year, and the warm season or summer from May till October.~~

We then investigated long-term trends in the ~~composite~~ meteorological records. Mean annual temperatures show significant increase during last two decades. We also observe higher than average values of mean decadal temperature in 1930-1940. And the beginning of the observations in the region, i.e. period from 1881 till 1900 was as cold as the 1990s. It is evident that last 20 years in ~~summer~~ warm season were the warmest for the whole observation period (fig. 8), while in ~~winter~~ cold the recent warming is not unprecedented. For example, ~~winters~~cold seasons in the 1960s – 1970s were even warmer (fig. 8). Multi-decadal patterns of temperature variations also differ in the late 19th Century, where negative anomalies are identified in ~~winter~~ cold season temperature (Fig. 8) but not in ~~summer~~warm season temperature (Fig 8). On the other hand in ~~winter~~ cold season temperatures we can observe lower temperatures at the end of 19th century that can be impact of the volcanic eruptions (Stoffel et al., 2015). We also noted the high temperature values in the 1910s - 1920s that is not completely understood. We did not find any trends in the precipitation rate for neither of the groups of stations (fig. S4).

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A significant anti-correlation is observed between temperature and the NAO index, both in ~~winter~~ cold and ~~summer~~warm seasons (Table 2, the information about the time series used for the correlation analysis can be found in Table 1). Stronger anti-correlations are identified between temperature and the NCP index, especially in ~~winter~~cold season, as also reported by Brunetti et al. (2011). ~~A weak positive correlation is identified between AMO and summer temperature.~~ Relationships with indices of large scale modes of variability are systematically weaker for precipitation, with contradictory results for the south\north Caucasus stack; they appear significant for the NCP ~~in summer and winter~~in both seasons (Table 2).

GNIP data are only available at low elevation stations. They show a rather uniform distribution of the isotopic composition of precipitation in the region during summer, as well as a gradual depletion of $\delta^{18}O$ at higher altitudes in winter.

GNIP records are too short and intermittent (one-two years with gaps) to investigate the variability and relationships with the local temperature on interannual scale. We therefore restrict discussion of GNIP data to seasonal variations. The $\delta^{18}O$ and δD in precipitation have a distinct seasonal cycle with maximum values observed in warm season (JJA) and minimum values observed in cold season (DJF). As an example we show the seasonal cycle of $\delta^{18}O$ and *d* for Bakuriani station in 2009 (fig. 7). This station is the only one in the region for which the whole uninterrupted dataset for one annual cycle is available. The seasonal amplitude of $\delta^{18}O$ is about ~~10~~ 17 ‰. The slope between δ18O and temperature is 0.32 ‰/°C. The *d* variations show no seasonal cycle varying randomly between 10 ‰ and 25 ‰. We found no significant correlation between $\delta^{18}O$ and *d*.

Climate variability as a driver for glacier variations in the Caucasus has recently been explored by several authors. Elizbarashvili et al. (2013) found the increased frequency of extremely hot months during the 20th century, especially over Eastern Georgia, whereas number of extremely cold months decreased faster in the Eastern than in the Western region. In addition, highest rates for positive trends of annual mean air temperature can be observed in the Caucasus Mountains. Shahgedanova et al. (2014) evidenced significant glacier recession at the northern slopes of the Caucasus, consistent with increasing air temperature of the ablation season. They report that the most recent decade (2001-2010) was 0.7 – 0.8 °C warmer than in 1960-1986 at Terskol and Klukhorskiy Pereval stations (see Table 1 for information on stations). However, the warmest decade for JJA was 1951-1960 (Shahgedanova et al., 2014). Tielidze (2016) reports recent increase of the annual mean temperatures at different elevations in the Georgian Caucasus. The region experienced glacier area loss over the 20th century at an average annual rate of 0.4% with a higher rate in eastern Caucasus than in the central and western sections.

The analysis of temperature and radiation regime of glaciers at the ablation period has been performed at Elbrus vicinities recently (Toropov et al., 2016). The authors prove that the observed waning of glaciers can not be explaned by increase of temperature during the ablation period because of increase of precipitation during the accumulation period. They concluded that the main driver of glacier retreat if increase of the solar radiation balance for 4% for the 2001-2010 period which corresponds to increase of ablation for 140 mm per ablation season (Toropov et al., 2016).

3.2 Ice core records

The comparison of the four cores obtained at the Western Plateau of Elbrus shows similar variations during overlap periods (see Fig. 2S). We therefore calculate a stack record for each season, based on the average value of individual ice cores for the overlapping seasons. The inter-core disagreement is almost negligible (fig. 2S) and can be explained by different sampling resolution.

We note that the shallow ice core from the Maili plateau of Kazbek shows the same mean values of $\delta^{18}O$ as the Elbrus ice cores during their overlap period. This is a result of a mutual compensation of δ18O increase due to lower elevation position (Kazbek drilling site is 500 m lower) and of δ18O decrease because of continentality effect (Kazbek is 200 km further from the sea). ~~This is a surprise, given the difference in elevation (500 m) and continentality (200 km distance).~~

The inter-annual variability in isotopic composition is about twice larger in ~~winter~~ cold season than in ~~summer~~ warm season for $\delta^{18}O$. Different patterns of inter-annual to multi-decadal variations appear in the instrumental temperature data (see section 3.1) and ice core $\delta^{18}O$ records (Fig 5) emerge for ~~winter~~ cold versus ~~summer~~warm season.~~ Consequently, we do not investigate annual mean results, and focus on each season.~~

The δD and $\delta^{18}O$ values are highly correlated (r = 0.99) on sample to sample scale so hereafter we use the $\delta^{18}O$ information for the dating and comparison with the other parameters. The slope between $\delta^{18}O$ and δD is 8.03 on sample to sample scale and 7.9 on seasonal scale without any significant difference between the two seasons.

No significant (R squared is insignificant at $p<0.05$) centennial trend is identified in ~~winter~~ cold / ~~summer~~warm season $\delta^{18}O$, nor in ~~winter~~ cold / ~~summer~~ warmaccumulation rate or deuterium excess. We observe large variations in $\delta^{18}O$ with high and variable values early 20th century, lower and more stable values in the 1940s-1960s, and a step increase in the 1970s with another level. These variations are coherent in both seasons as well as in annual means but are not reflected in the meteorological observations. There is also an increase of $\delta^{18}O$ in the last two decades in both seasons in regard to the 1970s-1980s values but the absolute values of $\delta^{18}O$ are close to the multiannual seasonal averages (Table 3). The highest decadal values of $\delta^{18}O$ in both ~~summer and winter~~ seasons are observed in 1912-1920. While a recent warming trend is observed in the regional meteorological data (in ~~summer~~warm season), it is much less prominent in the ice core $\delta^{18}O$ record, suggesting a divergence between $\delta^{18}O$ and regional temperature. One of the possible explanations for this feature is the post-depositional change of the isotopic composition. But we do not expect a significant influence of the post-depositional processes because of high snow accumulation rate. The highest $\delta^{18}O$ values for a single year correspond to the ~~summer~~ warm periods of 1984 and 1928, two years for which no unusual feature is identified from meteorological observations. The highest snow accumulation rate (fig. 9) is observed in both seasons of 2010, in coherence with the meteorological precipitation data, and also corresponding with a record low winter NAO index.

Our deuterium excess record (fig. 2b) does not depict any robust seasonal variation. Moreover, the distribution of deuterium excess as a function of $\delta^{18}O$ does not display any clear structure. By contrast, deuterium excess is weakly positively correlated with the accumulation rate during ~~summer~~ warm season (r = 0.~~2~~31~~7~~, $p<0.05$). This finding is consistent with the GNIP data in the region that show no link between $\delta^{18}O$ and deuterium excess. The smoothed values of deuterium excess have prominent cycles with a period of about 25 years that are synchronous in both seasons (fig. 6). Deuterium excess is highly sensitive to surface humidity, which itself is very different and depends on the arrival of maritime air masses or dry continental air masses. This may add to the complexity of the deuterium excess signal (Pfahl and Wernli, 2008).

3.3 Comparison of ice core records with regional meteorological data

We compared the ice core data with the regional meteorological data and the large scale modes of variability. The result of the correlation analysis is summarized in Table 4. Multiannual variations of the parameters are shown in fig. 9 for the ~~winter~~ cold ~~period~~season and in fig. 10 for the ~~summer period~~warm season.

We found no significant correlation between the ice core $\delta^{18}O$ record and regional temperature, neither with the reanalysis data, nor with the observation data, when using the whole period. A significant correlation (r = 0.~~5~~44~~2~~, $p<0.05$) emerges for ~~summer~~ warm season data, when calculated for the period since 1984. The slope for this period is 0.~~2~~6~~5~~ per mille per °C. We also repeated our linear correlation analysis using precipitation weighted temperature, and obtained the same results. The precipitation weighted temperature was calculated using daily meteorological data. We used data from two stations: Klukhorskiy Pereval (as a representative of southern stations) and Mineralnye Vody (as a representative of the northern stations). We didn't find any statistically significant correlations when compared 3-, 5-, 7-years running means of these parameters. This result implies that the isotopic composition at Elbrus is controlled by both local and regional factors such as changes in moisture sources. The possibilities for accurate reconstructions of past temperatures are therefore limited. For more accurate investigation of the $\delta^{18}O$ – temperature relation on-site experiments and subsequent modelling is required. Our results are comparable to those obtained in the Alps by Mariani et al. (2014): again, while the seasonal cycle of ice core $\delta^{18}O$ appears related to that of temperature, this is not the case for inter-annual variations, driven by other factors such as changes in moisture sources. Another research performed in the Alps by Bohleber et al. (2013) revealed significant correlation of modified local temperature and the ice core isotopic composition at decadal scale. The authors also report that there are some periods of correlation absence. The main finding is that for the periods of less than 25 years the difference between the modified according to the authors' method and original dataset temperature is crucial but for longer periods the two temperature datasets are close to each other. That conclusion implies that the isotopic composition reflects the local temperature in the high mountain regions to a limited extent. It seems to be impossible to calculate the modified temperature for the Caucasus region according to the methods described by Bohleber et al. (2013) because of the relatively short and sparse original datasets.

~~We also compared the annual mean temperatures and $\delta^{18}O$ values disregarding the difference in the isotopic composition trends in different seasons. The regression analysis showed significant negative correlation between the two parameters. The regression equation for 11-year running means in the 1914-1928 and 1994-2013 differs from the same for the 1929-1993 (see fig. 11 for the correlation plot and regression equations as well as for the sliding window correlation plot). The 10-years sliding window correlation shows the same result, i.e. sharp changes of the correlation between these parameters with predominant negative correlation. The shifts can be explained by a sharp change of the climatic system. The negative correlation between $\delta^{18}O$ and local temperature has already been observed in Antarctica (Vladimirova and Ekaykin, 2014). It can be explained by the change of the moisture source that can lead to increase of the difference between the source temperature and local temperature while local temperature slightly decreases.~~

Seasonal accumulation rate is linked to the precipitation rate on the stations situated south of the Caucasus in both seasons (r = 0.~~45~~49), and even more closely related to precipitation from Klukhorski Pereval station (r = 0.~~65~~ 63 for both seasons). We therefore establish a linear regression model for the period 1966-2013, and use this methodology to reconstruct past precipitation rates for the Klukhorskiy Pereval station (1914-1965), when meteorological records are not reliable or not available. The reconstructed records are shown on fig. 9 and 10 for the ~~winter~~ cold and ~~summer~~ warm seasons respectively. We found no significant trend in the reconstructed precipitation values. Even so, these results can be useful for validation of regional climate models and water resource assesment.

Calculation of the seasonal cycle of precipitation isotopic composition using the LMDZiso model (Risi et al., 2010) do not correspond to the results obtained from the ice core in absolute values or in amplitude (Fig. S5). This can be explained by a complicated relief of the region that influences strongly the isotopic composition, but it is not taken into account in the model. Also in summer Elbrus is in a local convective precipitation system that is not included in the model.

3.4 Comparison of ice core records with large scale modes of variability

We didn't find any statistically significant correlations between ice cores data and large scale modes of variability when using the mean annual values. We present the results of calculations in the table 4. We report a weak though significant ($p<0.05$) negative correlation (r = - 0.~~33~~18) between the ice core accumulation rate record and NAO in ~~winter~~cold season. Moreover, the year of extremely high accumulation in both seasons (2010) coincides with an extremely low NAO winter index. The role of NAO in regional climate had also been evidenced by Shahgedanova et al. (2005) for the mass-balance of the Djankuat glacier situated in 30 km south-east of Elbrus for the period of 1967-2001. Interestingly, the accumulation record is related to the variability of regional precipitation, but the latter is not significantly related to the NAO. This may suggest different influences of large-scale atmospheric circulation on precipitation at lower versus higher elevations.

The ice core ~~winter~~cold season $\delta^{18}O$ record shows a positive correlation with the NAO index (r = 0.~~42~~41), while the NAO index is negatively correlated with regional temperature (r = - 0.42). It also contradicts the findings of Baldini et al (2008) who, based on the GNIP low elevation dataset, extrapolated a negative correlation between the $\delta^{18}O$ of precipitation and the NAO in this region. This finding also suggests different drivers of temperature and $\delta^{18}O$ at low and higher elevation. We propose the following explanation for this correlation. During the positive NAO phase, the predominant moisture source for the Caucasus precipitation is the Mediterranean. During the negative NAO phase the moisture sourse is the Atlantic. In the first case the precipitation $\delta^{18}O$ preserved in the ice core is higher because of higher initial sea water isotopic composition (Gat et al., 1996) and shorter distillation pathway. It is also the continental recycling of moisture (Eltahir and Bras, 1996) that influences the water isotopic composition. Due to this process the δ18O values became lower while *d* values increase (Aemisegger et al., 2014) which is observed in our ice core data. In the opposite situation the initial water isotopic composition is close to 0 ‰ (Frew et al., 2000) and the distillation pathway is longer which leads to lower values of precipitation $\delta^{18}O$.

~~In order to explore the relationships of the Elbrus ice core datasets with the AMO, we used 20-year smoothed data. We show a negative correlation between the AMO index and the summer ice core $\delta^{18}O$ signal (r = - 0.53) and a positive correlation between the AMO index and the winter accumulation record (r = 0.52). As the correlation analysis between the ice core data and AMO index was performed with smoothed records it is not reported in Table 4, in order to avoid misunderstanding~~.

We explored the links between the ice core parameters ($\delta^{18}O$, accumulation rate) with the NCP index and found no significant correlation neither in winter nor in summer despite the significant correlation between the NCP and local temperature and precipitation. A possible explanation may be that the NCP pattern only affects low elevation regional climate but not high elevation climate.

No significant correlation was identified between deuterium excess and indices of large scale modes of variability. So far, no regional or large-scale climate signal could be identified in Elbrus deuterium excess. Further investigations using backtrajectories and diagnoses of moisture source and evaporation characteristics will be needed to explore further the drivers of this second-order isotopic parameter.

4 Conclusion

We found no persistent link between ice cores $\delta^{18}O$ and temperature on interannual scale, common feature emerging from non-polar ice cores (e.g. Mariani et al., 2014). This finding is not an artifact of high elevation versus low elevation difference because the variability of the regional temperature stack used for this comparison is in good agreement with the variability of the temperature at the drilling site as observed by the local AWS.

Our ice core records depict large decadal variations in $\delta^{18}O$ with high and variable values in the late 19th - early 20th centuries, lower and more stable values in the 1940s-1960s, followed by a step increase in the 1970s. No unusual recent change is detected in the isotopic composition or in the accumulation rate record, in contrast with the observed warming trend from regional meteorological data. The accumulation rate appears significantly related to the NAO index coherently with the earlier results for the Djankuat glacier (Shahgedanova et al. 2005).

Based on regional meteorological information and trajectory analyses, the main moisture source is situated not far from the drilling site in ~~summer~~warm season, and consists of evaporation from the Black Sea and continental evapotranspiration. Changes in regional temperature during ~~summer~~ warm season may affect the initial vapour isotopic composition as well as the atmospheric distillation processes, including convective activity, in a complex way. This may explain the significant albeit non persistent correlation of summer $\delta^{18}O$ and temperature. ~~Winter~~ Cold season moisture sources appear more variable geographically, with potential contributions from the North Atlantic to the Mediterranean regions. Changes in moisture origin appear to dominate in regional temperature-driven distillation processes. As a result, the ice core isotopic composition appears mostly related to characteristics of large –scale atmosphere circulation such as the NAO index. The changes in moisture origin also influence deuterium excess parameter, which does not have any prominent seasonal variations.

Our data can be used in atmospheric models equipped with water stable isotopes for instance in order to assess their ability to resolve NAO – water isotope relationships (Langebroek et al., 2011, Casado et al., 2014). The accumulation rate at the drilling site is ~~highly~~ significantly correlated with the precipitation rate and gives information about precipitation variability before the beginning of meteorological observations.

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Figures

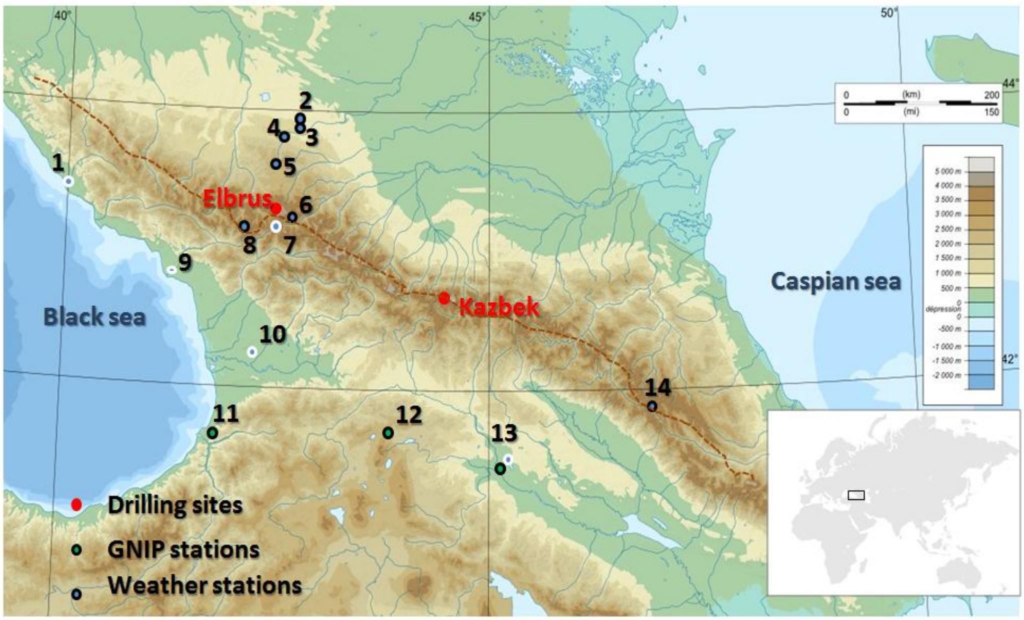


Fig. 1: Map showing the region around Elbrus (black rectangle in the world's map in the lower right corner), with shading indicating elevation (m above sea level). Drilling sites are indicated with red filled circles, GNIP stations as green filled circles, and meteorological stations as blue dots. Stations situated to the south of the Main Caucasus Ridge according to the precipitation cycle pattern are shown using a blue dot with white outside circle and the stations situated to the north are displayed with black outside circle (see text for the details). The brown dotted line shows the border between two types of precipitation seasonal cycles. The number of the various stations refers to Table 1 for their detailed description.

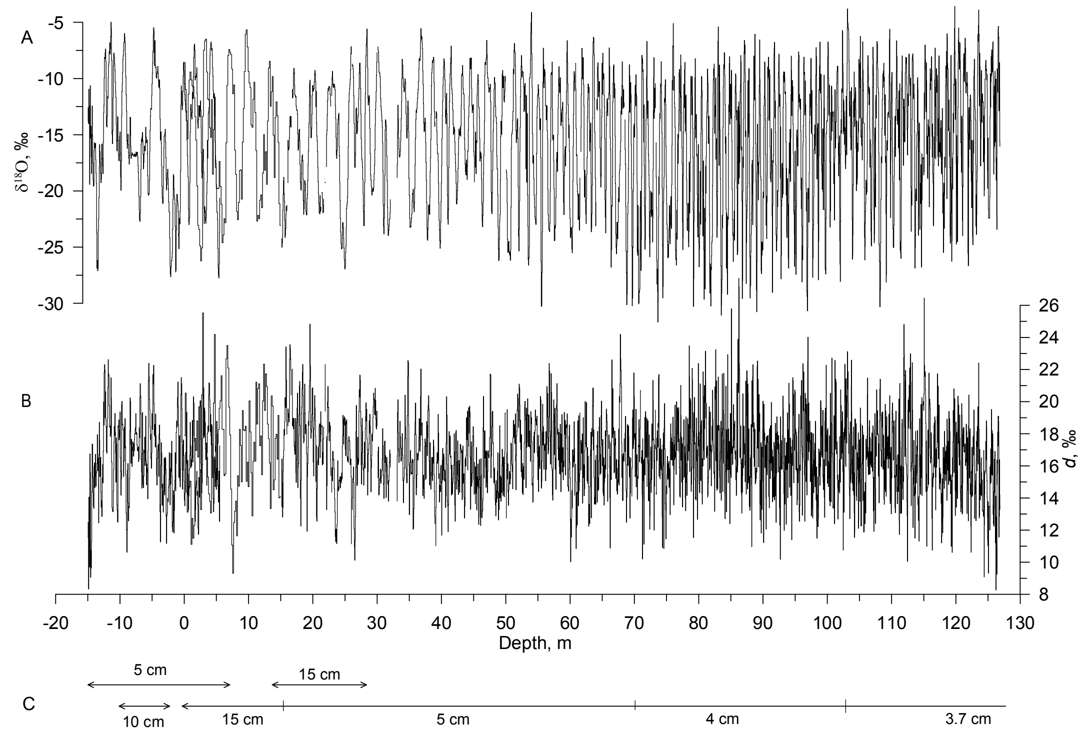
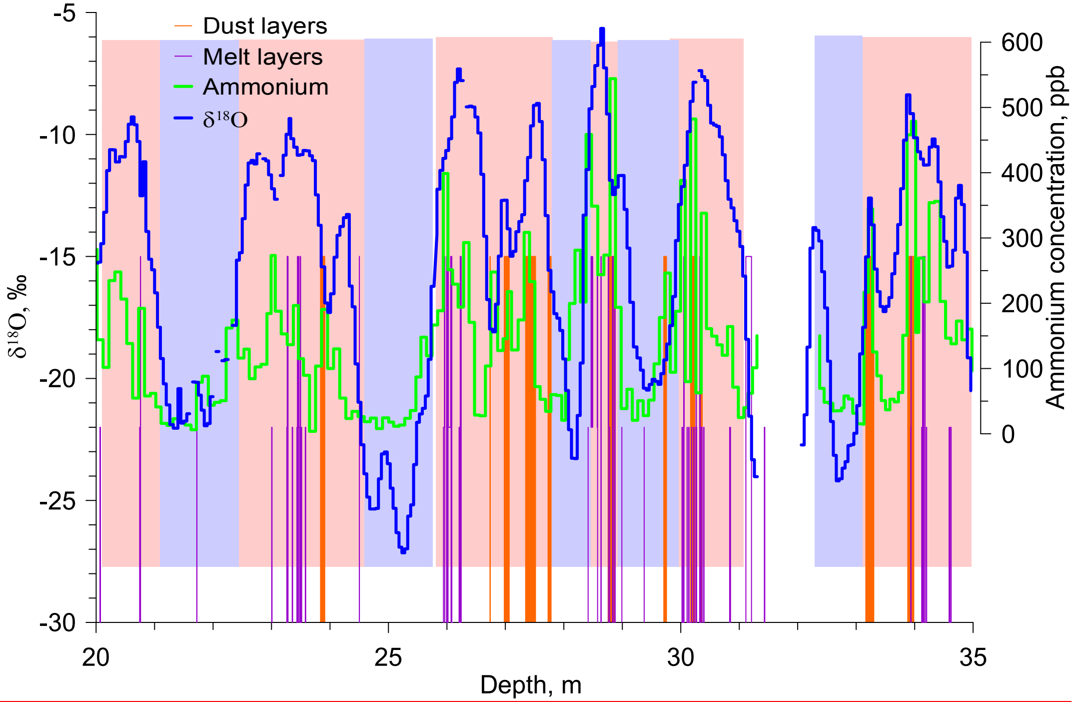


Fig. 2. Vertical profile of $\delta^{18}O$ (A), deuterium excess (B), and the number of the ice core as well as sampling resolution (C). 0 m depth corresponds to the surface of 2009.



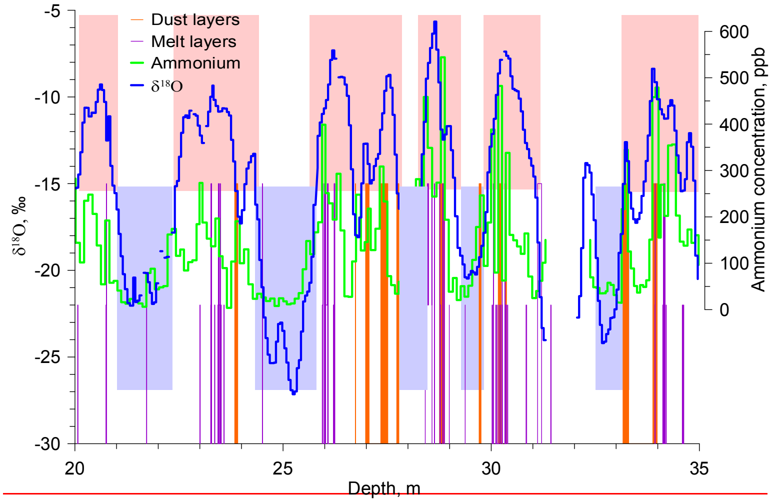


Fig. 3: Illustration of the scheme used to identify warm and cold half-years (respectively indicated by the light red and light blue shaded areas) based on the deviation of the mean $\delta^{18}O$ values from the long-term average value. The purple lines depict the melt

Отформатировано: Шрифт: 9 пт, полужирный

layers observed in the core, dust layers are shown in orange and ammonium concentration graph (Mikhalenko et al., 2015) is in green.

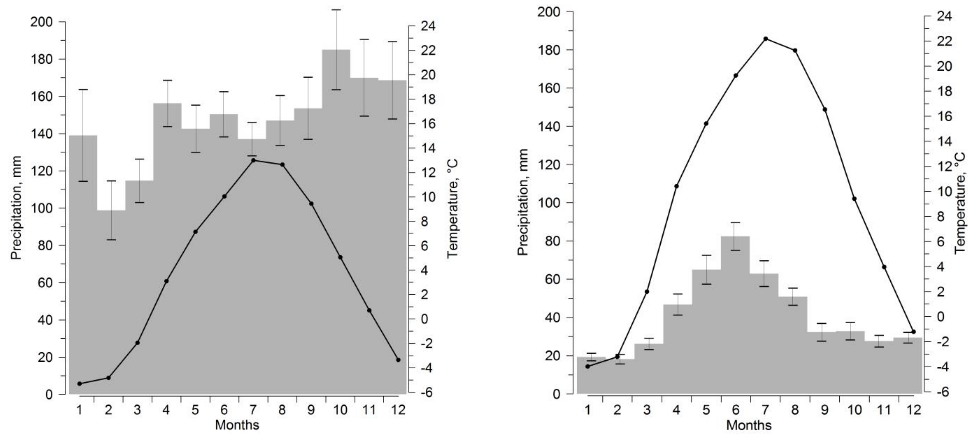
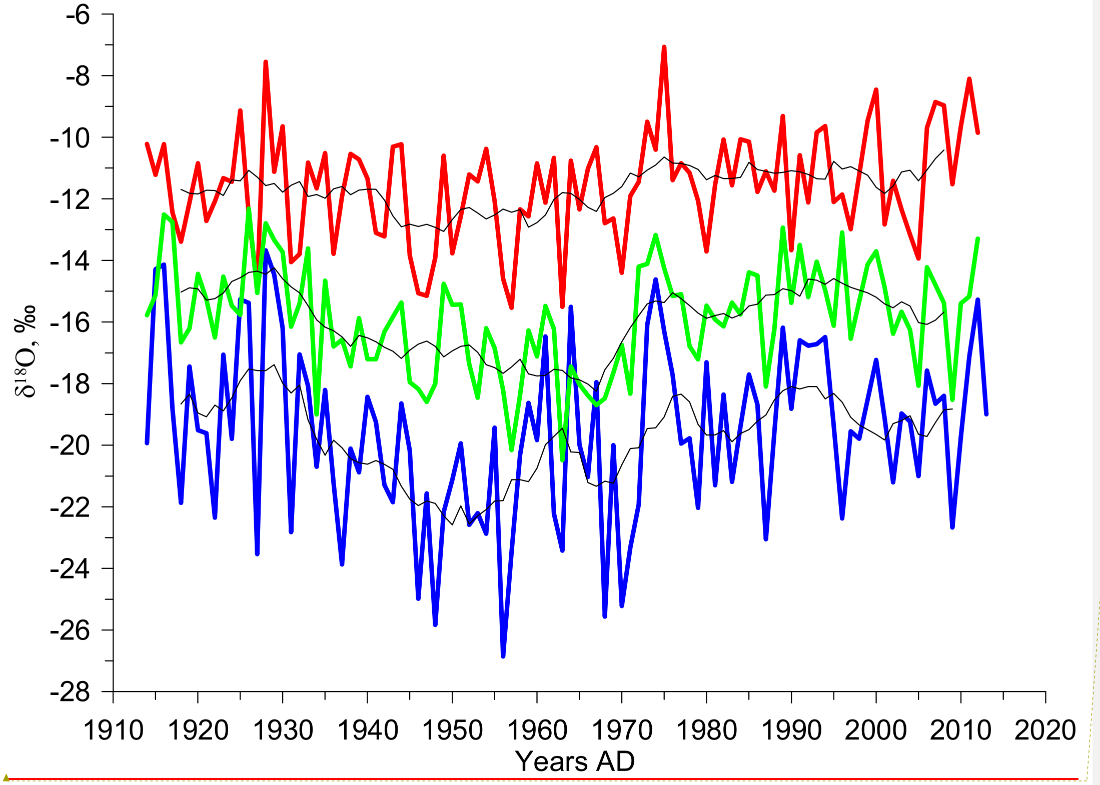


Fig. 4: Average seasonal cycle of temperature (black dots and line) and precipitation (grey bars) calculated over 1966-1990 period, a) for the Klukhorsky Pereval station (illustrating the lack of a distinct seasonal cycle in precipitation south of the Caucasus) and b) for the Mineralnye Vody station (illustrating the clear seasonal cycle in precipitation seen in stations north of the Caucasus). Error bars (SEM) are shown for the interannual standard deviation of the monthly precipitation rate while the same error bars for the temperature are dimensionless at the scale of the graph.



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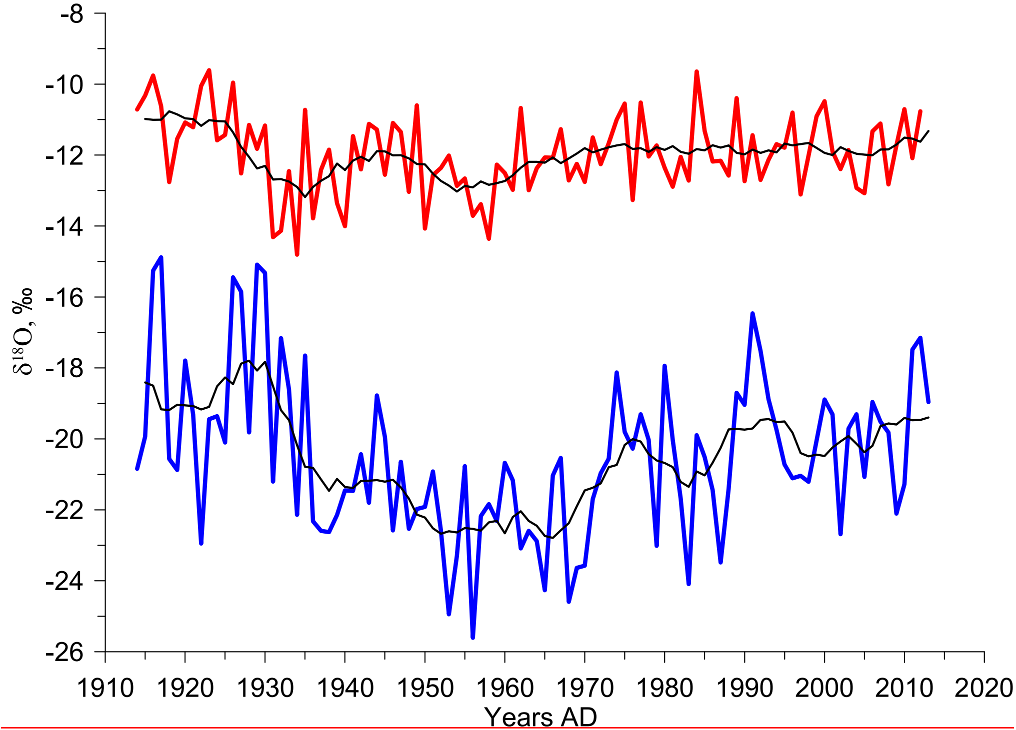

Fig. 5: Annual variations of δ^{18}O in ~~summer~~ warm season (red line), in cold season ~~and in winter~~ (blue line), and annual means (green line). Thin black lines show 10-year running means of these parameters.

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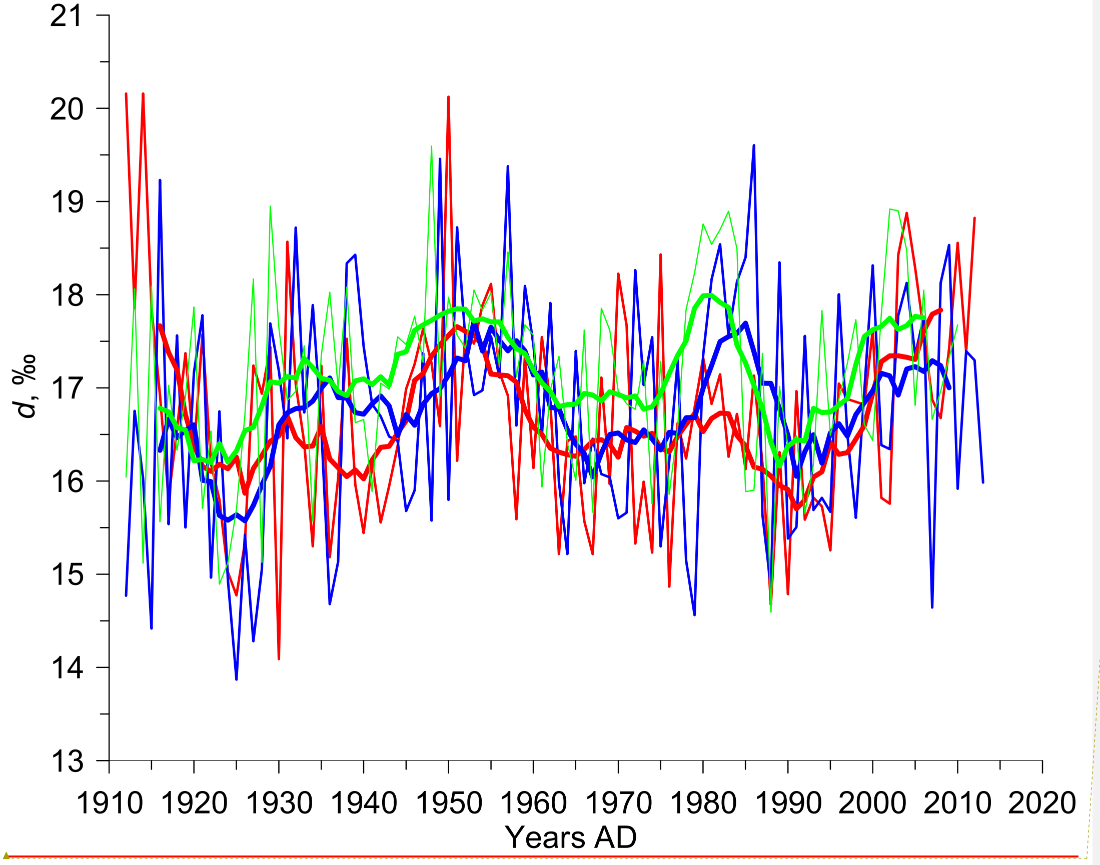

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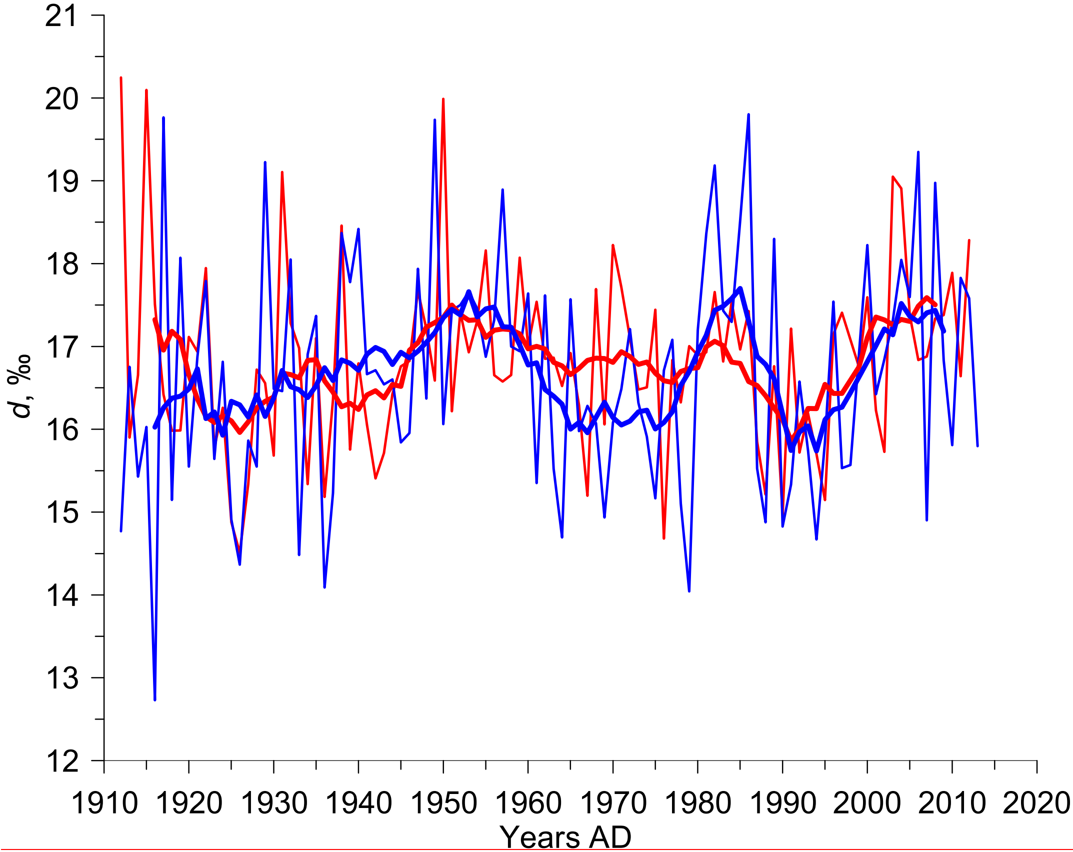


Fig. 6: Annual variations of deuterium excess in ~~summer~~ warm season (red line)~~, and~~ in ~~winter~~ cold season (blue line), and mean annual values (green line). Thick lines show the 10-year smoothed values and the thin ones display the raw values.

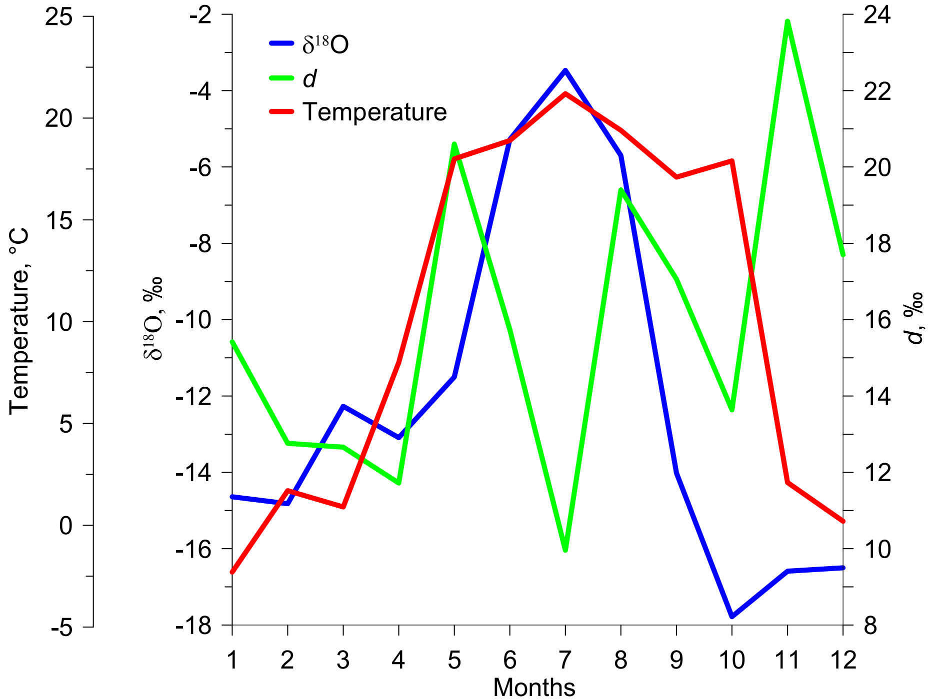
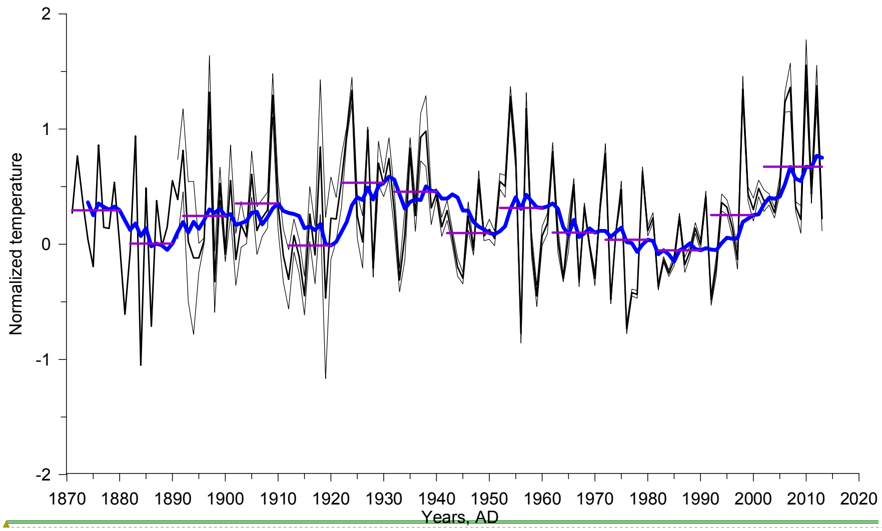


Fig. 7: Monthly $\delta^{18}O$ (blue line), *d* (green line) and air temperature (red line) data at Bakuriani GNIP station in 2009 (see Table 1 for information on station and Fig. 1 for its location). Note that there is no clear seasonal cycle in deuterium excess, in contrast with $\delta^{18}O$ showing maximum values in summer and minimum values in winter.



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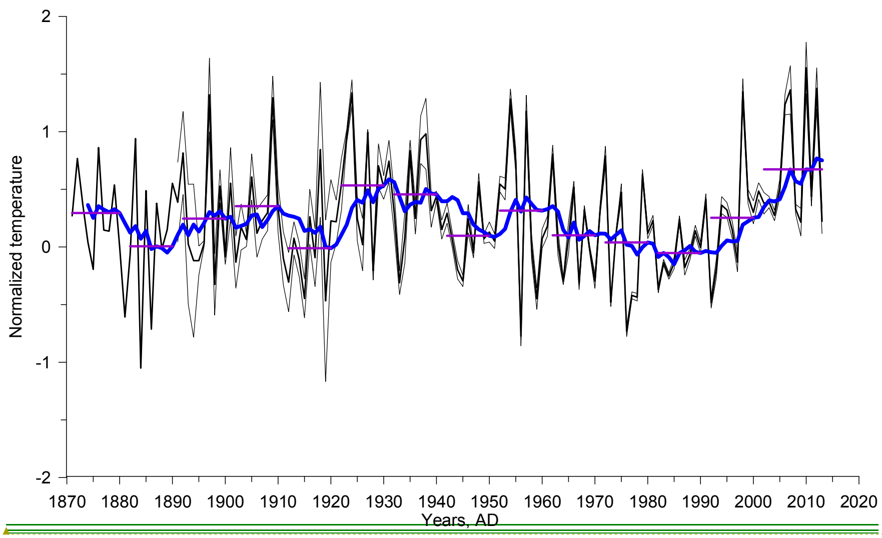

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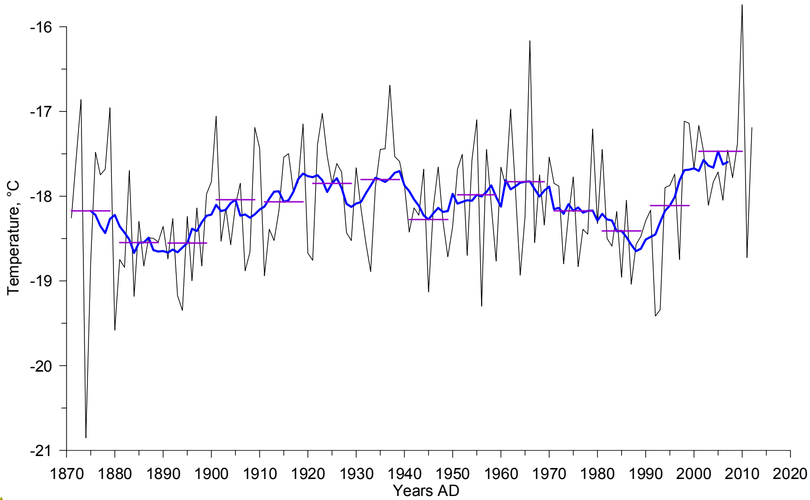

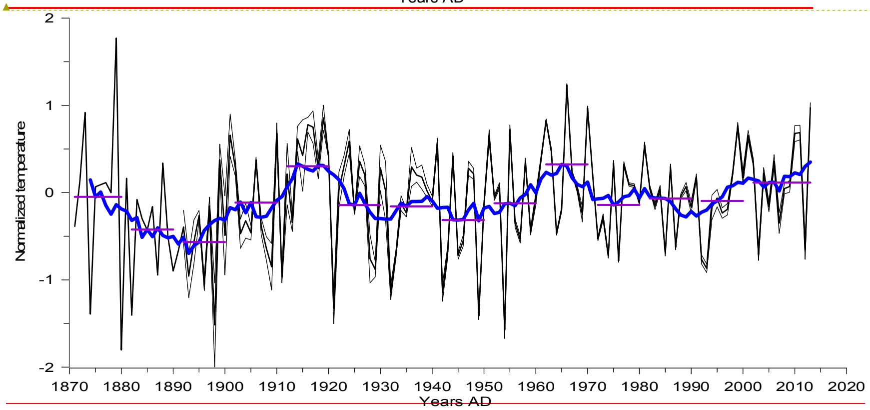

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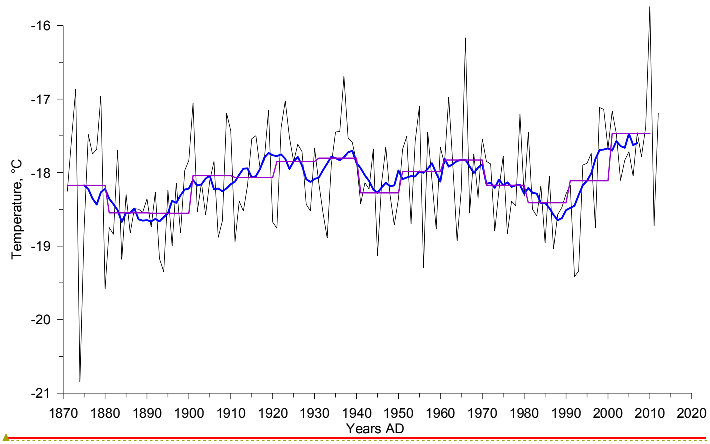

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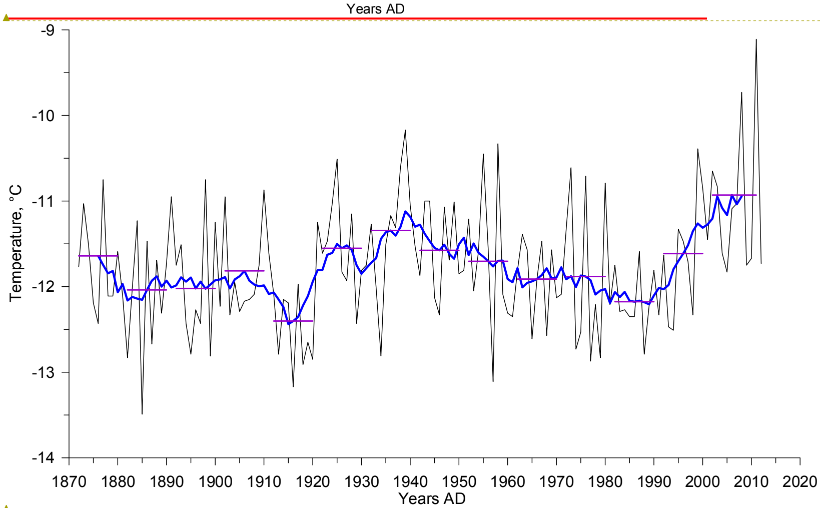

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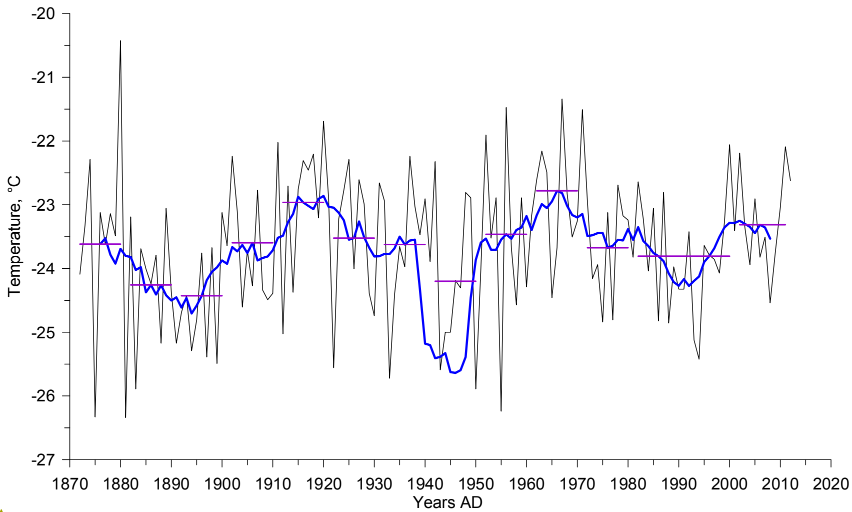

Fig. 8: Normalized regional temperature record based on meteorological data, with respect to the reference period 1966-1990, expressed as annual anomalies (°C). The thin lines illustrate the standard deviation across the individual records after accounting for the lapse rate from Fig. S3, the blue line shows 10 year running mean and the horizontal purple line demonstrates the decadal mean value, the upper panel for the annual means, middle panel for the warm season, and the lower panel for the cold season.

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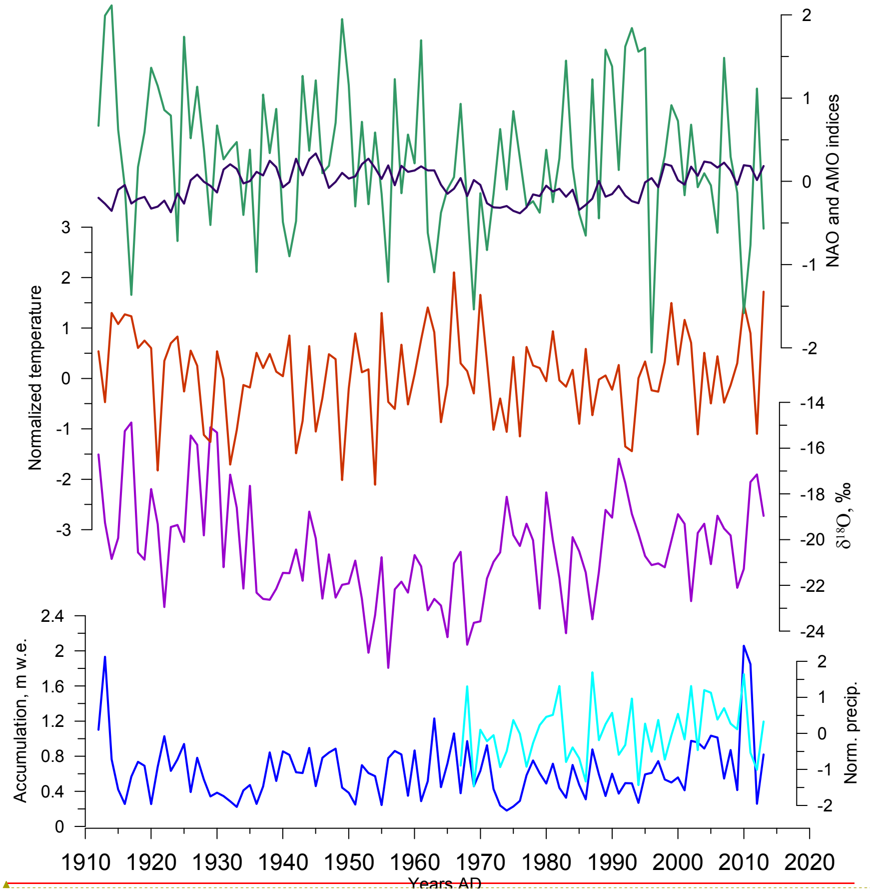

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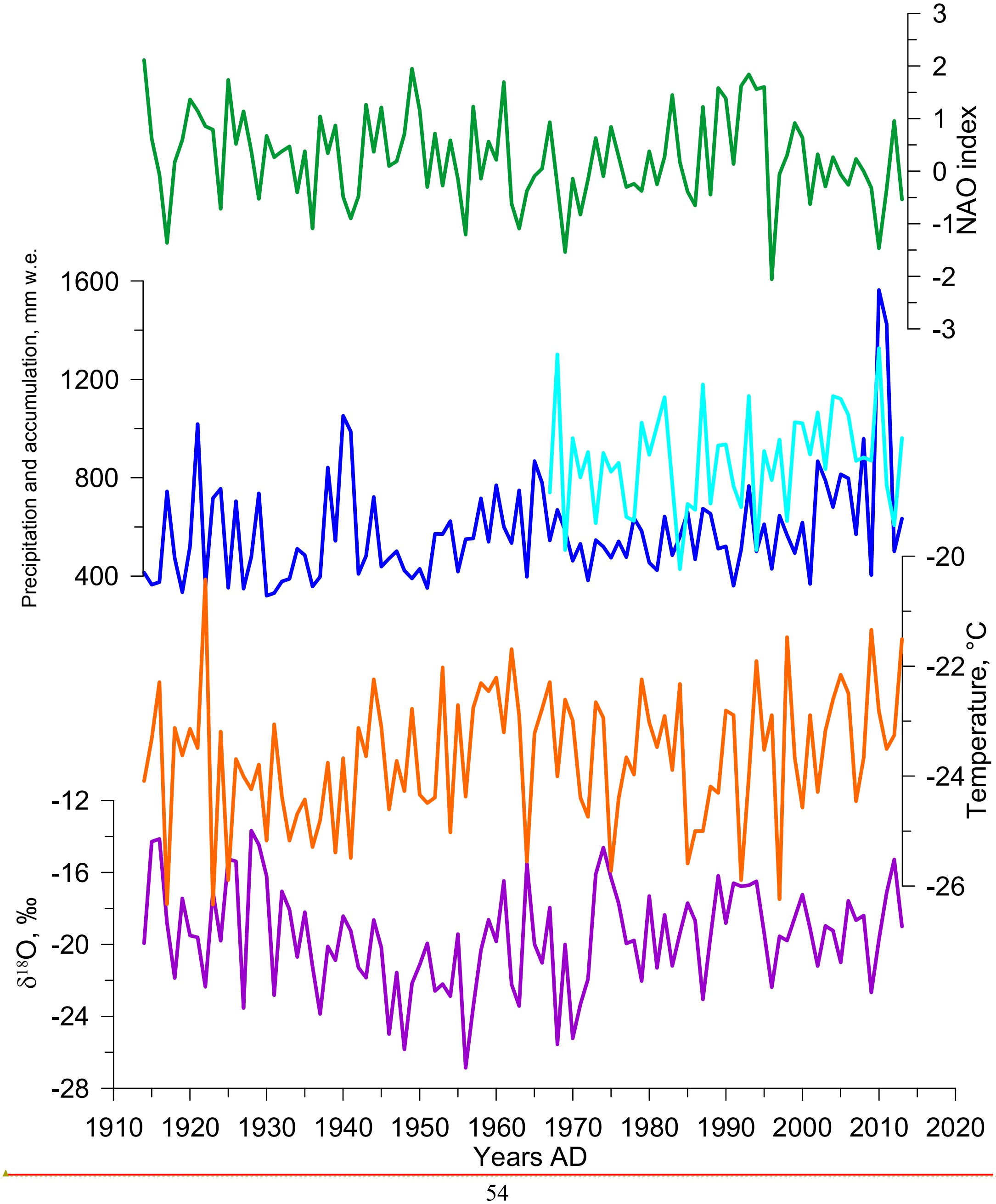

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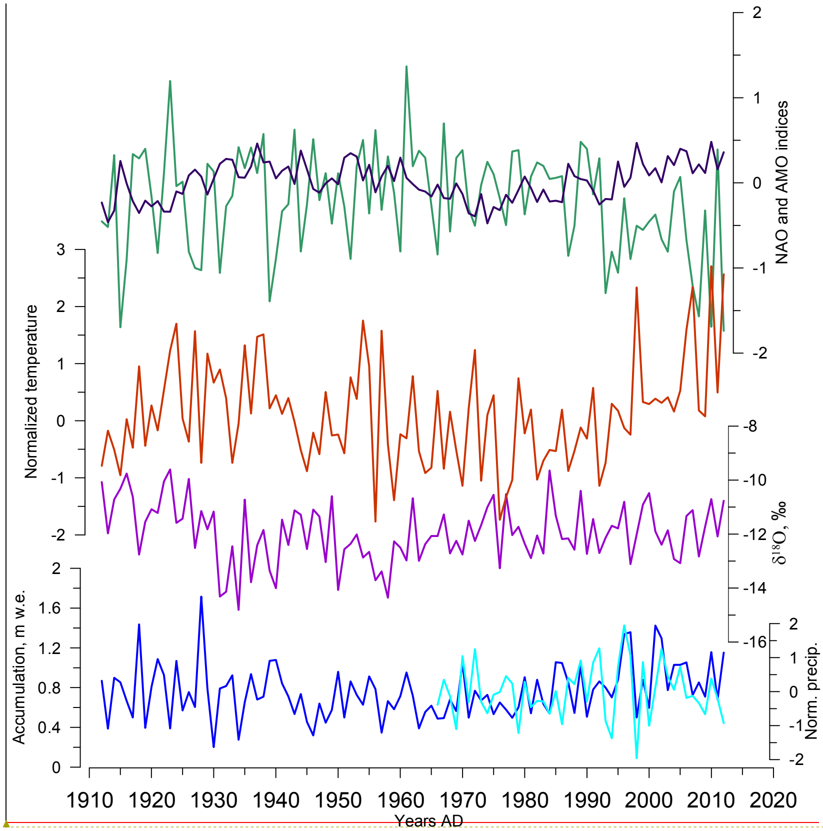
Отформатировано: Шрифт: 9 пт, полужирный

Fig. 9: Comparison of the ice core record with instrumental regional climate information, for the cold season: δ^{18}O composite (purple), ~~regional meteorological composites of temperature~~temperature at the drilling site calculated from the lapse rate (brown), precipitation ~~to the south from the Caucasus~~at the Klukhorskiy Pereval station (light blue) as well as the ice core accumulation estimate (dark blue) and NAO index(green) ~~and AMO (dark) indices~~.



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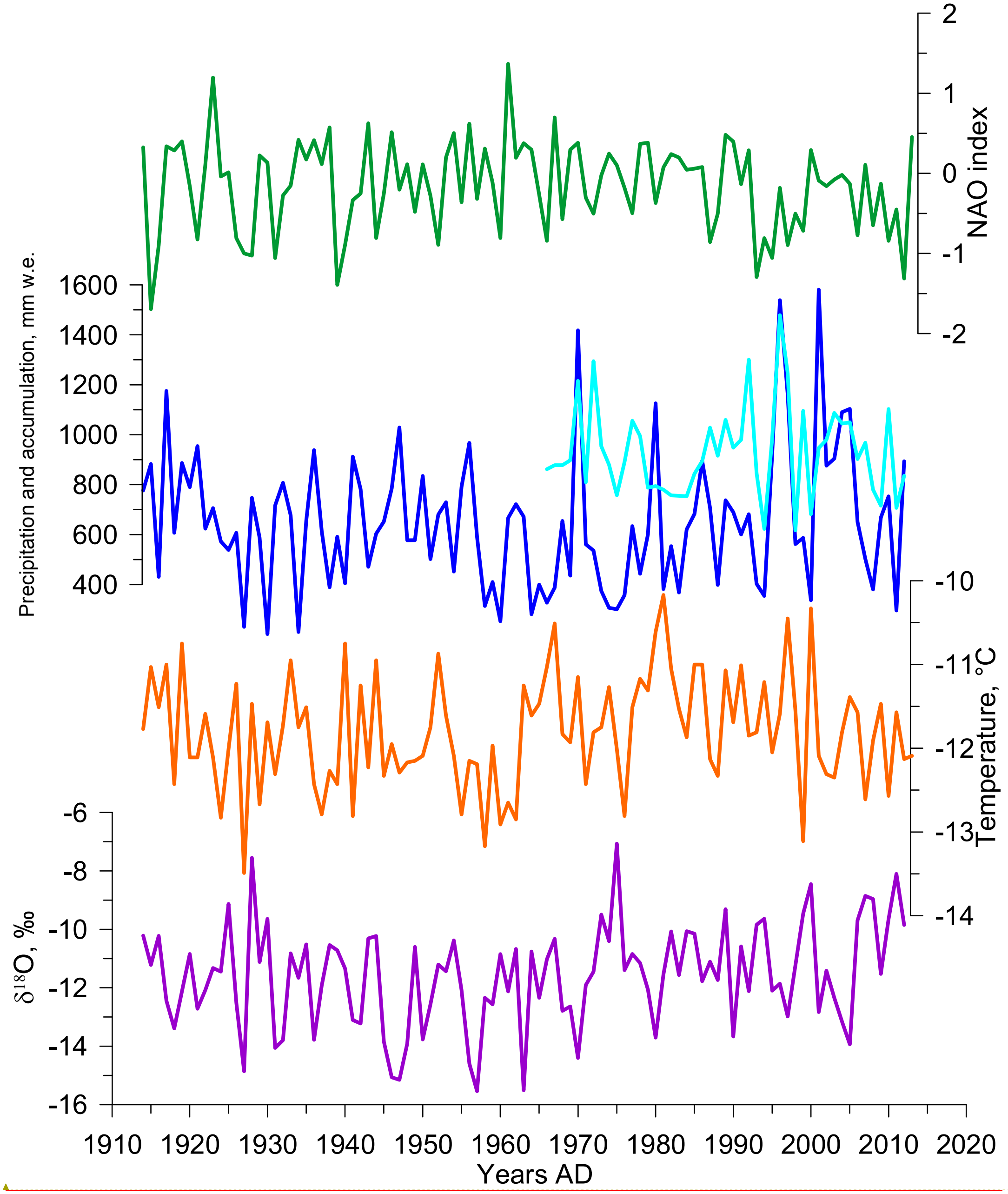

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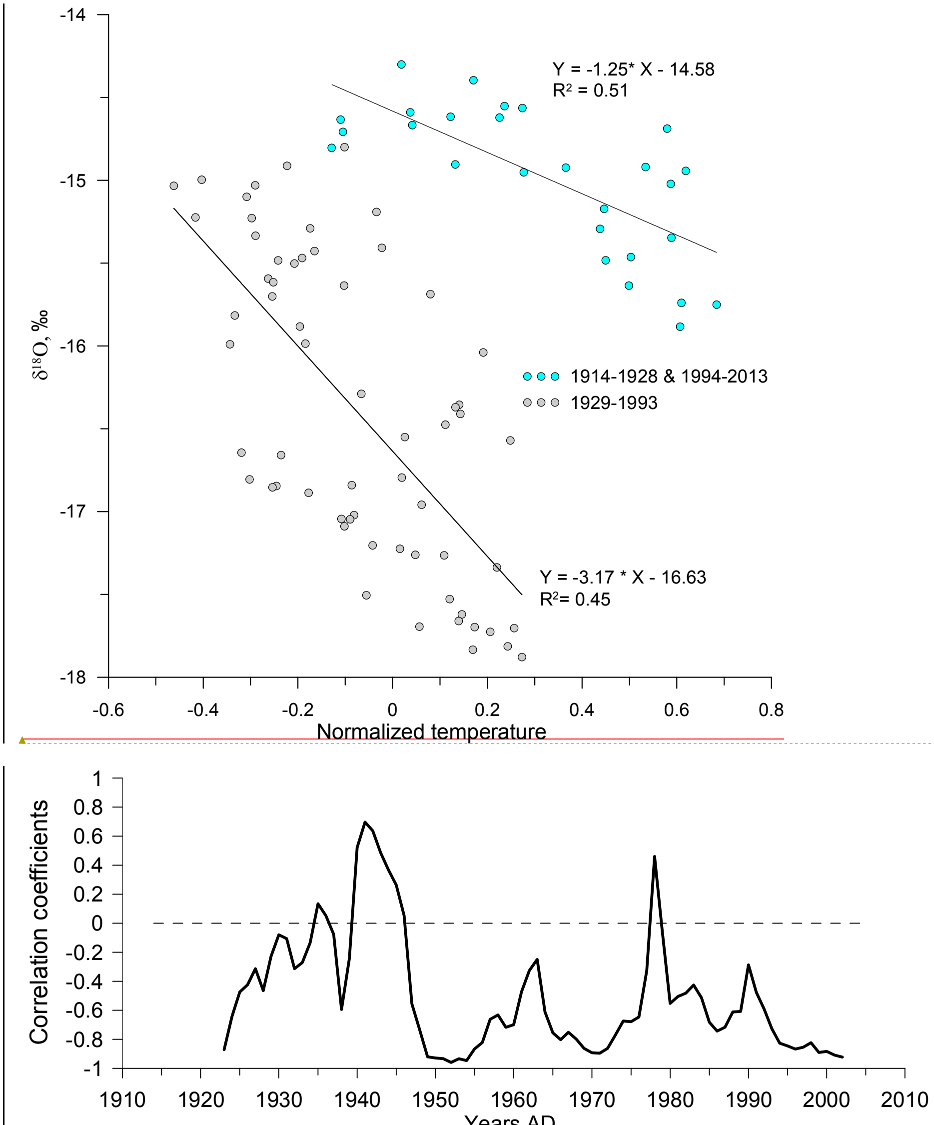
Fig. 10: ~~**Comparison of the ice core record with instrumental regional climate information, for the warm season: δ^{18}O composite (purple), regional meteorological composites of temperature (brown), precipitation to the south from the Caucasus (light blue) as well as the ice core accumulation estimate (dark blue) and NAO (green) and AMO (dark) indices**~~**Same as fig. 9 but for the warm season.**



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Отформатировано: Шрифт: 9 пт, полужирный

~~**Fig. 11. Correlation plot and regression lines for the 11-year running means of the annual local temperature and annual δ18O (upper panel) and 10-years sliding window correlation coefficients of the same parameters**~~.

Table 1: Description of meteorological and instrumental data used in the paper

Data type	Number on map (Fig. 1)	Location/Name	Altitude a.s.l.	Time span	Data source
Meteorological observations (temperature, precipitation rate) with daily resolution	1	Sochi	57 m	1871-present	www.meteo.ru
	2	Mineralnye Vody	315 m	1938-present	
	3	Kislovodsk	943 m	1940-present	
	4	Pyatigorsk	538 m	1891-1997	
	5	Shadzhatmaz	2070 m	1959-present	
	6	Terskol	2133 m	1951-2005	
	7	Klukhorskiy Pereval	2037 m	1959-present	
	8	Teberda	1550 m	1956-2005	
	9	Sukhumi	75 m	1904-1988	
	10	Samtredia	24 m	1936-1992	
	13	Tbilisi	448 m	1881-1992	
	14	Sulak	2927 m	1930-present	
	15	Mestia	1417 m	1930-1991	
GNIP data	11	Batumi	32 m	1980-1990	http://www-naweb.iaea.org/napc/ih/IHS_resources_gnip.html
	12	Bakuriani	1700 m	2008-2009	
	13	Tbilisi	448 m	2008-2009	
Circulation indices	n/a	NAO	n/a	1821-present	Vinter et al., 2009 https:\\crudata.uea.ac.uk\~timo\datapages\naoi.htm
			n/a	1950-present	http:\\www.cpc.ncep.noaa.gov\products\precip\CWlink\
	n/a	NCP	n/a	1948-present	
	n/a	AO	n/a	1950-present	
Reanalysis daily temperature	n/a	NCEP	500 mb level	1948-present	http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.html Kalnay et al., 1996
Back trajectories	n/a	Flexpart	n/a	2002-2009	Forster et al., 2007, Stohl et al., 2009
	n/a	Hysplit	n/a	1948-present	Draxler, 1999, Stein et al., 2015, Rolph, 2016
	n/a	LMDZiso	n/a	n/a	Risi et al., 2010

Table 2: Correlation coefficients between meteorological data and indices of large-scale modes of variability (statistically significant coefficients at $p < 0.05$ are highlighted in bold). The period of calculation and number of data points (n) for each coefficient is are shown in brackets.

	SUMMER			WINTER		
	Temperature	P south*	P north*	Temperature	P south*	P north*
NAO	**-0.47 (100)**	**0.23 (45)**	-0.03 (45)	**-0.41 (100)**	0.04 (45)	**0.26 (45)**
AO	-0.11 (63)	0.08 (45)	-0.14 (45)	**-0.40 (63)**	0.14 (45)	**0.37 (45)**
AMO	**0.24 (100)**	0.01 (45)	-0.02 (45)	0.07 (100)	**0.27 (45)**	**0.25 (45)**
NCP	**-0.50 (65)**	**0.34 (45)**	0.18 (45)	**-0.77 (65)**	**0.25 (45)**	**0.33 (45)**

Annual mean	Temperature	P south*	P north*
NAO	**-0.24** (1914-2013, n=100)	-0.24 (1966-2013, n=48)	-0.03 (1966-2013, n=48)
AO	**-0.34** (1950-2013, n=64)	-0.06 (1966-2013, n=48)	0.02 (1966-2013, n=48)
NCP	**-0.55** (1948-2013, n=66)	0.26 (1966-2013, n=48)	0.26 (1966-2013, n=48)
Warm season			
NAO	**-0.47** (1914-2013, n=100)	0.23 (1966-2013, n=48)	0.03 (1966-2013, n=48)
AO	-0.11 (1950-2013, n=64)	0.08 (1966-2013, n=48)	0.14 (1966-2013, n=48)
NCP	**-0.50** (1948-2013, n=66)	**0.34** (1966-2013, n=48)	**0.34** (1966-2013, n=48)
Cold season			
NAO	**-0.41** (1914-2013, n=100)	0.04 (1966-2013, n=48)	0.26 (1966-2013, n=48)
AO	**-0.40** (1950-2013, n=64)	0.14 (1966-2013, n=48)	**0.37** (1966-2013, n=48)
NCP	**-0.77** (1948-2013, n=66)	0.25 (1966-2013, n=48)	**0.33** (1966-2013, n=48)

*P south – precipitation rate at the weather stations to the South from the Caucasus, P north – precipitation rate at the weather stations to the North from the Caucasus.

Отформатировано: Английский (США)

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Отформатированная таблица

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Table 3: Mean characteristics of the Elbrus ice core records, calculated for the period from 1914 to 2013.

Annual means~~**Winter**~~	$\delta^{18}O$, ‰	δD, ‰	*d*, ‰	Accumulation rate (m~~m~~ w.e./year)
Mean	-15.90	-110.10	17.11	1,29
Standard deviation	1.76	14.03	1.02	0.44
Cold season				
Mean	~~-21.20~~-19.61	-~~152.42~~-140.11	~~17.16~~16.59	~~0.61~~0.71
Standard deviation	~~2.18~~2.81	~~17.44~~22.54	~~1.41~~2.11	~~0.31~~0.36
Warm season~~**Summer**~~				
Mean	~~-11.80~~-11.58	~~-77.32~~-75.97	~~17.06~~16.69	~~0.76~~0.65
Standard deviation	1.75~~1.02~~	~~8.10~~13.98	~~1.15~~1.14	~~0.26~~0.27

Table 4. Correlation coefficients between ice core data, meteorological data and indices of large-scale modes of variability (statistically significant coefficients at $p < 0.05$ are highlighted in bold). The period of calculation and number of data points (n) for each coefficient is shown in brackets.

Annual means	δ^{18}O	Accumulation	*d*	NAO	AO	NCP
T. °C	-0.01 (1914-2013, n=100)	0.16 (1914-2013, n=100)	0.00 (1914-2013, n=100)	**-0.24** (1914-2013, n=100)	**-0.34** (1950-2013, n=64)	**-0.55** (1948-2013, n=66)
P north*	-0.30 (1966-2013, n=48)	0.36 (1966-2013, n=48)	0.17 (1966-2013, n=48)	-0.03 (1966-2013, n=48)	-0.03 (1966-2013, n=48)	0.27 (1966-2013, n=48)
P south*	0.06 (1966-2013, n=48)	**0.52** (1966-2013, n=48)	0.07 (1966-2013, n=48)	-0.24 (1966-2013, n=48)	-0.06 (1966-2013, n=48)	0.18 (1966-2013, n=48)
δ^{18}O		-0.20 (1914-2013, n=100)	-0.06 (1914-2013, n=100)	0.07 (1914-2013, n=100)	**0.41** (1950-2013, n=64)	0.11 (1948-2013, n=66)
Accumulation			0.21 06 (1914-2013, n=100)	**-0.29** (1914-2013, n=100)	**-0.29** (1950-2013, n=64)	-0.03 (1948-2013, n=66)
d				-0.08 (1914-2013, n=100)	-0.26 (1950-2013, n=64)	-0.14 (1948-2013, n=66)
~~Summer~~Warm season	δ^{18}O	Accumulation	*d*	NAO	AO	NCP
T. °C	~~0.13 (100)~~0.13 (1914-2013, n=100)	~~0.09 (100)~~-0.04 (1914-2013, n=100)	~~0.21 (100)~~**0.20** (1914-2013, n=100)	~~-0.48 (100)~~-0.02 (1914-2013, n=100)	~~-0.10 (63~~-0.10~~)~~ (1950-2013, n=64)	~~-0.51 (65)~~**-0.51** (1948-2013, n=66)
P north*	~~0.07 (45)~~0.01 (1966-2013, n=48)	~~0.24 (45)~~0.16 (1966-2013, n=48)	~~0.11 (45)~~0.09 (1966-2013, n=48)	~~-0.03 (45)~~0.13 (1966-2013, n=48)	~~-0.14 (45)~~-0.14 (1966-2013, n=48)	~~0.18 (45)~~0.18 (1966-2013, n=48)
P south*	~~-0.12 (45)~~-0.27 (1966-2013, n=48)	~~0.44 (45)~~**0.49** (1966-2013, n=48)	~~-0.04 (45)~~-0.02 (1966-2013, n=48)	~~0.23 (45)~~-0.01 (1966-2013, n=48)	~~0.08 (45)~~0.07 (1966-2013, n=48)	~~0.34 (45)~~**0.34** (1966-2013, n=48)
δ^{18}O		~~-0.17 (100)~~**-0.42** (1914-2013, n=100)	~~-0.11 (100)~~-0.05 (1914-2013, n=100)	~~0.06 (100)~~-0.08 (1914-2013, n=100)	~~0.23 (63)~~0.16 (1950-2013, n=64)	~~-0.04 (65)~~0.00 (1948-2013, n=66)
Accumulation			~~0.27 (100)~~0.31 06 (1914-2013, n=100)	~~-0.25 (100)~~0.00 (1914-2013, n=100)	~~0.05 (63)~~0.09 (1950-2013, n=64)	~~0.07 (65)~~0.00 (1948-2013, n=66)
d				~~-0.17 (100)~~0.00 (1914-2013, n=100)	~~0.00 (63)~~-0.01 (1950-2013, n=64)	~~-0.18 (65)~~-0.14 (1948-2013, n=66)
~~Winter~~Cold season	δ^{18}O	Accumulation	*d*	NAO	AO	NCP
T. °C	~~-0.02 (100)~~-0.09 (1914-2013, n=100)	~~0.31 (100)~~0.11 (1914-2013, n=100)	~~-0.08 (100)~~-0.15 (1914-2013, n=100)	~~-0.42 (100)~~**-0.30** (1914-2013, n=100)	~~-0.45 (63)~~**-0.45** (1950-2013, n=64)	~~-0.79 (65)~~**-0.79** (1948-2013, n=66)
P north*	~~0.25 (45)~~0.20 (1966-2013, n=48)	~~0.13 (45)~~0.21 (1966-2013, n=48)	~~-0.01 (45)~~-0.12 (1966-2013, n=48)	~~0.26 (45)~~**0.51** (1966-2013, n=48)	~~0.37 (45)~~**0.37** (1966-2013, n=48)	~~0.23 (45)~~0.23 (1966-2013, n=48)

Отформатировано ... [3]
Отформатированная табли ... [1]
Отформатировано ... [5]
Отформатировано ... [4]
Отформатировано ... [6]
Отформатировано ... [2]
Отформатировано ... [9]
Отформатировано ... [7]
Отформатировано ... [8]
Отформатировано ... [11]
Отформатировано ... [13]
Отформатировано ... [10]
Отформатировано ... [12]
Отформатировано ... [15]
Отформатировано ... [14]
Отформатировано ... [17]
Отформатировано ... [18]
Отформатировано ... [19]
Отформатировано ... [16]
Отформатировано ... [20]
Отформатировано ... [21]
Отформатировано ... [23]
Отформатировано ... [22]
Отформатировано ... [24]
Отформатировано ... [25]
Отформатировано ... [26]
Отформатировано ... [27]
Отформатировано ... [28]
Отформатировано ... [29]
Отформатировано ... [30]
Отформатировано ... [31]
Отформатировано ... [32]
Отформатировано ... [33]
Отформатировано ... [34]
Отформатировано ... [35]
Отформатировано ... [36]
Отформатировано ... [37]
Отформатировано ... [38]
Отформатировано ... [39]

P south*	~~-0.09 (45)~~ **-0.30** (1966-2013, n=48)	~~0.44 (45)~~ **0.37** (1966-2013, n=48)	~~-0.06 (45)~~ -0.13 (1966-2013, n=48)	~~0.04 (45)~~ 0.26 (1966-2013, n=48)	~~0.14 (45)~~ 0.14 (1966-2013, n=48)	~~0.25 (45)~~ 0.25 (1966-2013, n=48)
$\delta^{18}O$		~~-0.05 (100)~~ 0.05 (1914-2013, n=100)	~~-0.04 (100)~~ 0.02 (1914-2013, n=100)	~~0.42 (100)~~ **0.41** (1914-2013, n=100)	~~0.34 (63)~~ **0.41** (1950-2013, n=64)	~~0.08 (65)~~ 0.19 (1948-2013, n=66)
Accumulation			~~0.04 (100)~~ 0.07 (1914-2013, n=100)	~~-0.34 (100)~~ -0.18 (1914-2013, n=100)	~~-0.35 (63)~~ -0.15 (1950-2013, n=64)	~~0.05 (65)~~ 0.18 (1948-2013, n=66)
d				~~0.05 (100)~~ -0.06 (1914-2013, n=100)	~~-0.09 (63)~~ -0.01 (1950-2013, n=64)	~~0.04 (65)~~ 0.11 (1948-2013, n=66)

*P south – precipitation rate at the weather stations to the South from the Caucasus, P north – precipitation rate at the weather stations to the North from the Caucasus.

Отформатировано: Шрифт: полужирный

Отформатировано: Шрифт: не полужирный

Отформатировано: Шрифт: не полужирный

Отформатировано: Шрифт: не полужирный

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Отформатировано: Шрифт: не полужирный

Отформатировано: Шрифт: не полужирный

Отформатировано: Шрифт: не полужирный

Стр. 63: [1] Изменение — Anna — 18.01.2017 2:40:00

Отформатированная таблица

Стр. 63: [2] Отформатировано — Anna — 18.01.2017 2:58:00

Английский (США)

Стр. 63: [3] Отформатировано — Anna — 18.01.2017 2:35:00

Шрифт: не курсив

Стр. 63: [3] Отформатировано — Anna — 18.01.2017 2:35:00

Шрифт: не курсив

Стр. 63: [4] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: полужирный

Стр. 63: [4] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: полужирный

Стр. 63: [5] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: Times New Roman, 10 пт, полужирный, Цвет шрифта: Авто, Английский (США)

Стр. 63: [5] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: Times New Roman, 10 пт, полужирный, Цвет шрифта: Авто, Английский (США)

Стр. 63: [5] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: Times New Roman, 10 пт, полужирный, Цвет шрифта: Авто, Английский (США)

Стр. 63: [5] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: Times New Roman, 10 пт, полужирный, Цвет шрифта: Авто, Английский (США)

Стр. 63: [6] Отформатировано — Anna — 20.01.2017 2:57:00

Шрифт: Times New Roman, 10 пт, полужирный

Стр. 63: [6] Отформатировано — Anna — 20.01.2017 2:57:00

Шрифт: Times New Roman, 10 пт, полужирный

Стр. 63: [6] Отформатировано — Anna — 20.01.2017 2:57:00

Шрифт: Times New Roman, 10 пт, полужирный

Стр. 63: [7] Отформатировано — Anna — 18.01.2017 2:31:00

Английский (США)

Стр. 63: [8] Отформатировано — Anna — 18.01.2017 2:35:00

Шрифт: не курсив

Стр. 63: [9] Отформатировано — Anna — 18.01.2017 2:37:00

Шрифт: Times New Roman, 10 пт, Цвет шрифта: Авто, Английский (США)

Стр. 63: [10] Отформатировано — Anna — 18.01.2017 2:31:00

Английский (США)

Стр. 63: [11] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: полужирный

Стр. 63: [12] Отформатировано — Anna — 18.01.2017 2:35:00

Шрифт: не курсив

Стр. 63: [13] Отформатировано — Anna — 18.01.2017 2:41:00

Шрифт: Times New Roman, 10 пт

Стр. 63: [14] Отформатировано — Anna — 18.01.2017 2:35:00

Шрифт: не курсив

Стр. 63: [15] Отформатировано — Anna — 20.01.2017 2:56:00

Шрифт: полужирный

Стр. 63: [16] Отформатировано	Anna	18.01.2017 2:35:00

Шрифт: не курсив

Стр. 63: [17] Отформатировано	Anna	20.01.2017 2:56:00

Шрифт: полужирный

Стр. 63: [18] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: полужирный

Стр. 63: [19] Отформатировано	Anna	18.01.2017 2:41:00

Шрифт: Times New Roman, 10 пт

Стр. 63: [20] Отформатировано	Anna	18.01.2017 2:35:00

Шрифт: не курсив

Стр. 63: [21] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [21] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [21] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [22] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [23] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [23] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [23] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [24] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [24] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [24] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [25] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [25] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [25] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [26] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: полужирный

Стр. 63: [27] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [27] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [28] Отформатировано	Anna	20.01.2017 2:57:00

Шрифт: не полужирный

Стр. 63: [29] Отформатировано	**Anna**	**20.01.2017 2:57:00**

Шрифт: не полужирный

Стр. 63: [30] Отформатировано	**Anna**	**20.01.2017 2:57:00**

Шрифт: не полужирный

Стр. 63: [31] Отформатировано	**Anna**	**20.01.2017 2:57:00**

Шрифт: не полужирный

Стр. 63: [31] Отформатировано	**Anna**	**20.01.2017 2:57:00**

Шрифт: не полужирный

Стр. 63: [32] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [32] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [33] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [33] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [34] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [34] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [35] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [35] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [36] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [36] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [37] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [37] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [37] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [38] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [38] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный

Стр. 63: [39] Отформатировано	**Anna**	**20.01.2017 2:58:00**

Шрифт: не полужирный