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# Winter and summer blocking variability in the North Atlantic region – evidence from long-term observational and proxy data from southwestern Greenland

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**Abstract**

We investigate the relationship between the North Atlantic atmospheric blocking and winter and summer temperature variability as derived from long-term observational and proxy records from southwestern Greenland. It is shown that during boreal winter warm (cold) conditions in southwestern Greenland are related with high (low) blocking activity in the Greenland-Scandinavian region. An index for the North Atlantic blocking is significantly correlated with an oxygen isotope record from Greenland ice cores suggesting a possible reconstruction of blocking variability in this region during past millennium. During summer, high (low) blocking activity in the Euro-Atlantic region is associated with cold (warm) conditions in southwestern Greenland. We conclude that historical temperature records as well as proxy data from Greenland can be used to obtain information related to multidecadal variation of summer blocking during past periods.

## 1 Introduction

Atmospheric blocking is a large-scale mid-latitude atmospheric phenomenon that induces significant climate anomalies over various regions of the North Atlantic realm. Recent studies (e.g. Bariopedro et al., 2006) detect significant decadal variability in atmospheric blocking frequency. However the blocking frequencies, which are obtained based on high-resolution observational data, are too short to have a clear picture of decadal and multidecadal variation in blocking frequency in the North Atlantic region. The main goal of this study is to put the multidecadal variations of winter and summer blocking frequency in the North Atlantic region into a long-term context using long-term observational and proxy data from Greenland.

Trigo et al. (2004) found that relatively high (low) blocking activity in the Atlantic-European region is associated with significant positive (negative) daily maximum and minimum temperature anomaly over Greenland. Enhanced blocking in this region is related also with positive anomalies of precipitable water as well as with enhanced meridional moisture transport (Trigo et al., 2004) which leads to positive anomalies of accumulation rates in Greenland ice cores (Rimbu et al., 2007). The blocking signal was detected also in accumulation records from southeastern Greenland (Hütterli et al., 2005).

Continuous long-term, measurements of Greenland temperature (Vinther et al., 2006) as well as high-resolution temperature reconstructions from Greenland ice cores are available (Crüger et al., 2004). The variability of these records is often related with atmospheric teleconnection patterns, in particular with the North Atlantic Oscillation (Appenzeller et al., 1998; Hanna et al., 2006). Based on the relationships between atmospheric teleconnection patterns and different proxy data from Greenland ice cores during observational period valuable information related to climate anomalies during pre-instrumental period has been obtained (e.g. Appenzeller et al., 1998). However, teleconnection patterns modulate the frequency, intensity and spatial distribution of synoptic scale atmospheric phenomena, including atmospheric blocking (e.g. Shabbar et al., 2001). In this way, indirect information about decadal variations in the properties of synoptic scale phenomena can be obtained.

The present study aims to investigate a direct relation between long-term observational temperature records from southwestern Greenland as well as proxy temperature records from Greenland and atmospheric blocking circulation. We investigate first the signature of blocking on observed and reconstructed temperature of this region during recent decades when observed atmospheric circulation data sets are available (Kalnay et al., 1996). Based on the relationship between blocking and temperature during the last decades we discuss the blocking variability during past periods.

The paper is organised as follows. Data and methods are described in Sect. 2. The relationship between winter temperature variability in southwestern Greenland and atmospheric blocking is presented in Sect. 3. A similar analysis but for the summer season follows in Sect. 4. A discussion as well as the main conclusions are presented in Sect. 5.



## 2 Data and methods

The main quantity used in our study is the published long-term observational record of air temperature ($T$) from southwestern Greenland. Using old temperature observations from early observers from three stations from southwestern Greenland: Ilulissat (69.23° N; 51.07° W), Nuuk (64.17° N; 51.75° W) and Qaqortoq (60.72° N; 46.05° W), a merged southwestern Greenland temperature record was constructed (Vinther et al., 2006). This temperature record covers the period 1784 to 2005 with monthly resolution. There are several gaps in this record especially during summer months before 1840 (Vinther et al., 2006). We calculated the winter and summer temperature time series by averaging the monthly temperature during December/January/February (DJF) and June/July/August (JJA), respectively. Prior to the statistical analysis these time series were linear detrended and normalised with the corresponding standard deviation. This record is available online (http://www.icecores.dk; Vinther et al., 2006).

Blocking activity in the Northern Hemisphere is based on the calculation of two blocking indicators using daily 500 mb geopotential height (Z500) from NCEP/NCAR reanalysis data base (Kalnay et al., 1996) for the period 1948 to 2005 (58 years). The NCEP/NCAR reanalysis data were derived through a consistent assimilation and modelling procedure that incorporated most available weather and satellite information. This field has a 2.5° latitude × 2.5° longitude horizontal resolution. The blocking indices were evaluated separately for warm (temperature anomaly higher than one standard deviation) and cold (temperature anomaly lower than minus one standard deviation) years in the southwestern Greenland.

The Northern Hemisphere blocking activity is described using the Tibaldi-Molteni (TM) one-dimensional index (Tibaldi and Molteni, 1990). For each daily Northern Hemisphere Z500 map we calculate the northern (GHGN) and the southern (GHGS) gradients as follows:

$$\text{GHGS} = (Z(\Phi_0) - Z(\Phi_s))/(\Phi_0 - \Phi_s)$$

$$\text{GHGN} = (Z(\Phi_n) - Z(\Phi_0))/(\Phi_n - \Phi_0)$$

where $\Phi_n = 80^\circ\,\text{N} + \Delta,\ \Phi_0 = 60^\circ\,\text{N} + \Delta,\ \Phi_s = 40^\circ\,\text{N} + \Delta,\ \Delta = -5^\circ,\ 0^\circ,\ 5^\circ$ latitude. A given longitude is blocked if the following conditions are satisfied for at least one value of Δ:

$$\text{GHGS} > 0 \text{and} \text{GHGN} < -10\,\text{m}/(\text{degree..latitude}) \quad (1)$$

We calculate the ratio of the blocked days at a certain longitude and the number of season days for high and low temperature years in southwestern Greenland. Since no time-duration constraint was imposed, this ratio represents the frequency of occurrence of blocking-like patterns rather than actual synoptic episodes (Tibaldi et al., 1997). Based on the longitudinal distribution of blocking-like circulation we construct blocking indices for which both persistence and spatial extension constraints are imposed.

An extension of this blocking index is given by Scherrer et al. (2006). The GHGN and GHGS gradients are evaluated in each grid-point using a latitudinal interval of 15° instead of 20° like in the case of one-dimensional TM index described above. A certain grid-point is considered to be blocked if conditions (1) are satisfied for at least five consecutive days (5-day persistence criterion). There are no exceptions allowed to this rule in contrast to some previous studies (e.g., D'Andrea et al., 1998). As a consequence, blocking frequencies are lower since only blockings that are stationary in space and uninterrupted in time are captured. These characteristics typically correspond to a mature blocking state which correspond to persistent quasi-stationary high pressure systems (Sherrer et al., 2006). The frequency of blocked grid-points is calculated as the ratio between number of days in a season when a certain grid-point was blocked to the total number of season days. Using Z500 data north of 20° N the frequency of blocked grid points from 35° to 75° N can be calculated. We compare the frequency of blocking, i.e. blocked grid-points, for high and low temperature years in southwestern Greenland.

Analysis of observational data revealed a strong relationship between blocking activity in the Atlantic regions and temperature variations in southwestern Greenland.



Therefore long-term reconstructions of southwestern Greenland temperature can give relevant information related to the blocking activity in the Atlantic region during past periods. For this purpose we have used the principal component (PC1) time series of 7 $\delta^{18}$O records from Greenland ice cores which is significantly correlated with southern Greenland temperature during observational period (Vinther et al., 2003). This record, referred further as PC1-$\delta^{18}$O, covers the period 1245 to 1970 with annual resolution.

The frequency of persistent high pressure anomalies in the regions where blocking events are frequent over period 1850 to 2003 is determined using the EMULATE sea level pressure data set (Ansell et al., 2006). This data set was created as part of a collaborative European Project named EMULATE (European and North Atlantic daily to MULtidecadal climate variability (http://www.cru.uea.ac.uk/cru/projects/emulate/). It is a daily resolution gridded data set that covers the North Atlantic and European area from 70° W to 50° E and 25° N to 75° N on a 5° × 5° grid from 1850 to 2003. Details of this data set can be found in Ansell et al. (2006).

## 3 Signature of blocking in south-western Greenland temperature during winter

Figure 1 shows the averaged frequency of blocking-like circulation over warm (cold) southwestern Greenland winters as a function of the longitude. A winter is classified as warm (cold) if the southwestern Greenland temperature index was higher(lower) than the mean plus(minus) one standard deviation. As has been noted extensively in the literature, (e.g., Diao et al., 2006) the highest frequency of blocking is recorded in the northeastern Atlantic and the northeastern Pacific sectors. Both during warm and cold winters blocking frequency is maximum in these regions. However the blocking frequency is higher during warm than during cold southwestern Greenland winters in the Atlantic sector (80° W–20° W). Outside this region there are no significant (95% level) differences between blocking activity during cold and warm winters in the southwestern Greenland (Fig. 1).

To better assess the relationship between blocking and southwestern Greenland temperature we define a blocking index by imposing both persistence and spatial extension constraints to blocking-like circulation regimes. Figure 2 shows boreal winter temperature and a blocking index. The blocking index is defined as the number of days in a winter when the sector (80° W–20° W) was blocked, i.e. the conditions (1) are satisfied for at least five consecutive longitudes within this sector (spatial criteria) for at least five consecutive days (persistence criteria). Five days is the persistence threshold largely used in the literature above which a blocking-like circulation is considered to be a blocking event (Treidl et al., 1981; Tibaldi and Molteni, 1990; D'Andrea et al., 1998). The resulting index shows important decadal variations (Fig. 2b). High frequency of blocking is recorded during 1955s to 1970s, 1980s and after 1995s. The temperature index (Fig. 2a) shows similar decadal variations. The two time series are significantly (95%) positively correlated both at interannual ($r = +0.45$) and decadal ($r = +0.70$) time scales. This suggests that temperature reconstructions from this region can be used to obtain information related to blocking variability during past periods.

To have a clear picture of the relationship of blocking and southwestern Greenland temperature we investigate the daily values of our blocking index for an extremly warm (1963/64) and an extremely cold (1984/85) winter in southwestern Greenland (Fig. 2a). As our blocking index shows (Fig. 3a) two blocking events (in red) and several blocking-like circulations were recorded during 1963/64 warm winter. Contrary, only two short blocking-like circulations were recorded during 1983/84 cold winter (Fig. 3b). As an example we present in Fig. 4 the atmospheric circulation at 500 mb during the onset (28 January 1964) of the second blocking event recorded in 1963/64 winter (Fig. 3a). Such a circulation favors advection of relative warm air from the south toward southwestern Greenland (Fig. 4). If the frequency of such type of circulation is relatively high during winter positive winter temperature anomalies are recorded in southwestern Greenland.

The two-dimensional climatological winter blocking frequencies based on meridional gradients of 500 mb geopotential height is displayed in Fig. 5. It indicates that the occurrence of blocking in the North Atlantic-European region depends both on latitude and longitude. Enhanced blocking variability is recorded from a region that stretches



from Davis Strait/Labrador Sea to southern Scandinavia as well as another region that extends from Azores to southern Scandinavia. Local maxima are found over southeastern Greenland and over North Sea where frequencies vary from 5% to 7% of season days. Similar results were obtained by Scherrer et al. (2006) (their Figure 2).

The resulting temperature-blocking composite frequencies (Fig. 6) show a clear distinction between warm and cold winters in southwestern Greenland. Warm conditions in southwestern Greenland are associated with increased blocking frequency over a broad region that extends from Greenland to southwestern Scandinavia with frequencies of 8% to 9% (Fig. 6b). Cold conditions in the southwestern Greenland on the other hand, are associated with enhanced blocking frequency along the Atlantic-European coast extending eastward over Europe (Fig. 6c) as well as with a significant decrease in the blocking frequency over Davis Strait/Labrador Sea region. The difference between blocking frequency during high and low southwestern Greenland temperatures (Fig. 6a) shows a dipole structure with out of phase variations of blocking anomalies from Greenland-Scandinavian region and Atlantic-European region.

As Fig. 2 shows decadal variations in blocking frequency are in phase with decadal variations of southwestern Greenland temperature. This suggests that long-term temperature reconstructions of temperature from this region can be related with decadal variations in the blocking in the North Atlantic region. Such a reconstruction is provided by Vinther et al. (2003) which is based on 7 $\delta^{18}$O records from Greenland and covers the period 1245 to 1970 with annual resolution. As Fig. 6 suggests warm southwestern Greenland winters are related with persistent highs (i.e. blocking) over a latitudinal band that extends from Greenland to Scandinavia. Based on Fig. 6a, we define a daily SLP index as the average of daily SLP anomalies over the area (60° W–10° W; 55° N–75° N). Winter daily SLP anomalies are taken from EMULATE SLP reconstruction (Ansell et al., 2006) which cover the period 1850 to 2003 (154 years). A blocking index is defined as the number of days in a winter when at least five consecutive values of this index were higher than one standard deviation. This index is significantly positively correlated ($r = 0.40$) with temperature index over the common period which is 1850 to 1970. The decadal variations of this index are similar with decadal variations of southwestern Greenland temperature over the common period, which is 1850–1970 (Fig. 7). Therefore this temperature reconstruction (Vinther et al., 2003) gives information about persistent high pressure systems and blocking back to 1245 (Fig. 7).

## 4 Signature of blocking in southwestern Greenland temperature during summer

The longitudinal distribution of blocking-like circulations during summer indicates relatively high (low) frequency of blocking in the Atlantic-European sector, (30° W–30° E), during cold (warm) conditions in southwestern Greenland (Fig. 8). Based on the distribution represented in Fig. 8 we construct a blocking index as follows. The sector (20° W–30° E) is considered to be blocked if at least five consecutive longitudes are blocked for at least five consecutive days. We are again interested in the temperature and blocking frequency relationship (Fig. 9). The blocking index is defined as the number of days in a summer when this sector was blocked according to the above criteria. The resulting index (Fig. 9b) is significantly correlated with southwestern Greenland temperature (Fig. 9a) at interannual time scales ($r = -0.53$). At multidecadal time scales is a clear out of phase variation of our blocking index and southwestern Greenland temperature ($r = -0.75$) (Fig. 9).

To have a clear image on how blocking in the (20° W–30° E) sector and southwestern Greenland temperature are related we selected one cold (1972) and one warm (2000) summer and look at the daily values of our blocking index. It is evident that during 1972 cold summer (Fig. 10a) the frequency of blocking was higher than during 2000 warm summer (Fig. 10b) in southwestern Greenland. As an example we plot in Fig. 11 the upper atmospheric circulation during 13 July 1972, a day that belongs to the second blocking event this summer (Fig. 10a). The blocking high in the Scandinavian region is accompanied by a low pressure system in the Greenland-Scandinavian region which advects cold air from the north over southwestern Greenland. An increased number of



such persistent events will produce extreme cold summers in southwestern Greenland.

Following the same strategy as in the case of winter months we calculate the frequency of blocking in each grid points using the algorithm described by Scherrer et al. (2006). High frequency of blocking is recorded over eastern Greenland as well as over a large area in the Scandinavian region (Fig. 12). When the data are stratified for warm and cold summers important changes in the blocking distribution appear (Fig. 13). Cold summers (Fig. 13c) are characterized by enhanced blocking frequency over Scandinavian region. During warm summers frequency of blocking is relatively high in the Greenland region (Fig. 13b). The blocking frequency decreases in the Scandinavian region and west of UK and increases in the other regions in warm relative to cold summers in southwestern Greenland (Fig. 13a).

Based on the blocking variation from warm to cold summers in southwestern Greenland (Fig. 13a) we define a daily SLP index by averaging the daily SLP anomalies over the area (10° E–40° E; 55° N–70° N) using EMULATE SLP data for the period 1850–2003. A blocking index is defined as the number of days in a summer when at least five consecutive days of this index was higher than one standard deviation. This index follows out of phase multidecadal variations with southwestern Greenland summer temperature (Fig. 14).

## 5 Discussion and conclusions

The relationship between temperature variability in south-western Greenland and atmospheric blocking variability has been investigated using instrumental and proxy data. We have shown that during winter high (low) temperature in southwestern Greenland is related with positive (negative) blocking frequency anomalies in the Atlantic sector, i.e. (80° W–20° W). This suggests that long temperature records from this region can be used to obtain relevant information related to the blocking activity in the Atlantic region during past periods. Using long-term observed temperature records from this region (Vinther et al., 2006) we can investigate the seasonal blocking variability in the Atlantic sector back to 1784. Relatively low temperature in southwestern Greenland during 1890s–1920s (Fig. 7) suggests a relatively low winter blocking activity in the Atlantic sector during this period. This is consistent with relatively low number of persistent high positive SLP anomalies in this region as shown by the EMULATE data (Fig. 7).

Based on the relationship between blocking and southwestern Greenland temperature established using observational data (Figs. 1 and 3) we suggest that blocking activity in the Atlantic region presents similar decadal and interdecadal variations as PC1-$\delta^{18}$O from Greenland ice cores (Fig. 7). The power spectrum of PC1-$\delta^{18}$O (not shown) shows a significant peak at about 20 years which may be also characteristic to blocking activity in the Atlantic sector. Similar quasi-periodic cycle was identified in Greenland ice cores (Hibler and Johnson, 1979) whose variability is related with blocking activity in the North Atlantic region (Rimbu et al., 2007). A detailed analysis of the relationship between quasi-periodic cycles of the frequency of daily circulation patterns in the North Atlantic region and quasi-periodic cycles in Greenland ice cores is the subject of a forthcoming paper.

For boreal summer we show that blocking frequency in the Atlantic-European (30° W–30° E) sector is enhanced during cold conditions in the southwestern Greenland. Pronounced minima in summer south-western Greenland temperature during 1865s, 1885s, 1930s and 1970s (Fig. 14) are most likely associated with enhanced summer blocking activity in the Atlantic-European region, i.e. 30° W to 30° E. More persistent blocks occur during low temperatures in southwestern Greenland. One can speculate that extreme phenomena which accompany such blocks (Trigo et al., 2004) were more frequent during these periods. Proxy data of summer temperature from south-western Greenland can be used to put the summer blocking variability from this sector into a long term context.

We conclude that the combination of high resolution (daily) atmospheric circulation data sets and long-term seasonally resolved climate variables allows to obtain relevant information about blocking activity during past periods. The reconstruction of synoptic scale activity from long-term observed and proxy data as presented in this study can



provide a better interpretation of the connection between proxy data and atmospheric circulation variability than the traditional atmospheric teleconnection approach, based on seasonal or annual averages. (e.g. NAO index). A logical next step would be the analysis of extreme events and their dynamical interpretation related to the long-term instrumental data sets and proxy data.

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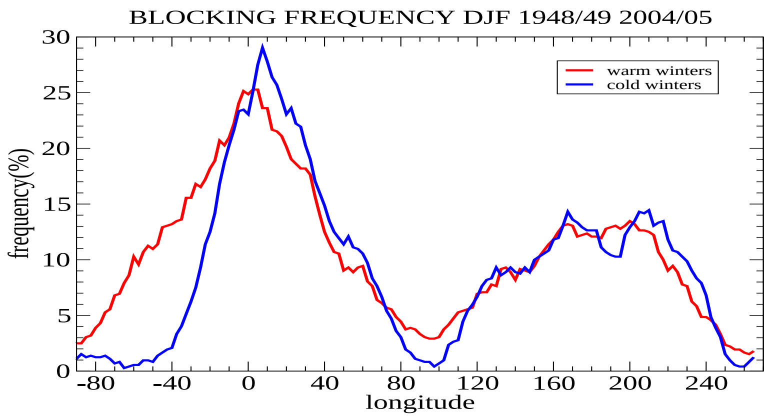


**Fig. 1.** Frequency composites of blocked days for positive (red) and negative (blue) temperature anomalies in southwestern Greenland.

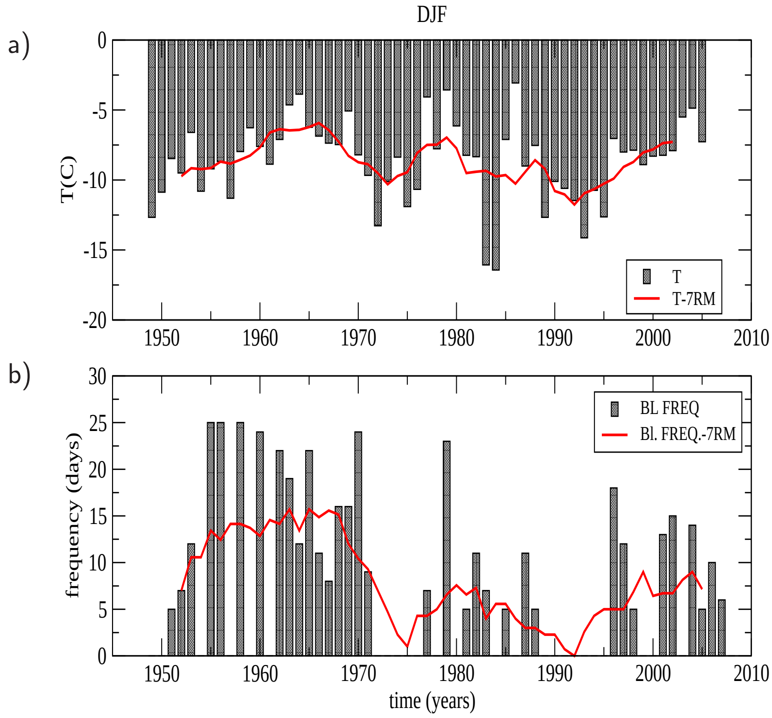


**Fig. 2.** **(a)** Southwestern Greenland temperature index (Vinther et al., 2006) (bar) and its decadal variation (7 year running mean) (red) for the period 1948/49 to 2004/05. **(b)** Blocking index (bar) and its decadal variations (7 year running mean) (red) for the same period.



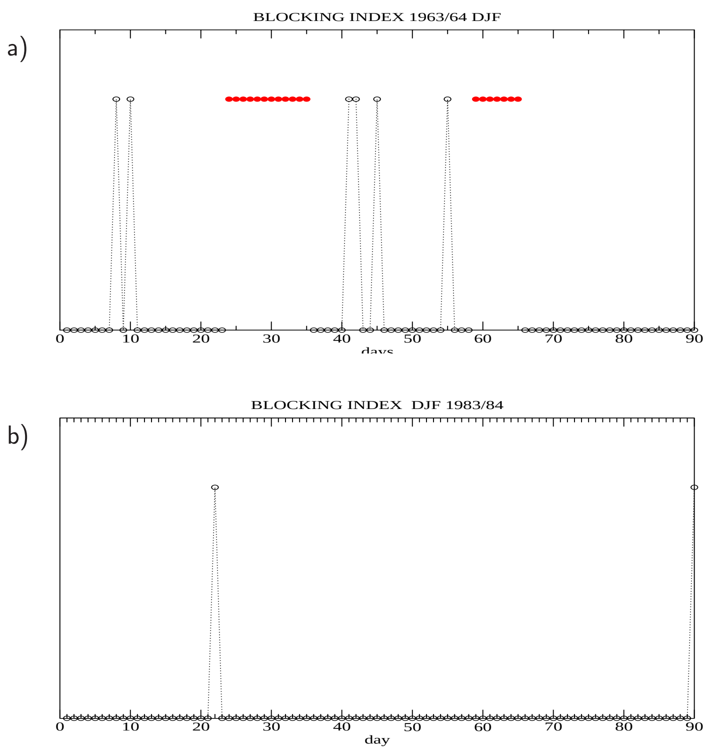


**Fig. 3.** Daily blocking index for **(a)** 1963/64 and **(b)** 1983/84 winters. Color (blocking events). Upper black circles (blocking-like circulations).

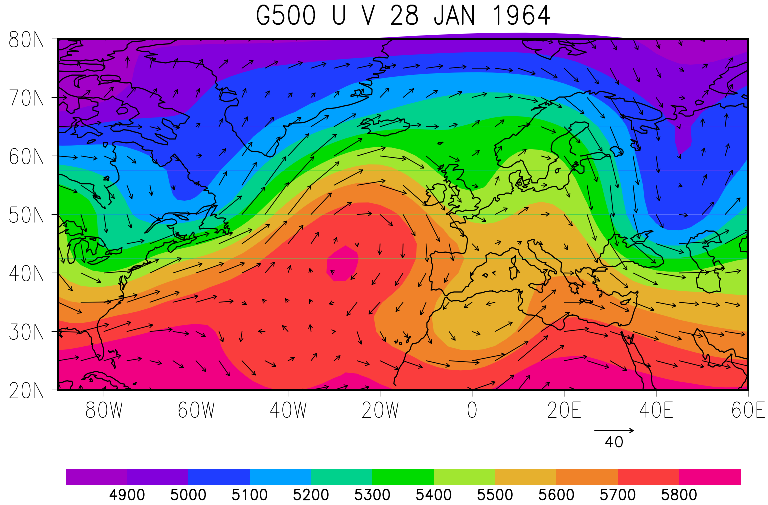


**Fig. 4.** Upper atmospheric circulation (500 mb) for 28 January 1964. Color (G500), vector (wind). Units m and ms$^{-1}$.



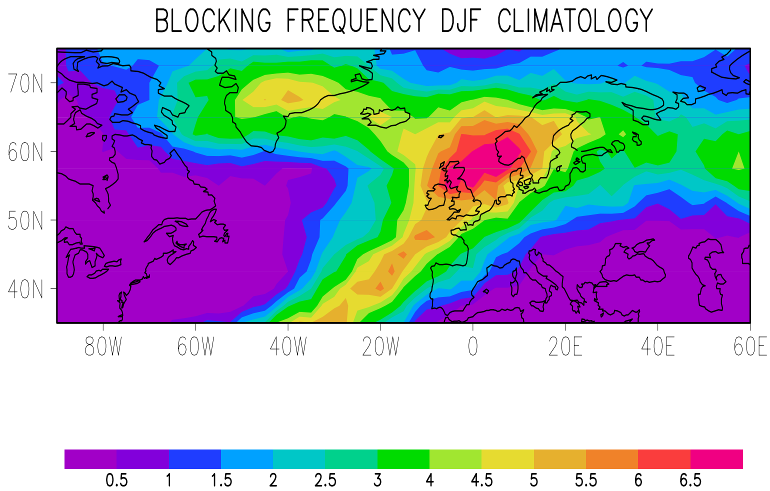


**Fig. 5.** Euro-Atlantic winter blocking frequency climatology of 5-day persistent blocking using the Sherrer et al. (2006) blocking indicator. Units are percentage of blocked days to total number of days per winter. Period is 1948–2005.

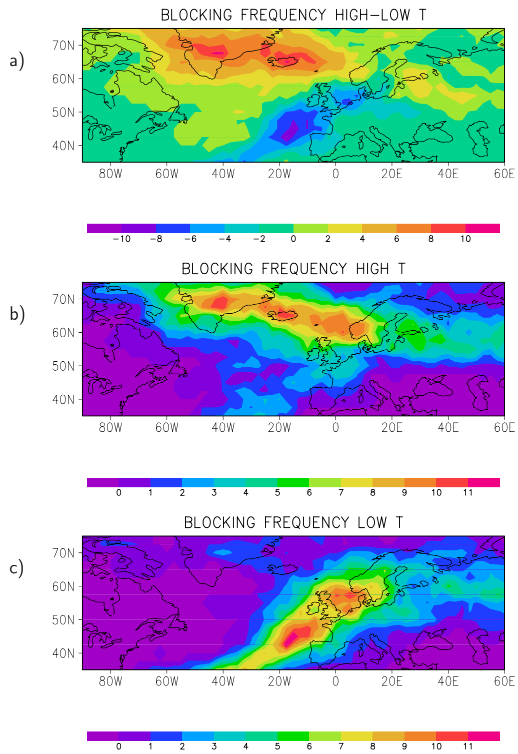


**Fig. 6.** **(a)** Difference between averaged blocking frequency over high and low temperature winters in southwestern Greenland. **(b)** Blocking frequency composite for high southwestern Greenland temperatures. **(c)** as in (b) but for low temperature winters in southwestern Greenland.

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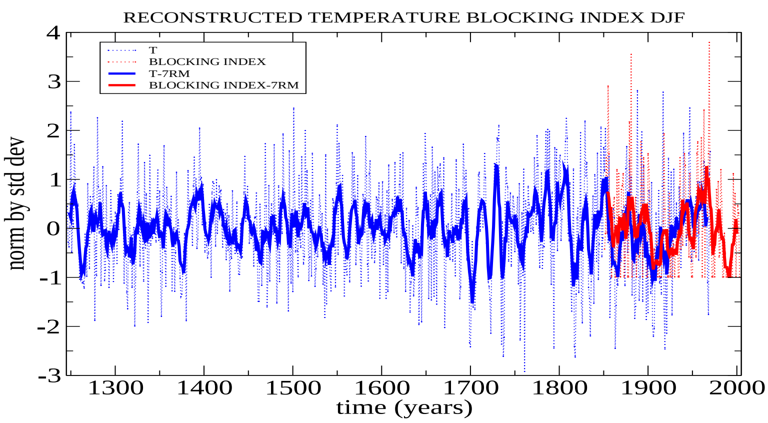


**Fig. 7.** Temperature reconstruction of southern Greenland temperature (Vinther et al., 2003) (blue) and blocking index (red). Both original (thin) and smoothed (7-year running mean; solid) time series are shown.

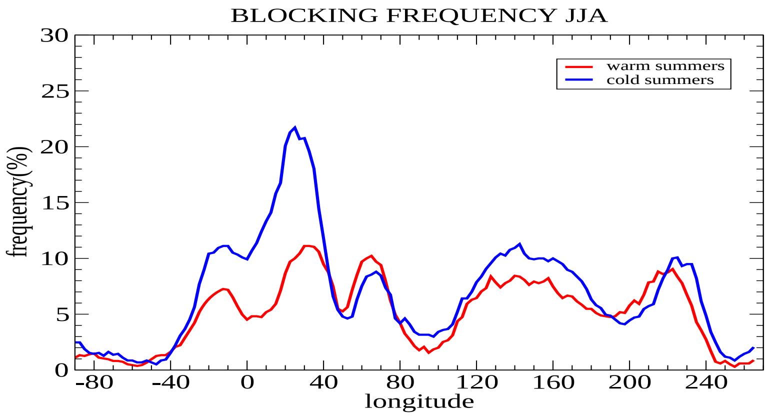


**Fig. 8.** Frequency composites of blocked days for positive (red) and negative (blue) summer temperature anomalies in southwestern Greenland.



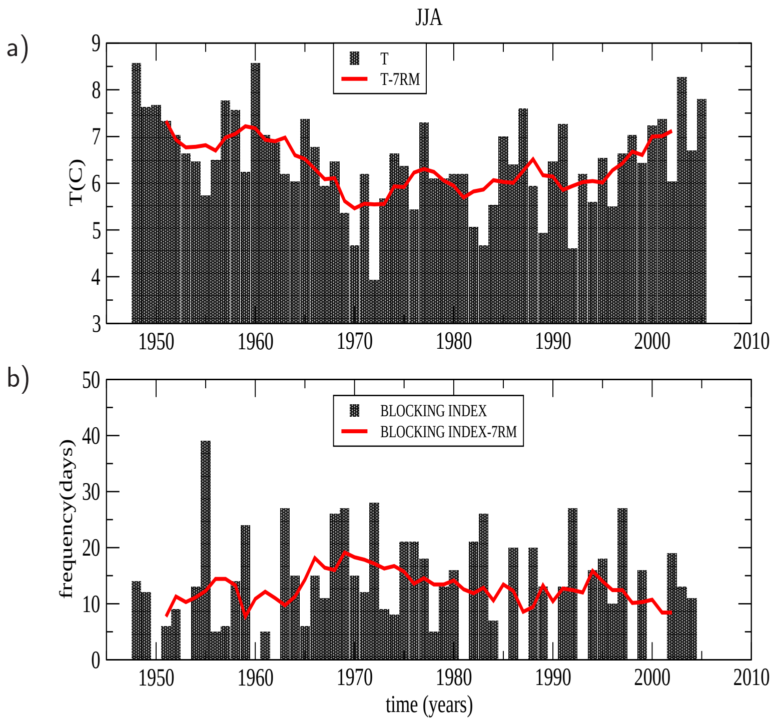


**Fig. 9.** **(a)** Southwestern Greenland summer temperature index (Vinther et al., 2006) (bar) and its decadal variation (7 year running mean) (red) for the period 1948–2005. **(b)** Summer blocking index (bar) and its decadal variations (7 year running mean) (red) for the same period.

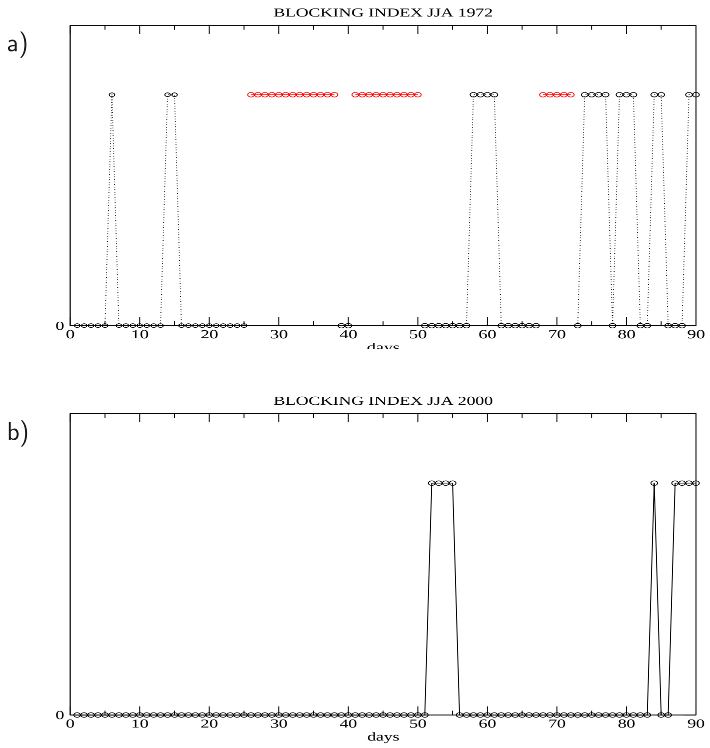


**Fig. 10.** Daily blocking index for **(a)** 1972 and **(b)** 2000 summers. Color (blocking events). Upper black circles (blocking-like circulations).



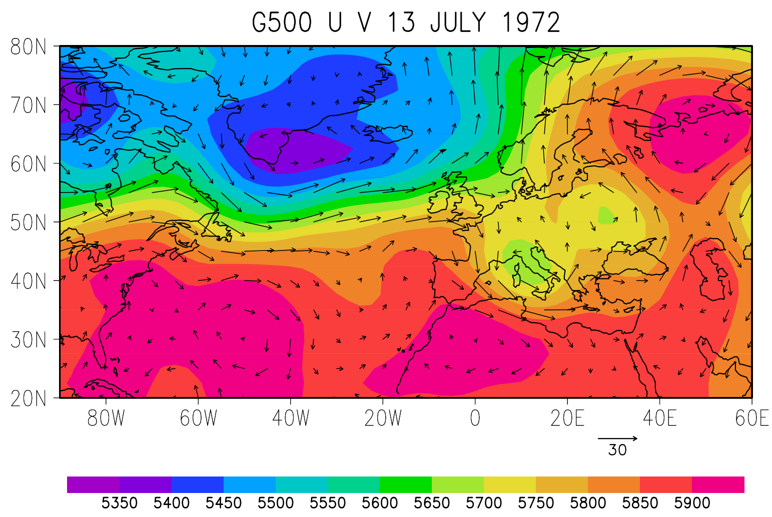


**Fig. 11.** Upper atmospheric circulation (500 mb) for 13 July 1972. Color (G500), vector (wind). Units m and $ms^{-1}$.

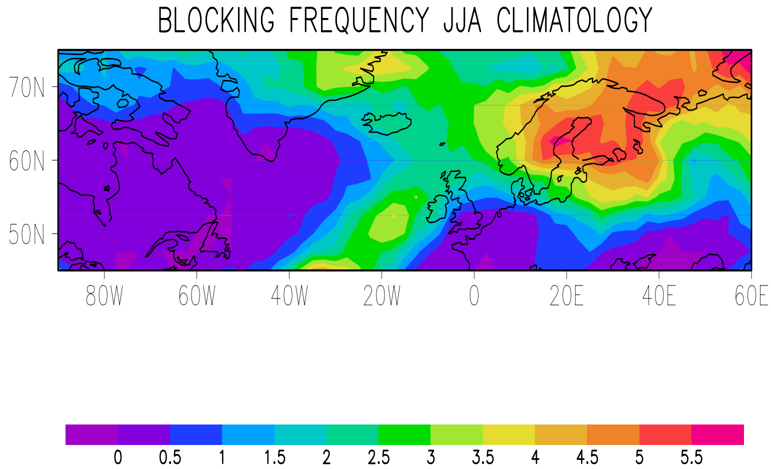


**Fig. 12.** Euro-Atlantic summer blocking frequency climatology of 5-day persistent blocking using the Sherrer et al. (2006) blocking indicator. Units are percentage of blocked days to total number of days per winter. Period is 1948–2005.



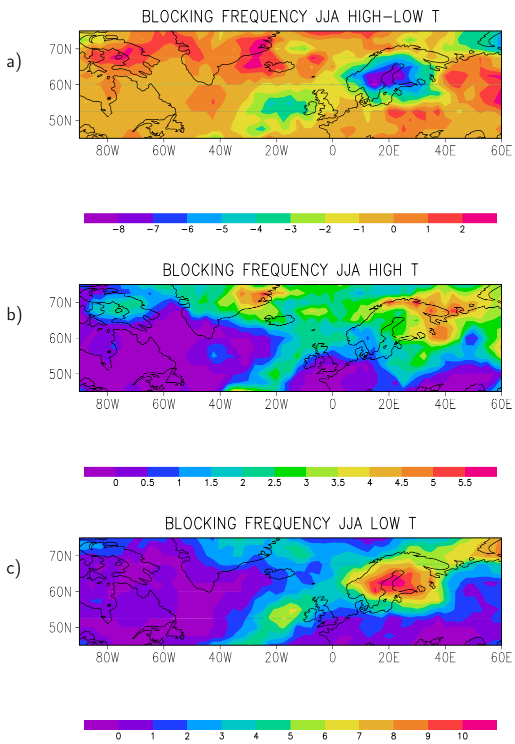


**Fig. 13. (a)** Difference between averaged blocking frequency over high and low temperature summers in southwestern Greenland. **(b)** Blocking frequency composite for high southwestern Greenland temperatures. **(c)** as in (b) but for low temperature summers in southwestern Greenland.

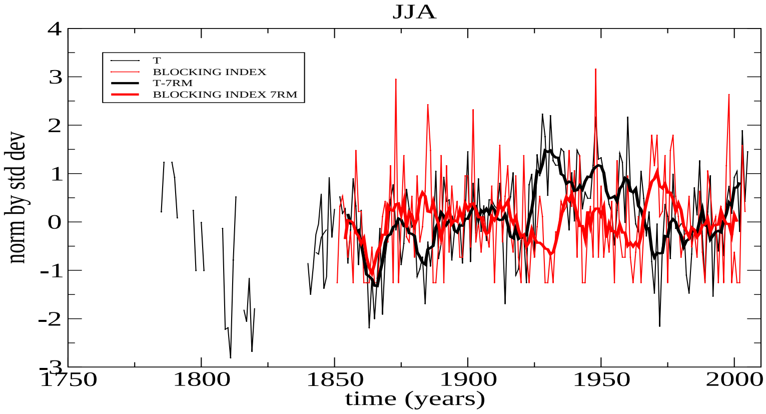


**Fig. 14.** Temperature in southwestern Greenland (black) and blocking index (red). Both original (thin) and and smoothed (7-year running mean; solid) time series are shown.