



Extremes atlas



A climatology of extremes for the UK.

A baseline for UKCP09

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June 2008

9 Storms and anti-cyclones

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9.1 Introduction

Synoptic scale variability is an important part of mid-latitude weather and climate and can be divided into 2 types, the transients with timescales of 2 to 6 days and the low frequency variability with timescales greater than 7 days. The transients are the mobile high and low pressure systems and the low frequency variability is made up of stationary systems such as blocking anticyclones. The frequency, distribution and intensity of middle latitude cyclones, anticyclone and blocking anticyclones have a large impact on the local scale. For example intense precipitation and wind events are associated with the storms and may cause flooding and storm damage to crops and buildings. In summer the frequency, duration or intensity of blocking anticyclones are strongly related to heat waves.

Here we provide an up-to-date assessment of the climatology of storms and blocking for the UK and North Atlantic / European region through a variety of synoptic variability measures. This provides a consistent baseline from which to measure future changes within UKCP09. Storms and blocks will be analysed in ERA40 reanalysis data and in the ERA40 driven 25km UKCIP RCM. The RCM data, due to its higher resolution, provides information on smaller phenomena such as frontal waves which are not represented in the coarser resolution ERA40 data.

The synoptic systems that affect the UK are large relative to the UK, can form in the lee of the Rockies and travel well into Russia. We therefore present results

for the whole of the northern hemisphere for the ERA40 data, but for the RCM the domain of the mode.

9.2 Data and Methodology

The ECMWF ERA40 reanalysis dataset (Uppala et al. 2005, ERA40) cover the period 1957-2002. These are considered as present day observations as they provides a comprehensive analysis of recent mid-latitude storms and blocks in a dynamically consistent way. We assume that the climate, with regards to synoptic variability, is stationary for this study.

The HadRM3 regional climate model (RCM) is the same as being used for the UKCIP 2008 climate projections. The HadRM3 RCM uses a rotated pole grid with a resolution of 25km and 19 levels in the vertical. It is parallel to HadAM3 (Pope et al. 2000) except for the resolution dependent parameters that have been tuned to 25km. The synoptic variability of the RCM is largely determined by the boundary forcing therefore errors in the location of the storm tracks in the driving data will also occur in the RCMs. A method of assessing the ability of the RCM model to simulate storms given “perfect” boundary conditions is to drive the RCM with boundary conditions derived from ERA40 data. This experiment will be referred to as ERA40RCM. The storms and blocks in ERA40RCM are comparable to those in ERA40, although differences in the analysis methods, due to model resolution (see Appendix 1), mean that only a qualitative comparison can be made.

Previous studies of mid-latitude cyclones have used a variety of methods for analysing storms and their activity in the storm track regions. These methods include band-pass filter statistics to look at variability on synoptic time-scales (e.g. Hall et al. 1994; Christoph et al. 1997), number of gales (e.g. Carnell et al. 1996; Weisse et al. 2005; Fischer-Bruns et al. 2005), cyclone densities without tracking (e.g. Lambert 1995); cyclone densities with tracking (e.g. König et al. 1993; Hodges 1994; Carnell et al. 1996) and the UK gale index (Jenkinson and Collison 1977).

In addition, a variety of different methods have been used to perform the location and tracking of individual synoptic systems and these have been applied to 1000 hPa geopotential height, mean sea level pressure and 850 hPa relative vorticity at either 24 hour, 12 hour or 6 hour intervals (e.g. König et al. 1993; Murray and Simmonds 1991; Carnell et al. 1996; Knippertz et al. 2000; Hoskins and Hodges

2002). The use of these different techniques makes it hard to compare the results of each study (Cubasch et al. 2001).

Here, mobile synoptic features are analysed using the Blackmon band-pass filtered storm track (BPF, Blackmon 1976), tracking of individual cyclones and anticyclones (Hodges 1994) and the UK Gale Index (Jenkinson and Collison 1977). The low frequency variability is analysed using the low-pass filtered storm track (LPF, Blackmon) and persistent anomalies (Dole and Gordon 1983).

The BPF and LPF diagnostics are calculated for 0Z 500 hPa geopotential height (Z500) and daily mean sea level pressure (MSLP). BPF and LPF storm tracks show the synoptic (2-6 day) and low frequency (>10 day) variability respectively. The 500 hPa height is the steering level for synoptic systems in the atmosphere. BPF and LPF both include variability due to cyclones and anticyclones. Areas of high variability are considered to represent the regions of most synoptic activity and are often collectively termed the storm track, the path which most synoptic systems travel. They don't capture small scale features and are most useful for looking at the large-scale features of the storm tracks rather than local detail. These diagnostics do not always give the same results as tracking the individual systems (e.g. Carnell et al. 1996).

The tracking diagnostics presented here are: the feature density (the average number of synoptic features in a region) the track density (the number of cyclones or anticyclones that are tracked across a region), the genesis density (the number of storms that form in that region), the lysis density (the number of storms decaying in the region) and the mean intensity of the storms for that region (spatially smoothed, measured in terms of relative vorticity at 850 hPa for the centre of the tracked feature). The units of the density measures are features per month per 106 km². The anticyclones identified by the tracking routine are not blocking anticyclones as they are transient and at 850 hPa whereas blocking anticyclones are usually analysed at the 500 hPa level and remain stationary.

Blocking anticyclone activity is measured by counting the number of anomalies that persist for longer than a specified time in daily 500 hPa geopotential height data (Dole and Gordon 1983). To be classed as blocks the anomalies must satisfy both a duration and magnitude criteria. Here we present results for anomalies which last 7 days or more and have a magnitude of 100m and 200m. In winter

anomalies are larger so 200m is more appropriate whereas in summer the Z500 gradients tend to be reduced so an anomaly magnitude of 100m is more relevant.

Detailed descriptions of the diagnostics are given in Appendix 1.

9.3 Results

9.3.1 ERA40 Reanalysis data

In general the BPF storm track (Fig. 9.1.1.a) has a maximum at the western end of the North Atlantic storm track where the systems are fast moving and in the central North Pacific. The LPF storm track (Fig. 9.1.1.b) has maxima at the eastern ends of the North Atlantic and North Pacific storm tracks where the systems are more stationary as they decay. The Mediterranean storms are not captured by these diagnostics as their scale is too small. The tracks are weaker in summer than in winter and the BPF maxima are shifted pole wards and towards the eastern end of the storm tracks.

Corresponding BPF and LPF storm tracks diagnostics from daily mean MSLP data are given in Fig. 9.1.2.a and 9.1.2.b. There are some differences in the location of storm tracks at sea level when compared with results from 500 hPa but in general the maximum variability occurs in the same region at both levels. The use of the daily mean, rather than instantaneous data, has little impact on the diagnostics as we are filtering out the variability that is less than 2 days. Therefore the daily mean MSLP BPF and LPF storm tracks give useful information about the synoptic variability at sea level. However the results are not necessarily the same as those with the Z500 BPF and LPF storm track because the behaviour of the storms at this higher level is not the same as at sea level.

The synoptic variability as characterised by tracking individual cyclones are plotted in Fig. 9.1.3.a-e and for anti-cyclones in Fig 9.1.4.a-e for each season.

The comparison between MSLP BPF and LPF and the tracks results in winter shows that:

- There is high frequency of cyclone tracks in regions where the BPF storm track has large values; in addition the tracking locates the Mediterranean cyclones.

- The cyclones are most intense towards the centre of the Atlantic and Pacific storm tracks, downstream from the maximum track density and the maximum activity in the BPF storm track but upstream from the maximum LPF storm track.
- The Atlantic cyclones form in the lee of the Rockies and off the east coast of North America. There is also a region of secondary genesis south of Greenland. The cyclones track north east and decay in the northern regions of the North Atlantic, over Scandinavia and northern Asia.
- In winter the BPF storm track is dominated by the cyclones and the LPF storm track by the anticyclones.

The comparison of the MSLP BPF and LPF storm tracks with the tracks results for summer anticyclones shows that:

- In summer the anticyclone tracks occur in the main storm track regions but there are fewer anticyclones than there are cyclones in winter. The tracks are further south and more meridional than the winter cyclone tracks. The cyclone tracks are also further south in summer than they are in winter. The maximum frequency of anticyclones is in the same location as the BPF maximum showing that in summer the BPF also contains anticyclones.
- The anticyclones are weaker than the winter cyclones.
- The high values of anticyclone intensity are where the track density is greatest, except for a local maximum in the eastern Atlantic, in the region where the LPF storm track also has high values.

The blocking climatology from persistent anomalies are plotted in Fig. 9.1.5.a-b for each season.

- In both winter and summer the blocks occur in three regions: the North Pacific, the North Atlantic and over high latitudes in a region extending from Europe to the central North Pacific. There are more blocks in summer than in winter; this is partly due to the reduced threshold criteria. The location of the blocking in ERA40 agrees well with the observations of Shukla and Mo (1983) although the frequency of the

blocking can not be directly compared as they counted each block only once and did not area weight the counts. Here we count the number of blocked days and then apply an area weighting to the counts.

- The regions with high frequency of blocking anticyclones correspond to the regions with high values of LPF variability in both seasons. Showing that the LPF storm track is a good indicator of the blocking activity.

9.3.2 *Reanalysis driven RCM*

The winter cyclone track density, intensity, genesis density, and lysis density from the RCM (Fig. 9.2.1) compare well with those of the ERA40 data (Fig. 9.1.3.c and 9.1.3.e). For example, the track density correctly simulates the split in the North Atlantic track around Norway and the Mediterranean track is well simulated. There are some edge effects caused by the tracking of cyclones along the RCM boundary and there are high genesis and lysis counts where the cyclones enter and leave the RCM domain. Overall the ERA40RCM is mostly able to correctly simulate the life cycle of cyclones, when it is given “perfect” boundary conditions.

Similarly the summer anticyclone track density (Fig. 9.2.2) compares fairly well with ERA40 (Fig. 9.1.4.c and 9.1.4.e), with the anticyclones mostly occurring in the correct locations in the ERA40RCM. The RCM has high values of intensity over the Alps, and other regions with high orography, that may be due to small-scale features that are missing from ERA40. The RCM anticyclone genesis and lysis are not as similar to ERA40 as the cyclones are. The main differences with the genesis are the small scale features in the RCM that are related to the high values of intensity. There is also a region of genesis over France that is missing from ERA40RCM. This is somewhat expected as during period of low-zonal flow (ie blocking) the synoptic situation is more influenced by local processes rather than the large scale allowing the internal RCM domain to wander from the driving data.

We can also compare the gales in the ERA40RCM to the gales in ERA40 using the UK Gale Index (Jenkinson and Collison 1977). The ERA40RCM UK Gale Index is a daily maximum derived from 3 hourly MSLP data (Table 9.1) where as the ERA40 UK Gale Index (Table 9.2) is a daily mean derived from the average of the 6 hourly MSLP data. The use of 3 hourly data helps with the inclusion of fast moving systems that may be missed with daily mean data. The use of the 3 hourly data for the ERA40RCM means that it has more gales than ERA40 (Table 9.1 and

Table 9.2). When the Gale Index is calculated for the RCM using daily mean MSLP (Table 9.3) the percentages of gales in each category are very similar to ERA40. This result confirms that deriving the UK gale index from daily mean MSLP data misses some of the extreme gales.

The cyclone tracking diagnostics can also be used to produce counts of cyclones over a given region, e.g. the UK (Table 9.4). There are 2 methods of producing these counts. The first counts all the cyclones that track over a 5° region (UK in Table 9.4) and the second counts all the tracks that have at least one feature in a specified region (NUK and SUK in Table 9.4). The cyclones in each region can then be split into those of weak, medium and intense strength using the 850 hPa wind speed at the centre of the cyclones. The maximum intensity during the whole of the lifetime of the system is used. The data is not available to produce these counts for the ERA40 tracks and so the results in Table 9.4 are provided as a baseline for the future changes as simulated by the RQUMP ensemble.

9.4 Tables

Table 9.1 ERA40RCM 1960-1989 % number of days with gales ($G>30$), severe gales ($G>40$) and very severe gales ($G>50$), calculated using the daily maximum calculated from 3 hourly MSLP

	Gales $G>30$	Severe Gales $G>40$	Very Severe Gales $G>50$
DJF	42.6	13.0	3.2
MAM	19.5	3.8	0.5
JJA	4.6	0.3	<0.1
SON	26.6	7.1	1.6

Table 9.2 ERA40 1960-1989 % number of days with gales ($G>30$), severe gales ($G>40$) and very severe gales ($G>50$), calculated using daily mean MSLP

	Gales $G>30$	Severe Gales $G>40$	Very Severe Gales $G>50$
DJF	23.4	4.0	0.5
MAM	9.2	1.3	0.1
JJA	1.2	<0.1	
SON	11.8	1.9	0.3

Table 9.3 ERA40RCM 1960-1989 % number of days with gales ($G>30$), severe gales ($G>40$) and very severe gales ($G>50$), calculated using daily mean MSLP

	Gales $G>30$	Severe Gales $G>40$	Very Severe Gales $G>50$
DJF	21.5	3.9	0.7

MAM	8.8	0.8	<0.1
JJA	1.5	<0.1	
SON	11.0	1.9	0.2

Table 9.4 UK cyclone counts: ERA40RCM, UK (point), north UK and south UK, weak, medium, intense. Intensity is maximum 850 hPa wind along the entire track.

Season	Region	Total Number per year (standard deviation)	Weak $I < 11.33$ ms^{-1} (standard deviation)	Medium $11.33 < I <$ 17.5 ms^{-1} (standard deviation)	Intense $I > 17.5 \text{ ms}^{-1}$ (standard deviation)
DJF	UK	67.11 (13.62)	2.11 (1.87)	16.75 (5.93)	48.25 (14.77)
	N UK	48.98 (10.51)	1.27 (1.56)	11.70 (4.61)	36.00 (10.82)
	S UK	45.36 (10.67)	1.57 (1.65)	11.66 (3.99)	32.14 (9.82)
MAM	UK	58.86 (10.30)	6.39 (2.59)	26.95 (7.23)	25.52 (8.92)
	N UK	44.23 (8.18)	4.68 (2.21)	19.86 (5.28)	19.68 (7.07)
	S UK	42.00 (8.14)	4.98 (2.28)	19.68 (5.13)	17.34 (6.14)
JJA	UK	53.41 (9.25)	10.86 (3.15)	31.91 (7.66)	10.64 (3.36)
	N UK	40.09 (7.37)	7.70 (2.54)	24.05 (6.11)	8.34 (3.03)
	S UK	35.55 (7.32)	7.89 (2.67)	20.89 (6.09)	6.77 (2.83)
SON	UK	64.35 (10.51)	4.16 (2.43)	23.95 (4.85)	36.23 (10.56)
	N UK	48.60 (9.29)	2.74 (1.79)	17.65 (5.30)	28.21 (8.43)
	S UK	40.56 (8.63)	3.05 (2.06)	16.00 (4.34)	21.51 (6.45)

9.5 Detailed description of methods

9.5.1 *Blackmon band-pass filter storm track*

In the band-pass filter (BPF) and low-pass filter (LPF) methods of storm track analysis a standard deviation is taken of 24 h instantaneous geopotential height data on 500 hPa after the application of a time-filter. The Blackmon band-pass filter and low-pass filter (Blackmon 1976) are used in this study. The BPF isolates the synoptic variability between 2 and 6 days and the LPF isolates the low frequency variability greater than 10 days. Both the BPF and LPF include variability due to cyclones and anticyclones (Wallace et al. 1988). The BPF storm track tends to have higher values in the genesis regions where the systems are faster moving and tends to be more indicative of intensity than number of cyclones. The LPF storm track has higher values at the eastern ends of the storm tracks where the systems are slower moving as they decay. Small scale systems such as Mediterranean storms are poorly simulated by these diagnostics. The future changes in the BPF and LPF storm tracks are not always the same as the changes in the cyclones (Carnell et al. 1996).

The BPF storm track can also be derived from 0Z mean sea level pressure (MSLP). Daily mean MSLP is being used in place of 24 h instantaneous data for the CMIP3 multi-model archive and for the TQUMP ensemble as daily data is not available. Tests with ERA40 data show that the results are similar with 0Z and daily mean MSLP data as the filter removes the high frequency variability.

9.5.2 *UK Gale Index*

Jenkinson and Collison (1977) developed an objective definition of a gale day using daily mean sea level pressure (MSLP) around the British Isles. The technique is also described in Hulme and Jones (1991). Daily MSLP is used on a $5^{\circ} \times 10^{\circ}$ latitude/longitude grid. Daily data has been known to miss some observed storms, such as the October 1987 storm as this was fast moving. The index can also be applied to sub-daily data and this should help to capture fast moving systems. In this study daily mean MSLP data is being used for the GCMs and 3 hourly MSLP for the RCMs. A daily maximum value of the gale index is then determined from the 3 hourly values.

The wind flow and vorticity are calculated as follows (grid-point numbers (x_i):

Wind Flow

westerly flow, $W = 0.5(x_{12} + x_{13}) - 0.5(x_4 + x_5)$

southerly flow, $S = 1.74\{0.25(x_5 + 2x_9 + x_{13}) - 0.25(x_4 + 2x_8 + x_{12})\}$

resultant flow, $F = \sqrt{S^2 + W^2}$

The geostrophic flow units are hPa per 10° latitude at 55°N and one unit is equivalent to 1.2kt.

Vorticity

westerly shear vorticity

$$ZW = 1.07\{0.5(x_{15} + x_{16}) - 0.5(x_8 + x_9)\} - 0.95\{0.5(x_8 + x_9) - 0.5(x_1 + x_2)\}$$

southerly shear vorticity

$$ZS = 1.52[0.25(x_6 + 2x_{10} + x_{14}) - 0.25(x_5 + 2x_9 + x_{13}) - \{0.25(x_4 + 2x_8 + x_{12}) - 0.25(x_3 + 2x_7 + x_{11})\}]$$

total shear vorticity, $Z = ZW + ZS$

The geostrophic vorticity units are hPa per 10° latitude at 55°N, per 10° latitude. 100 units are equivalent to $0.55 \times 10^{-4} = 0.46 \times$ Coriolis parameter at 55°N.

The gale index, G is then defined by $G = \sqrt{F^2 + (0.5Z)^2}$

A value of G greater than 30 is classified as a gale, a value of G greater than 40 is classified as a severe gale and a value of G greater than 50 is a very severe gale. The flow speed and direction and the vorticity can be used to classify the regime type. These are similar to the Lamb circulation types as the method used to derive the Lamb circulation types was based on the gale index method.

9.5.3 *Persistent anomalies*

A "persistent anomaly" at a point is defined as an anomaly which persists beyond some threshold value for a specified duration (Dole and Gordon 1983). Here an anomaly (h) at a point is defined as the 500 hPa height at that point minus the long term seasonal trend of 500 hPa height at that point. The anomalies are latitude normalized:

$$Z = \left(\frac{\sin 45}{\sin lat} \right) h$$

The method is as follows:

- 1) Specify a magnitude criterion M and a duration criterion T , where for positive cases $M \geq 0$ and for negative cases $M \leq 0$.
- 2) Define the occurrence of a persistent positive (negative) anomaly case at a particular grid point satisfying selection criteria (M, T) if the anomaly at that point remains equal to or greater (less) than M for at least T days.
- 3) Define the duration D for a positive (negative) case as the time from which the anomaly first becomes greater (less) than M to the time when the anomaly next becomes less (greater) than M at that point.

Persistent positive anomalies are considered to be blocking events.

9.5.4 Tracking Method

The tracks of extra-tropical cyclones and anticyclones in HadCM3 and HadRM3 data are diagnosed using an objective technique (see Hodges 1994; Hodges 1995; Hodges 1996; Hoskins and Hodges 2002).

The HadCM3 features are tracked in relative vorticity on 850 hPa data at 6 hourly intervals. The tracking is performed at a spectral resolution of T42 on a Gaussian grid so that synoptic scale features can easily be identified. The data is spatially filtered by removing a background field. This is done by setting the coefficients in the spherical harmonic expansion of the field at each time step to zero for total wavenumbers $n \leq 5$. The filtered fields are equivalent to the $5 < n \leq 42$ component of the original fields and the background fields are equivalent to the $n \leq 5$ component of the original fields. Individual cyclones are tracked as features in the filtered fields. Only those features with a magnitude greater than $1 \times 10^{-5} \text{ s}^{-1}$, in the filtered fields, are tracked and the cyclone and anticyclone tracks must last for at least 2 days and move a distance of 10° geodesic ($\sim 1000 \text{ km}$). In the Northern Hemisphere the cyclones are the positive relative vorticity anomalies and the anticyclones are the negative relative vorticity anomalies.

The RCM features are tracked in relative vorticity on 850 hPa data at 3 hourly intervals. The data is spatially filtered, to isolate synoptic scale features, before the cyclones and anticyclones are located and tracked. Regional model data is spatially smoothed using an R image processing routine called `image.smooth`. This uses FFTs to truncate the data. For UKCIP data at 25km the smoothing parameter is set to 2° . Individual cyclones and anticyclones are tracked as features in the filtered fields. Only those features with a magnitude greater than

$1 \times 10^{-5} \text{ s}^{-1}$, in the filtered fields, are tracked and the tracks must last for at least 12 hours and move a distance of 5° geodesic.

The features (cyclones and anticyclones) are located in the spatially smoothed data and then joined together to form tracks. The tracking program produces a set of cyclone (and anticyclone) locations (latitude and longitude) and intensity at 3 hourly time intervals for every 90 day season. These are then processed to form four types of data: track statistics; regional counts (number of tracks with at least one point in the specified region); cyclone or anticyclone intensity; and tracks that form in, decay in or cross a 5° region. The UK storms are defined as those tracks that cross a 5° region centred on Northern Scotland. With this method the track does not need to have a timestep location within the domain.

The spatial statistics are derived from the track ensembles using spherical kernel methods (Hodges 1996) which compute the statistics directly on the sphere making the statistics independent of projection biases (Bengtsson et al. 2006). Here the results are presented as cyclone track number densities with the track number densities calculated by using the single point from each track that is closest to the estimation point (see Hoskins and Hodges 2002). The densities are then scaled to number densities per month with a unit area equivalent to a 5° spherical cap ($\sim 10^6 \text{ km}^2$). These number densities integrate to a number greater than the total number of systems over the Northern Hemisphere because of multiple counting. They give a local measure of the storm track activity at a point (Hoskins and Hodges 2002) but are not the same as counting the systems in a box and area normalising. A set of tracking diagnostics are computed from the individual tracks. The intensity is defined as the magnitude of the features in the un-filtered relative vorticity field.

The RCM has more tracks than the GCM because the RCM is able to simulate smaller scale features, such as frontal waves. The tracking method is also configured to locate only large synoptic systems in the GCM. The number of cyclones in the RCM can be adjusted by applying different amounts of smoothing to the relative vorticity fields prior to the features being located.

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Figure Captions

Fig. 2.1.1.a Seasonal Z500 BPF storm tracks, ERA40, 1958-2002. The units are m. A9-3

Fig. 2.1.1.b Seasonal Z500 LPF storm tracks, ERA40, 1958-2002. The units are m. A9-4

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Fig. 2.1.3.e Strength of ERA40 cyclones by season, 1958-2002. The units are of vorticity at 850 hPa (s^{-1}). A9-11

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Fig. 2.1.4.c Winter ERA40 anticyclones: feature density, track density, genesis density, and lysis density, 1958-2002. The units are tracks per month per 10^6 km² (track density) or cyclones per month per 10^6 km² (feature, genesis and lysis density). A9-14

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Fig. 2.1.4.e Strength of ERA40 anticyclones by season, 1958-2002. The units are of vorticity at 850 hPa (s^{-1}) A9-16

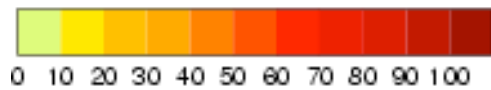
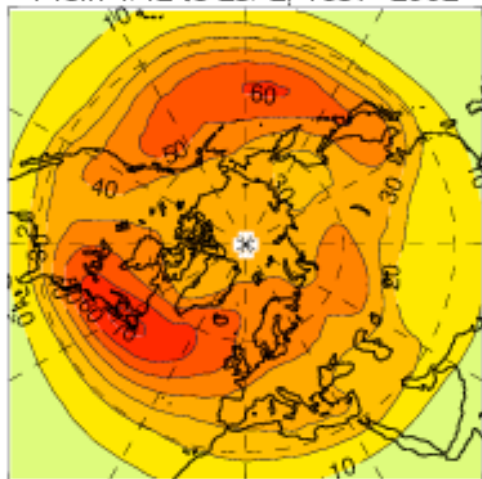
Fig. 2.1.5.a PA blocks Z500, with a duration of 7 days and a magnitude of 100m by season, ERA40 1961-2000. The units are number of blocked days per season per 10^6 km^2 . A9-17

Fig. 2.1.5.b PA blocks Z500, with a duration of 7 days and a magnitude of 200m by season, ERA40 1961-2000. The units are number of blocked days per season per 10^6 km^2 . A9-18

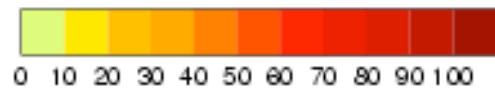
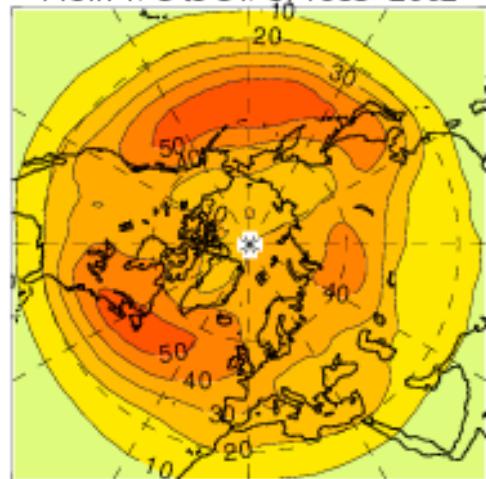
Fig. 2.2.1 ERA40RCM cyclone tracks, track density, genesis density, lysis density and relative vorticity on 850 hPa intensity, DJF 1961-2000. The units are tracks per month per 10^6 km^2 (track density), cyclones per month per 10^6 km^2 (genesis and lysis density) and s^{-1} (intensity). A9-19

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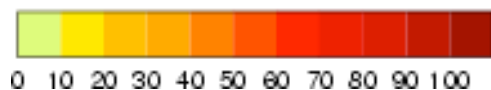
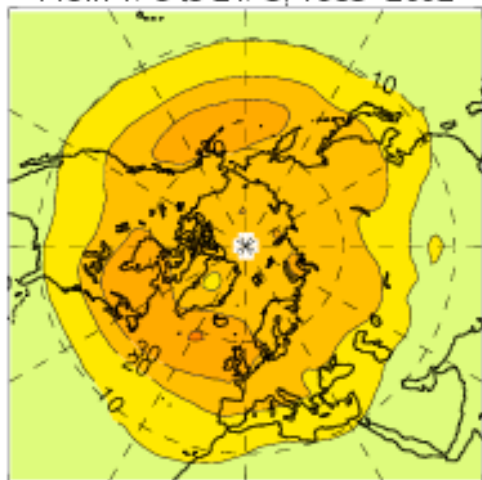
Blackmon BPF storm track 0Z Z500
ERA40
From 1/12 to 28/ 2, 1957–2002



Blackmon BPF storm track 0Z Z500
ERA40
From 1/ 3 to 31/ 5, 1958–2002



Blackmon BPF storm track 0Z Z500
ERA40
From 1/ 6 to 21/ 8, 1958–2002



Blackmon BPF storm track 0Z Z500
ERA40
From 1/ 9 to 21/ 8, 1958–2002

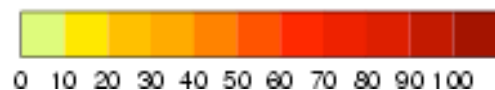
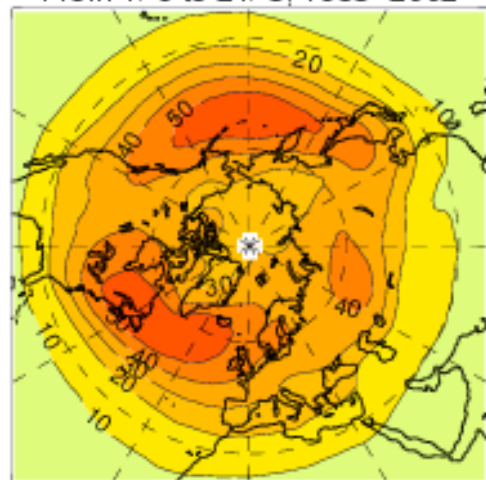
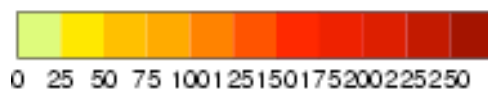
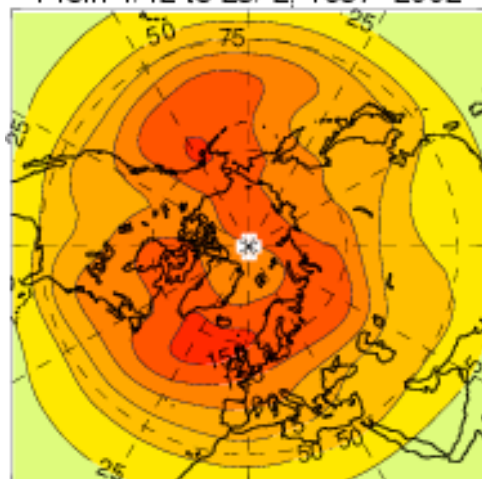
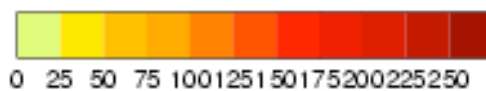
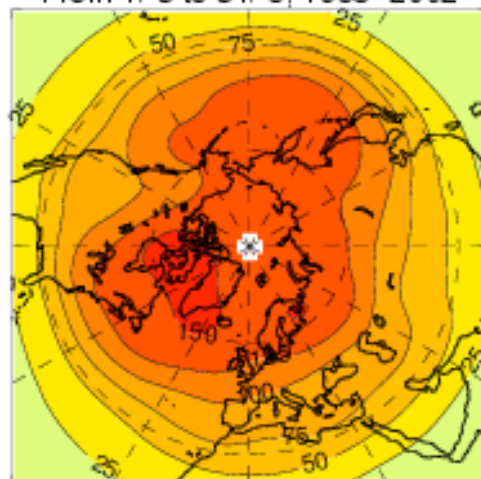


Fig. 2.1.1.a Seasonal Z500 BPF storm tracks, ERA40, 1958–2002. The units are m.

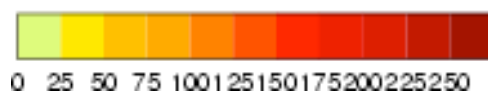
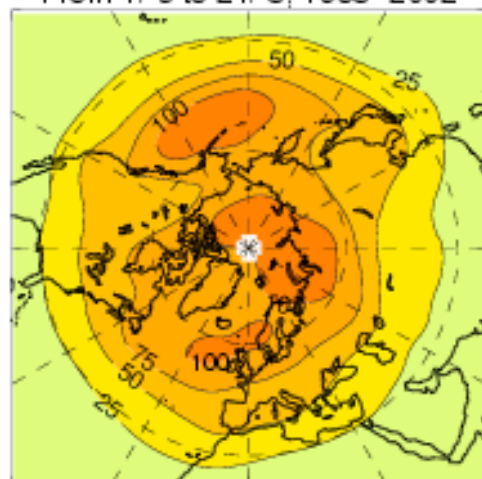
Blackmon LPF storm track 0Z Z500
ERA40
From 1/12 to 28/ 2, 1957-2002



Blackmon LPF storm track 0Z Z500
ERA40
From 1/ 3 to 31/ 5, 1958-2002



Blackmon LPF storm track 0Z Z500
ERA40
From 1/ 6 to 21/ 8, 1958-2002



Blackmon LPF storm track 0Z Z500
ERA40
From 1/ 9 to 21/ 8, 1958-2002

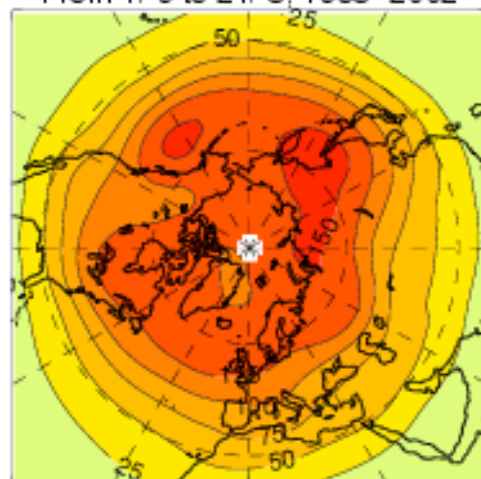
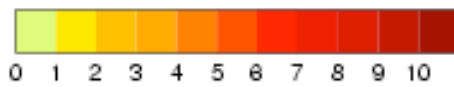
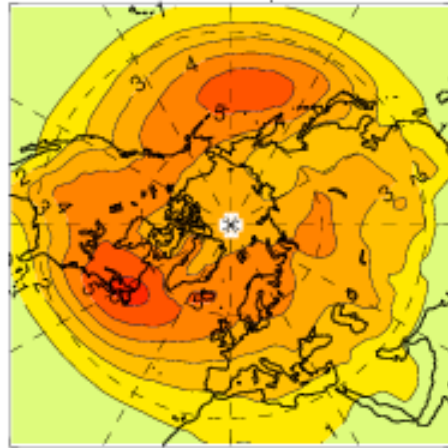
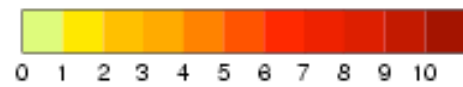
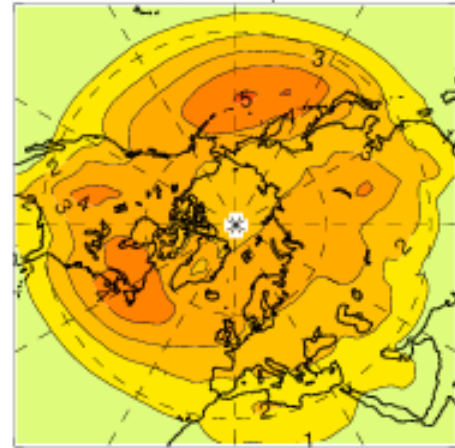


Fig. 2.1.1.b Seasonal Z500 LPF storm tracks, ERA40, 1958-2002. The units are m.

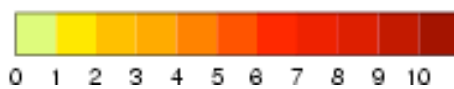
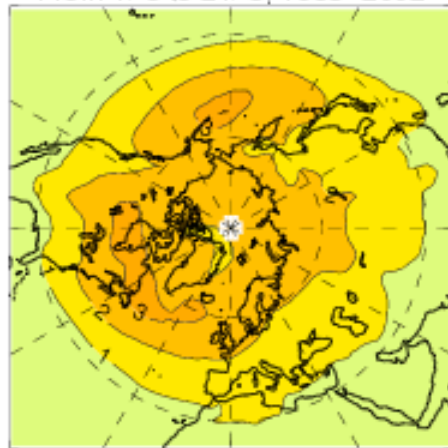
Blackmon BPF storm track daily mean MSLP
ERA40
From 1/12 to 28/2, 1957-2002



Blackmon BPF storm track daily mean MS
ERA40
From 1/3 to 31/5, 1958-2002



Blackmon BPF storm track daily mean MSLP
ERA40
From 1/6 to 21/8, 1958-2002



Blackmon BPF storm track daily mean MS
ERA40
From 1/9 to 21/8, 1958-2002

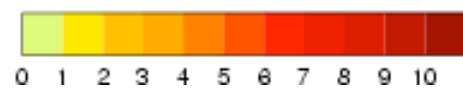
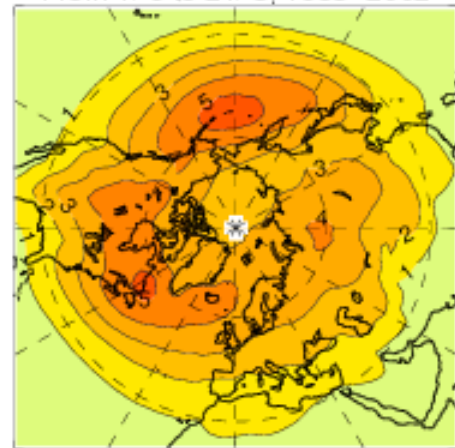
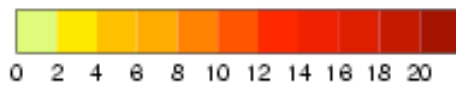
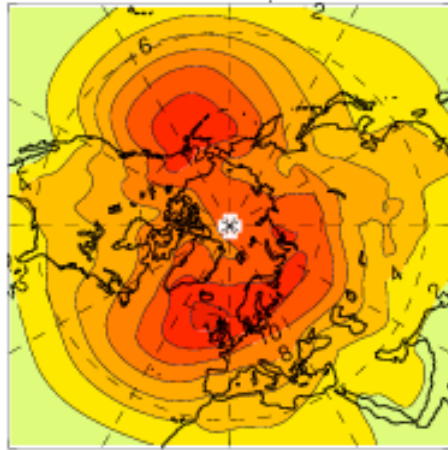
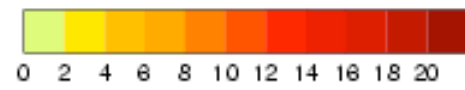
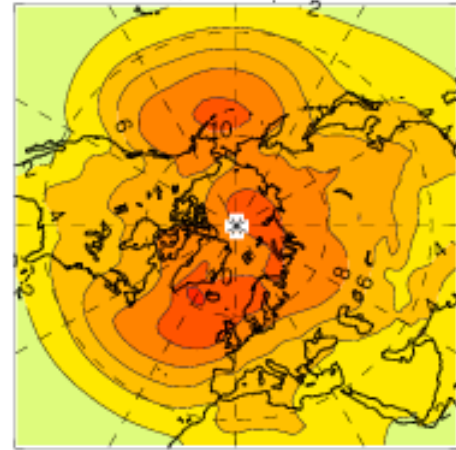


Fig. 2.1.2.a Seasonal MSLP BPF storm tracks, ERA40, 1958-2002. The units are hPa.

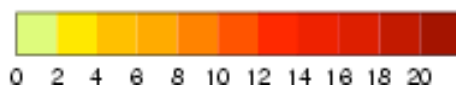
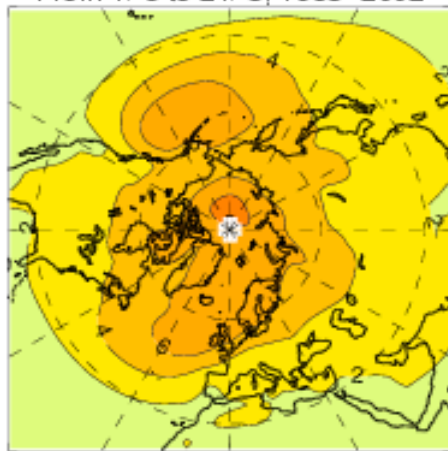
Blackmon LPF storm track daily mean MSLP
ERA40
From 1/12 to 28/2, 1957–2002



Blackmon LPF storm track daily mean MS
ERA40
From 1/3 to 31/5, 1958–2002



Blackmon LPF storm track daily mean MSLP
ERA40
From 1/6 to 21/8, 1958–2002



Blackmon LPF storm track daily mean MS
ERA40
From 1/9 to 21/8, 1958–2002

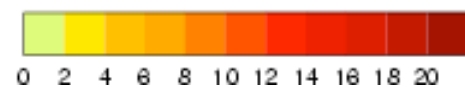
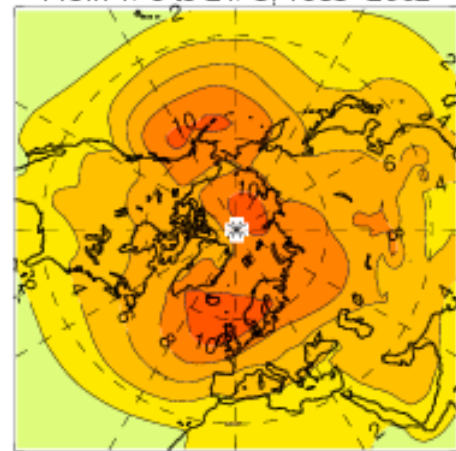
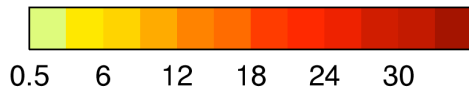
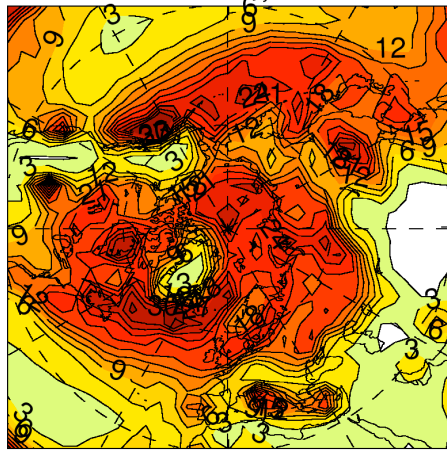
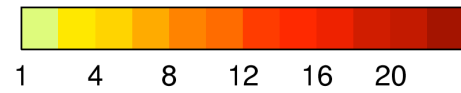
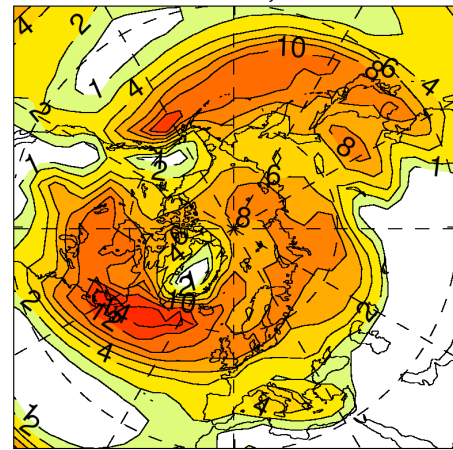


Fig. 2.1.2.b Seasonal MSLP LPF storm tracks, ERA40, 1958–2002. The units are hPa.

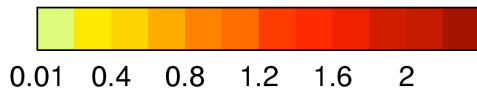
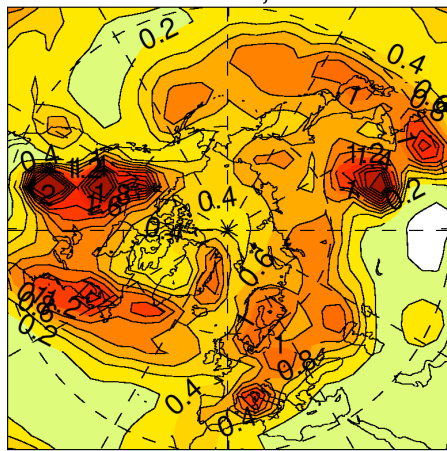
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/ 6 to 1/ 9, 1958–2002



Track dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/ 6 to 1/ 9, 1958–2002



Genesis dens $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/ 6 to 1/ 9, 1958–2002



Lysis dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/ 6 to 1/ 9, 1958–2002

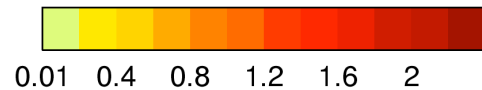
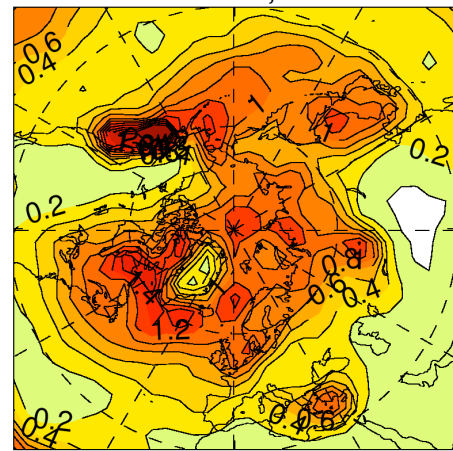
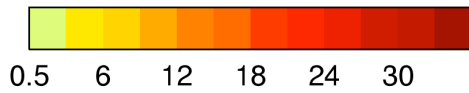
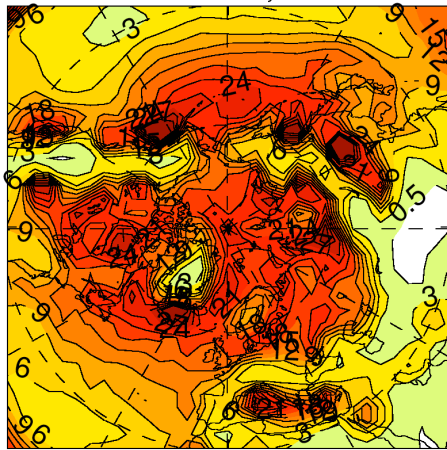
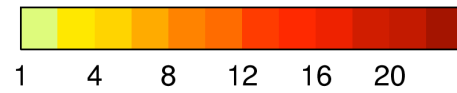
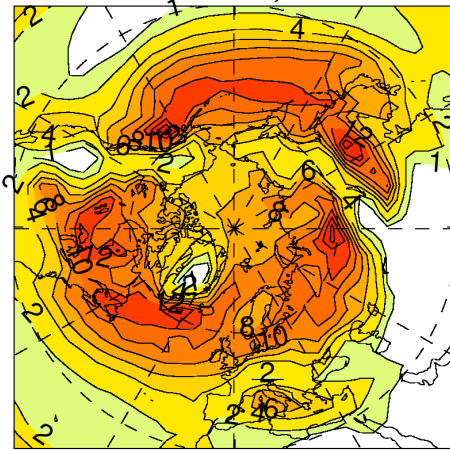


Fig. 2.1.3.a Summer ERA40 cyclones: feature density, track density, genesis density, and lysis density, 1958–2002. The units are tracks per month per 10^6 km^2 (track density) or cyclones per month per 10^6 km^2 (feature, genesis and lysis density).

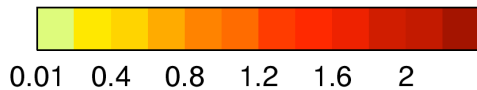
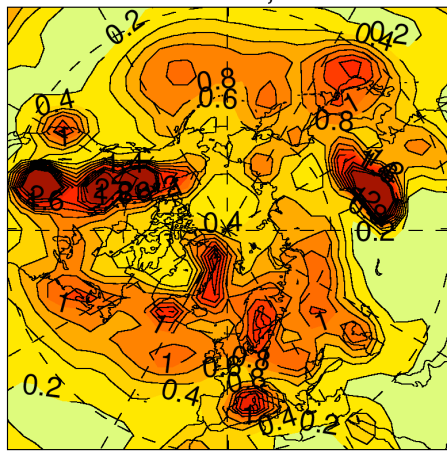
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/9 to 1/12, 1958–2002



Track dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/9 to 1/12, 1958–2002



Genesis dens $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/9 to 1/12, 1958–2002



Lysis dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/9 to 1/12, 1958–2002

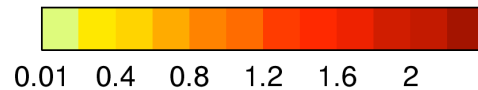
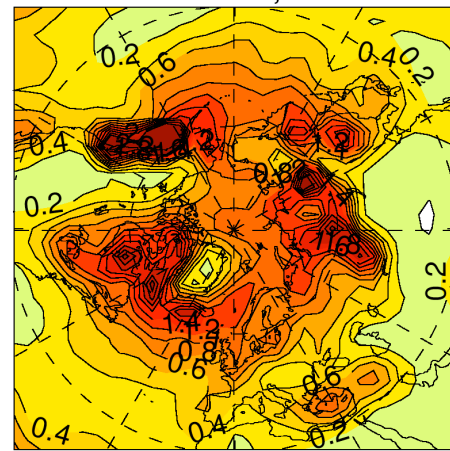
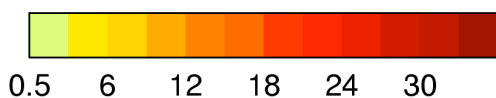
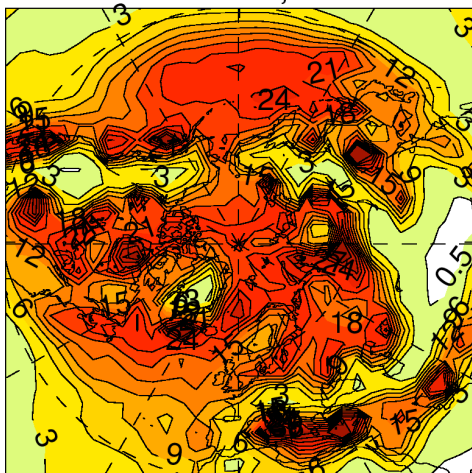
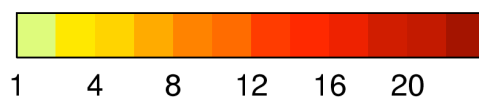
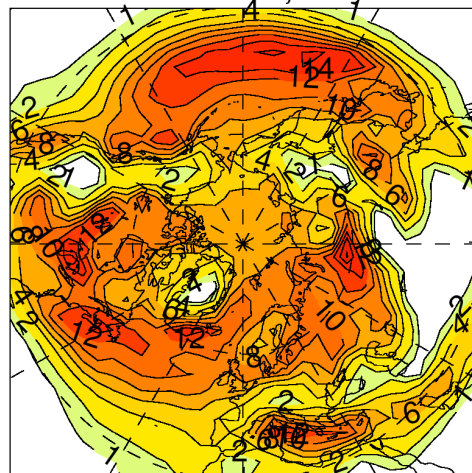


Fig. 2.1.3.b Autumn ERA40 cyclones: feature density, track density, genesis density, and lysis density, 1958–2002. The units are tracks per month per 10^6 km^2 (track density) or cyclones per month per 10^6 km^2 (feature, genesis and lysis density).

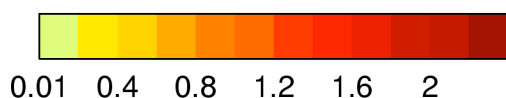
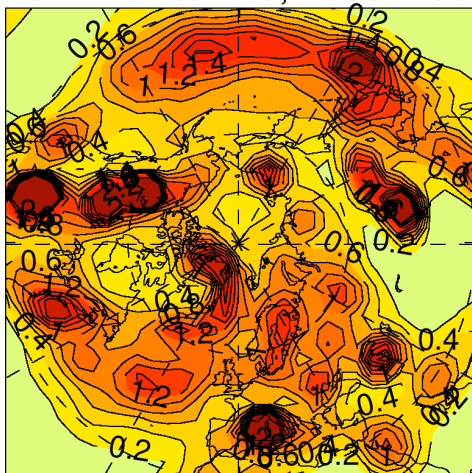
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002



Track dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002



Genesis dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002



Lysis dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002

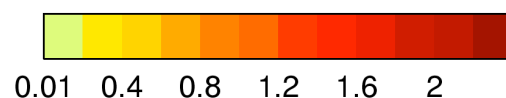
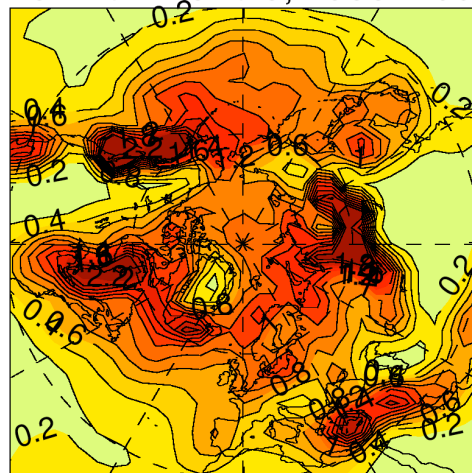
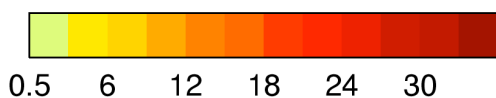
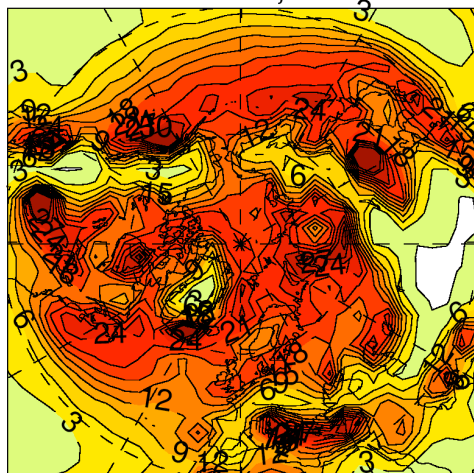
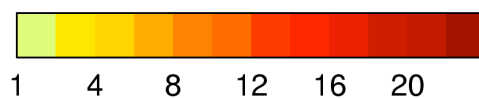
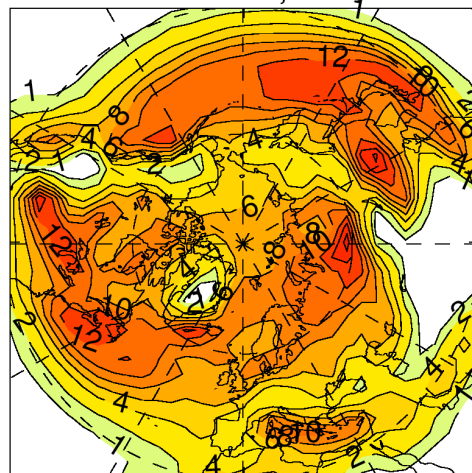


Fig. 2.1.3.c Winter ERA40 cyclones: feature density, track density, genesis density, and lysis density, 1958–2002. The units are tracks per month per 10^6 km^2 (track density) or cyclones per month per 10^6 km^2 (feature, genesis and lysis density).

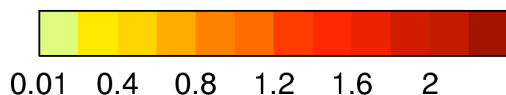
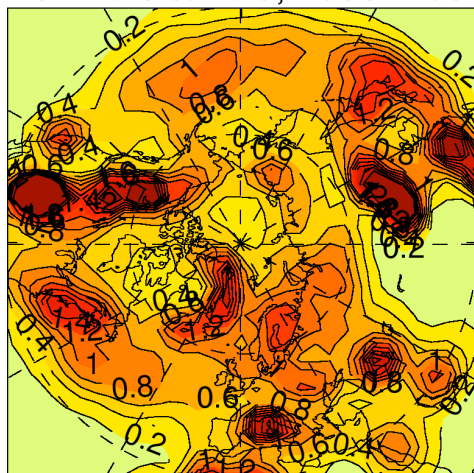
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002



Track dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002



Genesis dens $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002



Lysis dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002

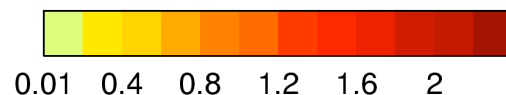
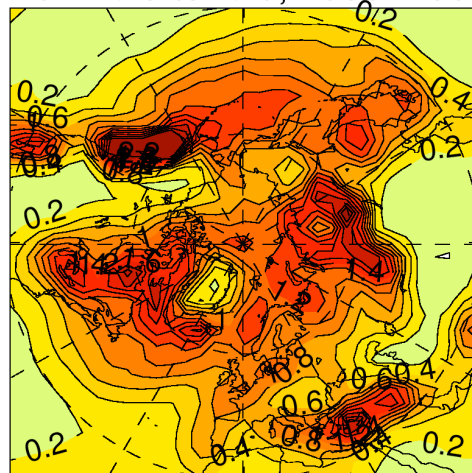
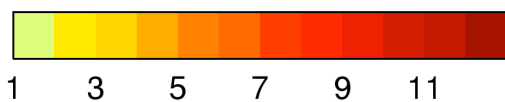
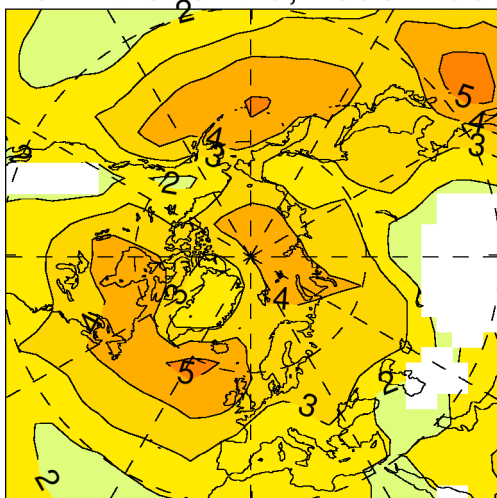
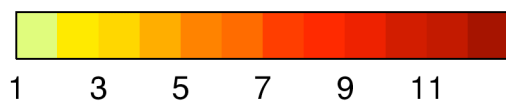
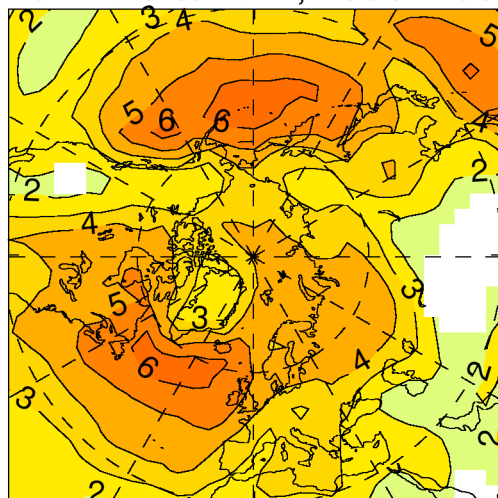


Fig. 2.1.3.d Spring ERA40 cyclones: feature density, track density, genesis density, and lysis density, 1958–2002. The units are tracks per month per 10^6 km^2 (track density) or cyclones per month per 10^6 km^2 (feature, genesis and lysis density).

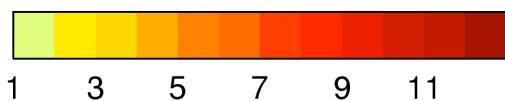
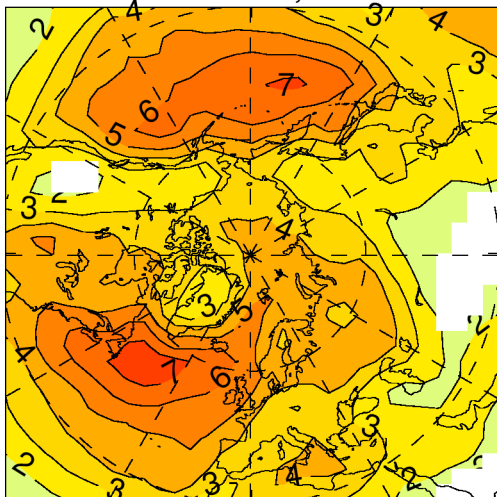
Strength (s^{-1})
ERA40
From 1/6 to 1/9, 1958–2002



Strength (s^{-1})
ERA40
From 1/9 to 1/12, 1958–2002



Strength (s^{-1})
ERA40
From 1/12 to 1/3, 1958–2002



Strength (s^{-1})
ERA40
From 1/3 to 1/6, 1958–2002

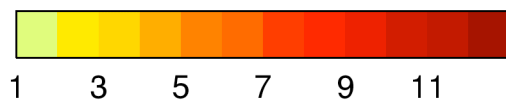
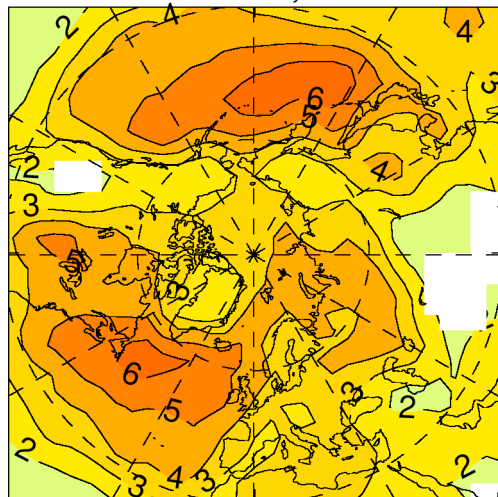
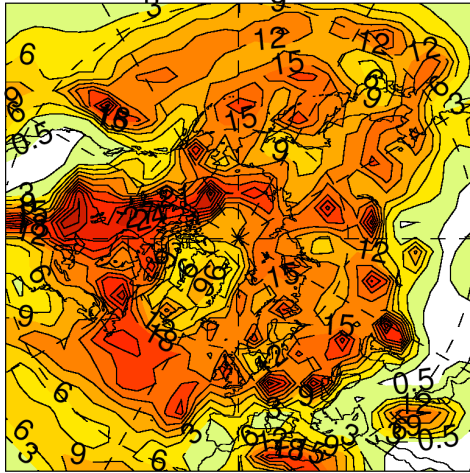
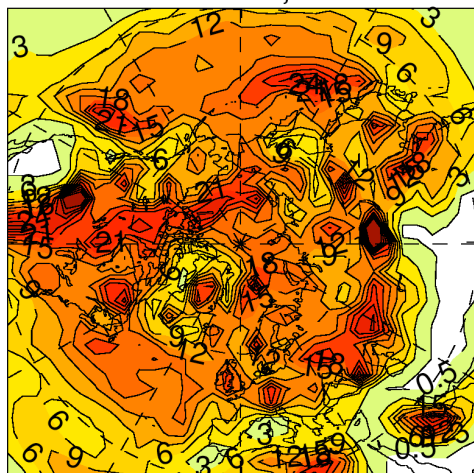


Fig. 2.1.3.e Strength of ERA40 cyclones by season, 1958–2002. The units are of vorticity at 850 hPa (s^{-1}).

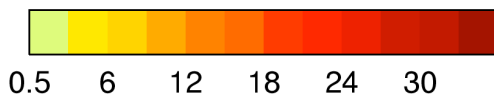
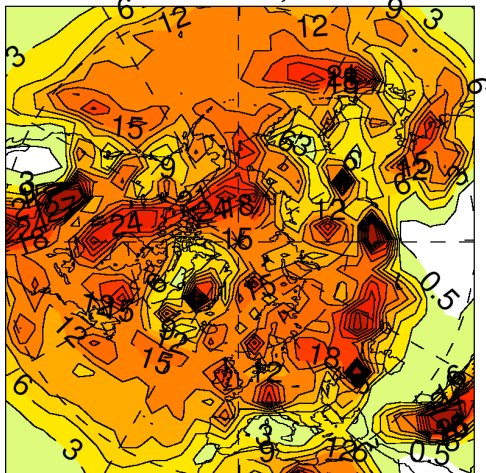
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/6 to 1/9, 1958–2002



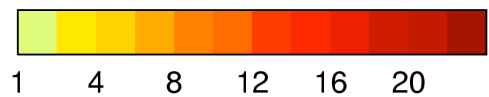
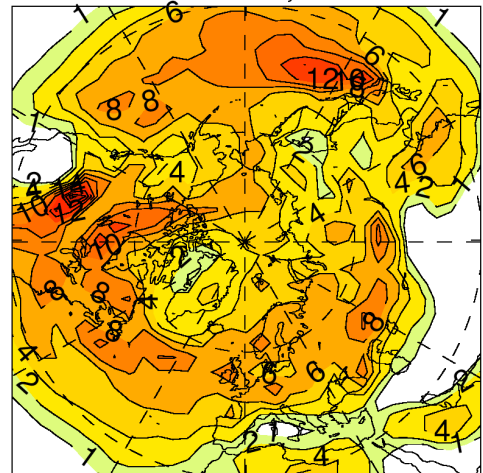
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/ 9 to 1/12, 1958–2002



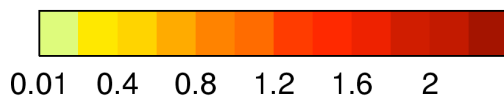
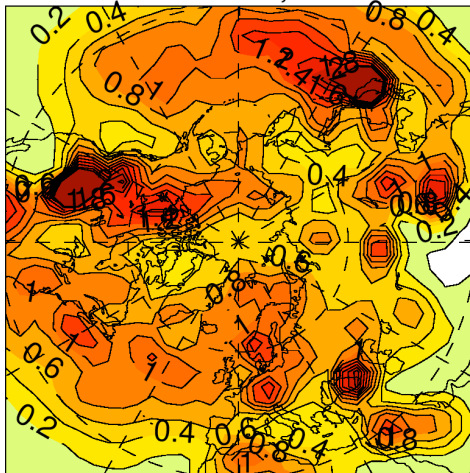
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002



Track dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002



Genesis dens $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002



Lysis dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/12 to 1/3, 1958–2002

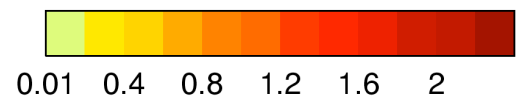
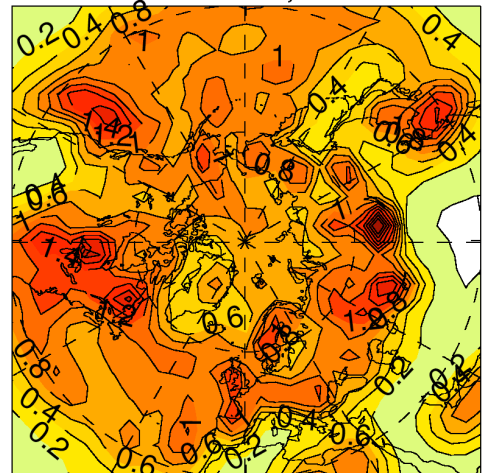
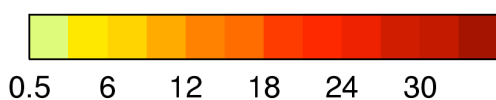
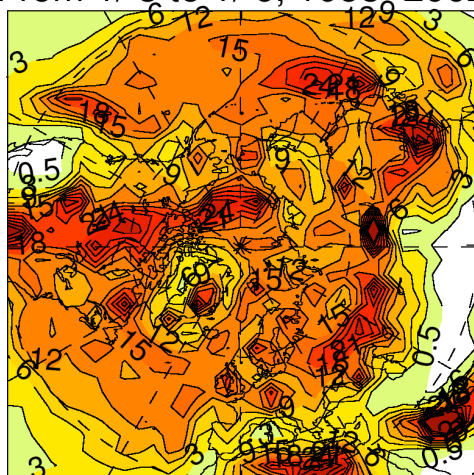
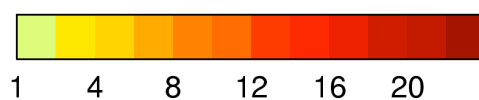
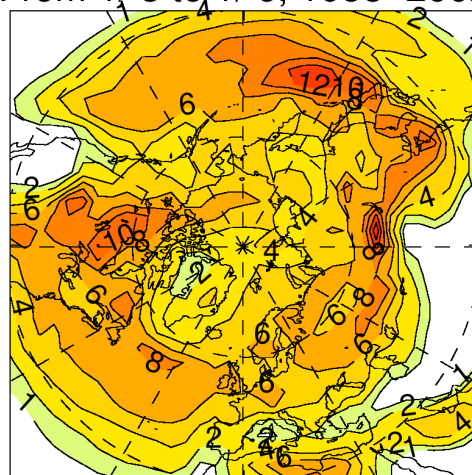


Fig. 2.1.4.c Winter ERA40 anticyclones: feature density, track density, genesis density, and lysis density, 1958–2002. The units are tracks per month per 10^6 km^2 (track density) or cyclones per month per 10^6 km^2 (feature, genesis and lysis density).

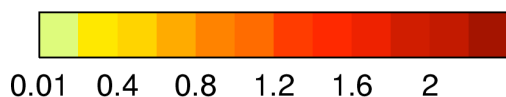
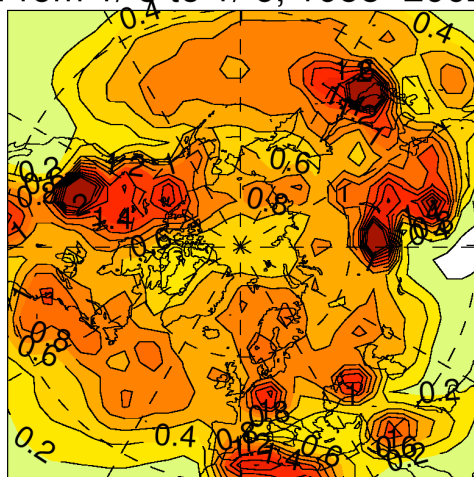
Feature dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002



Track dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002



Genesis dens $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002



Lysis dens. $((10^6 \text{ km}^2 \text{ month})^{-1})$
ERA40
From 1/3 to 1/6, 1958–2002

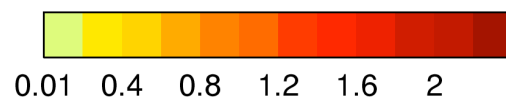
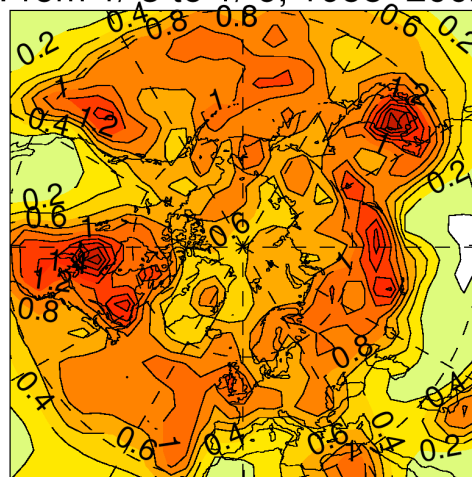
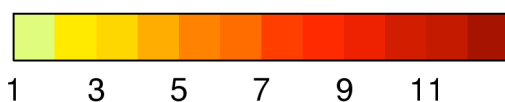
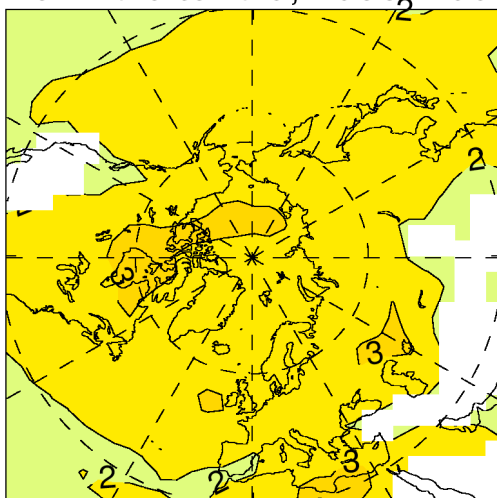
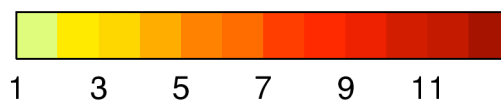
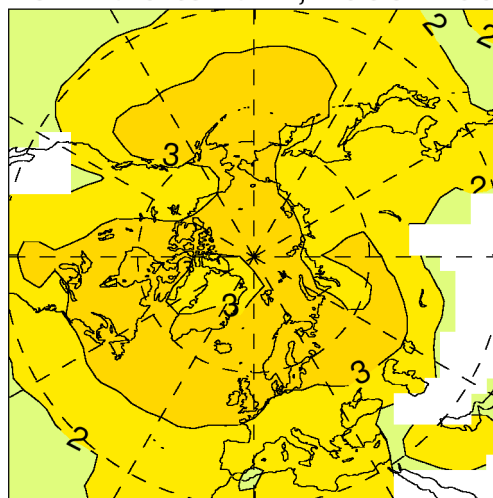


Fig. 2.1.4.d Spring ERA40 anticyclones: feature density, track density, genesis density, and lysis density, 1958–2002. The units are tracks per month per 10^6 km^2 (track density) or cyclones per month per 10^6 km^2 (feature, genesis and lysis density).

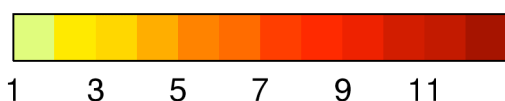
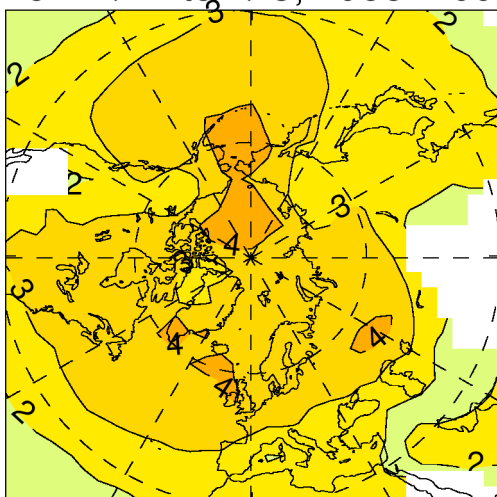
Strength (s^{-1})
ERA40
From 1/6 to 1/9, 1958–2002



Strength (s^{-1})
ERA40
From 1/9 to 1/12, 1958–2002



Strength (s^{-1})
ERA40
From 1/12 to 1/3, 1958–2002



Strength (s^{-1})
ERA40
From 1/3 to 1/6, 1958–2002

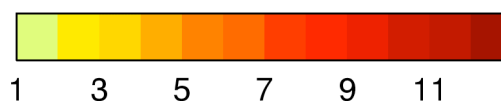
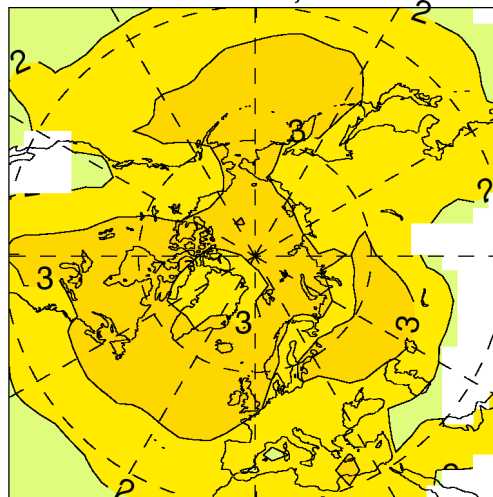


Fig. 2.1.4.e Strength of ERA40 anticyclones by season, 1958–2002. The units are of vorticity at 850 hPa (s^{-1})

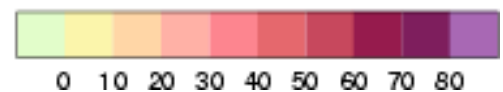
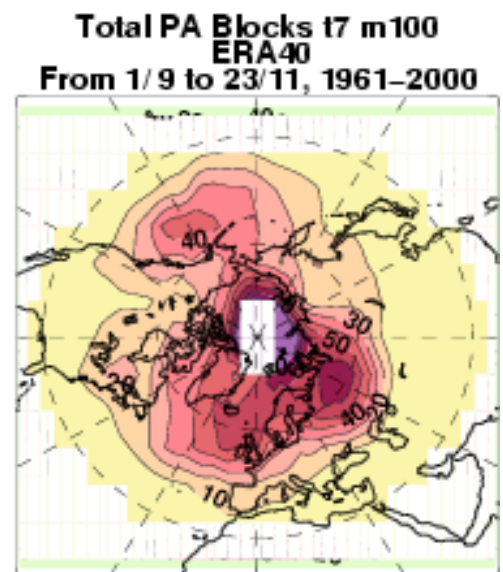
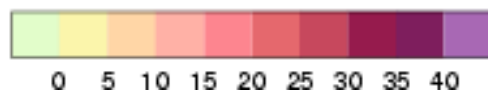
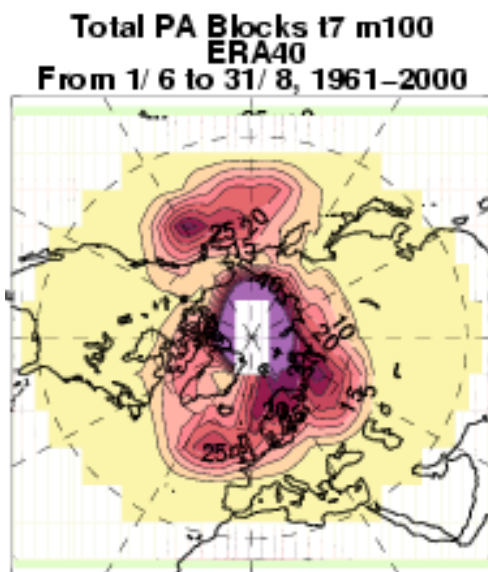
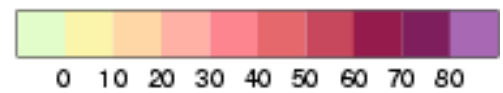
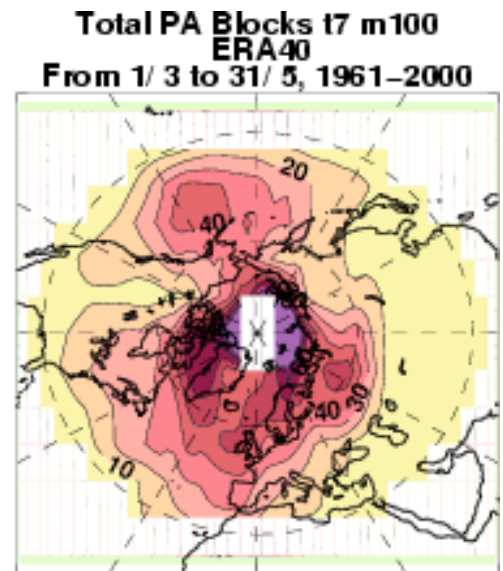
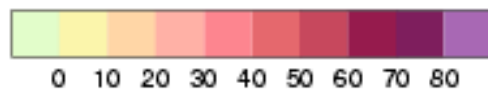
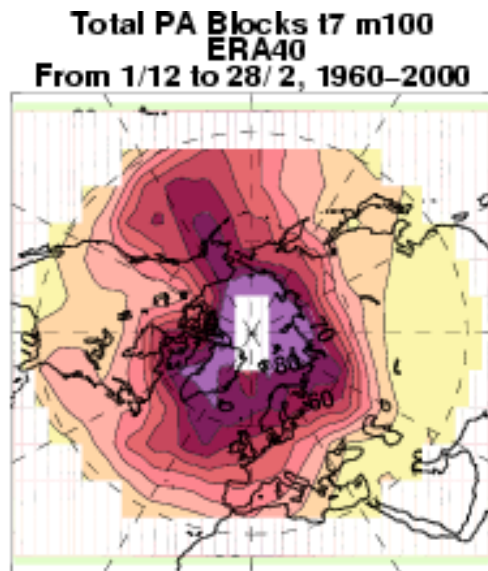


Fig. 2.1.5.a PA blocks Z500, with a duration of 7 days and a magnitude of 100m by season, ERA40 1961–2000. The units are number of blocked days per season per 10^6 km^2 .

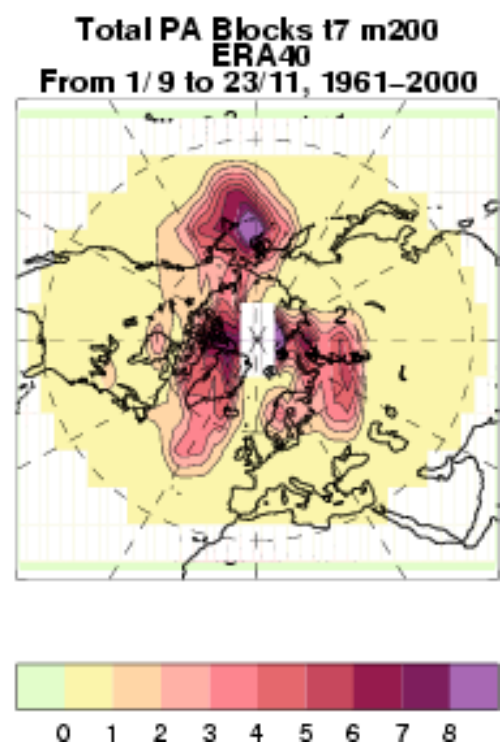
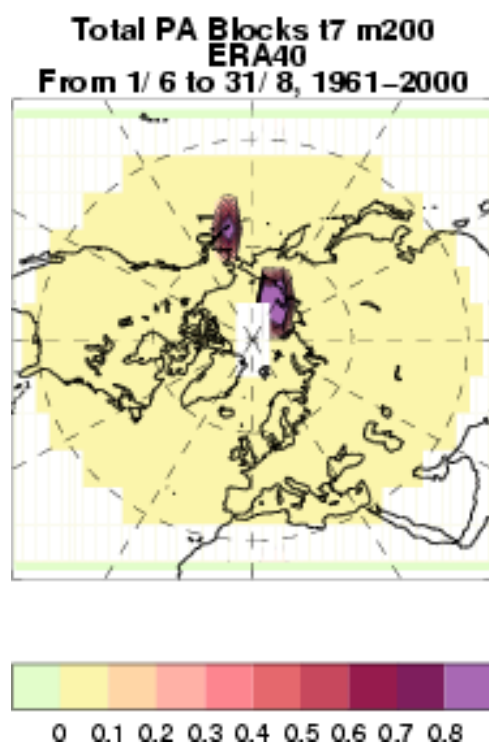
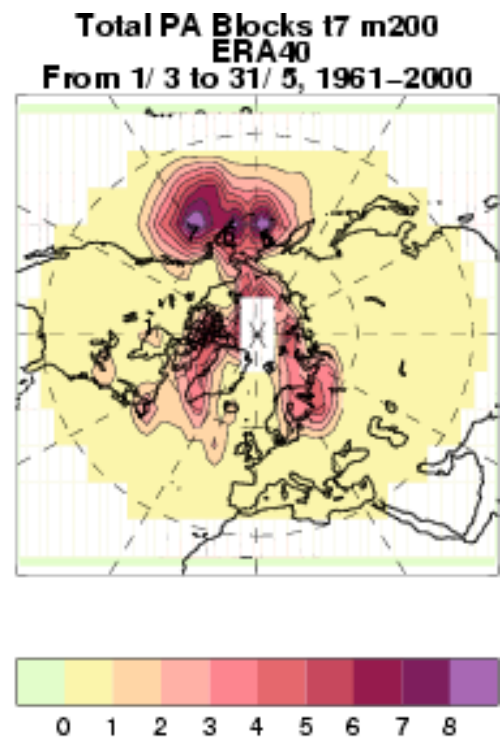
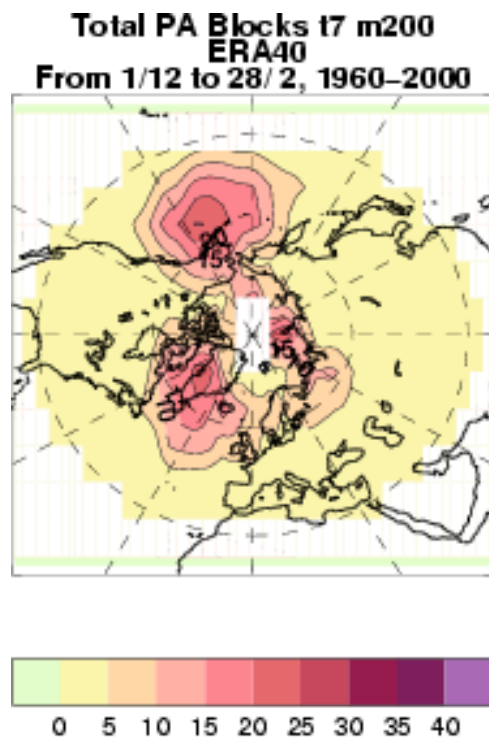
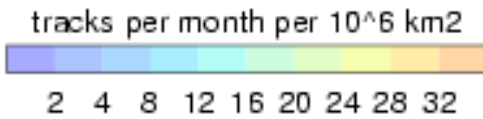
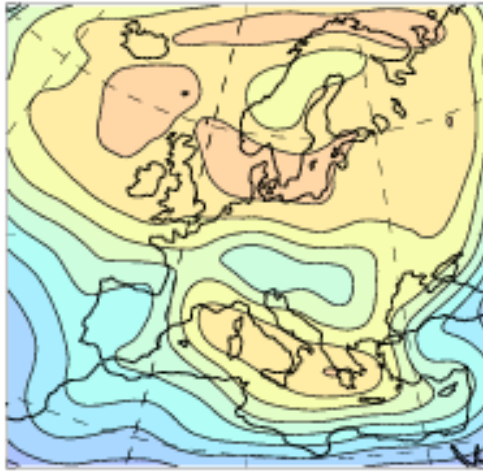
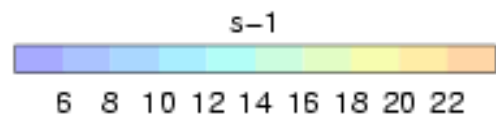
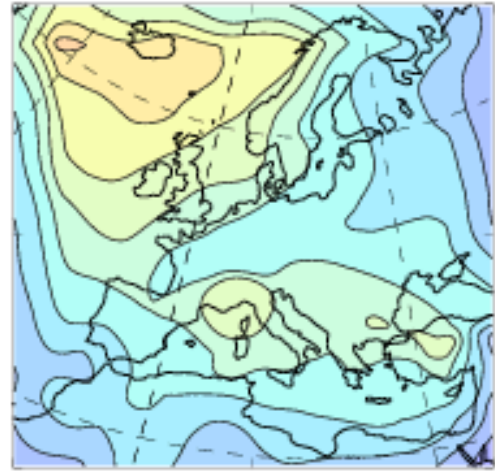


Fig. 2.1.5.b PA blocks Z500, with a duration of 7 days and a magnitude of 200m by season, ERA40 1961–2000. The units are number of blocked days per season per 10^6 km^2 .

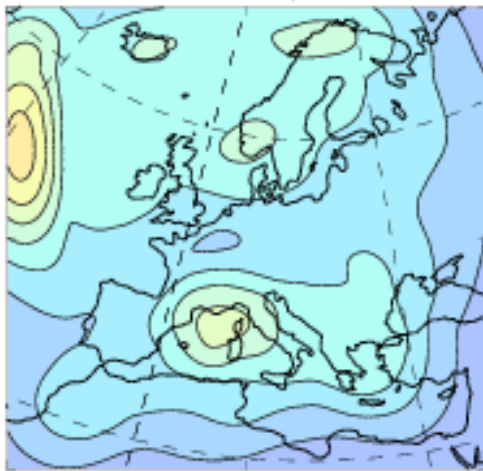
ERA40RCM Track density
From 1/12 to 1/3, 1960–2000



ERA40RCM Vorticity Intensity
From 1/12 to 1/3, 1960–2000



ERA40RCM Genesis density
From 1/12 to 1/3, 1960–2000



ERA40RCM Lysis density
From 1/12 to 1/3, 1960–2000

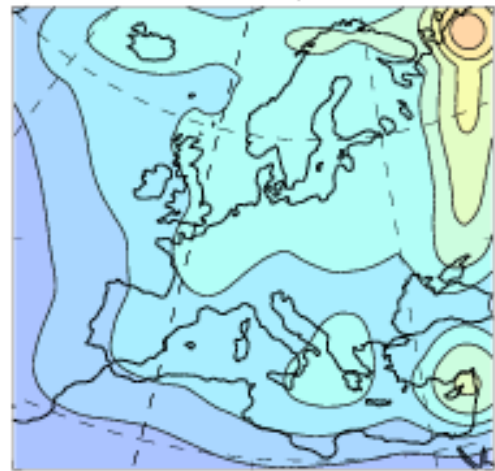
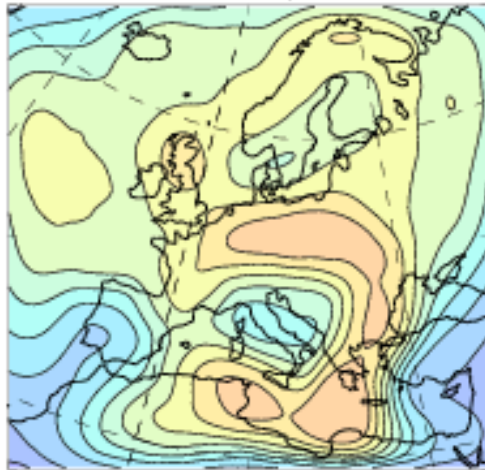


Fig. 2.2.1 ERA40RCM cyclone tracks, track density, genesis density, lysis density and relative vorticity on 850 hPa intensity, DJF 1961–2000. The units are tracks per month per 10^6 km^2 (track density), cyclones per month per 10^6 km^2 (genesis and lysis density) and s^{-1} (intensity).

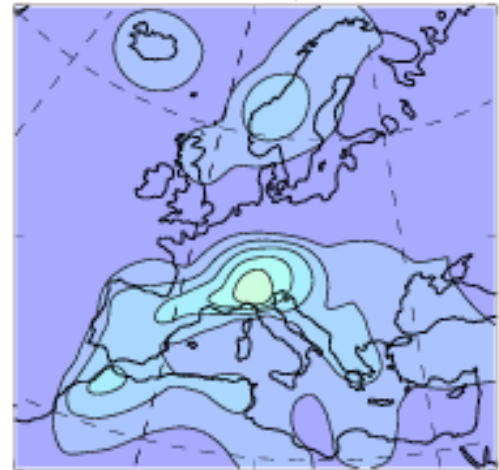
ERA40RCM Track density
From 1/ 6 to 1/ 9, 1961–2000



tracks per month per 10^6 km^2

2 4 8 12 16 20 24 28 32

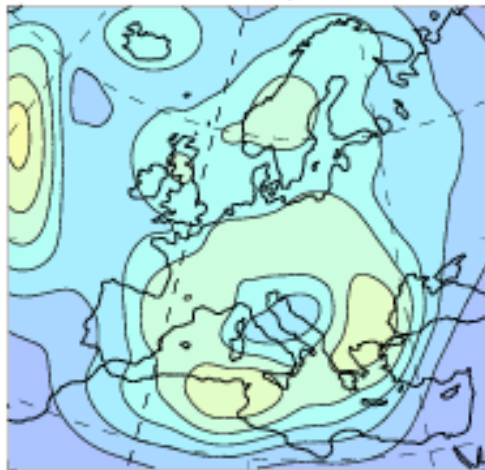
ERA40RCM Vorticity Intensity
From 1/ 6 to 1/ 9, 1961–2000



s^{-1}

6 8 10 12 14 16 18 20 22

ERA40RCM Genesis density
From 1/ 6 to 1/ 9, 1961–2000



ERA40RCM Lysis density
From 1/ 6 to 1/ 9, 1961–2000

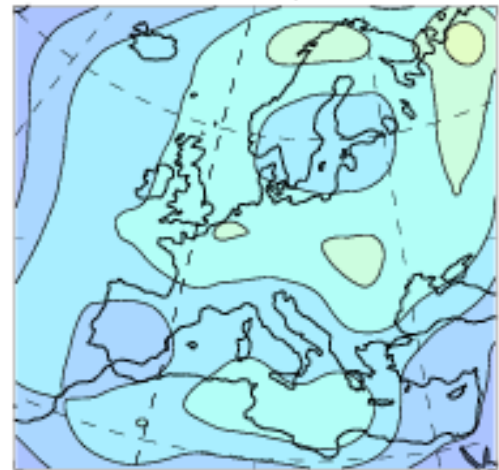


Fig. 2.2.2 ERA40RCM anticyclone tracks, track density, genesis density, lysis density and relative vorticity on 850 hPa intensity, JJA 1961–2000. The units are tracks per month per 10^6 km^2 (track density), anticyclones per month per 10^6 km^2 (genesis and lysis density) and s^{-1} (intensity)..