Discrepancies between different northern hemisphere summer atmospheric data products

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Abstract.

Northern hemisphere summer (July/August) data from the NCAR/NCEP and ERA-40 reanalyses are compared with each other and with Trenberth's sea level pressure (SLP) data set. We find discrepancies in SLP and 500 hPa height that are mostly confined to a band connecting North Africa and Asia. In the NCAR/NCEP reanalysis, there is a negative offset in SLP over North Africa and Asia prior to the late 1960's, together with a similar problem in 500 hPa height, and in Trenberth's data there is a negative offset in SLP over Asia prior to the early 1990's. Both these offsets magnify the linear trend from 1958 to 2002 over North Africa and Asia in the NCAR/NCEP and Trenberth data sets. On the other hand, the interannual variability in the three data sets is highly correlated during the periods between these offsets. Compared to SLP and 500 hPa height, there is a more extensive area of discrepancy in 2 m temperature that extends eastwards from North Africa across the subtropics into the Pacific, with an additional area of discrepancy over the Arctic and parts of the American continent. At 500 hPa and 100 hPa, the biggest differences in the temperature time series are found in the tropics, with a marked jump being evident in the late 1970's in the NCAR/NCEP, but not in the ERA-40 reanalysis, that is almost certainly associated with the introduction of satellite data. On the other hand, all three data sets agree well over Europe. The summer NAO, defined here as the first EOF of summer mean SLP over the Euro-Atlantic sector, agrees well between the different data sets. The results indicate that the upward trend in the summer NAO index in the 1960's is part of a longer period interdecadal cycle, with relatively high index values also being found during the 1930's. The running cross-correlation between the Central England Temperature record and the summer NAO shows a strong correlation throughout the last half of the 20th century, but much reduced correlation in the early part of the 20th century. It is not clear whether the change in correlation is real, or a data artifact, a topic that requires further research.

1. Introduction

Summer 2003 was exceptionally hot and dry in Europe, resulting in excess of 20,000 heat-related deaths and over US$10 billion of agricultural losses (Parker et al., 2004). At Paris, France, temperatures exceeded $35°C$ on 10 consecutive days in early August, and the UK recorded its highest-ever daily maximum temperature of $38.5°C$ on August 10 (Levinson and Waple, 2004). In Germany, it was the hottest summer since 1901 and in Switzerland, summer 2003 is believed to have been the hottest since 1540 (Beniston, 2004). Beniston (2004) notes the similarity between summer 2003 and model projections under increasing greenhouse gas forcing of summer conditions in Europe for the latter part of the 21st century.

While summer 2003 was clearly exceptional, many aspects of summer 2003 are consistent with recent trends in the atmospheric circulation over Europe during summer (e.g. Pal et al., 2004). Hurrell and Folland (2002) noted a shift towards more anticyclonic conditions over Europe during high summer that took place during the late 1960's. Associated with this shift, these authors note a warming trend in mean Central England surface air Temperature (CET, Manley, 1974; Parker et al. 1992), and a roughly 15% reduction in summer precipitation over much of northern Europe since the late 1960's compared to the previous 20 years (see also Pal et al., 2004). Hurrell and Folland (2002) relate these changes to a northward shift in the storm track over the North Atlantic Ocean and northern Europe that took place during the late 1960's. The shift in the storm track appears to be connected to an upward shift in the summer North Atlantic Oscillation (NAO) index that also took place during the late 1960's (Hurrell and Folland, 2002). The well-documented Sahelian drought also began during the 1960's (Folland et al. 1986; Ward, 1998), and Hurrell and Folland(2002) speculate that the regime shift over Europe may be connected with the onset of the drought. Some authors have related the drought to an upward trend in sea surface temperature (SST) in the tropical oceans, especially the Indian Ocean (Giannini et al. 2003; Bader and Latif 2003). Tropical SST trends have also been implicated in recent trends in the northern hemisphere winter atmospheric circulation (Hoerling et al., 2001; Lu et al., 2004). In addition, Chelliah and Bell (2004) have noted the close connection between what they call the "tropical multidecadal mode" and trends during the last half of the 20th century not only in the tropics, but also in the northern hemisphere extratropics in both the boreal winter and summer seasons.

Our original motivation for the work presented here was to try and determine the cause of the recent trend in the northern hemisphere summer circulation, following the approach used by Lu et al. (2004) to study the winter circulation trend; that is, using global, daily mean data to compute the forcing for a simple dynamical model, and then to use the model to determine the source of the trend. However, it soon became apparent that there are significant discrepancies between different data products (e.g. the NCAR/NCEP and ERA-40 reanalyses) for northern hemisphere summer, thereby casting doubt on the usefulness of these products for model diagnostics. Chelliah and Ropelewski (2000) claim that linear trend analyses applied to reanalysis products have limited usefulness as tools to detect climate change, except when the signal is large and shows consistency among all datasets. As we show in Section 3, there are differences in the linear trend 1958-2002 during boreal summer between the different data sets, especially over North Africa and Asia. Yang et al. (2002) have noted a discrepancy over eastern Asia between the NCAR/NCEP reanalysis and Trenberth's sea level pressure data set that is consistent with our findings (the details on the different data sets are given in Section 2), an issue that has been explored further by Inoue and Matsumoto (2004). Inoue and Matsumoto point to a specific problem with the NCAR/NCEP reanalysis prior to the late 1960's. Here we show that the problem over Asia noted by Inoue and Matsumoto is connected with a similar problem over North Africa, and in a band connecting the two regions. Problems with the data products over North Africa are particularly unfortunate given the possible connection between the drought in the Sahel region of Africa, and the recent, decadal trends over Europe (Hurrell and Folland, 2002).

In Section 3, the linear trend in some basic variables such as SLP, geopotential height, and air temperature are compared. In section 4 the summer NAO index is computed and compared in the different data sets, and a sliding window correlation between the NAO index and the CET time series is examined. Section 5 provides a summary and conclusions.

2. The data

The data used here come from three different main sources: the NCAR/NCEP reanalysis (e.g. Kistler et al., 2001), the ECMWF reanalysis (ERA-40; http://data.ecmwf.int/data) and Trenberth's SLP data set (Trenberth and Piolini, 1980; http://dss.ucar.edu/datasets/ds010.1/). The latter is included for comparison purposes (while recognising the much more comprehensive nature of the reanalysis products). The NCAR/NCEP and ERA-40 reanalyses have global coverage and a grid resolution of $2.5° \times 2.5°$, the NCAR/NCEP data covering the period from 1948 to 2003, the ERA-40 data from 1958 to 2002. Trenberth's SLP data cover the region north of $12.5° N$ at a grid resolution of $5° \times 5°$ from 1901 to 2003. For all data sets, the months of July and August are averaged to represent the summer climate. We concentrate on July and August since these are the boreal summer months that show particularly enhanced warmth during the 15 year period 1989-2003 in the CET record (see Figure 8b in Parker et al., 2004), although the results we show are not greatly changed by including June. CET is taken from the Hadley Center archive in the UK (http://www.met-office.gov.uk/research/hadleycentre/CR-data/Monthly/HadleyCET-act.txt). The CET is a reliable, quality-controlled temperature record that extends back several centuries.

3. The multi-decadal trend

Figures 1a,b,c show the linear trend over the time period 1958-2002 in mean SLP for July and August (hereafter the summer) computed from each of the three data sets. We choose 1958-2002 since this is the period for which the data from all three data sets overlap. There are three regions that stand out: the Euro-Atlantic sector (particularly the centre of action over Greenland), the Asian continent, and North Africa. As we shall see in Section 4, the trend in the Euro-Atlantic sector reflects the upward trend in the summer NAO index and is in general agreement with the upward transition in the summer NAO index noted by Hurrell and Folland (2002). However, there are some differences between the different data sets over Asia and Africa. For example, all three data sets show an upward trend in SLP over Asia, but the magnitude and location of the maximum trend varies from data set to data set. Likewise, there is a pronounced upward trend in SLP over North Africa in the NCAR/NCEP reanalysis that is less pronounced in the other data sets.

Figures 1d,f show the time series of summer mean SLP averaged within the green boxes over North Africa and central Asia shown in the upper panels, and Fig. 1e shows the time series of summer mean SLP over Central England. Over Central England, all three data sets show very close agreement (the three curves are almost indistinguishable), no doubt reflecting the very good data coverage in this area. Over North Africa on the other hand (Fig. 1d), there is a clear offset in the NCAR/NCEP reanalysis from the other data sets up until the late 1960's, at which time there is a sudden upward jump in the NCAR/NCEP time series that brings it into line with the other time series. It is clear that it is the early, negative offset in the SLP time series over North Africa that explains the pronounced trend over this area in Fig 1a, but not in Figs. 1b,c. In Fig. 1f, there is also the indication of a similar problem with the NCAR/NCEP reanalysis over Asia, a suggestion that is supported by overlapping the two time series in Fig. 2. Indeed, by comparing different data products with local station data, Inoue and Matsumoto (2004) conclude that the

NCAR/NCEP reanalysis has a problem over Asia prior to the late 1960's (a problem that is also evident in boreal winter; Yang et al., 2002). After the upward jump in the late 1960's, the NCAR/NCEP and ERA-40 time series show generally good agreement over both North Africa and Asia, although there is the suggestion of a further upward offset in the NCAR/NCEP time series that begins in the mid-1970's. By comparison, the time series from Trenberth's data shows a downward offset over Asia (Fig. 1f) prior to the early 1990's that clearly dominates the trend in this data set over Asia shown in Fig. 1c. Sudden jumps in the late 1960's in difference fields between the ERA-40 and NCAR/NCEP reanalyses have been noted previously by Sterl (2004). Sterl suggests that these jumps could arise from the use of different data streams in the two reanalyses. He notes that the ERA-40 reanalysis was conducted later than the NCAR/NCEP reanalysis, and that new data sets were used in the former. Sudden jumps in difference fields between the two reanalysis products during the 1970's could also be related to the introduction of satellite data (Sturaro, 2003; Sterl, 2004).

The general impression from the time series plotted in Fig. 1d,e,f is that apart from the discrepancies noted above, the interannual variability often agrees well between the different data sets. We can check this by computing correlations between the various time series, the results of which are shown in Table 1. All of the correlations shown are significantly different from zero at the 1% level. After 1967, the NCAR/NCEP and ERA-40 reanalyses are particularly highly correlated, with a correlation coefficient of 0.9 over North Africa and 0.8 over Asia. The correlations with Trenberth's data are also in the 0.7 to 0.8 range over Asia, but it is clear that Trenberth's data agrees less well with both NCAR/NCEP and ERA-40 over North Africa.

Next, we turn to 500 hPa geopotential height (HGT500). Fig. 3a,b show the linear trend in the NCAR/NCEP and ERA-40 reanalyses, respectively, again for the period 1958-2002 and for summer (July/August) mean values. Once again, the two spatial patterns generally agree with each other over the Euro-Atlantic sector. In particular, both show a lowering trend in HGT500 over Greenland and north of Norway that can be related to the downward trend in SLP noted in Fig. 1 over Greenland. However, while the centres of action appear in similar places over Asia, there is a much more pronounced trend over Asia in the NCAR/NCEP than in the ERA-40 data set. The bottom panels show the time series over North Africa, Central England and Asia, the values for Africa and Asia being averaged over the green boxes shown in the upper panels. (Note that the two panels are not exactly the same as in Fig. 1 because the spatial patterns, although roughly barotropic, slightly shift their locations with altitude.) Again, we find very good agreement over Central England, but we find a big departure between the data sets over Asia during the 1960's. In fact, the time series of HGT500 from the NCAR/NCEP reanalysis over Asia shows the same "dip" as the corresponding SLP time series in the early 1960's (Fig. 1f), suggesting that the problem in the 1960's is part of the same problem we encountered earlier with the NCAR/NCEP data set. Interestingly, after the mid-1970's, the two time series over Asia become almost identical (see also Table 2). Over North Africa, the discrepancy between the two data sets seems less severe at 500 hPa than in SLP, although a similar (if less severe) negative offset exists in the NCAR/NCEP reanalysis prior to 1970 to that found over Asia. One other point to note is that before 1977, there is the suggestion of the opposite trend in the ERA-40 data over Asia compared to the NCAR/NCEP data (Fig. 3c), which explains the difference between Figs. 3a,b over Asia.

The linear trend in summer 2 m air temperature (2mT), also between 1958 and 2002, is shown in Fig. 4a,b. There is a warming trend of 0.02 K/year over Central England that is found in both the NCAR/NCEP and ERA-40 reanalyses (see also Fig. 4d). This compares with a warming trend of 0.04 K/year in the CET time series over the same time period (the reduced magnitude in the reanalyses is probably because in the reanalyses, the temperature is averaged over a 2.5° grid box). Looking at the time series in Fig. 4c, we see the same "dip" over North Africa that we noted in the SLP time series (Fig. 1d), suggesting that it arises from the same cause, and over Asia, there is a notable offset between the two data products. Looking at Table 2, we see that the correlation between the two time series is higher over North Africa than over Asia during the period 1967-2002. Both data sets also show a marked upward trend in temperature within the African green box.

So far we have seen that there are discrepancies between the two data sets over North Africa and Asia. To appreciate the true spatial extent of the discrepancies, Fig. 5 shows the (undetrended) correlation between the different data sets, and for different fields, during the time periods the data sets overlap (so, when comparing either NCAR/NCEP or Trenberth's data with ERA-40, the time period is 1958-2002; for NCAR/NCEP and Trenberth's data, the time period is 1948-2003). Comparing the NCAR/NCEP and ERA-40 reanalyses, we see from Fig. 4a,b that Asia and North Africa are indeed regions of low correlation (the 10% significance level is about 0.3). Furthermore, there is a region of reduced correlation that connects these two regions, suggesting that the problem with the NCAR/NCEP reanalysis noted by Inoue and Matsumoto (2004) is not confined to Asia, but in fact extends in a band connecting Asia and North Africa. There is also the suggestion of reduced correlation in SLP over western North America that may be due to the Rocky Mountains and the extrapolation technique used to compute SLP. In 2mT the discrepancies spread more widely across North Africa, southern Asia and into the Pacific Ocean, and there is also a region of reduced correlation over the Arctic and parts of the American continent. Comparing Trenberth's SLP with the other two SLP data sets (Fig. 5d,e), North Africa and Asia again stand out, and also the western part of North America, as in Fig. 5a.

Finally, we turn to the temperature at 500 hPa and 100 hPa as revealed by the NCAR/NCEP and ERA-40 reanalyses. Looking at the trend in the two data sets (Fig. 6a,b), there are clearly many features in common at 500 hPa, notably a region of cooling that extends from Africa to Asia, and regions of warming over the British Isles and over North America, although there are also differences in detail between the two data sets. At 100 hPa, the NCAR/NCEP reanalysis (Fig. 6c) shows a strong warming trend in the tropics that is not found in the ERA-40 data (Fig. 6d), even though both data sets show a cooling trend over middle and high latitudes. Looking at the correlation between the two time series (Fig. 6e,f), we again find much better agreement at middle latitudes than in the tropics. It turns out that at 500 hPa, there are significant differences between the data sets in different locations in the tropics and subtropics, but when averaged around the globe, the two data sets agree quite well (see Fig. 7a). This is not true at 100 hPa, however, where the averaged temperature in the NCAR/NCEP reanalysis shows a strong upward shift in the late 1970's (Fig. 7b). We speculate that this is due to the introduction of satellite data (Sturaro, 2003).

4. Summer NAO

The NAO is the most important mode of variability (monthly time scales and longer) in the atmospheric circulation over the Euro-Atlantic sector (see Hurrell et al., 2003; Greatbatch 2000), and is the only teleconnection pattern that persists throughout the year in the northern hemisphere (Barnston and Livesey, 1987). The NAO is weaker in summer than in winter, but nevertheless contributes more than 20% of the variance in summer seasonal mean SLP over the Euro-Atlantic sector according to Hurrell et al. (2003). The trend since the 1960's towards increased anticyclonicity over Europe was noted earlier (Hurrell and Folland, 2002; Rodwell et al. 2002, 2003) and is associated with an upward transition of the summer NAO index that occurred during the 1960s. In this section the summer NAO pattern and index are computed and compared using the different data sets.

Fig. 8 shows the spatial patterns associated with the leading EOF and the corresponding Principal Component (PC) time series (defined here to be the NAO indices) for the NCAR/NCEP and ERA-40 reanalyses and Trenberth's SLP data set, and computed from SLP averaged over July and August in each year. In order to avoid using data over North Africa (and so avoid the problems noted in Section 3), the EOF's are computed over the domain $40°N$ - $70°N$ and $90°W$ - $30°E$, instead of $20°N$ - $70°N$ and $90°W$ - $40°E$ as in Hurrell et al. (2003). In each case, the EOF's are computed using the whole time series of available data (NCAR/NCEP: 1948 - 2003; ERA-40: 1958 - 2002; Trenberth: 1901 - 2003). Despite the different lengths of the data sets, the spatial patterns are very similar in all three cases, and, during the time of overlap, the PC time series are also almost identical (correlation of 0.95 in all cases, exceeding the 1 % significant level). The percentage of variance accounted for in each data set is also similar (33%, 28%, and 30% for NCAR/NCEP, ERA-40 and Trenberth's data, respectively. The corresponding percentages for the second EOF are 21%, 21% and 19%, respectively). The time series confirm the upward transition of the NAO index during the 1960's, but the longer record available in Trenberth's data set shows that the upward trend in the 1960's is really part of a multidecadal vacillation, with relatively high values of the index also being found during the 1930's. Fig. 9 shows the time series of CET averaged over July and August, the July/August NAO index computed using Trenberth's data, and the sliding window (of 19 years width) cross-correlation between the two time series. After about 1950, the NAO is accounting for about 60% or more of the variance in CET (correlation around 0.8 which is significantly different from zero at the 1% level), with positive NAO summers being associated with warmer than normal summers. This is not unexpected given that the positive phase of the NAO is associated with a high pressure anomaly over the British Isles. However, during the first half of the century the correlation is somewhat lower, and specifically for the 19 years centred around 1920, the correlation drops to zero. The (interannual) correlation between summer mean SLP and the CET record over the period 1912 to 1930, centered around 1920, is shown in Fig. 9c. The resulting pattern, while different from the NAO pattern

(Fig. 8c), is, nevertheless consistent with warm summer weather, and hence with the CET time series, since it is associated with anomalous southerly winds over the UK during anomalously warm summers. Nevertheless, it is not clear if the change in the relationship between the NAO and CET during the early part of the 20th century is real, a topic that remains for future research.

5. Conclusions

The exceptional summer of 2003 in Europe (Beniston, 2004) has raised interest in the summer season, especially since recent trends during the northern hemisphere summer are consistent with model projections under increasing greenhouse gas concentration in the atmosphere (Pal et al., 2004). Here we have documented some discrepancies between the trend in northern hemisphere summer (defined as July and August) as seen in a number of different variables in three different data sets; in particular sea level pressure (SLP), 500 hPa height, and temperature at 2 m, 500 hPa and 100 hPa in the NCAR/NCEP and ERA-40 reanalyses and Trenberth's SLP data set. Over the last 50 years, the NCAR/NCEP reanalysis shows an upward trend in SLP over North Africa, and all three data sets show an upward trend in SLP over Asia, and Europe, although over Asia the trend is larger for the NCAR/NCEP and Trenberth data sets. In the NCAR/NCEP reanalysis, the difference is accounted for by a negative offset of about 5-10 hPa (about 5-10 times larger than the magnitude of the interannual variability) over North Africa prior to the late 1960's, and also a similar problem at the same time over Asia that had been noted earlier by Yang et al. (2002) and Inoue and Matsumoto (2004). In Trenberth's SLP data there is an downward offset of about 5 hPa prior to 1994 over Asia that magnifies the trend in that data set. On the other hand, the interannual variability in the three data sets is highly correlated during the periods between these offsets. The problem with SLP in the NCAR/NCEP reanalysis prior to the late 1960's is also evident in 500 hPa height, especially over Asia. The discrepancies in SLP and 500 hPa height between the different data sets are confined mostly to a band between North Africa and Asia, but in 2 m temperature, there is a more extensive area of discrepancy extending eastwards from North Africa across the subtropics into the Pacific, with an additional area of discrepancy over the Arctic and parts of the American continent. On the other hand, there is strong agreement between the different data sets over Europe, both reanalyses indicating the same warming trend. At 500 hPa and 100 hPa, the biggest differences are found in the tropics. In particular, the NCAR/NCEP reanalysis shows an upward trend in the tropics at 100 hPa that is related to a strong upward jump in the late 1970's. The latter is almost certainly associated with the introduction of satellite data (Sturaro, 2003; Sterl, 2004).

At 500 hPa, both reanalyses show an upward trend in geopotential height over the British Isles and a corresponding downward trend over Greenland and the Arctic (Fig. 3). A downward trend is also found in SLP over Greenland in all three data sets, and a weaker upward trend over Europe. These changes in 500 hPa height and SLP are connected to an upward trend in the summer NAO index. (The spatial pattern of the trend shown in Fig. 3 projects strongly on to the pattern obtained by regressing 500 hPa height against the detrended summer NAO index shown in Fig. 8.) The NAO index was computed for all three data sets as the principal component time series associated with the first EOF in summer mean SLP over the Euro-Atlantic sector (the exact region used to compute the EOF is given in Section 4). The spatial pattern of SLP associated with the summer NAO, its time series, and the percentage of variance explained (about 30%) show excellent agreement between the three data sets. The running cross-correlation between the Central England Temperature record and the summer NAO shows a significant correlation (approaching 0.8 and significantly different from zero at the 1 % level) throughout the last half of the 20th century, but much reduced correlation in the early part of the 20th century. It is not clear whether the change in correlation is real, or a data artifact, a topic that requires further research.

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Figure Captions:

Figure 1: The upper panels show the linear trend in SLP (hPa/yr) over the period 1958-2002 in (a) the NCEP reanalysis, (b) the ERA-40 reanalysis, and (c) Trenberth's SLP data set. The lower panels show the time series of area-mean SLP over Africa and Asia ((d) and (f), respectively) within the enframed areas in the top panels, and for the different data sets. Fig. 1e shows the corresponding time series for Central England.

Figure 2: The time series of SLP in the NCEP reanalysis over Africa and Asia taken from Fig. 1.

Figure 3: Same as Fig. 1 except for 500 hPa geopotential height (gpm/yr), and for the NCEP and ERA-40 reanalyses only.

Figure 4: Same as Fig.3 except for 2 meter temperature (K/yr).

Figure 5: The (undetrended) interannual correlation between the different data sets during periods when each pair have overlapping availability (see text for details). Upper panels are for the NCEP and ERA-40 reanalyses (a) SLP, (b) 500 hPa geopotential height, and (c) 2 meter temperature. The lower panels are for Trenberth's data set compared with (d) the NCEP and (e) the ERA-40 reanalysis.

Figure 6: The upper panels show the linear trend in 500 hPa temperature (K/yr), 1958-2002, using (a) the NCEP and (b) the ERA-40 reanalyses. (c) and (d) show the corresponding linear trends at 100 hPa. (e) and (f) show the (undetrended) interannual correlation between the two data sets over the same time period, (e) for 500 hPa temperature and (f) for 100 hPa temperature.

Figure 7: (a) The average for the entire latitude band from $17.5°N$ to the equator for 500 hPa temperature, and (b) for 100 hPa temperature.

Figure 8: The upper panels show the spatial pattern obtained by regressing the respective NAO indices against the summer mean SLP for (a) the NCEP reanalysis, (b) the ERA-40 reanalysis, and (c) Trenberth's data set. Negative contours are

dashed and the zero and positive contours are solid. The contour interval is 5 hPa. The lower panel (d) shows the corresponding NAO indices (NCEP: dashed; ERA-40: solid; Trenberth: dot-dash).

Figure 9: (a) shows the time series of summer mean Central England Temperature (CET) (solid line) and NAO index (dashed line) from Trenberth's data set. (b) is the sliding window (19 years width) cross-correlation between the two time series in (a). (c) is the (interannual) correlation between summer mean SLP and CET over the 19 years centered at 1921. Dashed contours indicate negative correlations, solid contours the zero line and positive correlations. The contour interval is 0.15 and the 5% significance level is 0.45, indicating correlations significantly different from zero at the 5% level near the regions of maximum positive and negative correlation.

Table Captions:

Table 1. Correlation between the summer mean time series of interannually varying SLP from the different data sets over Asia and North Africa for the time periods shown.

Table 2. As Table 1, but for 500 hPa height and 2 m temperature.

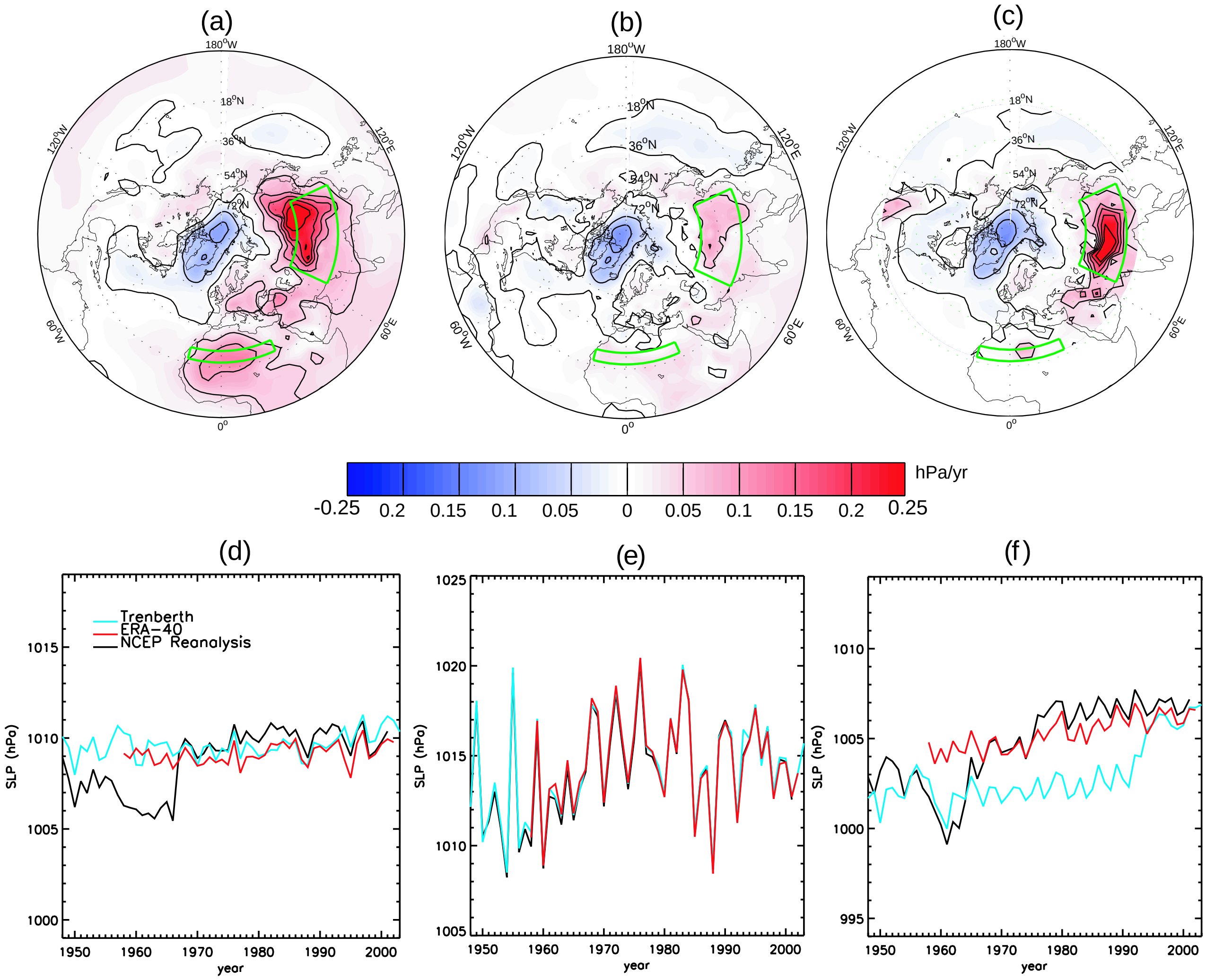

Fig. 1: The upper panels show the linear trend in SLP (hPa/yr) over the period 1958-2002 in (a) the NCEP reanalysis, (b) the ERA-40 reanalysis, and (c) Trenberth's SLP data set. The lower panels show the time series of area-mean SLP over Africa and Asia ((d) and (f), respectively) within the enframed areas in the top panels, and for the different data sets. Fig. 1e shows the corresponding time series for Central England.

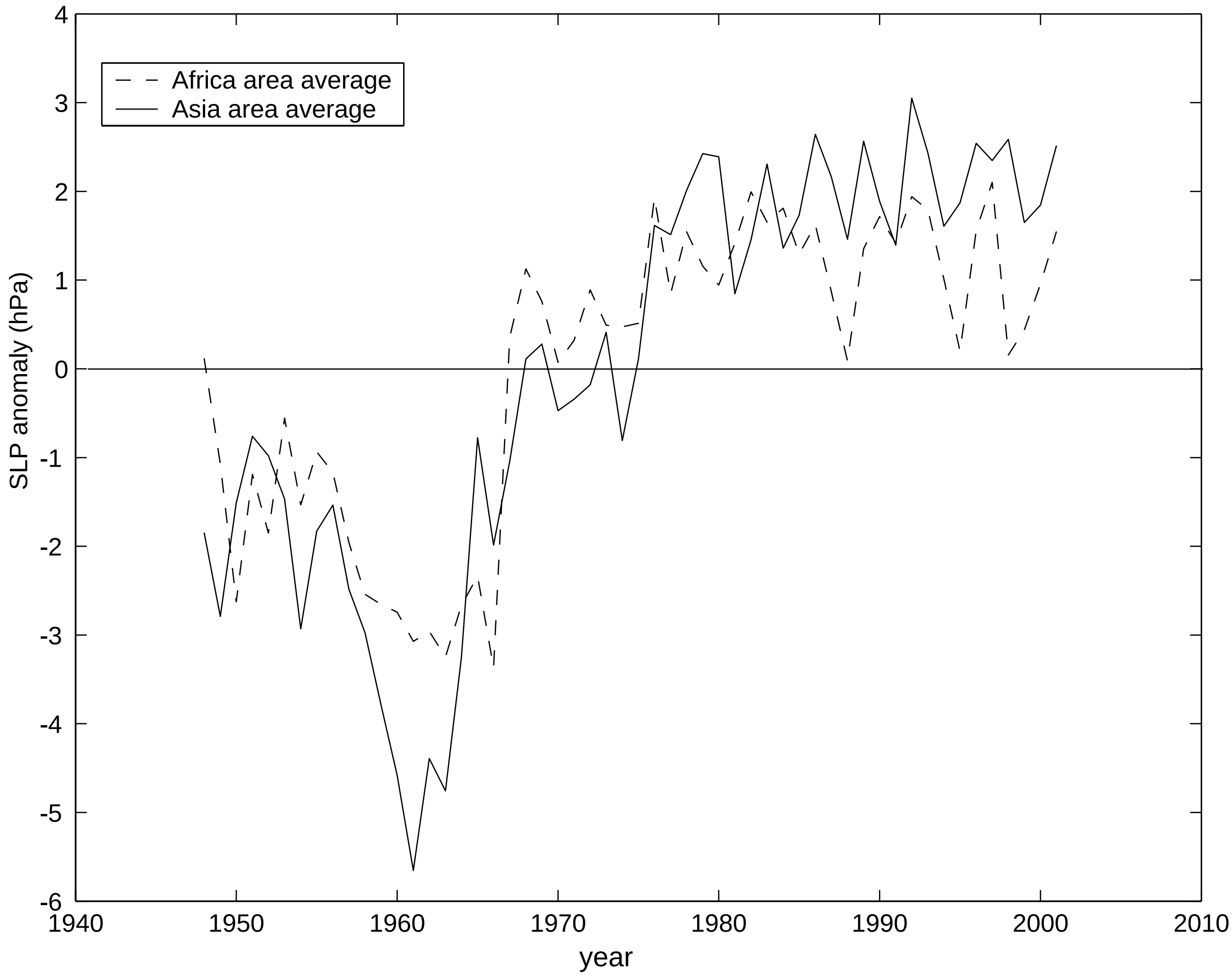

Fig. 2: The time series of SLP in the NCEP reanalysis over Africa and Asia taken from Fig. 1.

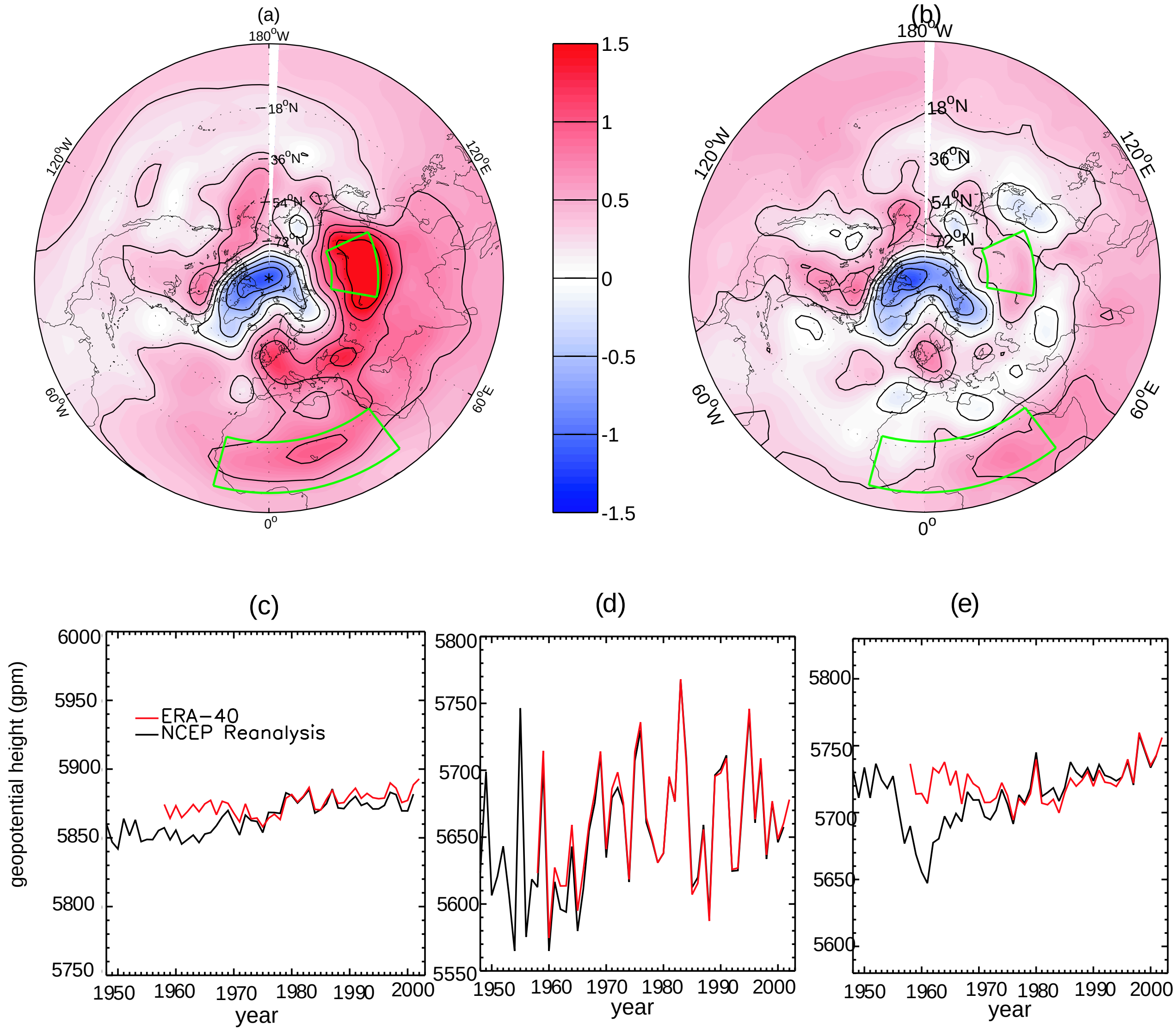

Fig. 3: Same as Fig. 1 except for 500 hPa geopotential height (gpm/yr), and for the NCEP and ERA-40 reanalyses only.

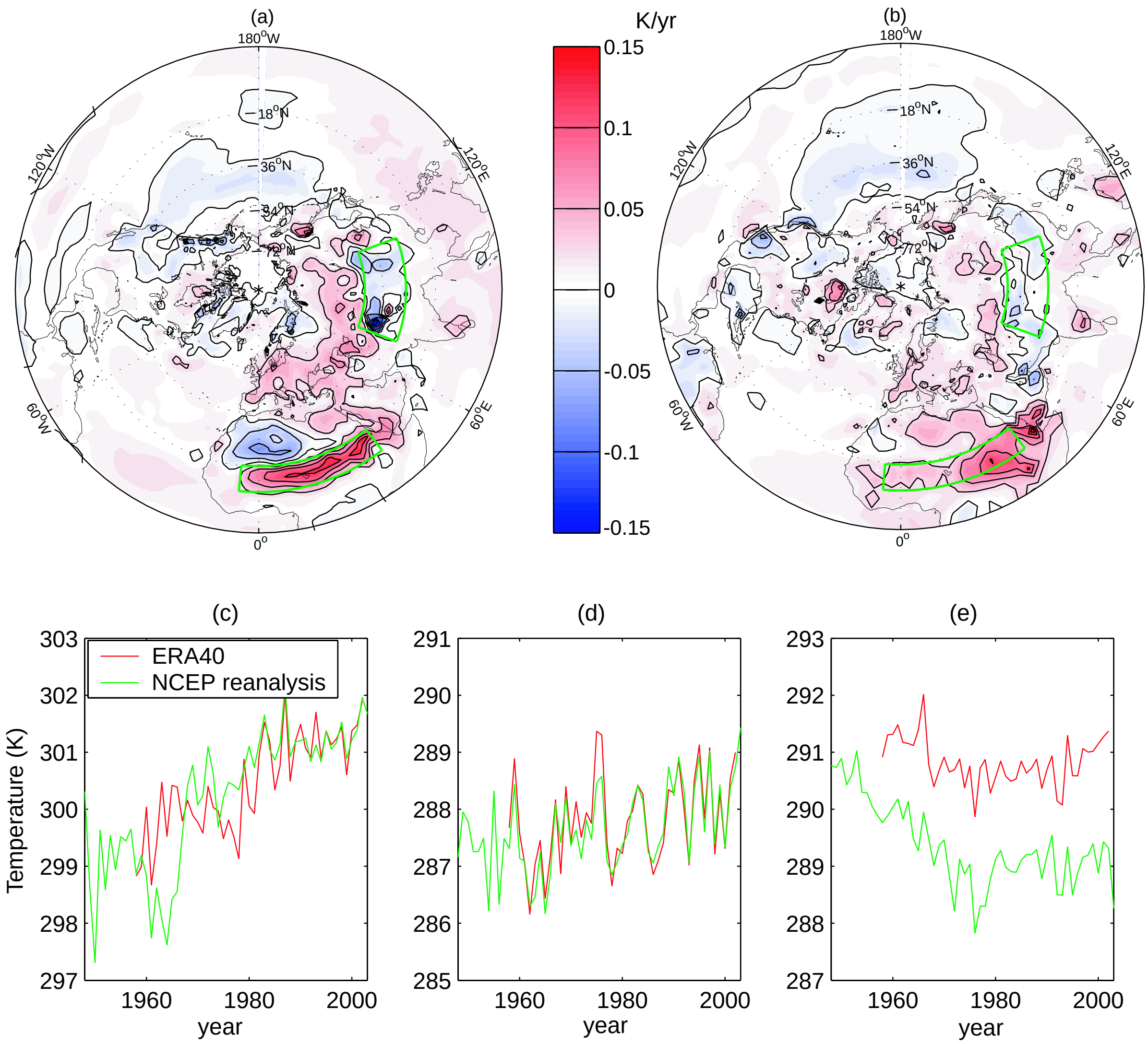

Fig. 4: Same as Fig.3 except for 2 meter temperature (K/yr).

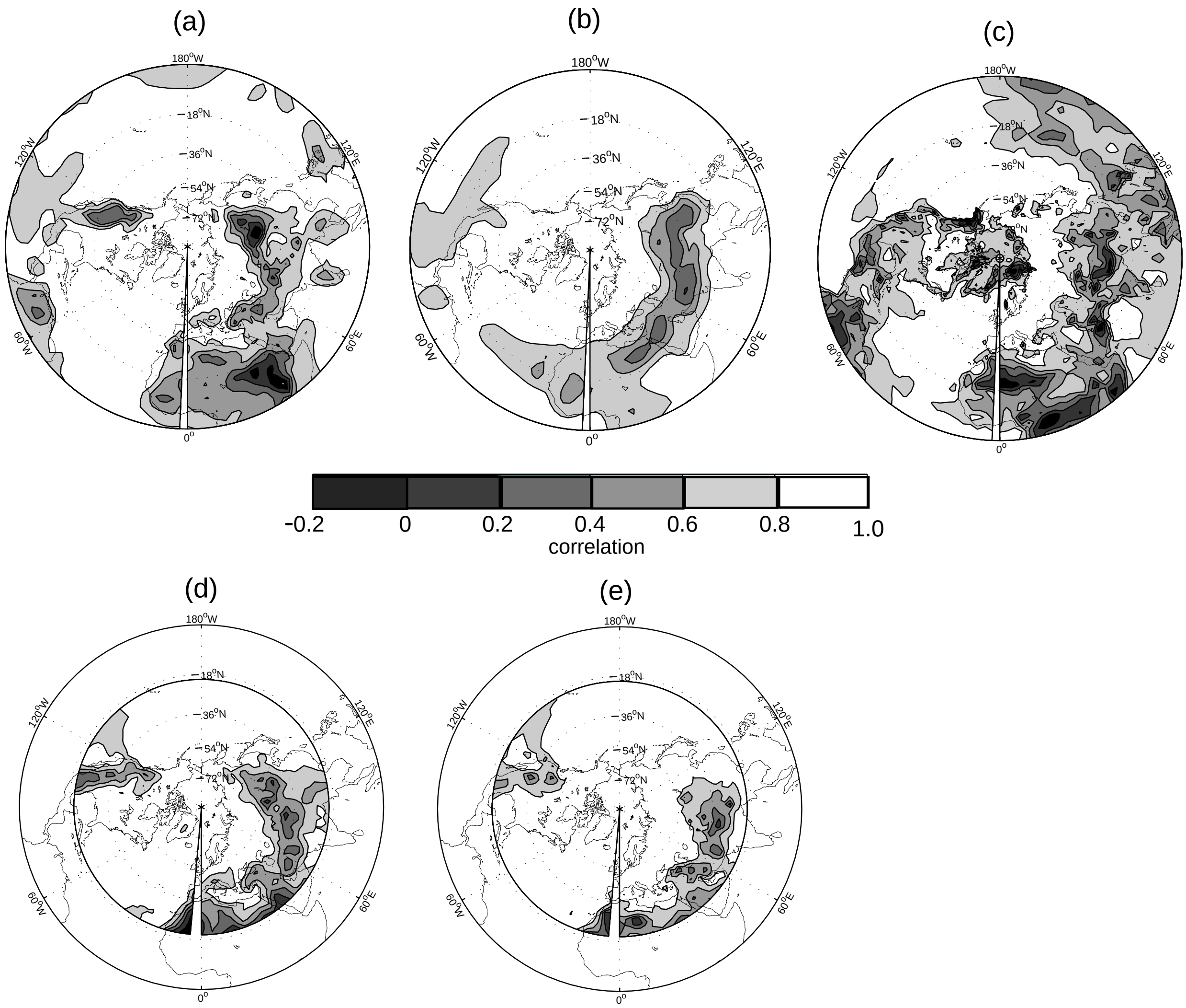

Fig. 5: The (undetrended) interannual correlation between the different data sets during periods when each pair have overlapping availability (see text for details). Upper panels are for the NCEP and ERA-40 reanalyses for (a) SLP, (b) 500 hPa geopotential height, and (c) 2 meter temperature. The lower panels are for Trenberth's data set compared with (d) the NCEP and (e) the ERA-40 reanalysis.

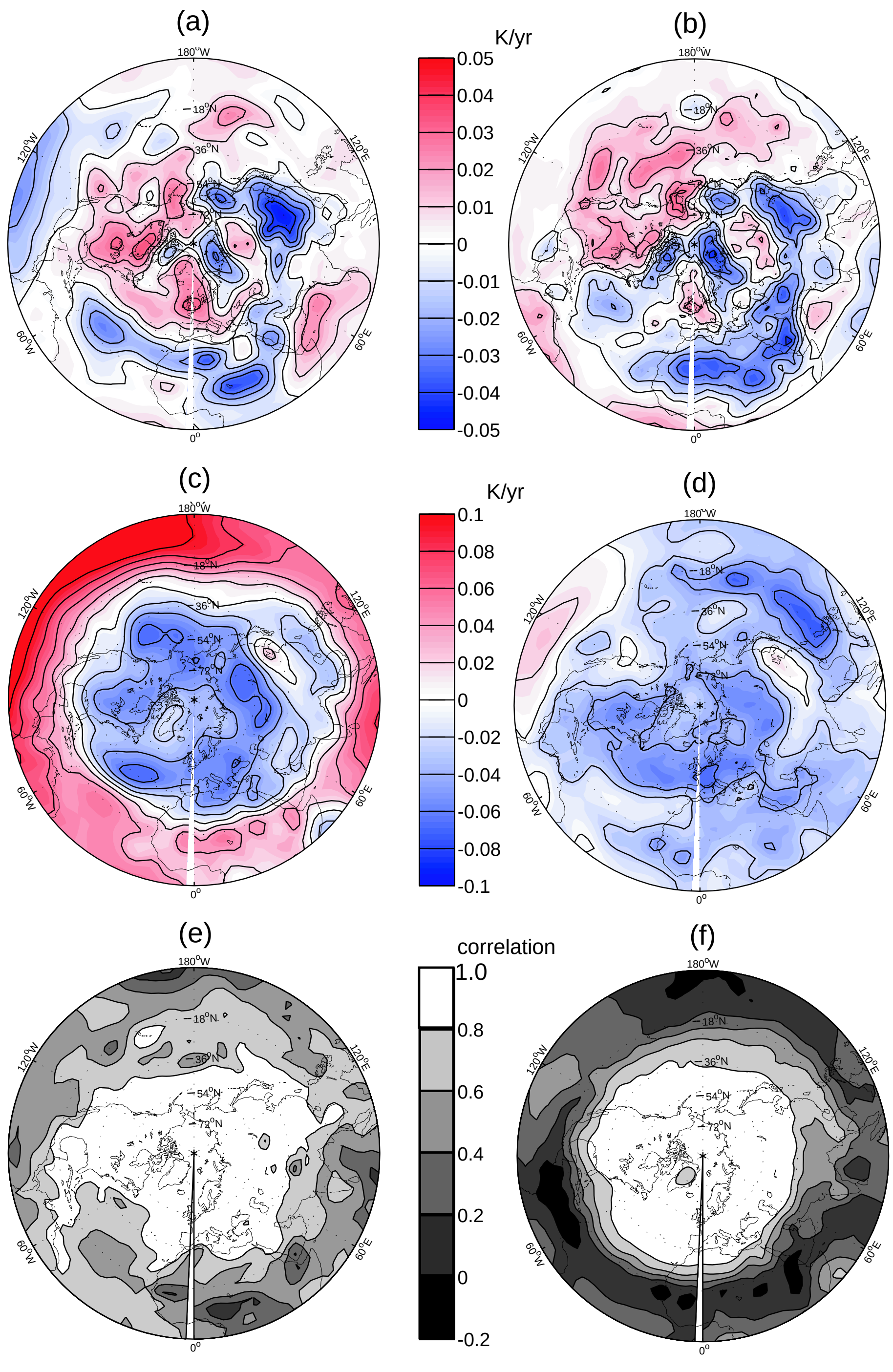

Fig. 6: The upper panels show the linear trend in 500 hPa temperature (K/yr), 1958-2002, using (a) the NCEP and (b) the ERA-40 reanalyses. (c) and (d) show the corresponding linear trends at 100 hPa. (e) and (f) show the (undetrended) interannual correlation between the two data sets over the same time period, (e) for 500 hPa temperature and (f) for 100 hPa temperature.

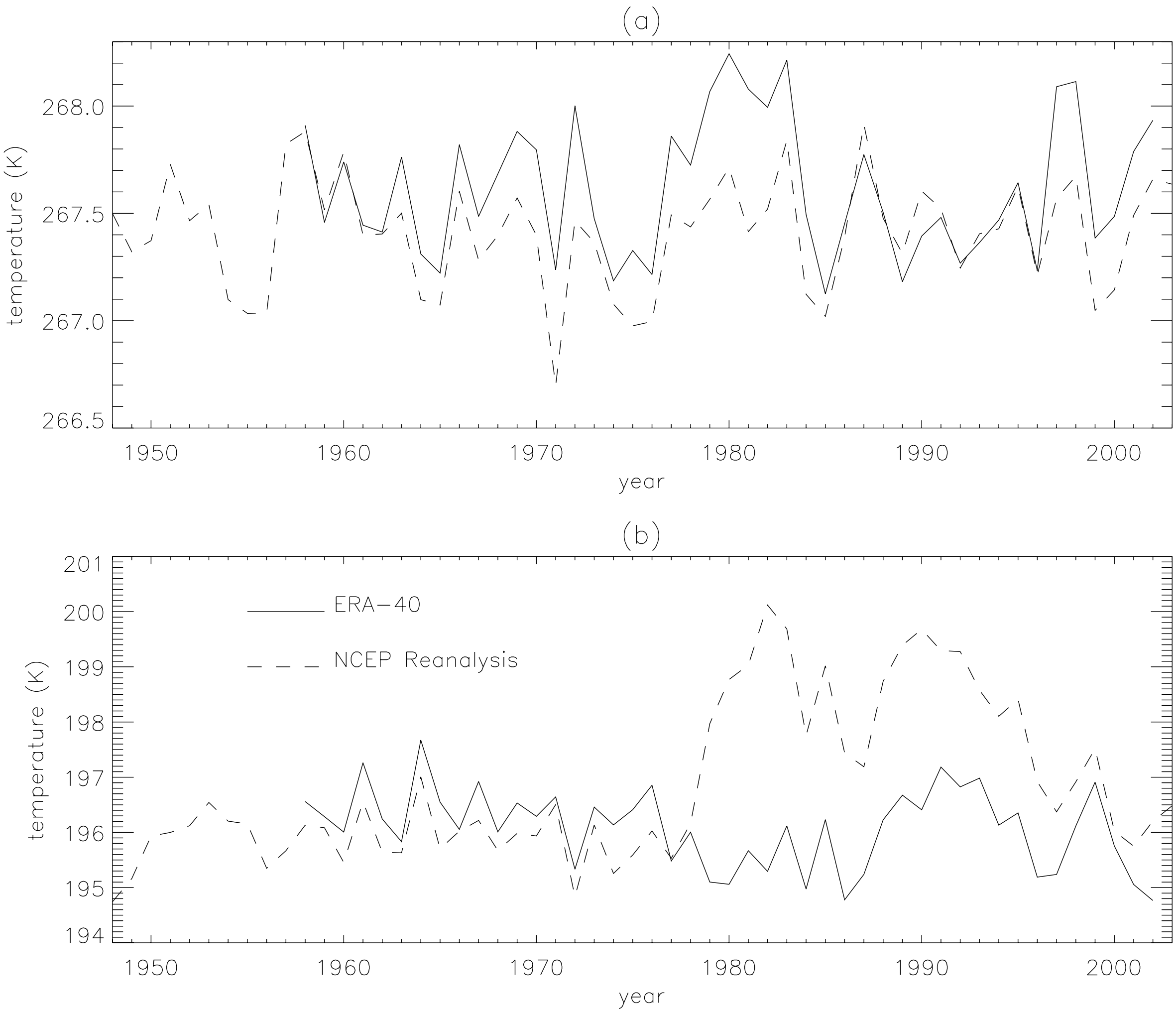

Fig. 7: (a) The average for the entire latitude band from 17.5°*N to the equator for 500 hPa temperature, and (b) for 100 hPa temperature.*

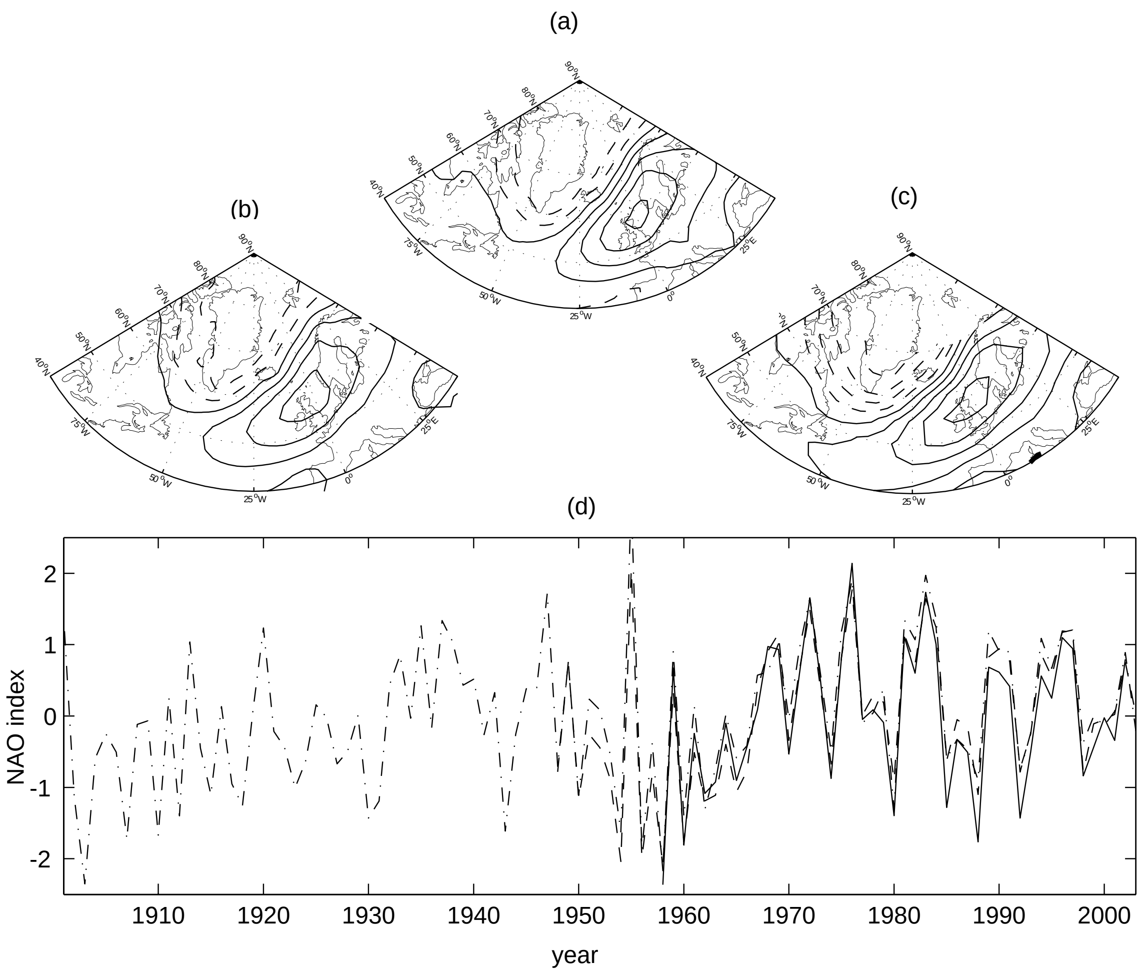

Fig. 8: The upper panels show the spatial pattern obtained by regressing the respective NAO indices against the summer mean SLP for (a) the NCEP reanalysis, (b) the ERA-40 reanalysis, and (c) Trenberth's data set. Negative contours are dashed and the zero and positive contours are solid. The contour interval is 5 hPa. The lower panel (d) shows the corresponding NAO indices (NCEP: dashed; ERA-40: solid; Trenberth: dot-dash).

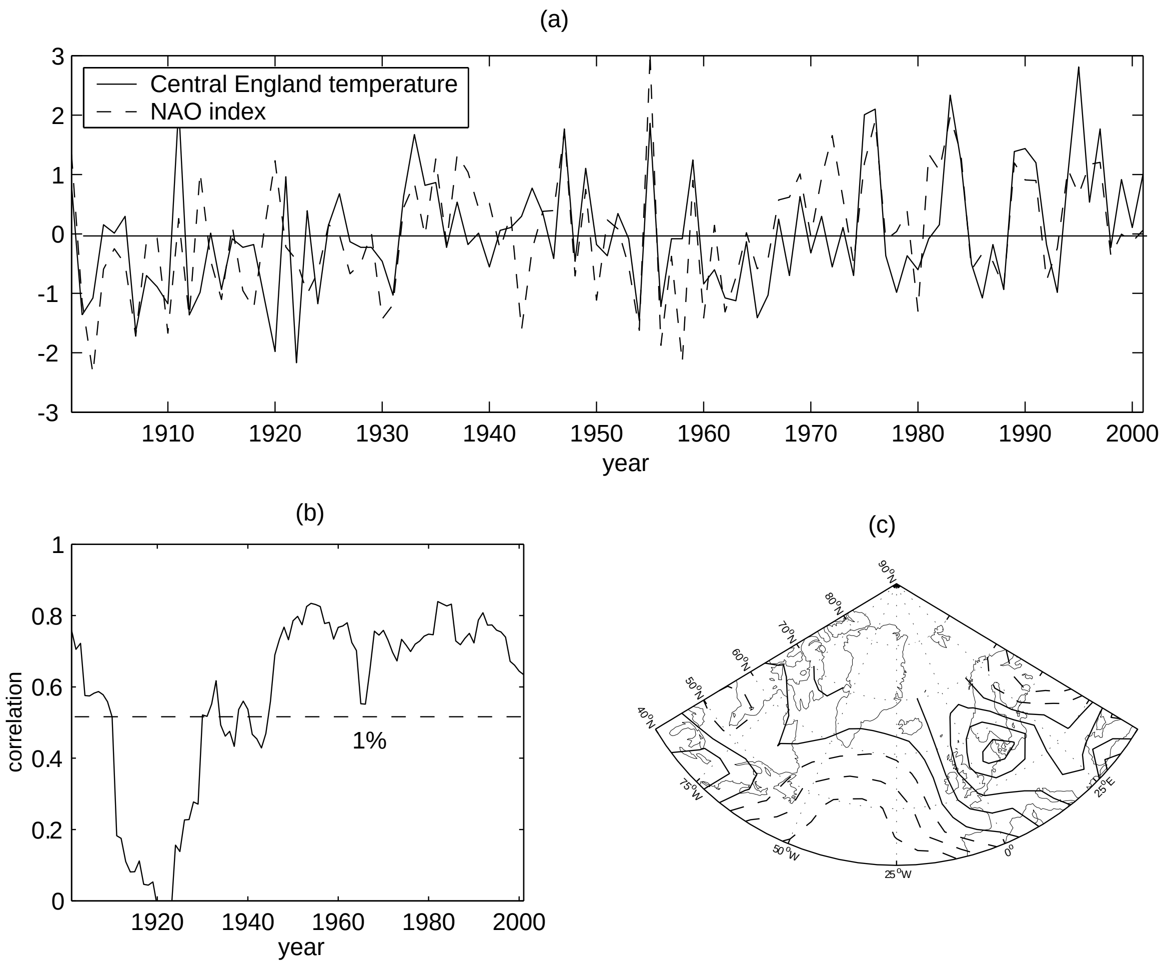

Fig. 9: (a) shows the time series of summer mean Central England Temperature (CET) (solid line) and NAO index (dashed line) from Trenberth's data set. (b) is the sliding window (19 years width) cross-correlation between the two time series in (a). (c) is the (interannual) correlation between summer mean SLP and CET over the 19 years centered at 1921. Dashed contours indicate negative correlations, solid contours the zero line and positive correlations. The contour interval is 0.15 and the 5% significance level is 0.45, indicating correlations significantly different from zero at the 5% level near the regions of maximum positive and negative correlation.

Table 1. Correlation between the summer mean time series of interannually varying SLP from the different data sets over Asia and North Africa for the time periods shown.

SLP	NCEP vs. ERA	ERA vs. Trenberth	NCEP vs. Trenberth
Asia	0.79 (1967-2002)	0.82 (1958-1993)	0.74 (1967-1993)
North Africa	0.89 (1967-2002)	0.55 (1958-2002)	0.51 (1967-2003)

Table 2. As Table 1, but for 500 hPa height and 2 m temperature.

NCEP vs. ERA	HGT500	2mT
Asia	0.89 (1967-2002)	0.62 (1967-2002)
North Africa	0.87 (1967-2002)	0.83 (1967-2002)