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Article

Stratospheric temperatures over the Arctic: Comparison of three data sets

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Abstract

Three sets of stratospheric temperatures (at the 50- and 30-hPa level) are compared for middle and particularly high northern latitudes. Two of the data sets are re-analyses (NCEP/ NCAR and ERA40) while the FU-Berlin data are historical hand-analyses. The time period covered is September 1957 till June 2001, because the FU-Berlin data span this period. As the variability and any trends over the Arctic are of profound interest in connection with *Global Change* and the ozone problem, it is very important to see if and how these data sets agree and to what extend the early data, before satellites became available, are reliable. Therefore, 30-hPa temperatures over the North Pole and 50-hPa temperatures at 80°N are compared, i.e. long-term monthly means, standard deviations and trends. In such a comparison one has to remember that the natural variability is very high during the arctic winter and that radiosonde stations are not available directly over the North Pole nor over the Arctic Sea. Further, the North Pole point is just one point and one shouldn't expect absolute agreement, particularly as we are dealing with three completely different analysis schemes. Considering these caveats, the agreement of the long-term mean temperatures and of the trends is in general surprisingly good. Of special interest is the agreement in the change of the sign of the trends between the two sub-periods during winter: During the first sub-period **cooling is observed in December** and **warming in March and April**. But during the second sub-period **warming is observed in December** and **strong cooling from February till April. Therefore, the overall trend is practically zero.** Time series of the original monthly mean 30-hPa temperatures are compared directly for December and March and it is of great interest to see the generally excellent agreement of most of the extremes in the analyses of FUB and NCEP throughout the whole period. This is valid also for ERA40 in the first sub-period (before satellite data became available). This gives confidence in the analyses of the early period.

Zusammenfassung

Es werden drei verschiedene Sätze von Stratosphärentemperaturen (im 50- und 30-hPa-Niveau) verglichen, mit Schwerpunkt über der Arktis. Zwei der Datensätze sind Re-Analysen (NCEP/NCAR und ERA40), während die Analysen der FU-Berlin historische Analysen sind. Der Vergleich gilt für den Zeitraum von September 1957 bis Juni 2001, weil die FU-Berlin Analysen für diesen Zeitraum vorhanden sind. Weil die Variabilität und alle Änderungen über der Arktis im Rahmen von *Global Change* und der Ozon-Problematik allgemein von großem Interesse sind, ist es wichtig festzustellen, in wieweit diese Daten übereinstimmen, insbesondere während der frühen Jahre, als noch keine Satellitendaten zur Verfügung standen. Es werden dafür 30-hPa-Temperaturen über dem Nordpol und 50-hPa-Temperaturen in 80°N verglichen, in der Form von langjährigen Mitteln, Standardabweichungen und Trends. Bei einem solchen Vergleich muss man bedenken, dass die natürliche Variabilität während des arktischen Winters sehr hoch ist und dass es keine Radiosondenstation direkt über dem Nordpol gibt. Man kann daher keine absolute Übereinstimmung erwarten, insbesondere da es sich um drei völlig verschiedene Analysenmethoden handelt. Eingedenk dieser Problematik ist die Übereinstimmung der langzeitigen Mitteltemperaturen und der Trends im allgemeinen erstaunlich gut. Besonders gut stimmen die Trends in einem Wechsel des Vorzeichens in den zwei Teilperioden im Frühwinter und im Frühling überein: Während der ersten Teilperiode wird **Abkühlung im Dezember und Erwärmung im März und April** festgestellt, während der zweiten Teilperiode aber **Erwärmung im Dezember und starke Abkühlung von Februar bis April. Insgesamt ist der Trend daher praktisch gleich Null.** Für Dezember und März werden Zeitreihen der originalen 30-hPa-Monatsmittel-Temperaturen verglichen. Im allgemeinen stimmen die Extreme während des gesamten Zeitraums hervorragend überein, außer bei ERA40 im Dezember während der zweiten Teilperiode. Dieses Ergebnis bestätigt besonders die Zuverlässigkeit der frühen Analysen.

1 Introduction

Three data sets are now available for the analysis of trends in the stratosphere:

1. The FU-Berlin (FUB) data series which comprises the historical analyses of the northern hemisphere stratosphere between 100 and 10 hPa (LABITZKE and COLLABORATORS, 2002);
2. the NCEP/NCAR re-analyses which are a global data set from the surface to the 10-hPa level (KALNAY et al., 1996), and

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Table 1: Long-term monthly mean 30-hPa temperatures (°C) over the North Pole for the periods and sources as indicated, together with the standard deviations (K), the linear trends (K/decade) and the probability of the trends, n is the number of years. The lowest temperatures are given in bold face, the highest in italic.

Comparison of 30-hPa North Pole Temperatures													
		T_m	*stdev*	*trend*	*prob*	T_m	*stdev*	*trend*	*prob*	T_m	*stdev*	*trend*	*prob*
		1957-2000 (n=44)				1957-1979 (n=23)				1979-2000 (n=22)			
SEP	FU	**-52.4**	1.3	-0.63	99%	*-51.8*	1.0	-0.01	2%	**-53.0**	1.3	-1.72	99%
	NCEP	-52.3	0.9	-0.25	98%	**-52.3**	0.9	-0.83	99%	-52.3	1.0	-1.18	99%
	ERA	*-52.1*	1.3	-0.15	64%	-52.1	0.8	-0.44	90%	*-52.1*	1.7	-0.48	59%
OCT	FU	**-63.2**	1.5	-0.68	99%	-62.6	1.4	-0.68	87%	**-63.9**	1.2	-1.15	99%
	NCEP	-62.8	1.7	-0.58	99%	*-62.5*	2.0	-1.66	99%	-63.0	1.2	-1.23	99%
	ERA	*-62.5*	2.1	0.38	87%	**-63.0**	1.4	-0.85	95%	*-62.0*	2.6	1.36	88%
NOV	FU	**-69.6**	3.7	-1.02	98%	-68.2	3.9	-0.83	49%	**-70.8**	3.1	-0.14	11%
	NCEP	*-68.8*	3.8	-1.32	99%	*-67.4*	4.1	-2.40	94%	-70.1	2.9	-0.23	19%
	ERA	-69.4	4.0	0.05	8%	**-69.0**	3.8	-0.70	43%	*-69.6*	4.1	2.89	97%
DEC	FU	**-73.9**	6.3	-0.23	24%	-73.4	5.9	-1.36	52%	**-74.3**	6.7	2.08	63%
	NCEP	*-72.2*	6.5	-0.63	58%	*-71.3*	6.1	-1.84	65%	*-73.1*	6.7	2.05	62%
	ERA	-73.8	7.0	0.68	58%	**-74.2**	6.6	-1.50	52%	-73.4	7.3	5.22	97%
		1958-2001 (n=44)				1958-1979 (n=22)				1979–2001 (n=23)			
JAN	FU	-72.2	8.8	-1.20	75%	-70.4	9.2	0.34	8%	**-74.0**	7.9	0.01	0%
	NCEP	*-71.2*	8.3	-0.79	57%	*-69.9*	8.7	1.07	27%	*-72.5*	7.6	-0.26	8%
	ERA	**-72.7**	8.9	-0.39	28%	**-71.4**	9.8	1.89	42%	**-74.0**	7.8	1.83	53%
FEB	FU	-66.3	9.3	0.20	14%	-67.0	9.4	-0.89	21%	-65.3	9.2	-1.79	45%
	NCEP	*-65.4*	8.8	0.46	33%	*-66.5*	9.0	-0.95	24%	*-64.0*	8.6	-2.11	55%
	ERA	**-66.6**	10.0	0.19	13%	**-67.1**	10.4	-0.31	7%	**-65.7**	9.7	-1.91	46%
MAR	FU	**-57.4**	7.9	-0.12	10%	**-57.7**	8.0	2.29	59%	**-56.8**	8.0	-5.22	96%
	NCEP	*-56.6*	8.0	-0.24	19%	*-56.9*	8.7	1.35	34%	*-56.2*	7.3	-4.40	95%
	ERA	-57.1	8.1	-0.11	9%	-57.4	8.1	1.85	49%	-56.6	8.2	-4.40	91%
APR	FU	*-47.5*	5.4	-0.28	34%	*-47.0*	5.5	2.88	88%	*-48.0*	5.2	-2.07	79%
	NCEP	**-48.6**	4.6	-0.01	1%	**-48.5**	4.5	1.90	78%	-48.6	4.6	-1.53	70%
	ERA	-48.3	4.8	-0.42	54%	-47.6	4.5	2.19	85%	**-49.0**	4.9	-1.39	62%
MAY	FU	*-42.5*	2.7	-0.89	99%	*-41.5*	2.4	0.14	13%	*-43.5*	2.6	-1.57	95%
	NCEP	**-44.4**	2.1	-0.19	55%	**-44.4**	2.2	-0.93	77%	-44.5	2.0	-0.29	34%
	ERA	-43.7	2.4	-1.08	99%	-42.5	2.1	-0.71	67%	**-44.8**	2.2	-1.51	97%
JUN	FU	*-39.1*	1.4	-0.71	99%	*-38.3*	1.3	0.00	0%	*-39.8*	1.1	-1.30	99%
	NCEP	**-41.2**	1.1	0.06	35%	**-41.6**	1.2	-0.80	95%	-40.9	0.8	-0.49	96%
	ERA	-40.5	1.8	-0.75	99%	-39.8	1.3	-0.26	43%	**-41.0**	2.2	-2.12	99%
		1958-2000 (n=43)				1958-1979 (n=22)				1979-2000 (n=22)			
JUL	FU	*-39.0*	1.1	-0.70	99%	*-38.3*	0.6	-0.41	95%	*-39.7*	1.1	-1.32	99%
	NCEP	**-40.7**	0.8	-0.02	13%	**-40.9**	0.9	-0.91	99%	**-40.5**	0.8	-0.32	78%
	ERA	-40.2	1.5	-0.46	99%	-39.9	0.9	-0.40	83%	-40.4	1.9	-1.72	99%
AUG	FU	*-43.1*	1.0	-0.39	99%	*-42.7*	0.8	0.27	67%	*-43.4*	1.1	-1.38	99%
	NCEP	**-44.2**	0.8	-0.09	67%	**-44.3**	0.9	-0.63	97%	**-44.1**	0.6	-0.72	99%
	ERA	-43.9	1.3	-0.26	89%	-43.9	0.6	-0.19	66%	-44.0	1.7	-1.37	99%

3. the ERA40 data which are the re-analyses of the ECMWF, again for the globe (RANDEL et al., 2004).

The comparison shown here uses the time period from September 1957 till June 2001, because the FUB 30-hPa data span this period. For the discussion of trends, the data are considered for the whole period (n=43/44 years) and two sub-periods: I = September 1957 till December 1979, i.e. the period without satellite data, and II = January 1979 till June 2001. The FUB data for the 50-hPa level are available only since July 1964.

As the climate of the winter stratosphere with its high natural variability is an often studied subject, especially as regards the question of trends in the arctic of temperatures and ozone (LABITZKE and VAN LOON, 1994 and 1999; LABITZKE and NAUJOKAT, 2000; RAMASWAMY et al., 2001; REX et al., 2004), it is of particular interest to compare the three data sets over the north polar region.

2 Data

While the re-analyses are based on the knowhow and analysis tools of today (data assimilation methods, etc.), the FUB analyses are a completely independent data set, based on daily hand-analyses of the height and temperature fields from the 50- to the 10-hPa level. They are made by experienced meteorologists. As the Berlin data are historical there was time to take care of some late data and to assure a consistency in the vertical and in time. On the other hand, the re-analyses have been supplemented with radiosonde data (e.g., from the USSR and from China) which had not been available in real time for the FUB analyses.

The FUB analyses are done for 00.00 UT, which means night time over the European sector and day time over the Pacific. The re-analyses use analyses made four times a day. This has some influence on the temperature and height distribution, but mainly over the sub-tropics.

Until 1978 the analyses of the three data sets are based on radiosonde data only which were often sparse, especially in the beginning of the period. Starting in 1979 satellite radiance measurements from the SSU (Stratospheric Sounding Unit (BAILEY et al., 1993)) became available. They are fully integrated in the re-analyses, but only partly in the FUB data where we started in 1984 to supplement the analyses in data-sparse areas with thicknesses derived from satellite data, the so-called SATEMS, which were transmitted together with the radiosonde data through the Global Telecommunication System (GTS) of WMO. But during dynamically disturbed periods priority was given to the radiosonde data, because these give the more reliable vertical resolution (LABITZKE and COLLABORATORS, 2002).

3 Comparison of long-term mean temperatures

3.1 Monthly mean 30-hPa North Pole temperatures

We are using the 30-hPa North Pole temperatures for this comparison because this is the longest temperature series available for the three data sets. In such a comparison one has to remember that the natural variability is very high during the arctic winter (see Table 1-upper part, standard deviations) and that radiosonde stations are not available directly over the North Pole nor over the Arctic Sea (except some ice floe stations during the early years). Further, the North Pole point is just one point and one shouldn't expect absolute agreement, particularly as we are dealing with three completely different analysis schemes. On the other hand the North Pole represents the characteristics of the circulation, like the NAM (Northern Annular Mode (BALDWIN and DUNKERTON, 2001)) and therefore any trends and changes of trends are of great interest.

In Table 1 the long-term monthly means for the three different periods as well as the standard deviations, the linear trends (K/dec) and the probability of the trends are summarized.

Considering the caveats above, the agreement of the long-term monthly mean temperatures between the different data sets is surprisingly good: During the winter half year, from September till March, upper part of Table 1, there is a clear tendency for FUB to be somewhat **colder** than NCEP, but only in 5 cases are the differences larger (up to 2.1 K) than 1 K, i.e. during all 3 periods in December and during the second sub-period (1979–2001) in January and February. However, during these periods the ERA40 data agree within a few tenth of a degree with FUB.

The ERA40 means are sometimes warmer, sometimes colder than FUB means, but the differences are small, usually less than 0.5 K. Only in 6 cases the differences are between 0.5 and 1 K. But larger differences (up to 1.9 K) exist during the second sub-period (1979–2000) in October, November and December. At the same time the differences between FUB and NCEP are small, so there appears to be a problem with the ERA40 data during these months, (see also discussion for the trends).

During summer, from April till August, lower part of Table 1, FUB is **always warmer** than NCEP and ERA40, with differences above 1 K in about 50% of the cases. The largest differences (up to 3.3 K) exist against the NCEP data during the first sub-period (1958–1979) but at the same time the differences against ERA40 are smaller. The consistently warmer FUB data hint to some radiation corrections in the re-analyses during the summer half year.

3.2 Monthly mean 50-hPa temperatures at 80°N

The results described above for the 30-hPa temperatures are similar for the 100- and 50-hPa levels. Table 2 gives the data for the 50-hPa zonal mean temperatures at 80°N which span the central Arctic and may be more representative than the single North Pole point.

The agreement between the FUB data and the re-analyses is again surprisingly good and in half of the cases the differences between the monthly means are only between +/– 0.5 K. Similar to the 30-hPa North Pole data FUB is **always warmer** than NCEP and ERA40 during the summer, cf. Table 1. The larger differences observed between ERA40 and the other data sets at the 30-hPa level during the second sub-period are not found at the 50-hPa level, (see discussion in Sections 3.1 and 4).

3.3 Monthly mean 30-hPa maps for January

A comparison between a long-term mean of the northern hemisphere 30-hPa temperatures in January is shown in Fig.1a. The period here is 1965 till 2001. The monthly means are shown for all three data sets, as well as the differences against the FUB data. As mentioned in Section 2, the FUB analyses are for 00.00 UT. For this comparison we calculated the monthly mean of the ERA40 data also for 00.00 UT. The differences are small, between +/– 0.5 K poleward of 30°N, Fig.1a (middle). This is an astonishing result considering the large temperature gradient over middle and particularly high latitudes and the very large interannual variability during this time of year.

The NCEP data set consists of 4 analyses per day. Therefore, for the FUB data we must expect lower temperatures over the European sector of the map (night

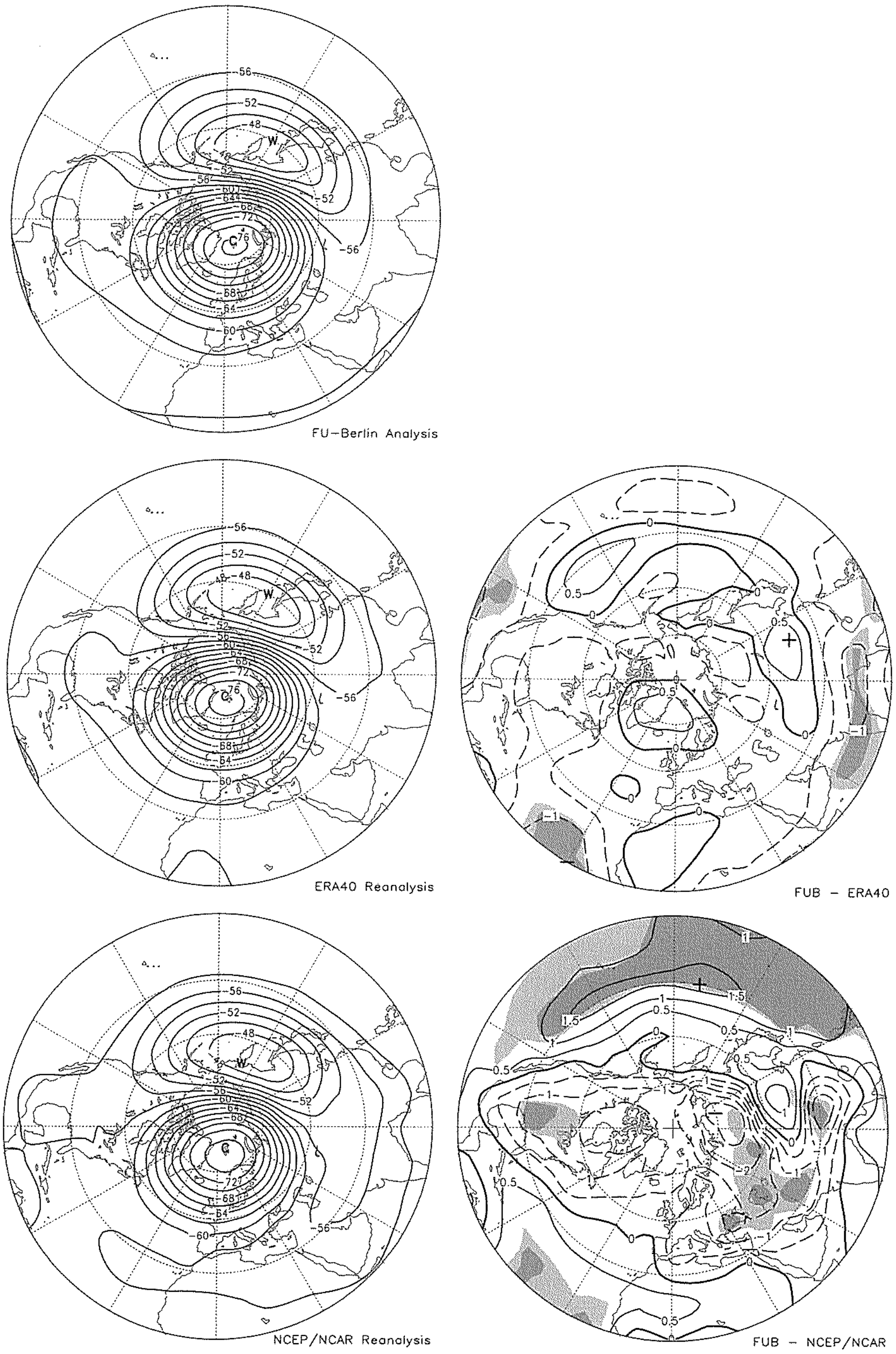

Figure 1a: Left: 30-hPa long term (1965–2001, n=37) monthly mean temperature (°C) fields over the northern hemisphere (10 to 90°N) for **January**. Top: FU-Berlin data; middle: ERA40/00.00 UT; bottom: NCEP/NCAR-re-analysis 1. Right: Deviations of the respective fields from the long-term mean of the FU-Berlin analysis. Contour interval is 0.5 K. Dark (light) shaded areas denote regions where the differences are significant at the 99% (95%) level, estimated with a Student's T-Test.

side), and higher temperatures over the Pacific sector (day side). Such a structure is indeed found in the temperature differences.

The differences between FUB and NCEP are somewhat larger than against ERA40, with a colder vortex (– 1.5 to –2.5 K) in the FUB data.

The structure of the differences between the FUB data and ERA40 is similar from September till April with values between +/– 0.5 K, and similarly against the NCEP data for the winter period November through March.

During the summer (April through August, not shown) **FUB is always warmer over the Arctic than NCEP and ERA40** (+1.5 to +2.0 K). This hints to some radiation corrections in the re-analyses during the summer half year. Outside the Arctic the differences are

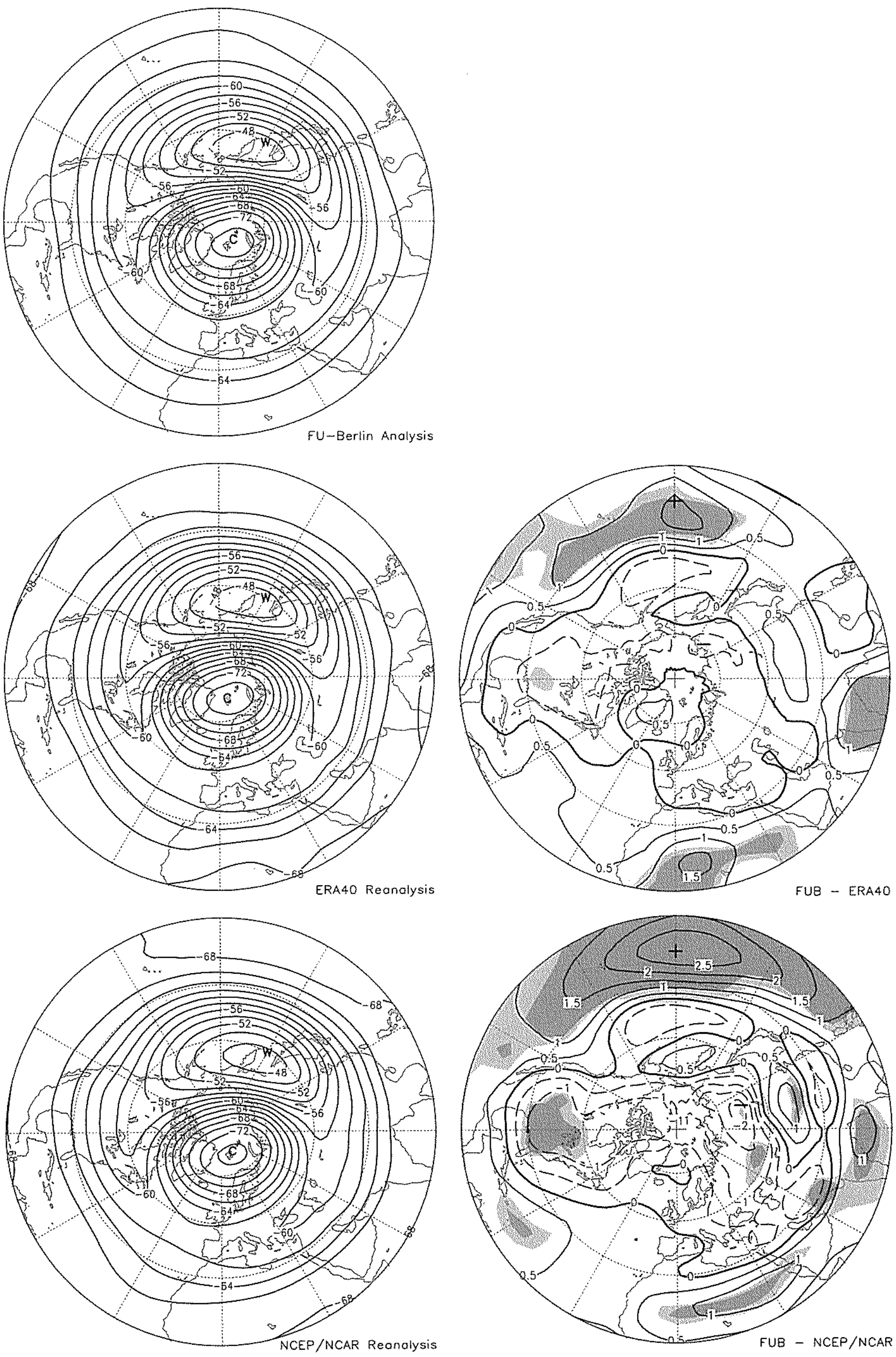

Figure 1b: as Fig. 1a, but for the 50-hPa level.

small (mainly within +/– 0.5 K) and reflect mainly the day-night differences, as discussed above.

3.4 Monthly mean 50-hPa maps for January

Figure 1b shows the comparison at the 50-hPa level. This level represents the lower stratosphere and is often considered for the detection of changes over the Arctic, e.g. REX et al., 2004. The differences between ERA40 and the FUB data are again only about +/– 0.5 K poleward of 30°N.

The differences between FUB and NCEP are somewhat larger than against ERA40, with a colder vortex (–1.5 to –2.5 K) in the FUB data. In general, the results are similar to the comparison at 30-hPa, as discussed above.

4 Comparison of trends over the Arctic

Figures 2 (a–d) show the march through the year of the trends, for the different periods, as given in Table 1 for the 30-hPa North Pole temperatures. Fig. 2e shows the

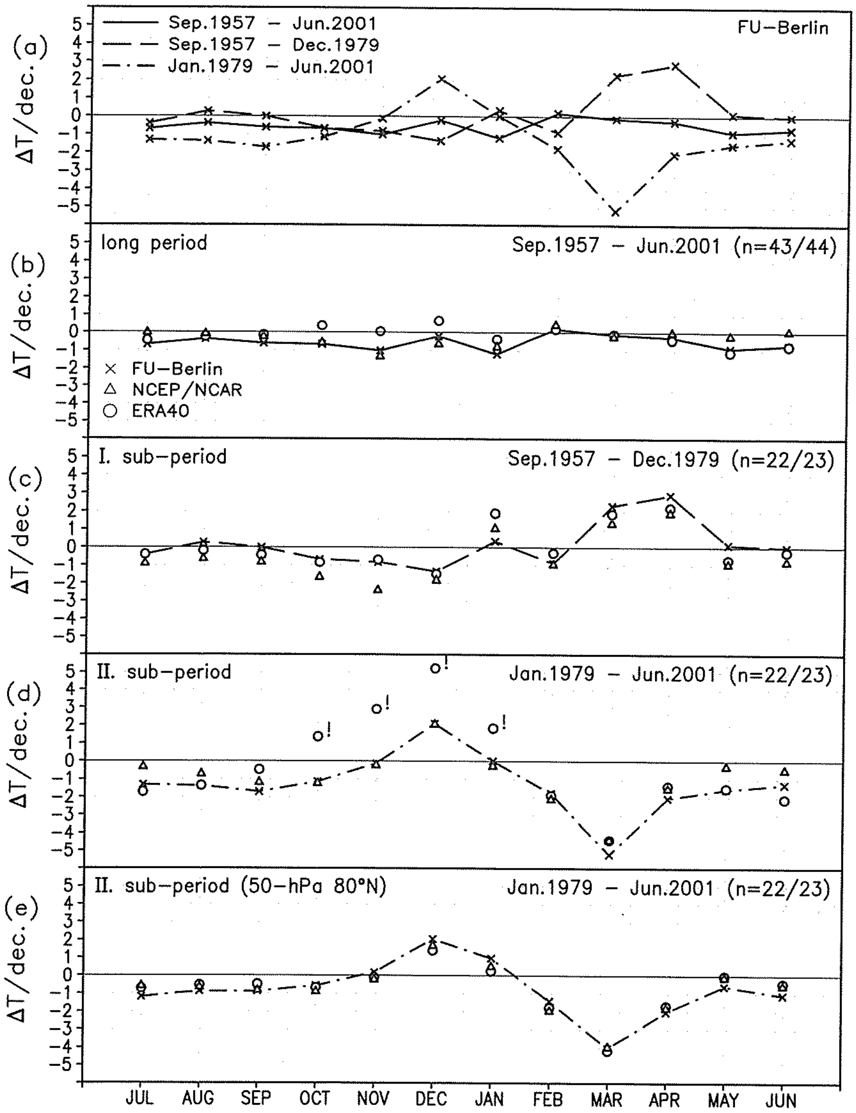

Figure 2: Time series of the trends (K/decade) of the 30-hPa temperatures over the North Pole through the year. (a) The trends of the FU-Berlin data for the three periods (cf. Table I). (b) Trends during the whole period, July 1957 till June 2001, (n=44). The line gives the trend of the FU-Berlin data. (c) as (b), but for the first sub-period; (d) as (b), but for the second sub-period. (e) as (d), but for the **50-hPa zonal mean temperatures** at 80°N.

results for the second sub-period of the 50-hPa temperatures, as given in Table 2.

4.1 30-hPa North Pole temperatures in winter

The results given in Table 1 and Fig. 2 (a–d) can be summarized as follows:

September till December:

During the long period, 1957–2000, there is general agreement between FUB and NCEP; the trends of ERA40 are completely different with different sign from October till December (and into January), see discussion in Section 3.1.

During the first sub-period, 1957–1979, all three data sets agree in the sign of the trend which is cooling, ERA40 trends are very close to FUB, but NCEP exhibits much larger values in October and November.

During the second sub-period, 1979–2000, there is very good agreement between FUB and NCEP, with cooling from September till November, then warming. ERA40 trends are completely different from October till December (and into January).

January till March:

During the long period, 1958–2001, there is general agreement of the trends in sign and intensity. ERA40 agrees very well with the two other data sets in February and March.

During the first-sub period, 1958–1979: Agreement between all three data sets in the sign of the trends.

During the second sub-period, 1979–2001: Very good

Table 2: Long-term monthly mean of the zonal mean 50-hPa temperatures (°C) at 80°N for the periods and sources as indicated, together with the standard deviations (K), the linear trends (K/decade) and the probability of the trends, n is the number of years.

Comparison of 50-hPa 80°N zonal mean Temperatures													
		T_m	*stdev*	*trend*	*prob*	T_m	*stdev*	*trend*	*prob*	T_m	*stdev*	*trend*	*prob*
		1964-2000 (n=37)				1964-1979 (n=16)				1979-2000 (n=22)			
SEP	FU	-51.0	0.9	-0.49	99%	-50.5	0.8	0.17	30%	-51.4	0.8	-0.88	99%
	NCEP	-51.1	0.7	-0.37	99%	-50.9	0.5	-0.55	95%	-51.3	0.7	-0.82	99%
	ERA	-51.4	0.7	-0.52	99%	-50.9	0.5	-0.55	97%	-51.8	0.5	-0.48	99%
OCT	FU	-59.5	1.0	-0.52	99%	-59.0	1.1	-0.64	71%	-59.8	0.9	-0.56	95%
	NCEP	-59.0	1.1	-0.57	99%	-58.6	1.2	-1.20	95%	-59.3	0.9	-0.88	99%
	ERA	-60.1	1.2	-0.68	99%	-59.4	1.0	-0.83	88%	-60.6	1.0	-0.67	96%
NOV	FU	-65.6	2.7	-0.82	95%	-64.4	2.7	-1.22	57%	-66.4	2.5	0.17	16%
	NCEP	-65.2	2.7	-0.92	98%	-64.0	2.7	-1.50	67%	-65.9	2.4	-0.20	19%
	ERA	-66.2	2.8	-0.96	97%	-64.8	2.6	-1.20	58%	-67.0	2.6	-0.10	9%
DEC	FU	-70.0	5.3	-0.32	30%	-69.3	4.9	-3.54	81%	-70.5	5.6	2.05	72%
	NCEP	-69.2	5.6	-0.66	55%	-68.2	5.6	-4.12	81%	-69.9	5.5	1.68	62%
	ERA	-70.5	5.7	-0.49	42%	-69.7	5.0	-3.14	74%	-71.0	6.0	1.40	50%
		1965-2001 (n=37)				1965-1979 (n=15)				1979-2001 (n=23)			
JAN	FU	-70.4	7.2	-1.44	80%	-68.0	8.0	-1.92	30%	-72.0	6.1	0.96	37%
	NCEP	-69.5	7.1	-1.51	83%	-67.3	7.9	-2.45	38%	-71.0	6.2	0.52	20%
	ERA	-70.4	7.5	-1.52	81%	-68.1	8.2	-1.48	23%	-71.9	6.5	0.24	9%
FEB	FU	-66.2	7.4	-0.20	14%	-66.0	7.1	1.20	21%	-66.0	7.6	-1.42	43%
	NCEP	-65.4	7.4	0.07	4%	-65.8	7.4	1.24	21%	-64.8	7.5	-1.94	58%
	ERA	-65.9	7.5	0.05	3%	-66.1	7.6	2.00	32%	-65.4	7.6	-1.78	53%
MAR	FU	-58.4	6.7	-0.28	21%	-58.6	6.0	6.48	93%	-58.1	7.2	-4.04	93%
	NCEP	-58.2	6.5	-0.17	13%	-58.5	6.1	6.25	91%	-57.7	6.8	-3.97	94%
	ERA	-58.3	6.5	-0.21	17%	-58.7	6.2	6.52	92%	-57.9	6.8	-4.18	95%
APR	FU	-48.6	4.4	-0.89	81%	-47.5	3.9	4.41	94%	-49.3	4.5	-2.02	85%
	NCEP	-49.3	3.9	-0.71	75%	-48.4	3.5	3.95	95%	-49.8	4.1	-1.80	83%
	ERA	-49.1	4.1	-0.83	80%	-48.1	3.6	3.93	93%	-49.8	4.3	-1.69	78%
MAY	FU	-44.3	1.8	-0.76	99%	-43.5	1.8	-1.39	80%	-44.8	1.6	-0.59	74%
	NCEP	-45.4	1.7	-0.50	95%	-44.9	1.8	-2.19	97%	-45.7	1.6	-0.09	14%
	ERA	-45.0	1.8	-0.74	99%	-44.1	1.8	-2.14	96%	-45.6	1.4	-0.02	3%
JUN	FU	-41.7	1.3	-0.85	99%	-40.8	1.1	-0.44	49%	-42.3	1.0	-1.10	99%
	NCEP	-42.8	0.9	-0.46	99%	-42.4	1.0	-1.36	98%	-43.0	0.7	-0.56	99%
	ERA	-42.2	0.9	-0.63	99%	-41.6	1.0	-1.20	97%	-42.7	0.6	-0.44	98%
		1964-2000 (n=37)				1964-1979 (n=16)				1979-2000 (n=22)			
JUL	FU	-41.4	1.1	-0.84	99%	-40.7	0.7	-0.94	99%	-42.0	0.9	-1.20	99%
	NCEP	-42.4	0.8	-0.53	99%	-42.0	0.8	-1.39	99%	-42.7	0.7	-0.57	99%
	ERA	-42.0	0.9	-0.69	99%	-41.3	0.6	-1.03	99%	-42.5	0.7	-0.72	99%
AUG	FU	-44.1	0.7	-0.46	99%	-43.7	0.5	0.04	12%	-44.4	0.8	-0.88	99%
	NCEP	-45.0	0.7	-0.46	99%	-44.6	0.6	-0.99	99%	-45.3	0.6	-0.63	99%
	ERA	-44.8	0.7	-0.49	99%	-44.3	0.5	-0.69	99%	-45.1	0.6	-0.53	99%

agreement between all three data sets in February and March.

4.2 30-hPa North Pole temperatures in summer

April till August:
For the whole period, 1958–2001(1958–2000), there is general agreement between the three data sets in the sign of the trends which is cooling. But the trends are much weaker in the NCEP data.
During the first sub-period, 1958–1979, there is agreement of warming in April and cooling in July, but no consensus in May, June and August.
During the second sub-period, 1979–2001(1979–2000), all data sets agree in the sign (cooling) of the trends, but the trends are much weaker in the NCEP data.

4.3 Trends of the 50-hPa temperatures over the inner Arctic

Figure 2e shows the trends of the zonal mean 50-hPa temperatures at 80°N for the second sub-period. The trends are generally somewhat weaker than observed at the 30-hPa level at the North Pole.

The most important results are:

1. the very close agreement between the three data sets, including ERA40, and
2. the change of the sign of the trend between December and March – in agreement with the results shown for the 30-hPa level, Fig. 2d.

5 Trends at the North Pole in December and March

Figure 2 (a–d) shows for most months negative trends of the 30-hPa North Pole temperatures in all three data sets and for all three periods. Interesting exceptions are observed in December and in March/April.

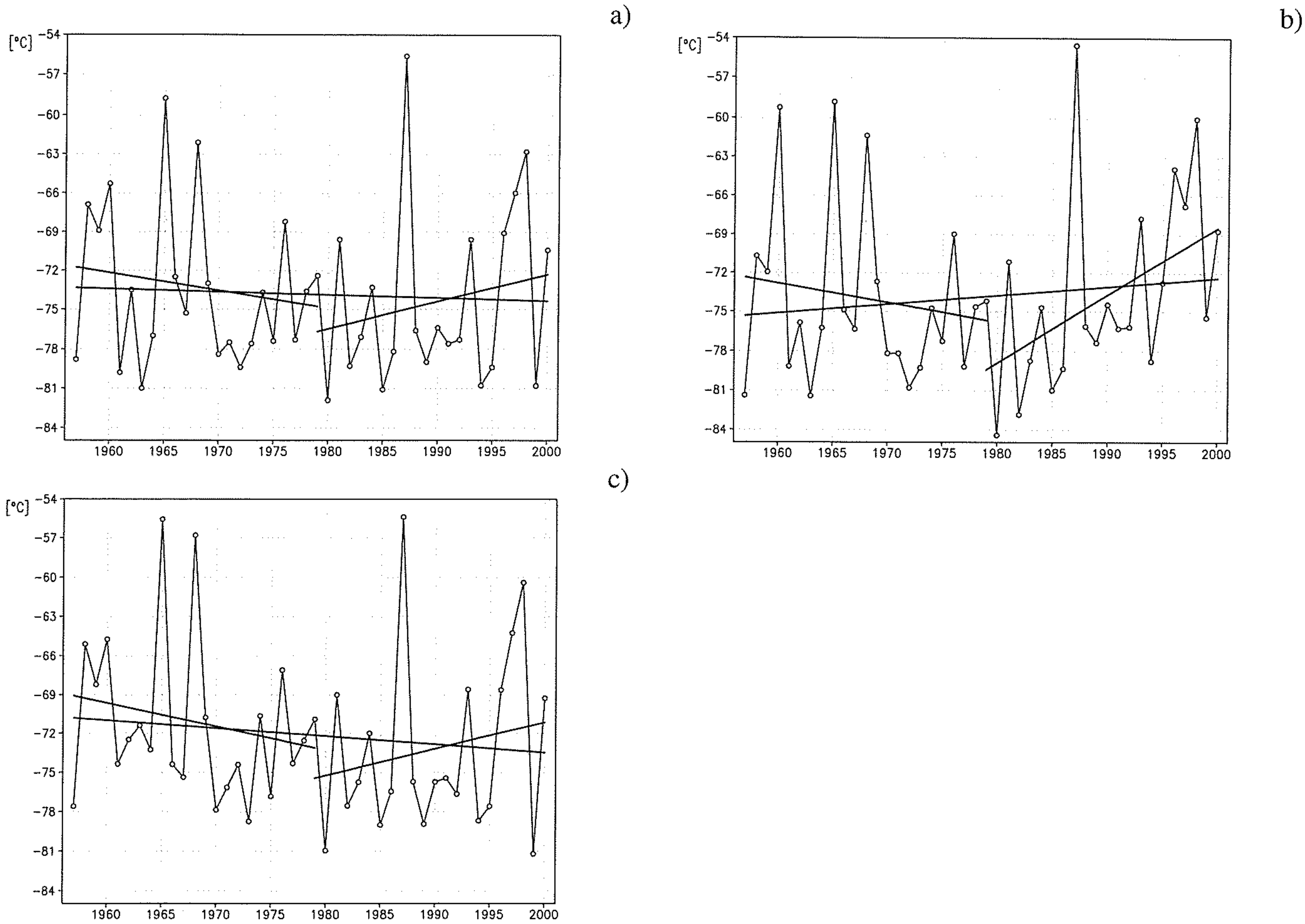

Figure 3: Time series of the monthly mean 30-hPa North Pole temperatures (°C) in **December**, 1957 till 2000. Trend lines are given for the whole period as well as for both sub-periods, (see text). (a) FU-Berlin; (b) ERA40; (c) NCEP/NCAR.

5.1 December

Figure 3 gives for all three data sets the complete time series of the monthly mean 30-hPa temperatures at the North Pole for December, with the trend lines for the three different periods. For the whole period the trend in the FUB and NCEP data is weakly negative, for the first sub-period strongly negative in all three data sets (between –1.4 and –1.8 K/dec) and for the second sub-period strongly positive (+2 K/dec) in the FUB and NCEP data, but too strong in the ERA40 values. Comparing the single monthly means it becomes obvious that the ERA40 data are definitely colder than the two other sets in the beginning of the 1980s, and warmer at the end of this sub-period. This results in a too large positive trend. (The same is true from October through January, see Table 1.)

At the same time it is of great interest to see the generally excellent agreement of most of the extremes in the analyses of FUB and NCEP throughout the whole period. This is valid also for ERA40 in the first sub-period (before satellite data became available). This gives confidence in the analyses of the early period.

5.2 March

Figure 4 gives for all three data sets the complete time series of the monthly mean 30-hPa temperatures for March, with the trend lines for the three different periods. Considering the large natural interannual variability and the discussion above about the quality and availability of the data, especially in the early part of the period, the agreement between the three data sets is amazing. The different long-term means agree with each other within a few tenths of a degree. And the often described fact that the overall trend is practically zero while the sign of the trends is clearly and strongly opposite between the earlier and the later period (LABITZKE and VAN LOON, 1999), is beautifully confirmed by the reanalyses, both of ERA40 and NCEP.

March is an important time of the winter, as a long lasting undisturbed cold polar vortex is a meteorological situation in which ozone can be destroyed, while earlier break-ups of the vortex are connected with ozone transport into the Arctic. The spring of 1997 is the coldest within the data series of 44 years. As pointed out above, the overall trend is practically zero in all three data sets. Whether the negative trend during the later pe-

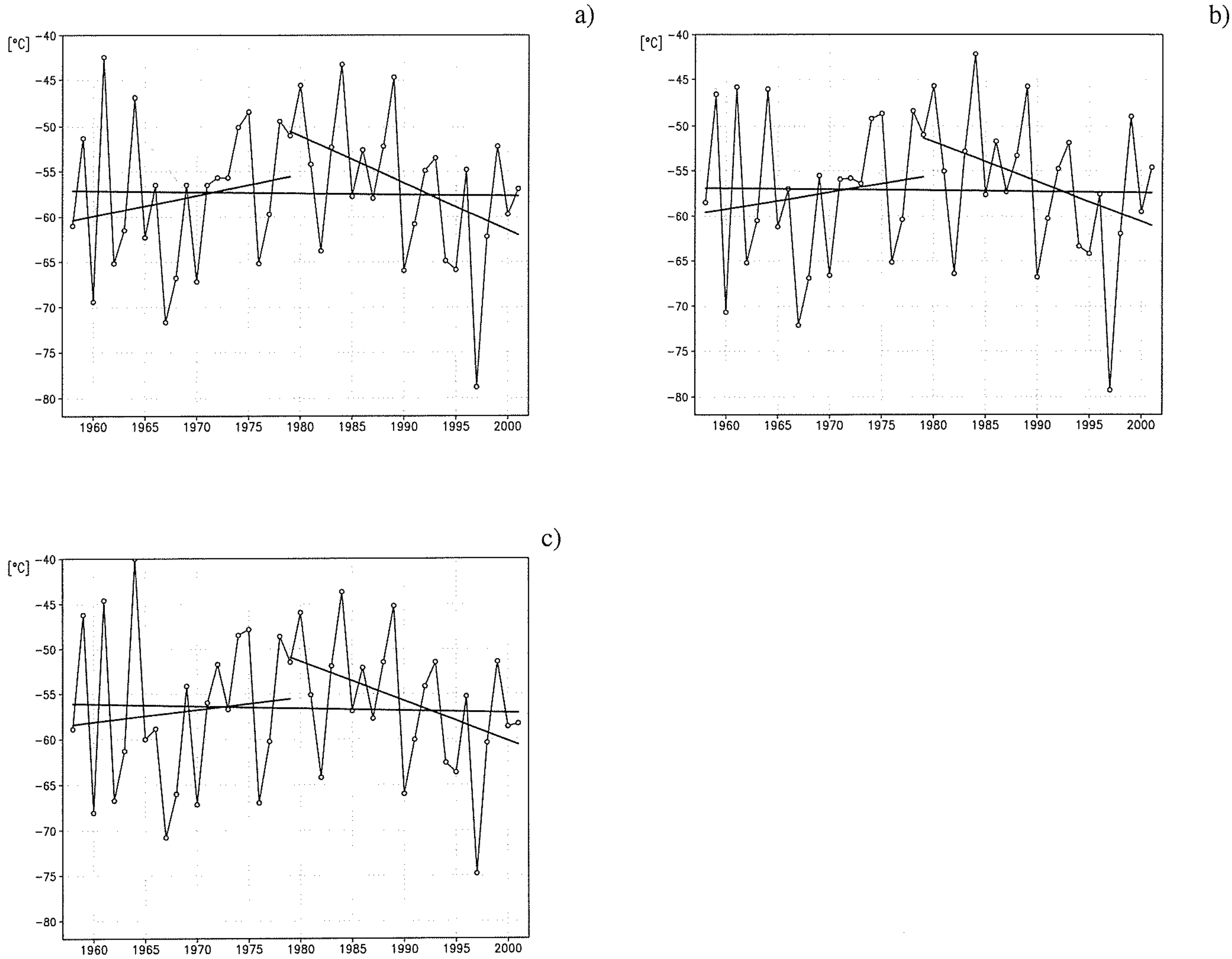

Figure 4: As Fig.3, but for **March**, 1958 till 2001.

riod is a persistent feature, indicating a real change of the circulation, cannot be decided with certainty. One could also prolong the positive trend of the early period. As pointed out before (LABITZKE and VAN LOON, 1999), one should be careful when dealing with trends in the Arctic, because of the high variability:...*the trend depends on how one cuts the cake.*

6 Summary

Three sets of stratospheric temperatures (50- and 30-hPa) are compared for middle and particularly high northern latitudes. Two of the data sets are re-analyses (NCEP/ NCAR and ERA40) while the FUB data are historical hand-analyses. The time period covered is July 1957 till June 2001, because the FUB 30-hPa data span this period.

A comparison between a long-term mean of the northern hemisphere 50- and 30-hPa temperatures is shown for January. For this comparison the monthly mean of the ERA40 data are calculated for 00.00 UT. The differences against FUB are small, between +/– 0.5 K poleward of 30N. This is an astonishing result considering the large temperature gradient over middle and particularly high latitudes and the very large interannual variability during this time of year.

The comparison of the different trends over the Arctic shows mainly a very good agreement between the three data sets. ERA40 seems to have a problem with the 30-hPa data from October till January during the second sub-period, but agrees well with the other data sets at the 50-hPa level.

Of special interest is the agreement in the change of the sign of the trends between the two sub-periods during winter: During the first sub-period **cooling is observed in December** and **warming in March and April**. But during the second sub-period **warming is observed in December** and **strong cooling from February till April**. Within the context of this comparison the simultaneous change of sign of the trends within the two sub-periods is a significant result.

Considering the large natural interannual variability and the discussion above about the quality and availability of data, especially in the early part of the period, the agreement between the three data sets is amazing. The different long-term means agree with each other within a few tenths of a degree. **And the often described fact that the overall trend is practically zero** while the sign of the trends is clearly and strongly opposite between the earlier and the later period (LABITZKE and VAN LOON, 1999), is beautifully confirmed by the re-analyses, both of ERA40 and NCEP.

March is an important time of the winter, as a long lasting undisturbed cold polar vortex is a meteorological situation in which ozone can be destroyed, while earlier break-ups of the vortex are connected with ozone transport into the Arctic. The spring of 1997 is the coldest within the data series of 44 years. As pointed out above, the overall trend is practically zero in all three data sets. Whether the negative trend during the later period is a persistent feature, indicating a real change of the circulation, cannot be decided with certainty at present (LANGEMATZ, 2000; REX et al., 2004).

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Links to the different data are as follows:
FU-Berlin:
http://strat-www.met.fu-berlin.de/products/cdrom
NCEP/NCAR:
http://wesley.wwb.noaa.gov/reanalysis.html
ERA40:
http://www.ecmwf.int/research/era

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