Classic Examples of Inhomogeneities in Climate Datasets

The following examples, which are contributed by experts from different parts of the world, illustrate the main causes of inhomogeneities in climate datasets and their impact on climate trends. Changes in instruments and in observing procedures have made the observations easier and more accurate but they may have also created artificial biases in long-term time series. Station relocation is often the prime source of inhomogeneity. Not all changes are recorded in the station history reports and observing manuals. This is why many approaches and statistical techniques have been developed for detecting inhomogeneities and adjusting climate datasets; however, further research is still required to fully address this difficult issue.

1. Impact of Station Relocation on Mean and Extreme Temperatures in Australia

Blair Trewin, National Climate Centre, Australian Bureau of Meteorology

A station move or other inhomogeneity may have a different impact on the extremes of temperature than it does on the mean. This is especially true in situations where there is a marked topographic contrast between the old and new site (e.g. moving from a hilltop to a flat plain), or in close proximity to the coast.

Port Macquarie (31°26' S, 152°55' E) is a town on the east coast of Australia, between Sydney and Brisbane, with a rapidly growing population of about 60,000. The long-standing observation site (Hill Street) was within the town area, and within 1 km of the coast, although its exposure was good for an urban site (in a suburban area, over short grass and about 25 metres from the nearest building or hard surface), and it was partially protected from marine influence by a ridge (height 30-40 metres) between it and the ocean.

A new site opened at the airport, 5 km further inland (to the WNW), in 1995. This is on a flat river floodplain and outside the town. The Hill Street site closed in 2003. Seven years of parallel observations, from 1996 to 2002, are used for comparison.

During the overlap period, mean daily maximum temperatures at the airport are 0.6°C higher than those at Hill Street, with the difference ranging from 0.2°C in winter to 0.9°C in summer. Mean minimum temperatures at the airport are 1.5°C lower than those at Hill Street, with little seasonal variation.

The differences between the two sites tend to be much greater than this on most days of extreme high maximum temperatures and extreme low minimum temperatures (Table 1), as the marine influence at the coastal site is at its greatest under conditions of clear skies and light winds. The 99^{th} percentile maximum temperature is 3.3°C higher at the airport than at Hill Street, whilst the 1^{st} percentile minimum temperature is 2.7°C lower. To complicate matters still further, on the very hottest days (which, at Port Macquarie, typically occur when strong NW winds advect dry air from central Australia), strong winds can suppress the sea breeze and reduce the temperature differential. On the hottest day of the 7-year comparison period, 2 January 2002, the maximum temperature was 38.3°C at Hill Street and 40.2°C at the airport, a difference of only 1.9°C. (Hill Street has experienced a maximum as high as 42.3°C in November 1968). It follows from this that adjusting for such an inhomogeneity using a flat annual adjustment (or even a separate one for each month) will be inadequate to homogenize the higher-order moments of the frequency distribution in this situation.

Parameter	Maximum temperature (°C)			Minimum temperature (°C)		
	Hill Street	Airport	Difference	Hill Street	Airport	Difference
Annual mean	22.9	23.5	-0.6	14.3	12.8	1.5
Summer mean (Dec-Feb)	26.1	27.0	-0.9	19.0	17.6	1.4
Winter mean (Jun-Aug)	19.1	19.3	-0.2	8.9	7.5	1.4
Lowest in period	12.5	11.3	1.2	0.0	-2.7	2.7
1st percentile	15.7	15.8	-0.1	3.9	1.2	2.7
5th percentile	17.2	17.5	-0.3	6.2	3.9	2.3
10th percentile	18.1	18.3	-0.2	7.6	5.8	1.8
90th percentile	27.2	28.4	-1.2	20.1	19.1	1.0
95th percentile	28.0	29.8	-1.8	21.2	20.2	1.0
99th percentile	30.0	33.3	-3.3	22.4	21.9	0.5
Highest in period	38.3	40.2	-1.9	24.2	23.7	0.5

Table 1. Comparison of temperatures at Port Macquarie (Hill Street) and Port Macquarie Airport, 1996-2002.

2. Impact of Station Relocation on Temperature in Canada

Lucie Vincent, Climate Research Division, Environment Canada

Station relocation, and in particular changes in instrument exposure, can often create inhomogeneities in temperature time series. In this example, the annual mean daily minimum temperatures of Amos, Canada (48°34'N, 78°07'W) were tested for homogeneity over the period 1915 to 1995. The technique used was based on regression models (Vincent 1998). It identified steps in the temperature difference between Amos and a reference series computed from surrounding stations.

The technique detected two statistically significant steps: a step of -0.8°C in 1927 and a step of 1.3°C in 1963 (Fig. 1). The station history files revealed that the Stevenson screen was located at the bottom of a hill prior to 1963 and was moved on a levelled ground, several metres away from its original place, after 1963 (Fig. 2). The former site was sheltered by trees and buildings which could have prevent the cold air to drain freely at nighttime. The current site has better exposure and the observations are more reliable. The station history files do not provide any information on the cause of the first step.

Daily minimum temperatures were adjusted for the steps identified in the annual values using a technique based on interpolation (Vincent et al. 2002). Monthly and annual averages were then re-computed from the homogenized daily values. After adjustments, the annual mean minimum temperatures show an increasing trend of 0.8°C over 1915 to 1995 where as the original values show an increase of 2.4°C (Fig. 3). The current trend is in agreement with the nighttime warming observed at surrounding sites over the same period.

This procedure was applied to homogenize the daily maximum and minimum temperatures of 210 climatological sites in Canada (Vincent and Gullett 1999). From this work, it was found that station relocation and changes in observing time were the most common causes of inhomogeneities in Canadian surface temperature. The homogenized temperatures are available at http://www.cccma.bc.ec.gc.ca/hccd/.

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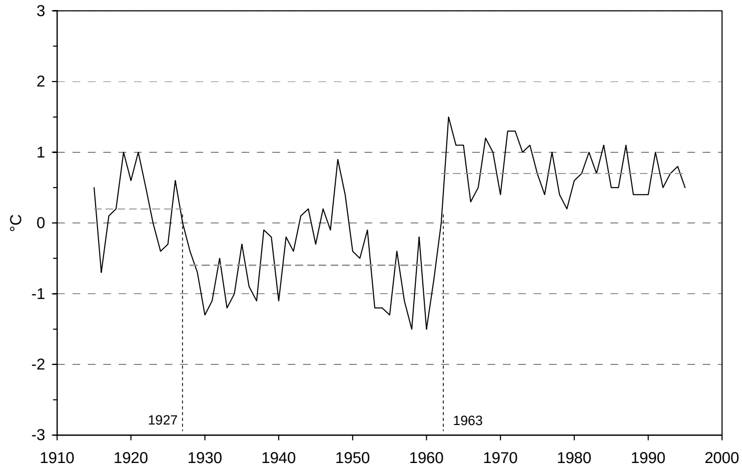

Figure 1. Difference between the annual mean of the daily minimum temperatures of Amos and a reference series computed from surrounding stations.

Figure 2. Screen location before and after 1963.

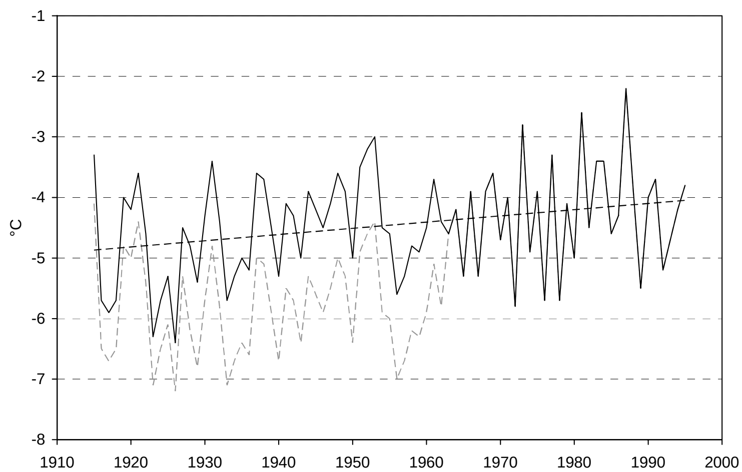

Figure 3. Original (dashed line) and adjusted (full line) annual mean of daily minimum temperatures for Amos, Canada, 1915-1995.

3. Impact of Station Relocation on Temperature in China

Qingxiang Li, National Meteorological Center, CMA, Beijing, China

Station relocation is the main cause of inhomogeneities in Chinese surface air temperature series during the last 50 years (Li et al, 2004a). This is an example showing an inhomogeneity of greatest deviation in time series suffered from station relocation.

Wutaishan (53588) of Shan Xi Province was established in October 1955, situated on Zhongtaiding (39°02'N, 113°32'E) on Wutai Mountain at an altitude of 2895.8 meters (Fig. 1). It was moved to Muyushan (38°57'N, 113°31'E) on Wutai Mountain on January 1st 1998, 20 kilometers away from its original place, but with an altitude of 2208.3 meters, which is about 700 meters lower than the previous location. In recent 50 years, except for station relocation, others "non-climatic" factors such as daily mean temperature computing methods, instrumentation, and surrounding environment, etc., had no significant changes.

The base series are the annual mean, maximum, and minimum temperatures recorded at Wutaishan for the 49-year period from January 1956 to December 2004. The reference series was constructed by combining the surface temperatures records at several nearby stations having the largest correlation to the candidate station (Peterson and Easterling, 1994). The likelihood ratio technique was used to find out critical values which give an objective way of classifying series as homogeneous or non-homogeneous (Alexandersson, 1986). The results are listed in Table 1.

According to the results, the annual mean temperatures were adjusted before 1997. The trend was calculated before and after adjustment: 1.100°C/10 years and 0.367°C/10 years respectively. The adjusted trend corresponds to the regional average temperature changes in China (Li et al. 2004b).

To adjust the inhomogeneities in Chinese surface air temperatures time series, the E-P technique, the daily adjustment method (Vincent et al. 2002), and the FDM method (Peterson et al. 1997) were used along with the station history files, and the China Homogenized Historical Temperature Datasets (CHHT1.0) was developed. In the CHHT, there are about 200 surface air temperature series for the in situ China Mainland, which include daily and monthly maximum, minimum and mean temperatures series, and monthly 2.5*2.5 resolution gridded datasets. The CHHT was officially released in December 2006 by the China Meteorological Administration, which became valuable basic datasets for climate change research in China. The datasets are available at http://cdc.cma.gov.cn.

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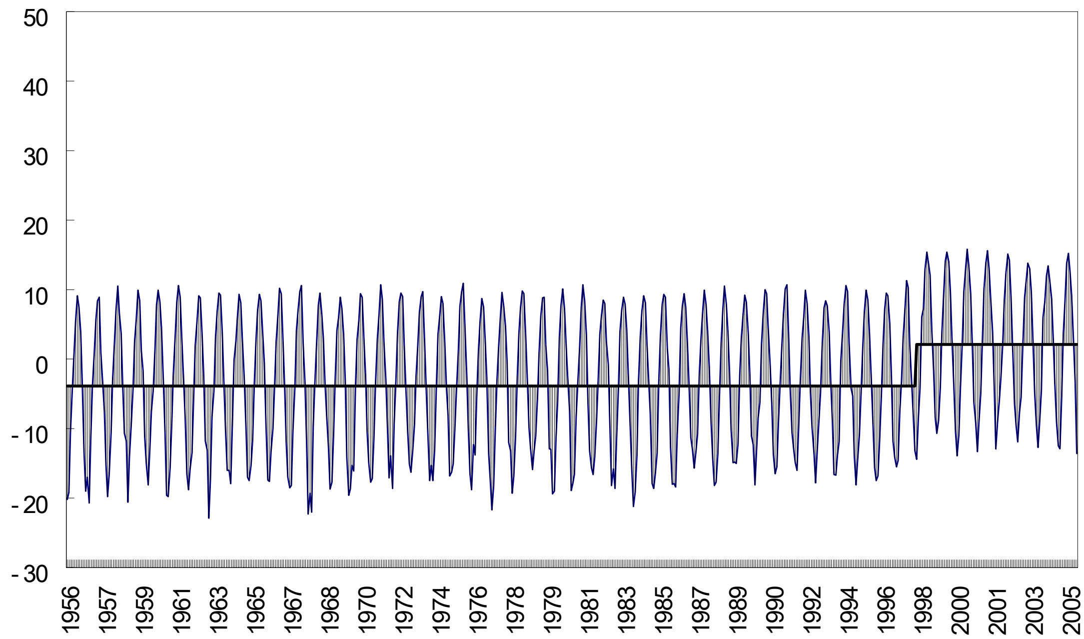

Figure 1. Step change (Jan 1998) in monthly mean surface air temperatures series on Wutaishan (53588)

Annual average temperatures	Discontinuities	Offsets (°C)
Mean	1997	5.2
Maximum	1997	5.5
Minimum	1997	4.2

Table 1. Discontinuities and offsets in the temperature of Wutaishan observations

4. Reasons for Inhomogeneities in Temperature in Norway

Øyvind Nordli, Norwegian Meteorological Institute

Testing of the temperature homogeneity within the Norwegian network of stations has been performed for the period 1876 – 1995 (Nordli 1997). The method used was the SNHT (Standard Normal Homogeneity Test) developed by Hans Alexandersson (Alexandersson 1986). A variety of inhomogeneities was detected that are shown in Figure 1 together with their relative frequency of occurrence. As expected relocations was the most common reason for inhomogeneities (37 %). As wall cages were common in the Norwegian network until the 1930s, short wave radiation on the wall, or even directly on the cage, was also a common reason for inhomogeneity (24 %).

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Nordli, Ø. 1997: Homogenitetstesting av norske temperaturseriar II. (In Norwgian: Homogeneity testing of Norwegian Temperature series), *DNMI-raport*, 29/97Klima, 1-43.

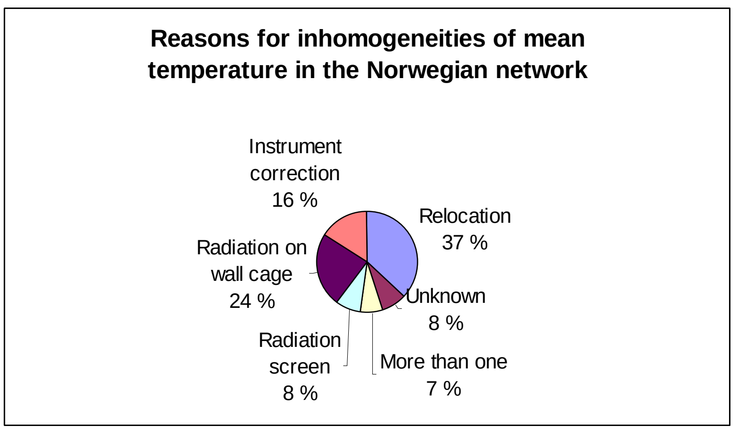

Figure 1. Reasons for inhomogeneities in the Norwegian station network as detected by the SNHT for the period 1876 – 1995 (Nordli 1997).

5. Inhomogeneities due to Changing Temperature Day for Maximum and Minimum Temperatures in Norway

Øyvind Nordli, Norwegian Meteorological Institute

Originally the “minimum temperature day” in Norway was defined from morning to morning observations. This practice was much criticised at the meteorological congress in Warsaw in 1935, which led to a change of definition also in Norway. From the 1st of January 1938, the minimum temperature day was defined from evening to evening observations.

As this was performed for the whole network of stations, relative homogeneity tests could not be applied for detection of the difference. However, the differences were derived by using the old practice on modern data (Nordli 1997; Tuomenvirta et al. 2000). The effect of the change varied much through the year and also with station category. As expected, the effect was largest in spring and autumn, the time of the year when the minimum temperature tends to occur near the time of the morning observation, as shown in the figure. During winter the occurrence of minimum temperature is almost randomly distributed throughout the day, and in summer the daily minimum tends to occur several hours earlier than the morning observation. Therefore, the effect of changed practice is small in winter as well as in summer. Generally the effect of the change is largest for sites that has large DTR (Daily Temperature Range); i.e. continental stations as in the figure. For maritime stations the difference is much smaller.

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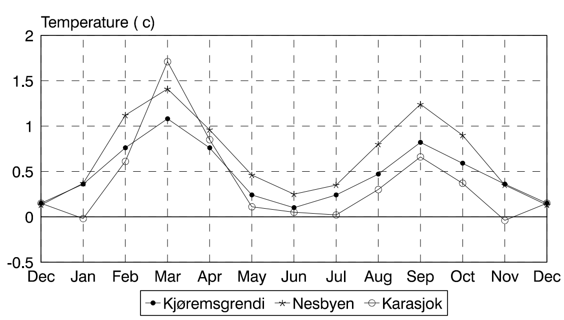

Figure 1. Mean monthly differences between daily minimum temperature computed according to the present definition minus the one used during the period 1894 – 1937. The three stations represented on the figure are all situated in continental climate.

6. Inhomogeneities due to Temperature Screen changes in Nordic Countries (Denmark, Finland, Iceland, Norway, Sweden)

Øyvind Nordli, Norwegian Meteorological Institute

For the Nordic countries, the effect of temperature radiation screen changes has been investigated by Nordli et al. (1997). The historic development of the screens has gone from single louvers, through old double louvers, double walls (designed for harsh weather conditions, only used in Norway and Iceland), and to the present day double louvered Stevenson screens. Comparisons between the screens and ventilated thermometers show that the changes do not affect temperature series during autumn and winter, but the historical improvements of the screen have had significant impact on the series during spring and summer, as illustrated in Figure 1. Thus, screen changes may affect temperature trends during those seasons.

References

Nordli, Ø., H. Alexandersson, P. Frich, E. Førland, R. Heino, T. Jónsson, O. E. Tveito. 1997: The effect of radiation screens on Nordic time series of mean temperature. *Int. J. Climatol.*, **17**, 1667-1681.

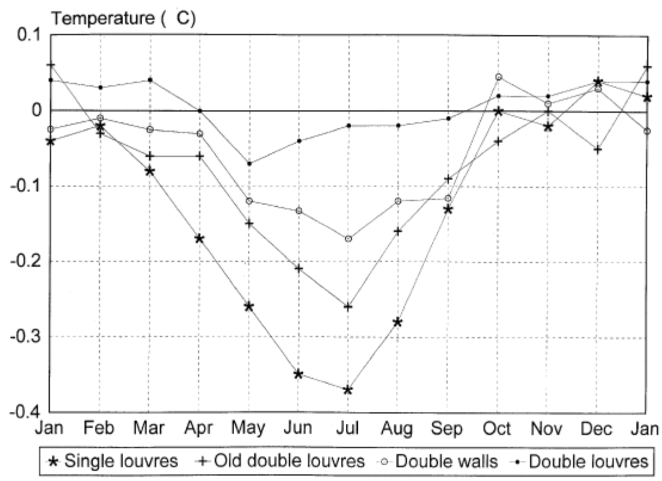

*Figure 1. Nordli, Ø., H. Alexandersson, P. Frich, E. Førland, R. Heino, T. Jónsson, O. E. Tveito. 1997: The effect of radiation screens on Nordic time series of mean temperature. Int. J. Climatol., **17**, 1667-1681.*

7. Impact of Station Relocation on Temperature in Uruguay

Madeleine Renom, Universidad de la Republica, Montevideo, Uruguay
Matilde Rusticucci, Universidad de Buenos Aires, Argentina

The most frequently encountered causes for the breaks detected in the minimum and maximum temperatures series were station relocations or changing in observing practices. In this example, the annual mean daily minimum and maximum temperature and the mean diurnal temperature range (mDTR) of Salto, Uruguay (31° 24' S, 57° 58' W) were tested for homogeneity over the period 1970 to 2002. Different homogenization procedures were used together with the aim of comparison. The selected test methods are: the Standard Normal Homogeneity Test (SNHT); Alexandersson (1986); Buishand Range Test Buishand (1982); and the Homogeneity test proposed by Vincent (1998) using regression models. The selected method was the Homogeneity test proposed by Vincent (1998) using regression models.

For the SNHT and Buishand test, the selected tested variable, at first, was annual mean of the diurnal temperature range (mDTR), suggested by J.B. Wijngaard et al (2003). In some cases we applied these tests to annual mean maximum and minimum temperature series. The other test uses as a tested variable the annual mean of maximum and minimum temperature separately.

There was a documented relocation of the station, in year 1976. Before this change, station was inside of the city of Salto and more accurately in the backyard of the observer house. It was changed to a big park, Parque Harriague, which is an open place. This relocation is detected for the entire test selected, when the variables tested are the annual mean of maximum and minimum temperature series. While if we use the variable mDTR, SNHT and Buishand test are not capable to detect this change. The test proposed by Vincent detect a statistically significant step of 3.1 °C for maximum temperature and a step of 2.4 °C for minimum temperature series in 1976 (Fig. 1).

With respect to homogeneity test applied, for the Uruguayan station we have to mention that not always the documented relocation of stations were detected, meaning that relocation does not make a step in the series, such are the cases of other stations analyzed.

We did not try to adjust the daily series for the inhomogeneities detected. Doing so require close neighbor stations and detailed metadata (Vincent, 2002). These two points are the biggest problem in Uruguay. It is hard to find closer station with same periods of records to compare and stations metadata are very poor in Uruguay. Not all the relocations of stations are documented and changes in instrumentation locations, measuring techniques are even more poorly so.

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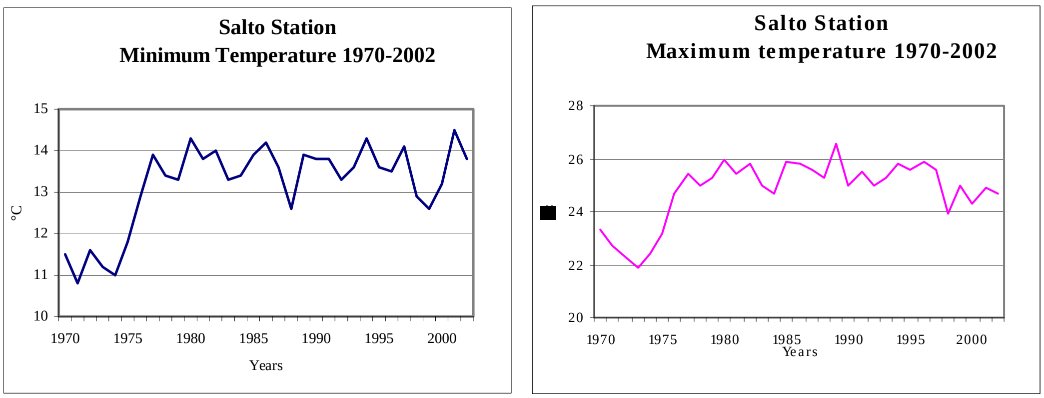

Figure 1. a) Annual mean minimum temperature and b) annual mean maximum temperature for Salto, 1970-2002.

8. Impact of Screen Change and Relocation on Temperature in the Netherlands

Albert Klein Tank, Royal Netherlands Meteorological Institute (KNMI)

De Bilt (52°06´N, 05°11´E) in the Netherlands is an example of a climate monitoring station with a well documented station history. Because it served as one of the main climate stations in the Netherlands, parallel measurements were generally undertaken in case of temperature screen changes or relocations. However, the main relocation of the station in August 1951 (movement of the screen 200 m in southerly direction to a more open terrain) was not timely anticipated and parallel measurements could not be undertaken because building activities permanently disturbed the old location. To complicate the situation, a small relocation took place shortly earlier in September 1950 combined with a major change in thermometer screen.

Figure 1 shows the old situation with temperature measured in a large pagoda which was open at the bottom. Parallel measurements in a Stevenson screen show that especially the maximum temperatures Tx in that screen differ form those in the pagoda. In the summer months Tx of the Stevenson screen is on average up to 0.6°C lower than Tx of the pagoda, while in winter Tx of the Stevenson screen is on average up to 0.2°C higher than Tx of the pagoda. Figure 2 shows the new situation after the transition to the new site in September 1951 and the screen replacement.

Figure 3 shows the mean Tx in the summer half year (April-September), further denoted as Tx_sum. The figure shows that the changes around 1950/51 suggest a decrease in Tx_sum. Because the magnitude of the inhomogeneity due to the screen change is known but not the effect of the relocation, we decided to estimate the magnitude of both inhomogeneities together. We compared Tx_sum of De Bilt with Tx_sum of other series in the Netherlands in the period 1941–1960. Comparison of the series for both the 1941–1950 and the 1952-1960 period, resulted in an estimated artificial decrease in Tx_sum of 0.62°C. From the parallel measurements, we know that the effect of the screen change (in combination with a small relocation) is about 0.48°C. So the extra effect of the relocation of the screen 200 m southwards is small and amounts only 0.14°C. Figure 3 also shows the adjusted data where corrections have been made for both inhomogeneities.

Further reading

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Brandsma, T., G.P. Können and H.R.A. Wessels. 2003. Empirical estimation of the effect of urban heat advection on the temperature series of De Bilt (The Netherlands). *Int. J. Climatology*, **23:** 829-845.

Figure 1. Overview of the measurement site in De Bilt up to September 1950. The pagoda at the back is the operational thermometer screen and the Stevenson screen at the right is used for making parallel measurements (anticipating a screen change from pagoda to Stevenson). Both screens measure temperature at 2.20 m above ground level.

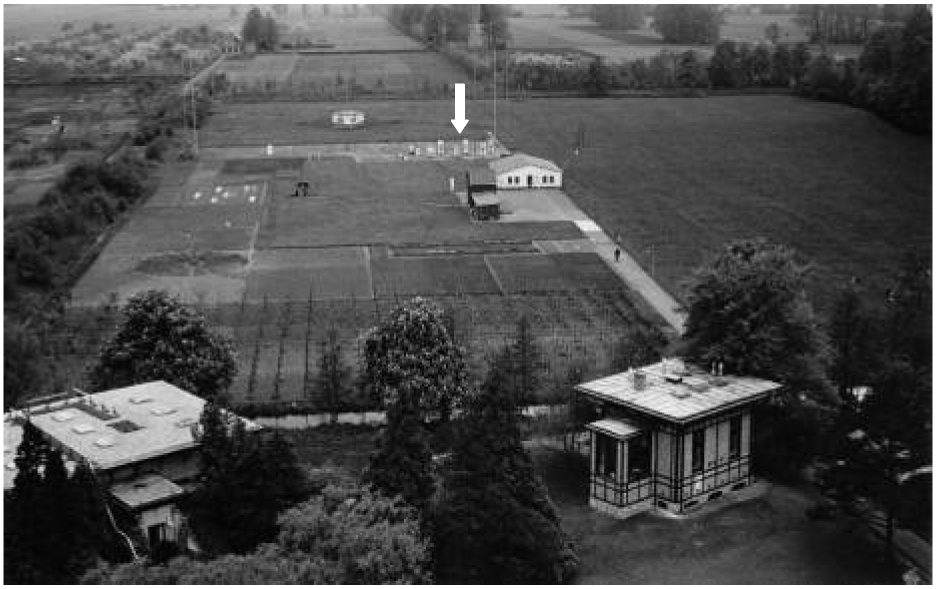


Figure 2. Overview of the measurement site in De Bilt (white arrow) from August 1951 onwards. The pagoda is replaced by a wooden Stevenson screen.

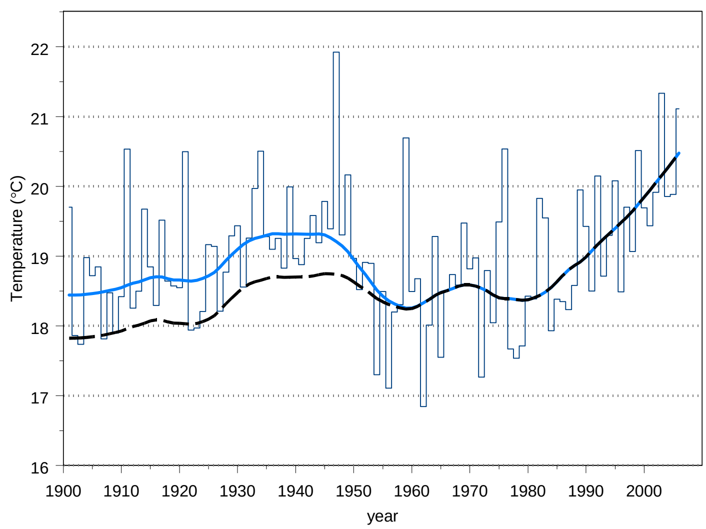


Figure 3. Mean maximum temperature in the summer half year (April-September) for De Bilt (1901-2006). The smooth line represents a locally weighted running line smoother through the data with a span of 20 years. The dashed line gives the smooth after correction for the inhomogeneities in 1950 and 1951.

9. The effects of rounding on temperature threshold time series

Blair Trewin, National Climate Centre, Australian Bureau of Meteorology

Changes in the precision with which temperature measurements are made should, over the long term, have no effect on mean temperatures. They can, however, have a substantial impact on time series of the number of days above or below thresholds, particularly in climates with low daily temperature variability.

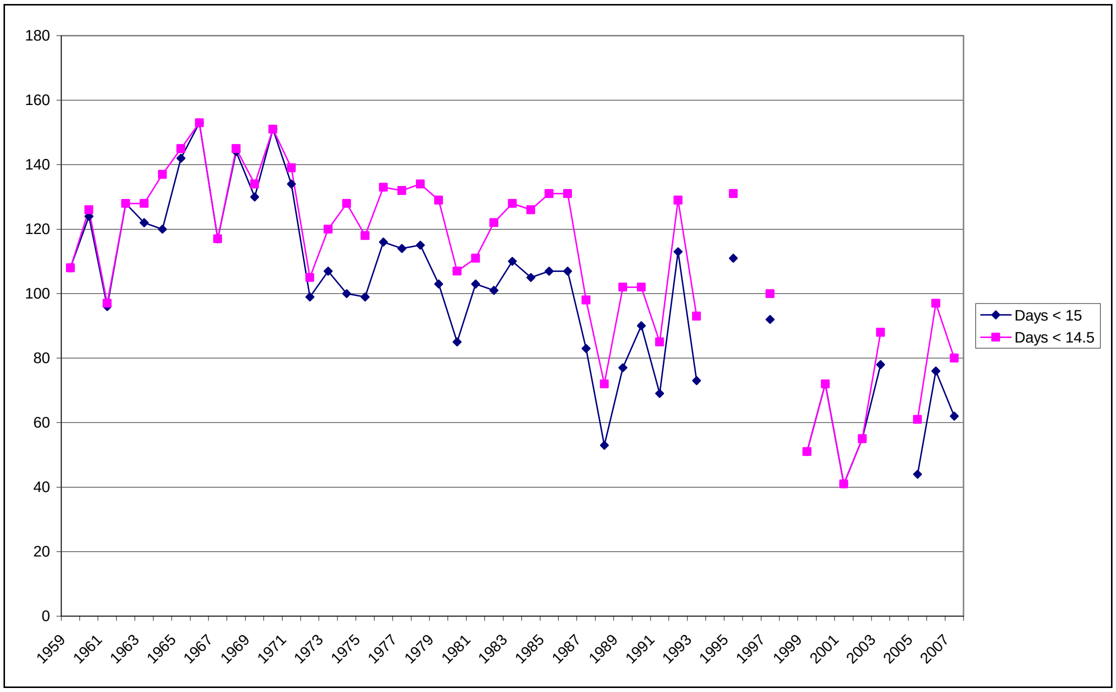
The graph below shows the annual number of days with maximum temperatures below 15°C and 14.5°C at Eddystone Point, on the east coast of Tasmania, Australia (40.99°S, 148.35°E). This is a very exposed coastal site with low temperature variability, especially in winter (the 10th and 90th percentiles of daily maximum temperature for July are 11.1 and 15.0°C respectively).

Over time, the precision of temperature measurements has been as follows:

- 1959-August 1972: temperatures recorded in degrees Fahrenheit, theoretically with 0.1°F precision but in practice normally with 1.0°F precision. Under this regime, temperatures of 14.5, 14.6 or 14.7°C will be recorded as 14.4°C (58°F), while those of 14.8 and 14.9°C will be recorded as 15.0°C (59°F), leading to an overstatement of the number of days under 14.5°C and an understatement of the number of days under 15.0°C.
- September 1972-January 1998 and August 2003-present: temperatures recorded in degrees Celsius to 0.1°C precision.
- February 1998-July 2003: temperatures recorded in degrees Celsius to 1.0°C precision. (This was a consequence of the limitations of early generations of data transmission software from automatic weather stations, one of which was installed at Eddystone Point in 1998). The effect of this is that temperatures from 14.5-14.9°C inclusive were rounded up to 15.0°C (values ending in .5 are rounded to the nearest odd number), leading to an understatement of the number of days under 15.0°C while leaving the number of days under 14.5°C unaffected.

Due to the low variability of winter temperatures at Eddystone Point the number of days with maximum temperatures in the 14.5-14.9°C range is substantial (a mean of 19 days/year over the 1973-1997 period). As a consequence, measuring temperatures to a precision of 1.0°C results in a negative bias of approximately 19 days/year (16% of the 1961-90 mean annual total) in the number of days with maximum temperatures below 15.0°C at this location.

A negative trend in the number of days with maximum temperatures below 15.0°C would be expected given the trends in mean maximum temperatures (approximately +0.6°C over the 1960-2007 period over the year, and +0.8°C for winter), but the changes in data precision have exaggerated the recent decline.



Annual number of days with maximum temperatures below 15.0°C (blue line) and 14.5°C (pink line) at Eddystone Point. Note that the numbers closely or exactly match during the 1959-1972 and 1999-2003 periods.

10. Reasons for Inhomogeneities in Precipitation in Norway

Eirik J. Forland, Norwegian Meteorological Institute

Hanssen-Bauer & Førland (1994) examined the homogeneity in 165 Norwegian precipitation series of 75 years or more by the Standard Normal Homogeneity Test, SNHT (Alexandersson, 1986). Application of SNHT revealed inhomogeneities in 70% of the longest Norwegian precipitation series. Relocation of the gauge was found to be the most frequent reason (46%) for inhomogeneities. Relocations caused adjustment factors (AF) in the interval 0.80-1.19.

For the station Briksdal in Western Norway the SNHT indicated a highly significant inhomogeneity around 1940. The inhomogeneity is also visible as a change in the mean value of the q-ratio (Figure 1 left). The reason for this inhomogeneity was found in the metadata; the station was moved 4 km in January 1940. The series from Briksdal was adjusted by multiplying annual precipitation for the period 1895-1939 with an adjustment factor AF=0.81. The results from testing the adjusted series showed no significant inhomogeneities, and the mean value of q is fairly constant throughout the series (Figure 1 right).

Figure 2 shows smoothed series of unadjusted and adjusted annual precipitation at Briksdal. According to the unadjusted values, the precipitation level was at a maximum in the beginning of the series, while the adjusted shows a maximum level in the end of the series.

References

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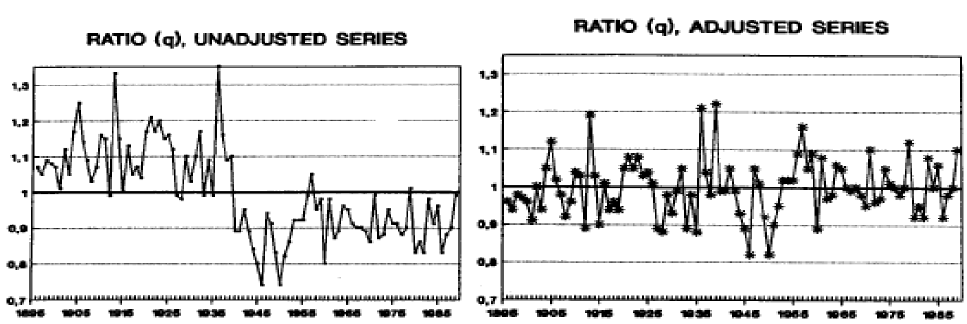

Figure 1. Results from performing the SNHT on unadjusted and adjusted annual precipitation series (1895-1990) from Briksdal. q is the ratio between normalised precipitation at Briksdal and selected reference stations (from Hanssen-Bauer & Førland, 1994).

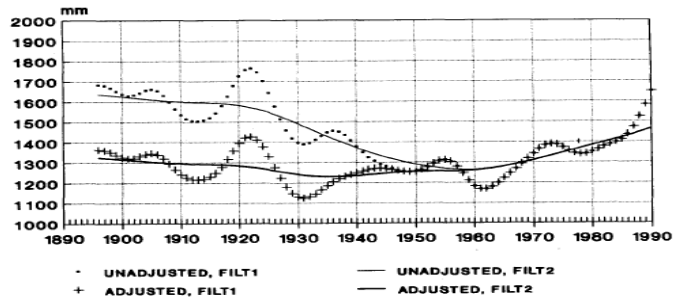

Figure 2. Unadjusted and adjusted series of annual precipitation at Briksdal. FILT1 and FILT2 are low-pass filters involving Gaussian weighting functions with standard deviations 3 resp. 9 years (from Hanssen-Bauer & Førland, 1994).

11. Impact of Station Relocation on Precipitation in Norway

Eirik J. Forland, Norwegian Meteorological Institute

Homogeneous time series of climate elements are essential for studies of climatic fluctuations and changes. However, at most stations with long time series, instruments have been altered or relocated and surrounding buildings and vegetation have changed. For precipitation measurements, progressive improvements of instrumentation have also introduced artificial systematic increases, and thus long-term variations should be interpreted cautiously at stations not checked for inhomogeneities.

Hanssen-Bauer & Førland (1994) examined the homogeneity in 165 Norwegian precipitation series of 75 years or more by the Standard Normal Homogeneity Test, SNHT (Alexandersson, 1986). Different significance levels were chosen for accepting inhomogeneities with and without support in metadata. Application of SNHT revealed inhomogeneities in 70% of the longest Norwegian precipitation series. The adjustment factors were ranging from 3-23 %.

Table 1 shows that for 79 series with just one inhomogeneity, relocation of the gauge is the most frequent reason (46%) for inhomogeneities. Relocations caused adjustment factors (AF) in the interval 0.80-1.19. The distribution of the AFs was nearly symmetric around 1.0, and the mean value does not differ significantly from unity (Table 1). Consequently it seems to be no systematic tendency for moving the gauge to more (or less) wind-exposed sites.

Changes in vegetation or buildings within a radius of 20-30 m around the gauge explained 21% of the inhomogeneities, and caused AFs in the interval 0.90-1.19. Three out of four detected environmental changes led to an increase in measured precipitation, and Table 1 shows that the mean AF (1.05) differs significantly from unity. This indicates that a majority of the environmental changes have led to increased sheltering of the gauge and consequently increased gauge catch.

Installation of Nipher windshield at some stations in the beginning of the 20th century explains 9% of the inhomogeneities, with an average AF of 1.13. The “reason unknown” group caused AFs in the interval 0.90-1.19. The mean value of the AFs for the “reason unknown” group does not differ significantly from unity.

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		Adjustment factor	
Reason for inhomogeneity	N	Mean	Std.dev.
Relocation	36	1.005	0.098
Changed environment	17	1.051	0.072
Installation of windshield	7	1.131	0.027
New observer	4	1.078	0.015
Other reasons	2	0.945	_
Reason unkown	13	1.014	0.067
All cases	79	1.030	0.088

Table 1.Number of cases (N) and mean and standard deviations for adjustment factors for 79 series with one inhomogeneity (from Hanssen-Bauer & Førland, 1994).

12. Impact of Site Exposure on Pan Evaporation in Australia

Blair Trewin, National Climate Centre, Australian Bureau of Meteorology

Pan evaporation measurements are highly sensitive to wind speed near the pan surface. In turn, wind speed near the ground is strongly influenced by local site exposure. Hence, any change in local site exposure, such as vegetation growth or building construction near an evaporation pan, can have a major impact on observed pan evaporation.

An example of the impact of vegetation growth on pan evaporation is the situation at Rabbit Flat (20°11' S, 130°01' E), one of the most remote observing locations in Australia, in the central west of the Northern Territory (Fig. 1). The old site became progressively more overgrown through the 1980's and 1990's, and was closed at the end of 1998. A new, much more exposed, site was established 198 metres to the west in late 1996, giving two years of parallel observations of pan evaporation, as well as of wind speed at the pan surface.

During the two years of parallel observations (Fig. 2), pan evaporation at the new site was 32% greater than that at the new site, whilst mean wind speed at the pan surface (not shown) was nearly three times that at the old site (6.0 km/h at the new site, 2.2 km/h at the old).

Figure 1. Rabbit Flat observing sites – new site (left, taken in 2006) and old site (right, taken in 1997).

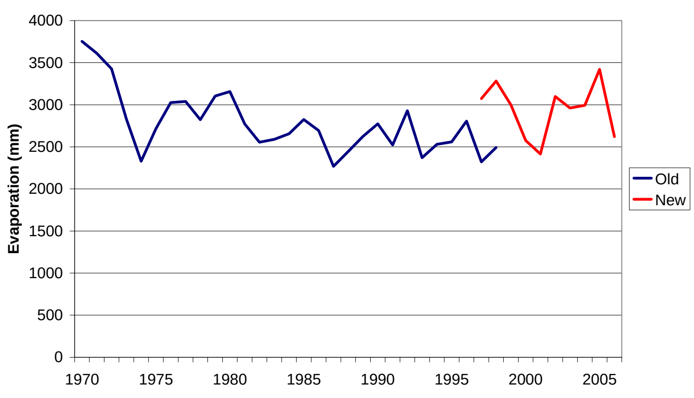

Figure 2. Rabbit Flat annual pan evaporation, old (1970-98) and new (1996-2006) sites.

13. Impacts of Wind System Relocation and Instrument Changes on Wind Speed in Canada

Xiaolan Wang, Climate Research Division, Environment Canada

This is an example showing the impacts of wind system relocation and instrument (anemometer type or wind speed detector/sensor) changes on wind speed time series. The base series here is the time series of monthly surface wind speeds recorded at Nanaimo Airport (Canada) for the 50-year period from January 1954 to December 2003. The geostrophic wind speed series that is derived from homogenized hourly sea level pressure series from a pressure triangle in the region and is best correlated with the Nanaimo wind series is used as a reference series. Note that monthly mean wind speed (non-negative) data are not expected to have a Gaussian distribution. However, the non-Gaussian behavior can be greatly diminished by using the reference series (both base and reference series were de-seasonalized before being tested; see Wang 2008a).

For the Nanaimo-minus-reference wind speed series, the PMTred algorithm (Wang 2008a, Wang and Feng 2007, Wang et al. 2007) identifies 12 changepoints that are significant at 5% level (see Table 1). The changepoint in September 1995 may or may not be significant without metadata support, because its PTmax value lies within the 95% uncertainty range of its 95-th percentile (Wang 2008a); and there is no metadata available to verify this changepoint. Thus, it was determined to be insignificant. As shown in Table 1, all the other 11 shifts have metadata support. Figure 1 shows the regression fits with the 11 shift-sizes estimated from the de-seasonalized base series (solid trend line), and from the base-minus-reference series (dashed trend line).

Table 1. The results of applying the PMTred algorithm to the Nanaimo-minus-geostrophic wind speed series, and the related metadata. Note that only those Type-0 changepoints that have metadata support are listed here. The dates are in the format of YYYY/MM(/DD); and the two dates connected with the word "to" is used to indicate the period in which the change(s) happened (the exact date is unknown). The p-values are estimated with the assumption that the changepoint

Type	Date	p $[p^L, p^U]$	PT_{max} $PT_{max,0.05}$ $[\hat{\phi}^L, \hat{\phi}^U]$	Documented date of change: change(s)
1	1960/02	1.0000 [1.0000, 1.0000]	5.36 [2.96, 3.44]	1957/05/03 to 1961/02/03: Anemometer type change (45B to U2A).
1	1965/07	0.9999 [0.9998, 0.9999]	3.95 [2.97, 3.45]	1961/02/03 to 1967/03/20: Anemometer height change (63 ft to 33 ft, i.e., 19.2 m to 10 m)
0	1974/02	1.0000 [1.0000, 1.0000]	4.26 [2.96, 3.43]	1974/01/24: Advised that the wind speed detector should be replaced because it has a rusted U-arm, which was however not done during the following summer visit on 1974/09/27.
0	1976/01	1.0000 [1.0000, 1.0000]	4.92 [2.93, 3.39]	1975/12/03: Wind speed detector replaced on this day.
1	1980/03	1.0000 [1.0000, 1.0000]	6.32 [2.93, 3.39]	1981/03/04: U2A speed detector **had** bearings jam and was replaced
1	1982/08	1.0000 [1.0000, 1.0000]	4.64 [2.92, 3.38]	1984/01/06: Wind speed detector **was** sticking at low wind speeds and giving a low indication at higher wind speed. Unit was replaced.
1	1985/02	1.0000 [1.0000, 1.0000]	4.72 [2.90, 3.35]	1985/03/20: Wind system relocated on this day.
1	1985/11	0.9999 [0.9999, 0.9999]	3.86 [2.94, 3.41]	1986/06/03: Wind system was given a complete recalibration.
1	1993/02	1.0000 [1.0000, 1.0000]	9.17 [2.95, 3.42]	1993/01/11: Wind speed detector was replaced on this day, with a new tiltpole installed and the old tower removed.
1	1994/06	1.0000 [1.0000, 1.0000]	5.91 [2.89, 3.34]	1994/06: Wind speed detector was replaced, a new tiltpole installed
1	**1995/09**	0.9968 [0.9963, 0.9970]	**3.03 [2.89, 3.34]**	**1994/07 to 1997/04: No metadata available.**
1	1997/04	1.0000 [1.0000, 1.0000]	8.30 [2.95, 3.42]	**1994/07 to 1997/04: No metadata available.**

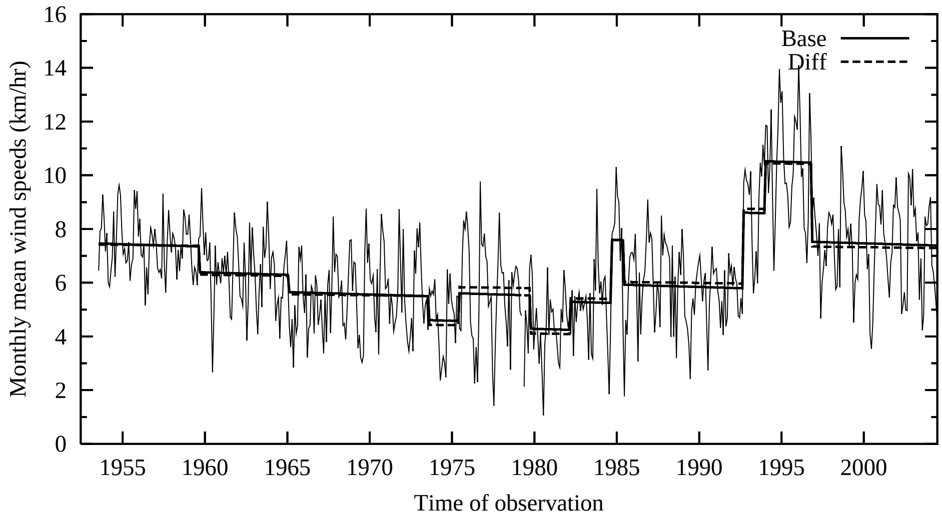

Figure 1. Time series of monthly mean surface wind speeds recorded at Nanaimo Airport (Canada) for the 50-year period from January 1954 to December 2004, and it multi-phase regression fits (Wang 2008a).

The 11 shift-sizes are estimated to be -1.07, -0.69, -1.07, 1.42, -1.69, 1.33, 2.19, -1.55, 2.78, 1.70, and -3.07 km/hr, respectively, from the base-minus-reference series, and -0.96, -0.64, -0.89, 1.03, -1.24, 1.05, 2.35, -1.66, 2.82, 1.94, and -2.95 km/hr, respectively, from the de-seasonalized base series. The shift-adjusted monthly mean wind speed series is estimated to have a linear trend of –0.000663 km/hr per month with adjustments estimated from the difference series, or –0.001510 km/hr per month with the adjustments estimated from the de-seasonalized base series (Wang 2008a). Ignoring these artificial shifts will result in an estimate of linear trend to be 0.002404 km/hr per month, which is of the opposite sign to the estimated from the adjusted series.

Note that another algorithm, the PMFred algorithm (Wang 2008a and 2008b, Wang and Feng 2007) was also applied to the de-seasonalized base series. Although no reference series was used in this application, the PMFred algorithm also identifies all the major shifts (except the fifth, seventh, and eighth in Table 1).

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14. Global Stratospheric Temperature from Reanalyses

Dian Seidel, NOAA Air Resources Laboratory, US

Reanalyses are data products based on blending a variety of observations by assimilating them into a global weather forecasting model to obtain meteorological fields that are consistent both with the observations and with the model physics (Kalnay et al. 1996, Kistler et al. 2001, Uppala et al. 2005). These fields are potentially appealing for climate research because they are spatially and temporally complete and include a full suite of variables. Furthermore, reanalyses are done with a fixed numerical weather model, thus avoiding inhomogeneities associated with changes in forecast models and analysis methods over time.

However, holding the reanalysis model constant is not sufficient to ensure the homogeneity of the resulting datasets. The assimilations only optimize the observational data for a limited time window, relevant to synoptic-scale weather systems. They are not capable of identifying and adjusting time-varying data biases that lead to inhomogeneities in climate records. On the contrary, inhomogeneities in the input data, and in the mix of data types, have been shown to lead to inhomogeneities in the reanalyses (Pawson and Fiorino 1999, Kistler et al. 2001, Randel et al. 2004, Karl et al 2006). As seen in Fig. 1, stratospheric temperature data from different reanalyses show very different long-term behavior. Therefore, several studies have concluded that analyses and reanalyses should not be used, or used only with caution, for the detection of climate trends (Trenberth and Guillemot 1995; Kistler et al. 2001, Karl et al. 2006,)

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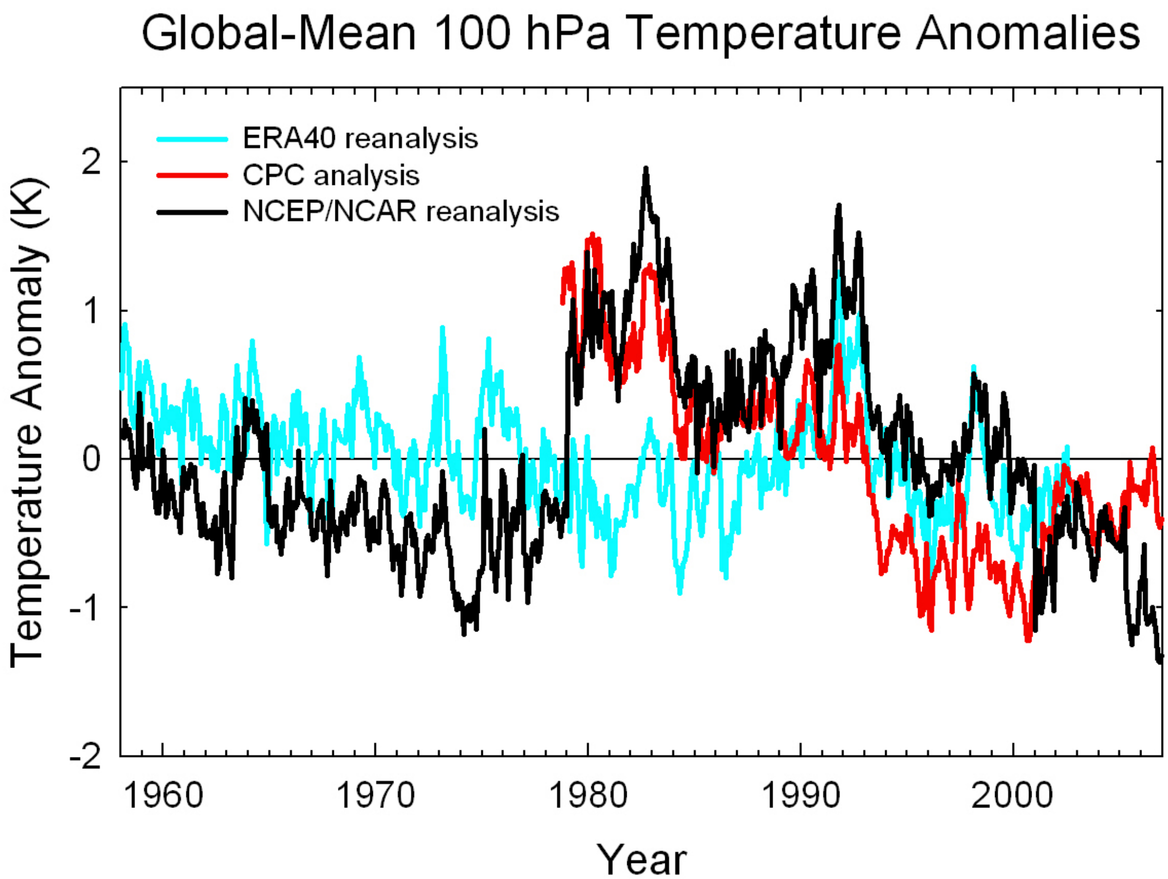

Figure 1. Time series of global-mean 100 hPa monthly temperature anomalies from two reanalyses (ECMWF Reanalysis (ERA40) and NCEP/NCAR) and the NOAA Climate Prediction Center (CPC) analyses. The sharp increase in temperature in the NCEP/NCAR reanalysis in 1978 coincides with the introduction of satellite data. The CPC analysis method changed in 2001, which may explain the upward temperature step in that data product. (Data provided by Bill Randel and Fei Wu (NCAR). The NCEP/NCAR reanalysis, ERA40, and CPC analyses are described by Kalnay et al. (1996), Gelman et al. (1986), and Uppala et al. (2005), respectively.)

15. Effects of Changes in Instruments and Methods of Observation on Radiosonde Temperature and Humidity Data

Dian Seidel, NOAA Air Resources Laboratory, US

Radiosondes are balloon-borne expendable instruments that have been flown daily or twice-daily, at hundreds of stations around the world, since the 1950's, to measure temperature, humidity, pressure, geopotential height, and winds from the surface to the lower stratosphere (about 10 hPa). The following factors have all been shown to cause potential inhomogeneities in radiosonde data time series (Gaffen 1994, Parker and Cox 1995, Lanzante et al. 2003, Thorne et al. 2005):

- Changes in sensor type and design
- Changes in sensor housing
- Changes in balloon type, balloon rate of rise, and the length of the cord attaching the sonde to the balloon
- Changes in data correction methods for radiation and lag errors
- Changes in ground systems, including balloon tracking methods and data processing techniques
- Changes in ground station location

It is difficult to adjust radiosonde data to remove artificial inhomogeneities (Free et al. 2002). This is because of the general lack of near-neighbor stations, or the likelihood that similar changes were made across entire national radiosonde networks. Several very different approaches have been used to identify and adjust for breakpoints (Lanzante et al. 2003, Thorne et al. 2005, Haimberger 2007). None of these approaches can be considered perfect. Inhomogeneities may be evident at some altitudes and not others (Lanzante et al. 2003) and may vary with time of day and season (Elliott et al. 2002), due to solar radiation effects. Furthermore, adjustments to one meteorological element (e.g., temperature) should be done consistently with other elements (e.g. geopotential height) and in such a way as to maintain hydrostatic balance, etc. Consequently, adjustment methods have addressed only temperature data and in most cases only monthly anomaly values (Parker et al. 1997, Lanzante et al. 2003, Free et al. 2005, Thorne et al. 2005), not daily soundings or even monthly mean temperature. To date, only the method of Haimberger (2007) produces launch-resolution absolute and anomaly temperatures.

Figures 1 and 2 provide two examples of inhomogeneities in radiosonde data due to known causes. However, radiosonde metadata are neither complete nor necessarily always accurate, so it is good practice to be dubious of the homogeneity of any unadjusted long-term radiosonde data record. Even adjusted radiosonde temperature datasets are imperfect (Karl et al. 2006, Sherwood et al. 2006, Randel and Wu 2006) and should be used with caution.

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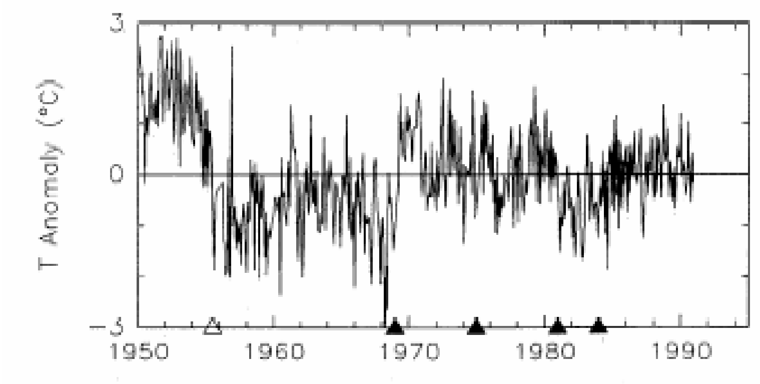

Figure 1. Time series of 200 hPa monthly temperature anomalies at Hong Kong. Open triangle shows the date of a change in radiation corrections applied to the radiosonde temperature data. Solid triangles show the dates of known changes in radiosonde types. (Taken from Gaffen (1994), Figure 3.)

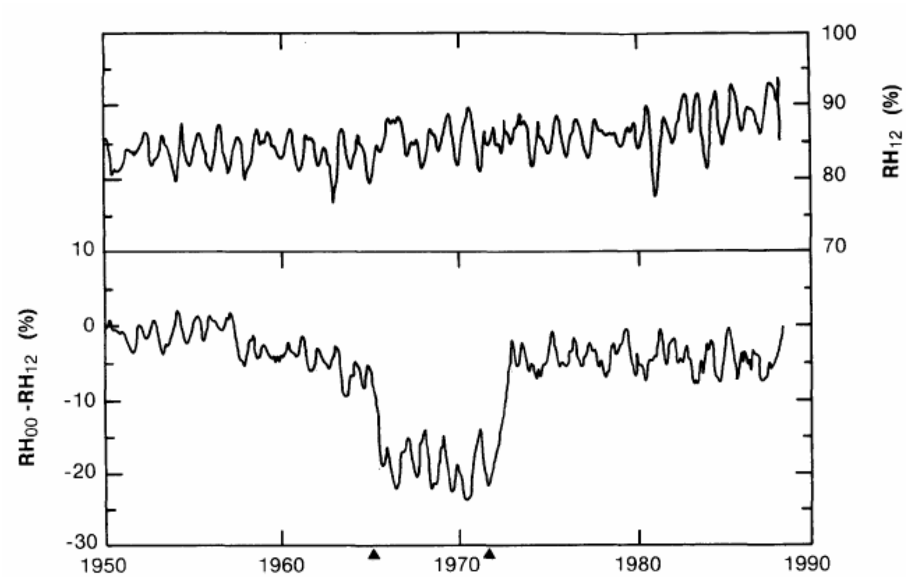

Figure 2. Monthly 850 hPa relative humidity anomalies at Hilo, Hawaii. The top panel shows nighttime (1200 UTC) observations, and the bottom panel shows the day/night difference (0000 minus 1200 UTC). Triangles show dates of a change in humidity sensor type in 1965 and a change in the housing of the humidity sensor in 1973. During the period 1965-1973, daytime relative humidity RH observations were about 15% RH lower than the preceding and following periods, but nighttime data appear unaffected. (Before 1957, soundings were taken at 0300 and 1500 UTC, but the data are plotted here as 0000 and 1200 UTC data.) (Taken from Elliott and Gaffen (1991), Figure 4.)

16. Deep-layer Atmospheric Temperatures from Satellite-borne Microwave Sounders

Carl Mears, Remote Sensing Systems, Santa Rosa, California, US

Satellite-borne sounders use microwave emission from Oxygen molecules to measure the temperature of deep layers of the atmosphere. To construct a long-term temperature record from these data, measurements from multiple, sequentially-launched, polar-orbiting satellites must be combined. To ensure accuracy, it is important to account for a number of inhomogeneities:

- Intersatellite biases (Spencer and Christy 1990).
- Calibration issues due to changes in sensor and calibration target temperature These temperature changes are caused by changing exposure to solar radiation(Christy et al. 1998; Christy et al. 2003; Mears et al. 2003; Vinnikov et al. 2005).
- Drifting of spacecraft (vertically and longitudinally) from original insertion point (Christy et al. 1998; Wentz and Schabel 1998; Mears and Wentz 2005).
- Changing measurement frequencies and bandwidths as newer generation instruments come on-line.

These effects are often of the same order of magnitude as the long-term signal of variability and change, making it critically important to accurately assess and adjust for each effect. In the figure below, we show an example of the removal of the first 3 types of inhomogenities for two overlapping satellites, NOAA-12 and NOAA-14. An example is shown in Fig. 1.

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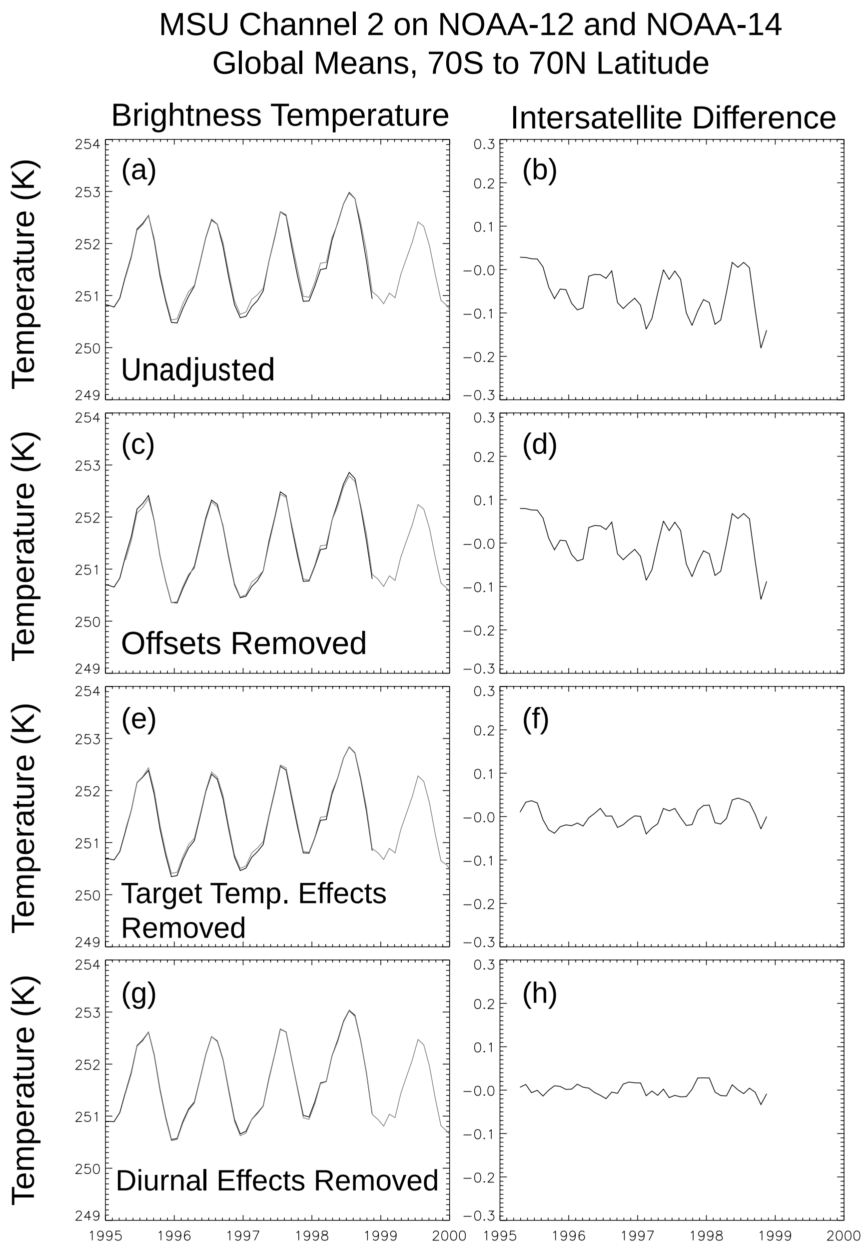

Figure 1. An example of the effects of the MSU/AMSU calibration procedure. The left column shows the temperatures measured by MSU2 on the NOAA-12 (black) and the NOAA-14 (grey) satellites, and the right column shows the difference between the temperatures. (a) and (b) show the unadjusted data. In (c) and (d) the overall offset has been removed, but large fluctuations remain which are due to calibration errors caused by changes in the temperature of the calibration target, which are removed in (e) and (f). Note that small fluctuations remain in the difference time series, including a small slope from 1995 onwards, caused by the diurnal cycle aliasing into the time series because of drifting measurement time. The diurnal cycle is removed in (g) and (h) using a model-based diurnal adjustment.