Classic Examples of Inhomogeneities in Climate Datasets

Following examples, which are contributed by experts from different parts of the world, illustrate the main causes of, and possible impacts on climate trend analyses from, inhomogeneities in climate datasets. Many approaches and statistical techniques have been developed for detecting the inhomogeneities and adjusting climate datasets but further research is still required to fully address this difficult issue. For example, observations are often taken for forecasting purposes and not for long-term climate monitoring. Changes in instruments and in observing procedures may have made the observations easier or more accurate, they may have also generated artificial biases in the long-term time series.

Surface air temperature

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(This activity is coordinated by Lucie Vincent (Lucie.Vincent at ec.gc.ca) of Climate Research Division, Environment Canada)

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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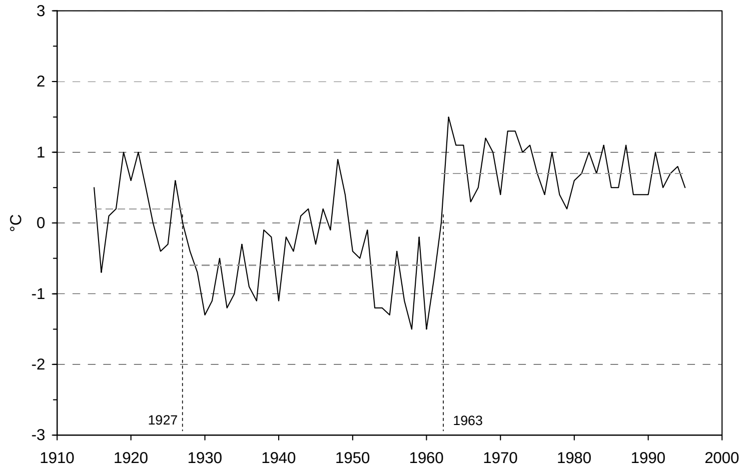

Figure 1. Difference between the annual mean of the daily minimum temperatures of Amos and a reference series computed from surrounding stations.

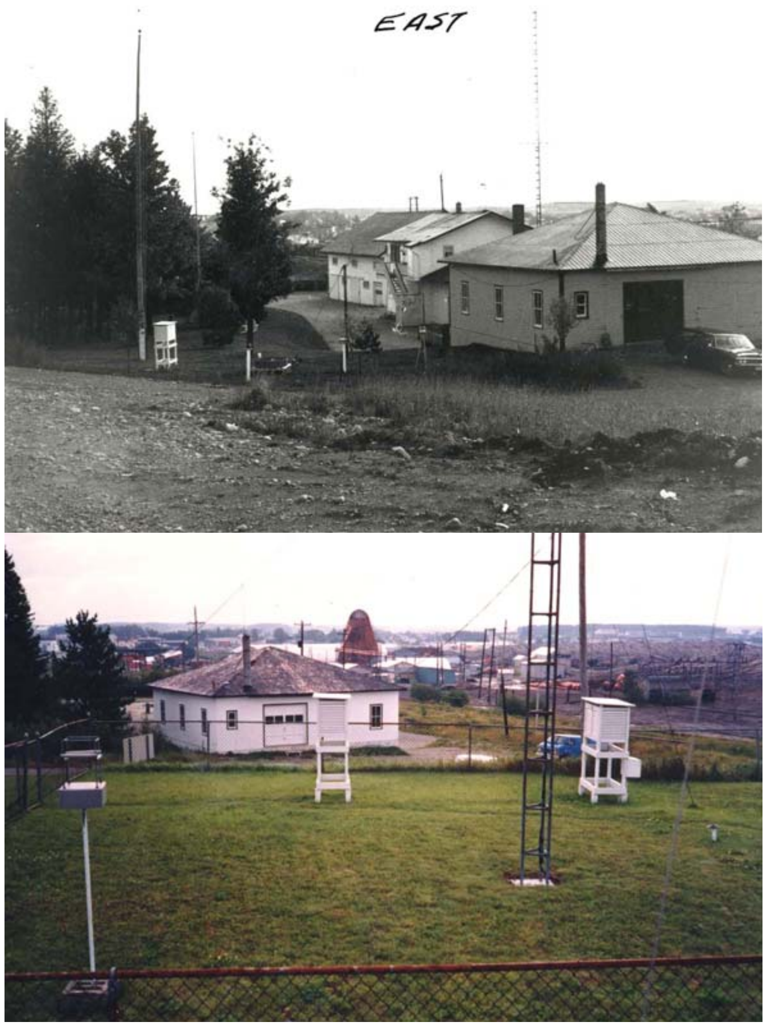

Figure 2. Screen location before and after 1963.

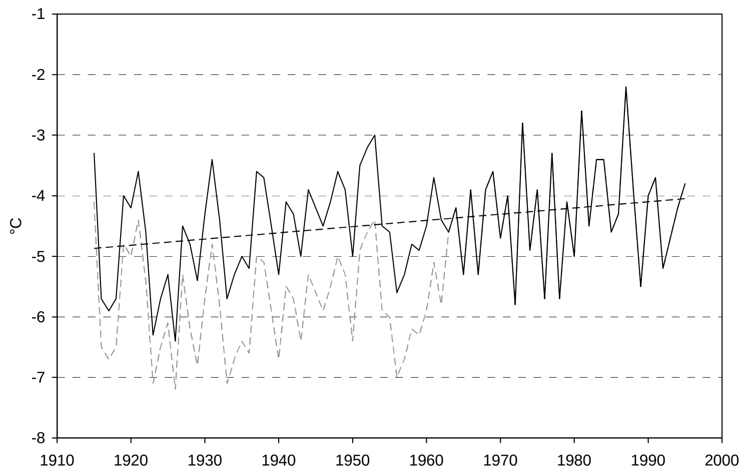

Figure 3. Original (dashed line) and adjusted (full line) annual mean of daily minimum temperatures for Amos, Canada, 1915-1995.

3. Impact of Station Relocation on Temperature in China

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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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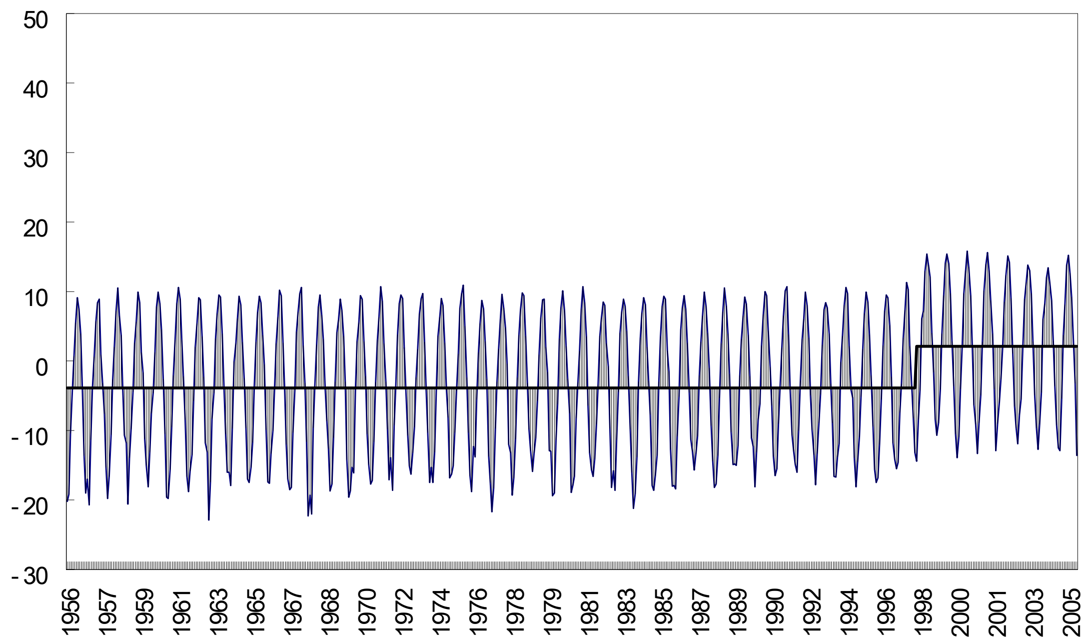

Figure 1. Step change (Jan 1998) in monthly mean surface air temperatures series on Wutaishan (53588)

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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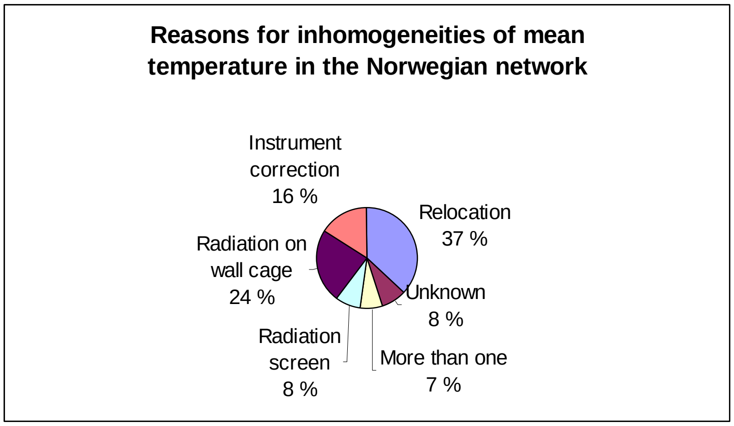

Figure 1. Reasons for inhomogeneities in the Norwegian station network as detected by the SNHT for the period 1876 – 1995 (Nordli 1997).

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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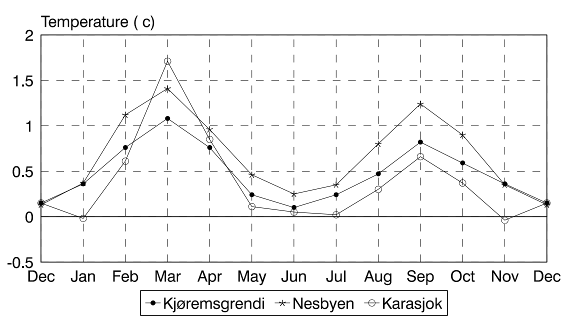

Figure 1. Mean monthly differences between daily minimum temperature computed according to the present definition minus the one used during the period 1894 – 1937. The three stations represented on the figure are all situated in continental climate.

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.

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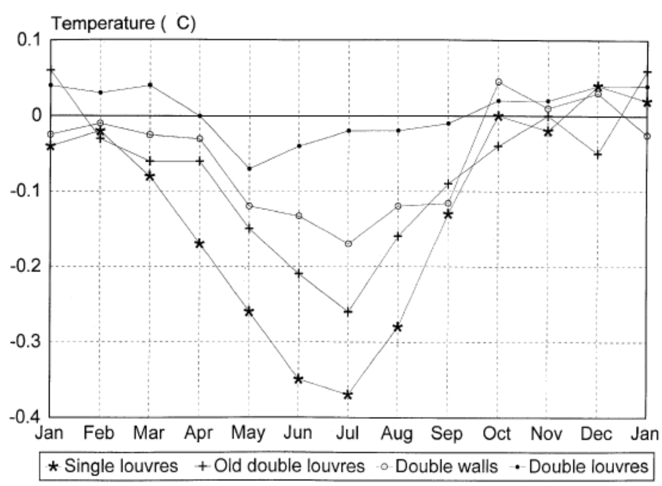

Figure 1. Nordli, Ø., H. Alexandersson, P. Frich, E. Førland, R. Heino, T. Jónsson, O. E. Tveito. 1997: The effect of radiation screens on Nordic time series of mean temperature. Int. J. Climatol., ***17****, 1667-1681.*

7. Impact of Station Relocation on Temperature in Uruguay

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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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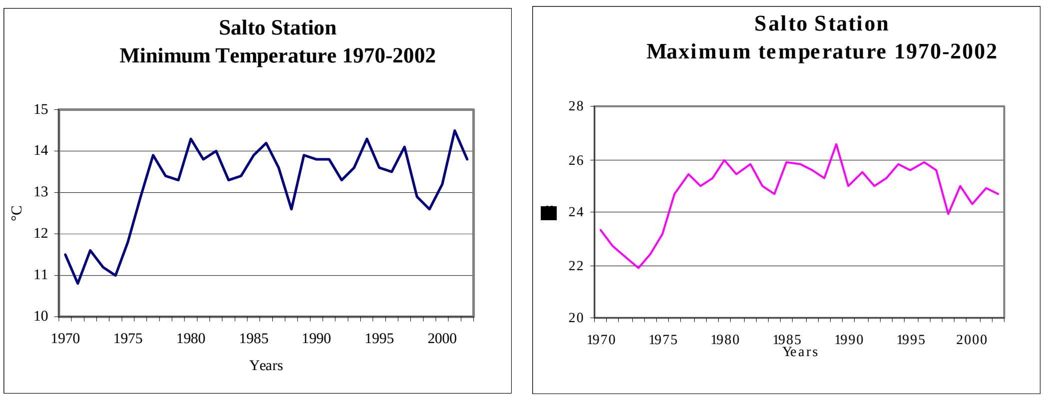

Figure 1. a) Annual mean minimum temperature and b) annual mean maximum temperature for Salto, 1970-2002.

8. 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.

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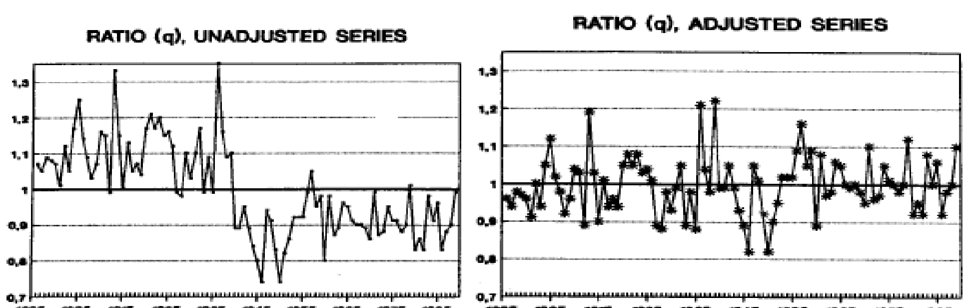

Figure 1. Results from performing the SNHT on unadjusted and adjusted annual precipitation series (1895-1990) from Briksdal. q is the ratio between normalised precipitation at Briksdal and selected reference stations (from Hanssen-Bauer & Førland, 1994).

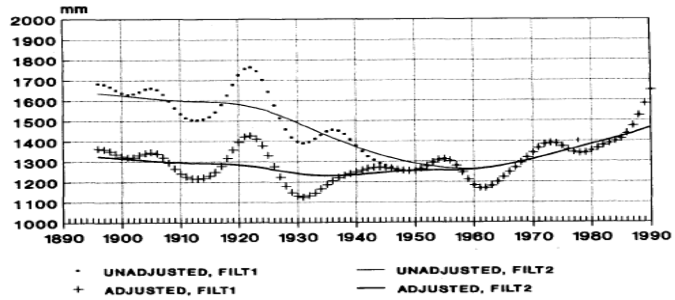

Figure 2. Unadjusted and adjusted series of annual precipitation at Briksdal. FILT1 and FILT2 are low-pass filters involving Gaussian weighting functions with standard deviations 3 resp. 9 years (from Hanssen-Bauer & Førland, 1994).

9. 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 20^{th} 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.

References

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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).

10. 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).

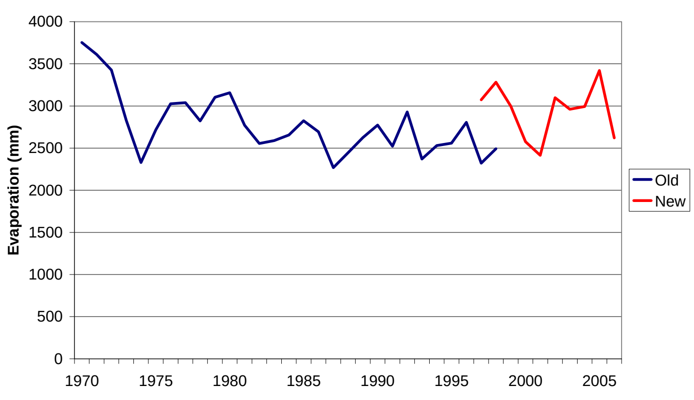

Figure 2. Rabbit Flat annual pan evaporation, old (1970-98) and new (1996-2006) sites.

11. 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. A reference series was constructed by averaging the surface wind speeds recorded at 5 other stations in the same province that are most closely correlated with the Nanaimo series. This reference series was first subject to homogeneity tests and *preliminarily* homogenized through adjustments for two significant undocumented mean-shifts. 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.

For the Nanaimo-minus-reference wind speed series, the PMTred algorithm (Wang 2007a, Wang and Feng 2007, Wang et al. 2007) identifies 5 changepoints that are significant even without metadata support (i.e., significant undocumented or Type-1 changepoints); these are October 1960, August 1971, February 1985, February 1993, and April 1997. Although statistically significant at the 5% level, the August 1971 shift is estimated to be negligible ($\hat{\Delta} = -0.023$ m/s; it is not even visible in Fig. 1; also it has no metadata support. Thus, it was concluded to be of no physical significance for the base series (it may be due to a problem in the reference series) and thus not to be adjusted (adjustment for this changepoint would make little difference for the base series anyway).

Investigation of the Nanaimo metadata reveals that: 1) the anemometer was changed from Type 45B to Type U2A in February 1961; 2) the wind system was relocated on 20 March 1985; 3) the wind speed detector was replaced in January 1993. These documented changes confirm the first three changepoints identified by the PMTred algorithm; the estimated times of change are only one or 4 months apart from their true times of change. Since station inspection reports are missing for the period of 1994-1998 (a paper-to-digital report transition period), the last shift (April 1997) can not be verified at this time. However, it is suspected that this shift is very likely due to the introduction of wind speed sensor (which often took place in the 1990s in Canada).

The four shift sizes are estimated to be -1.07, 1.43, 4.20, and -2.03 m/s, respectively; and the shift-adjusted monthly mean wind speed series is estimated to have a linear trend of -0.004501 m/s per month and an autocorrelation of 0.310 (Wang 2007a). Ignoring these artificial shifts will result in an estimate of linear trend to be 0.002404 m/s per month.

Note that another algorithm, the PMFTred algorithm (Wang 2007b and 2007c, Wang and Feng 2007, Wang 2003) was also applied to the time series of Nanaimo monthly mean wind speed anomalies (i.e., the base series with its mean annual cycle subtracted). Although no reference series was used in this application, the PMFTred algorithm also identifies all the four shifts, estimating the changepoint times to be October 1960, January 1984, February 1993, and April 1997, which are also of good accuracy (almost the same as does the PMTred algorithm, which needs to use a reference series).

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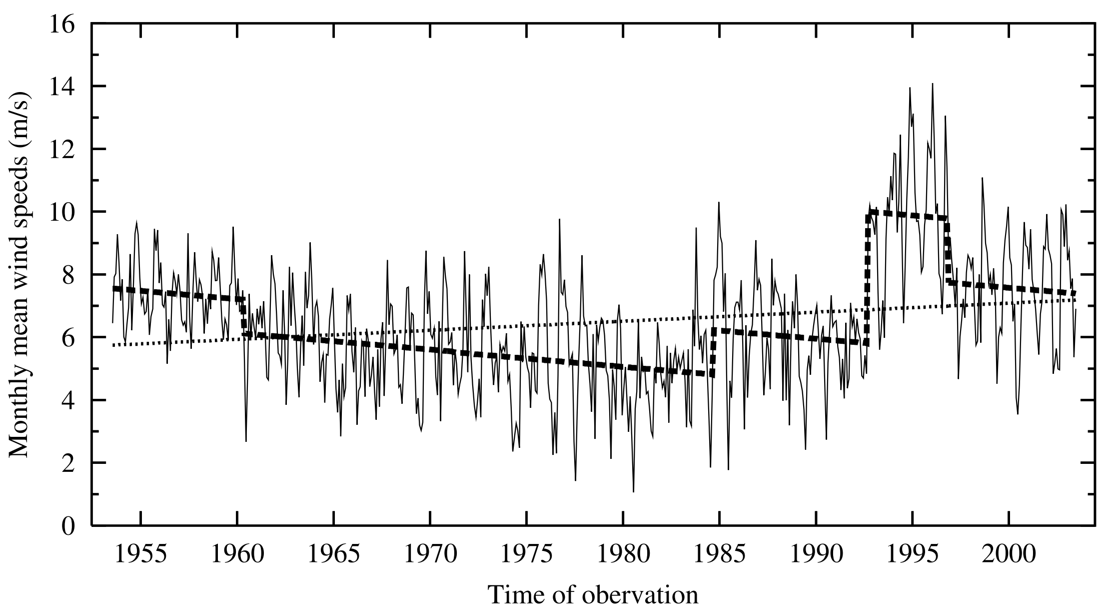

Figure 1. Time series of monthly surface wind speeds recorded at Nanaimo Airport (Canada) for the 50-year period from January 1954 to December 2003. The thick dashed line is the multi-phase regression fit (Wang 2007a). The dotted line is the linear trend estimated from the unadjusted data series.

12. 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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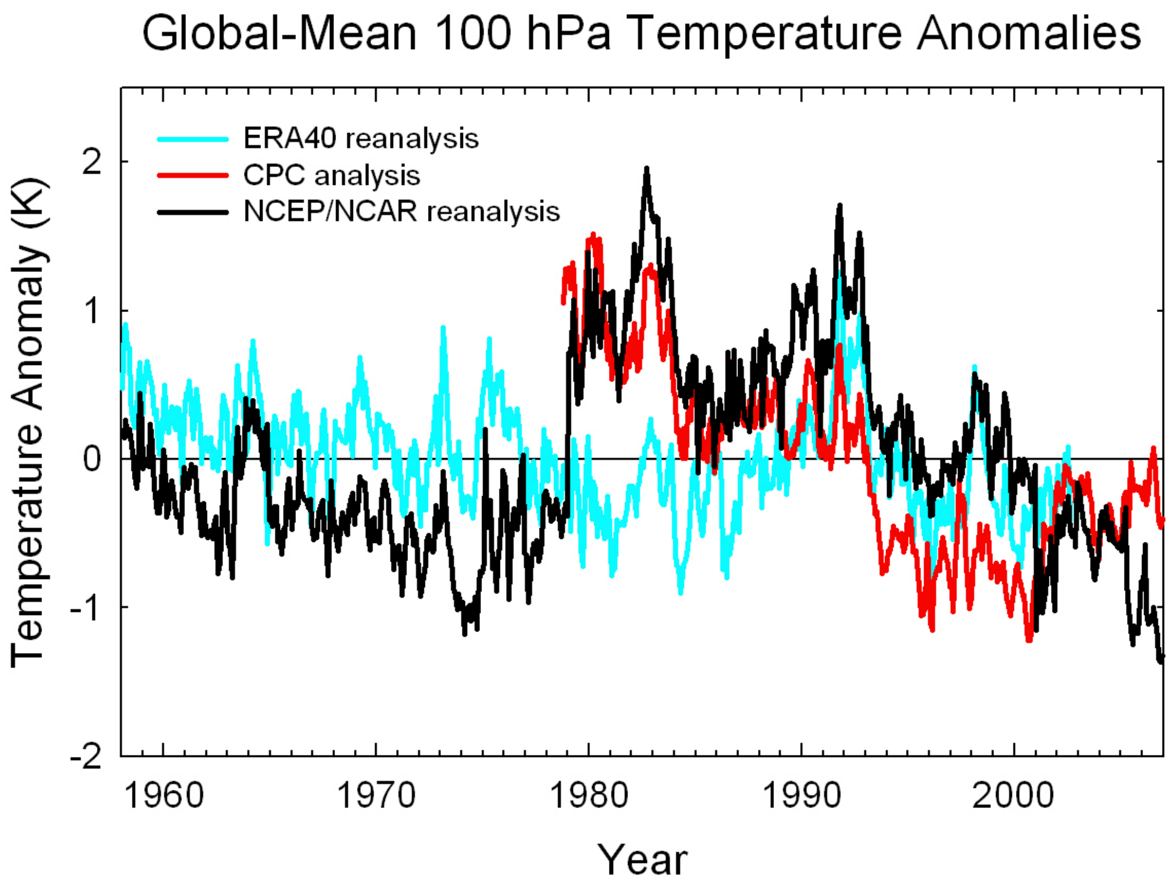

Figure 1. Time series of global-mean 100 hPa monthly temperature anomalies from two reanalyses (ECMWF Reanalysis (ERA40) and NCEP/NCAR) and the NOAA Climate Prediction Center (CPC) analyses. The sharp increase in temperature in the NCEP/NCAR reanalysis in 1978 coincides with the introduction of satellite 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.)

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

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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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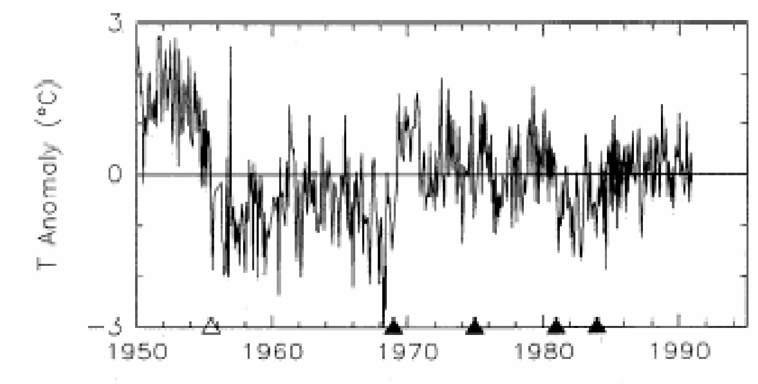

Figure 1. Time series of 200 hPa monthly temperature anomalies at Hong Kong. Open triangle shows the date of a change in radiation corrections applied to the radiosonde temperature data. Solid triangles show the dates of known changes in radiosonde types. (Taken from Gaffen (1994), Figure 3.)

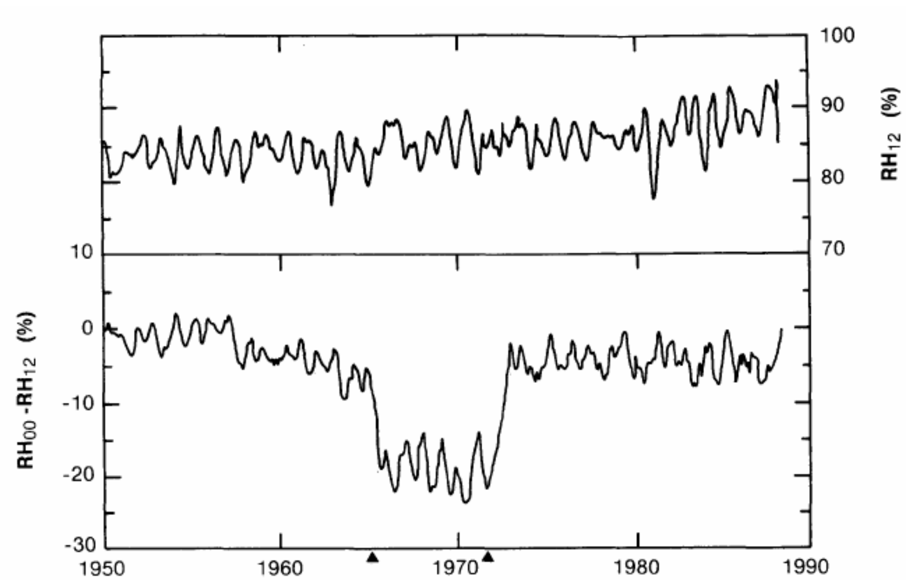

Figure 2. Monthly 850 hPa relative humidity anomalies at Hilo, Hawaii. The top panel shows nighttime (1200 UTC) observations, and the bottom panel shows the day/night difference (0000 minus 1200 UTC). Triangles show dates of a change in humidity sensor type in 1965 and a change in the housing of the 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.)

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

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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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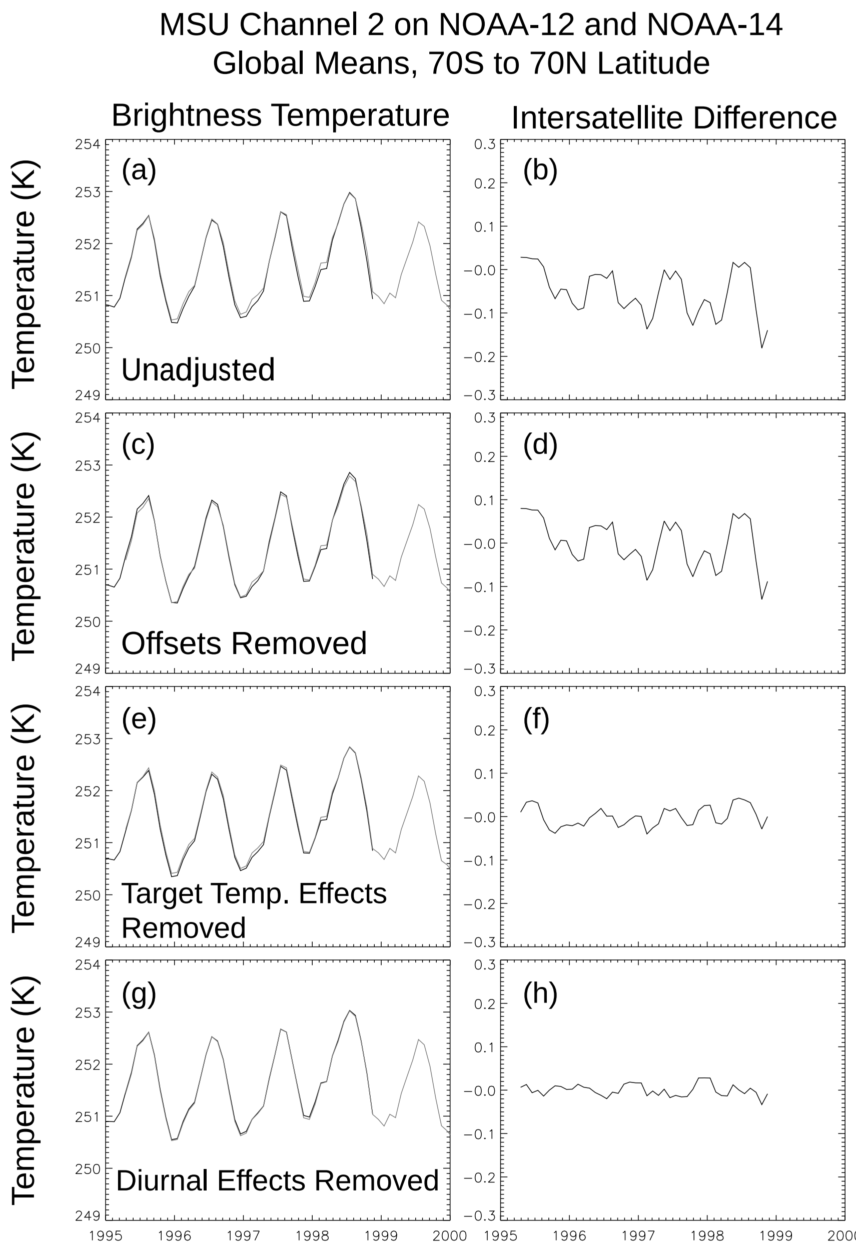

Figure 1. An example of the effects of the MSU/AMSU calibration procedure. The left column shows the temperatures measured by MSU2 on the NOAA-12 (black) and the NOAA-14 (grey) satellites, and the right column shows the difference between the temperatures. (a) and (b) show the unadjusted data. In (c) 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.