A Physics-based Correction Model for Homogenizing Sub-daily Temperature Series

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Abstract

A new physics-based technique for the correction of inhomogeneities present in sub-daily temperature records is proposed. The approach accounts for changes in the sensor-shield characteristics that affect its energy balance dependent on ambient weather conditions (radiation, wind). For this purpose an empirical model is formulated that reflects the main atmospheric processes and can be used in the correction step of a homogenization procedure by distributing a known mean step-size to every single measurement. It thus provides a reasonable alternative correction procedure for high-resolution historical climate series.

1. Introduction

Homogeneous long-term climatological data in high temporal resolution is desirable to address trends and variability in the mean climate and in climatic extremes (1,2). But long records often contain ***inhomogeneities due to non climatic changes.***

High temporal resolution data series in combination with multivariate data allows more physics-based correction methods for subdaily temperature series (3).

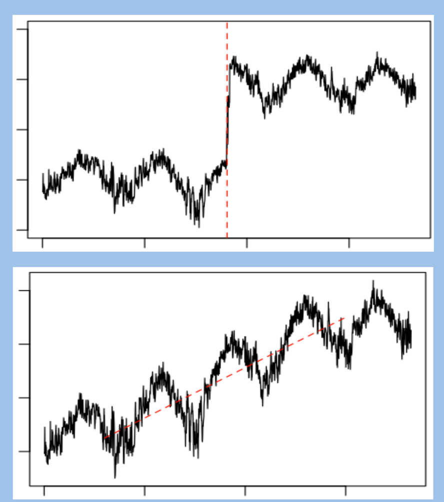

Fig. 1: Examples of in-homogeneities (artificial).

2. Inhomogeneity in Temperature Series: Basel, 1966

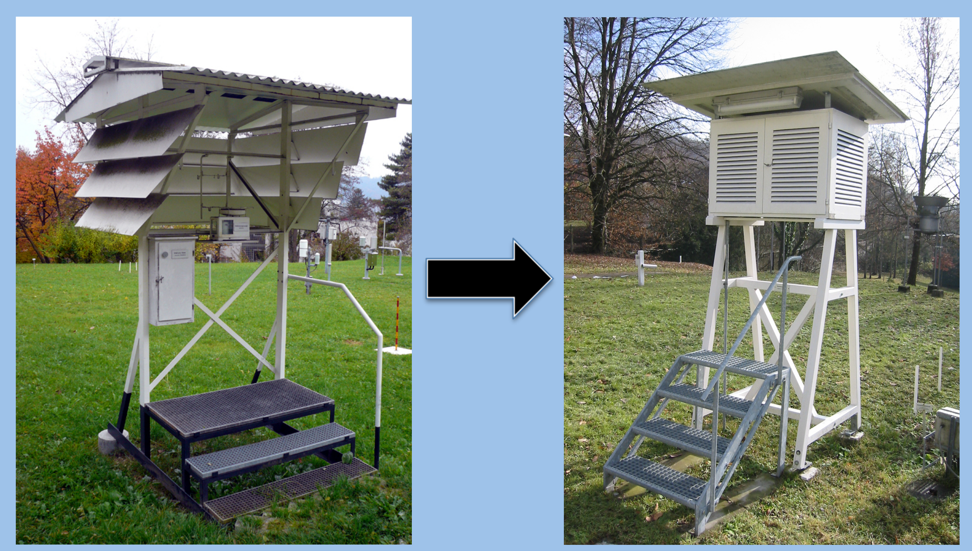

Fig. 2 and 3: In 1966 the Wild screen (left) was replaced by a Stevenson screen (right) (3) which produced a break in the Basel temperature series (4,5) (pictures: Della-Marta P.).

Tab. 1: Step sizes in the subdaily Basel temperature series on 1. 1. 1966, statistically estimated differences from the reference series Zurich between period H1 (1966-70) and H2 (1956-65).

difference series	$T_{Ref\_H2} - T_{Wild\_H2}$ μ	sd	$T_{Ref\_H1} - T_{Stev\_H1}$ μ	sd	$\overline{\Delta e_r}$ μ
morning	0.68	1.48	0.82	1.38	**-0.14**
noon	1.29	2.02	0.87	1.91	**0.42**
evening	0.76	1.5	1.22	1.34	**-0.46**

Parallel measurements taken in the Stevenson screen during the period 1956-62 were recently digitized and serve as reference for our adjustments.

3. Error Model

unequal shielding characteristics

unequal heating of sensors

$$dQ_{sensor1} \neq dQ_{sensor2}$$

$$dQ_{sensor} = c_1\, R_{sensor} + c_2\, Q_{sensible} = c_1\, R_{sensor} + c_2\, R_{screen}\ vent$$

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Approach : simple energy balance

heat (dQ) may reach sensor in two ways, either as radiative flux (R_{sensor}) or as sensible heat flux from the screen ($Q_{sensible}$), modulated by the wind speed ($vent$)

⇒ difference between two sensor-shield-systems expressed by difference parameters

$$dQ_{sensor1} - dQ_{sensor2} = \underbrace{(c_{1,1} - c_{1,2})}_{\dot{c}_1} R_{sensor} + \underbrace{(c_{2,1} - c_{2,2})}_{\dot{c}_2} R_{screen}\ vent$$

3 model parameters: $\dot{c}_0,\ \dot{c}_1,\ \dot{c}_2$

3 model constraints: $\overline{\Delta e_j}$ mean shift for j *in* $T_{morn},\ T_{noon},\ T_{eve}$

$$\overline{\Delta e_j} = \dot{c}_0 + \dot{c}_1 \sum_{i_j=1}^{n} R_{sensor,i,j} + \dot{c}_2 \sum_{i_j=1}^{n} R_{screen,i,j} \left(1 - \exp\left(\frac{-k}{v_{i,j}}\right)\right)$$

$\overline{\Delta e_j}$ mean shift at time of screen change for j

$\dot{c}_0$ offset (e.g. instrumental offset)

k coefficient

v_i wind speed (i = state observation)

4. Results

4.1 Physics-based Derived Corrections

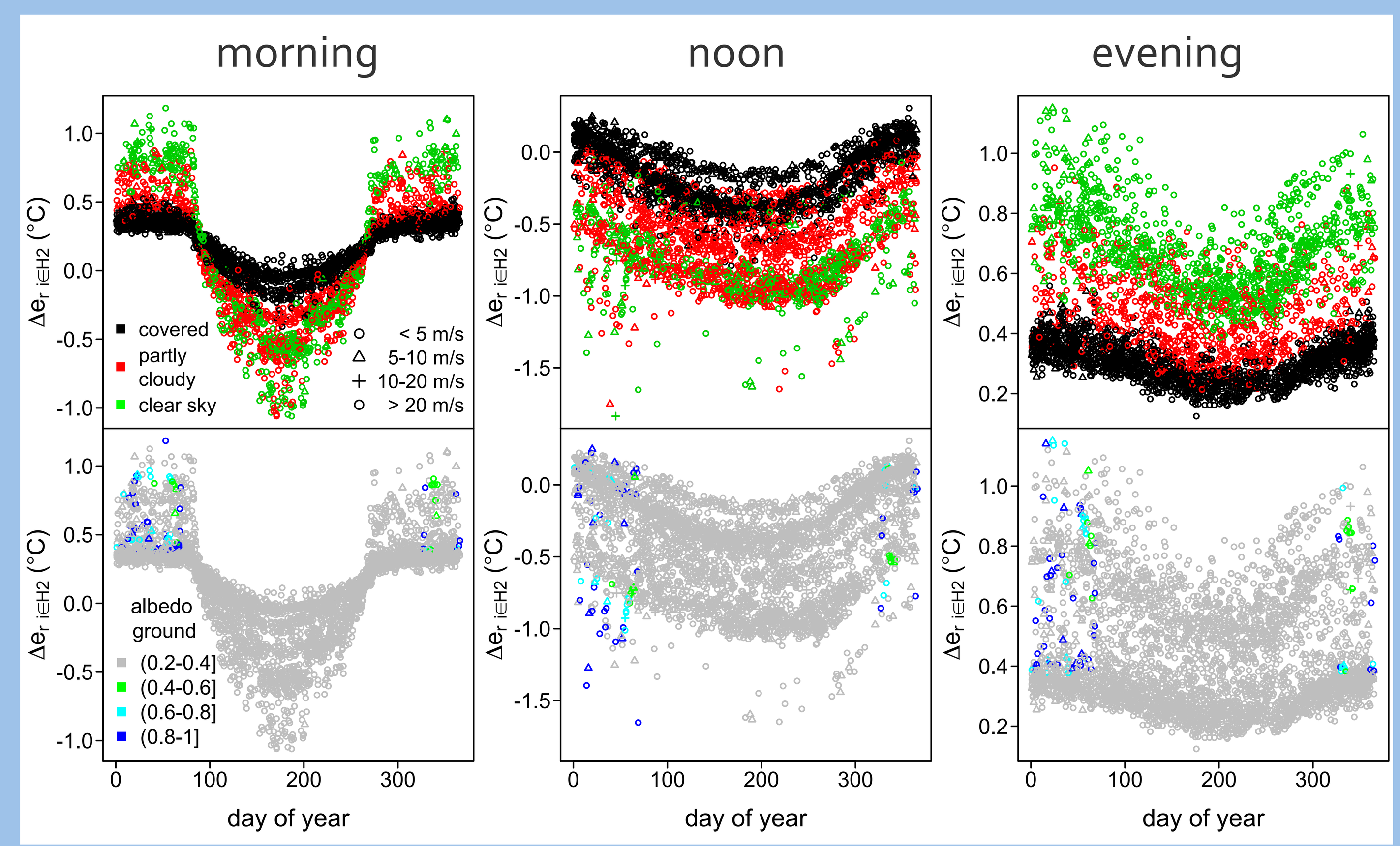

Fig. 4: Derived corrections as function of day-of-year for, top row: different cloudiness conditions (symbol colors) and wind speeds (symbol style) and bottom row: different ground albedo values (symbol colors). Ground albedo values were derived from a snow-accumulation model accounting for snow covered days and aging snow.

4.2 Validation: Corrections vs. Parallel Series

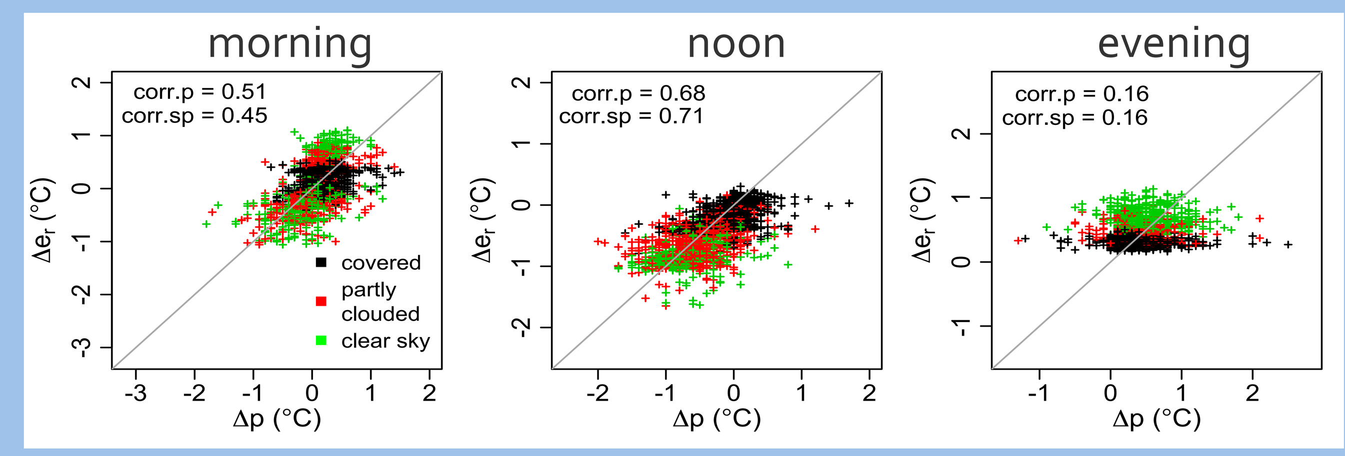

Fig. 5: Correlation (*corr.p = Pearson; corr.sp = Spearman*) between differences from parallel measurements, *Δp* (*observed*), and physics-based corrections, *$Δe_r$* (*calculated*).

4.3 Improvement After Correction

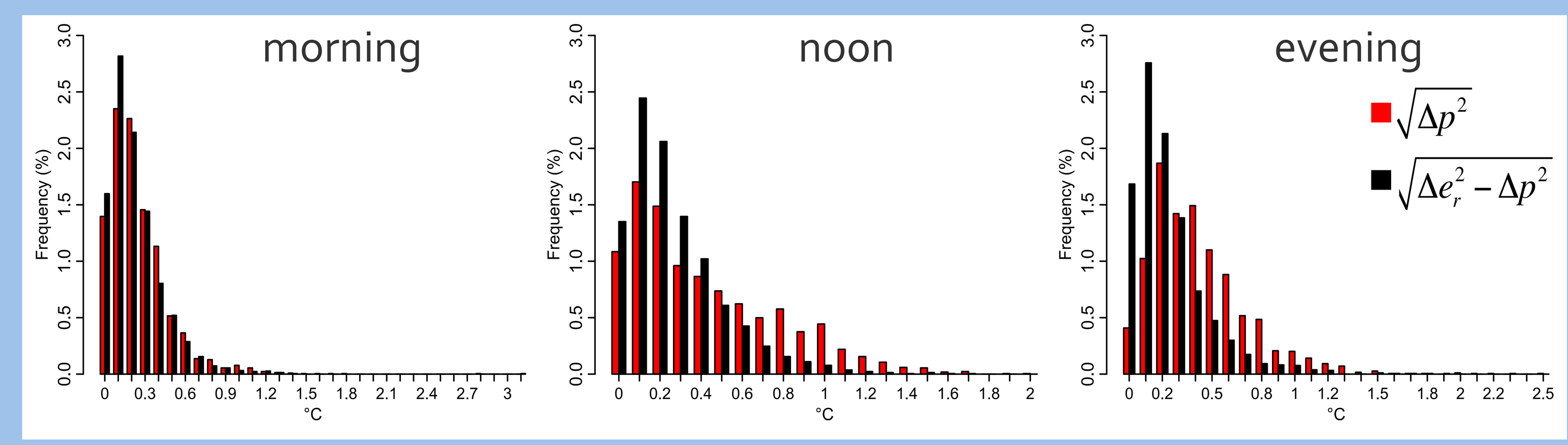

Fig. 6: Histograms of absolute differences from parallel measurements, $\sqrt{\Delta p^2}$ (observed) (red) and the absolute remaining errors after correction, $\sqrt{\Delta e_r^2 - \Delta p^2}$ *(calculated minus observed)* (black). Correction addresses mean (error distribution shifted towards zero) and tails of the distribution (distribution gets narrower, large errors decrease) for all three observation times.

4.4 Impact on Extreme Temperatures

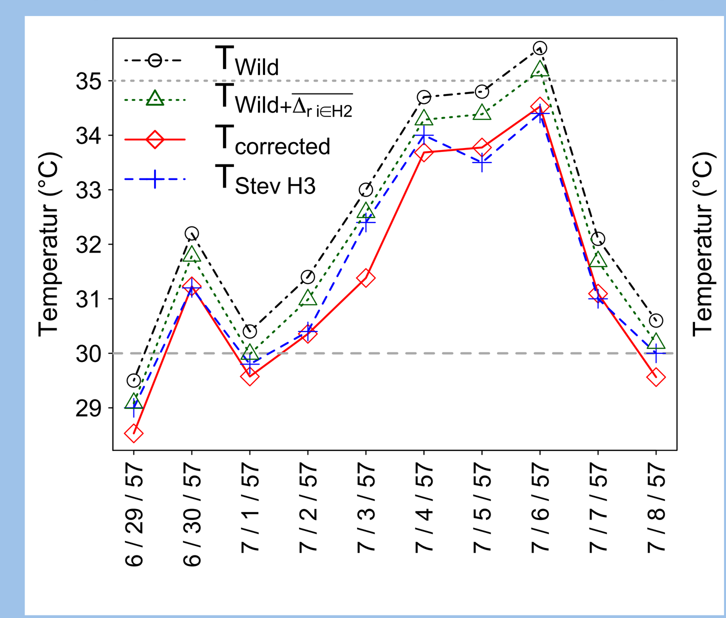

Fig. 7: Comparison of the uncorrected series (T_{Wild}), the series corrected for a mean shift ($T_{Wild+\Delta r}$), the physics-based corrected series ($T_{corrected}$), and the parallel measurements in the overlapping period (T_{Stev}) during a period of consecutive hot days in the beginning of July 1957 for noon temperature.

Conclusions

- **The wealth of information in a multivariate, high temporal resolution data series allows a physics-based break correction approach**
- **Error is distributed to every single value based on physical assumptions, mean shift is preserved**
- **Improvement of series after correction (error distribution gets narrower)**
- **Remarkably good agreements of corrections with parallel measurements in period with extreme high temperatures**

References

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