TemperatureImputations

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Contents

1 Introduction

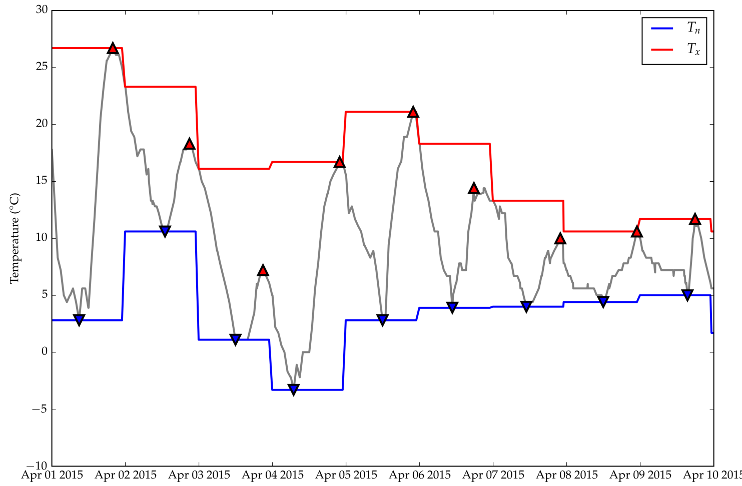
- explain the problem we're trying to solve

1.1 bias in recorded daily minima and maxima induced by time of measurement

- explain
- demonstrate using hourly temperatures from one station: reduce to daily min and max and show difference as a function of measurement hour

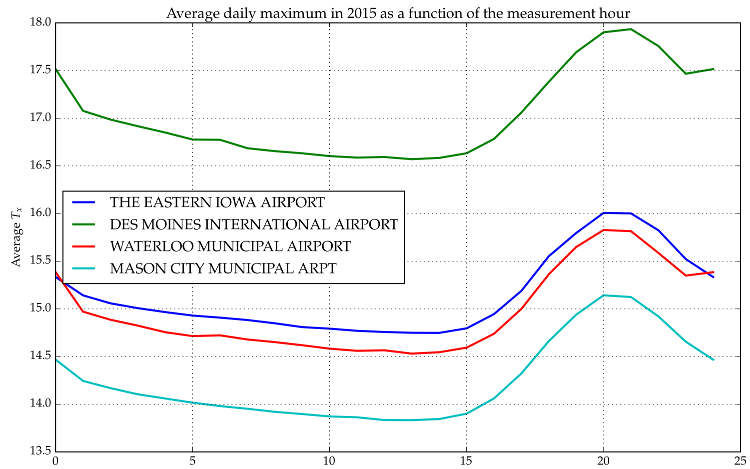
We illustrate the measurement bias in daily maxima and minima with ten days of hourly temperature measurements from the Waterloo Municipal Airport station in Iowa. Ideally, T_x measurements should capture the peak of each diurnal cycle, and T_n its trough. In Figure X, those ideal measurements are indicated by the red and blue triangles respectively. The actual measurements are obtained by dividing the data into 24 hour measurement windows, and extracting the minimum and maximum. For each window, we plot these extrema with a red and blue horizontal line.

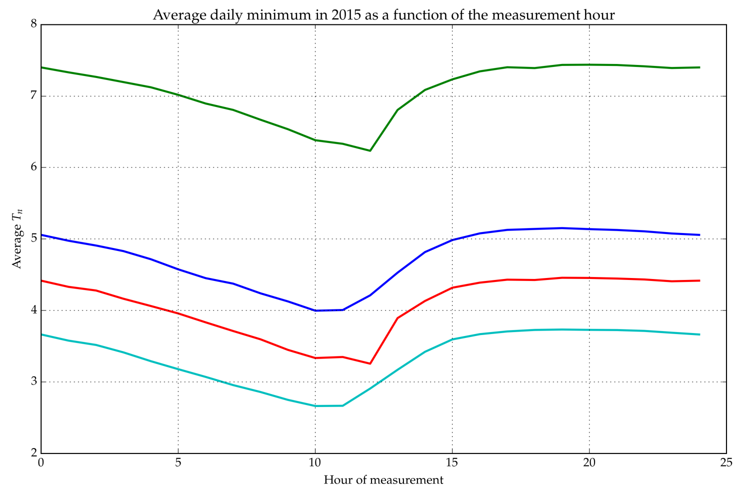
Most of the time, the ideal measurement and the actual measurement coincide: the triangle is on that day's line. But there are also several misses. The most blatant example occurs on April 3rd, where the peak of the diurnal cycle is {{apr3_realmax}}°C and occurs at 21:00 UTC. However, because the previous day was much warmer, the day's T_x record of {{apr3_measured}}°C is reached immediately after the previous day's measurement. The measured T_x therefore overestimates the diurnal cycle's peak by {{round(apr3_measured-apr3_realmax,1)}}°C.

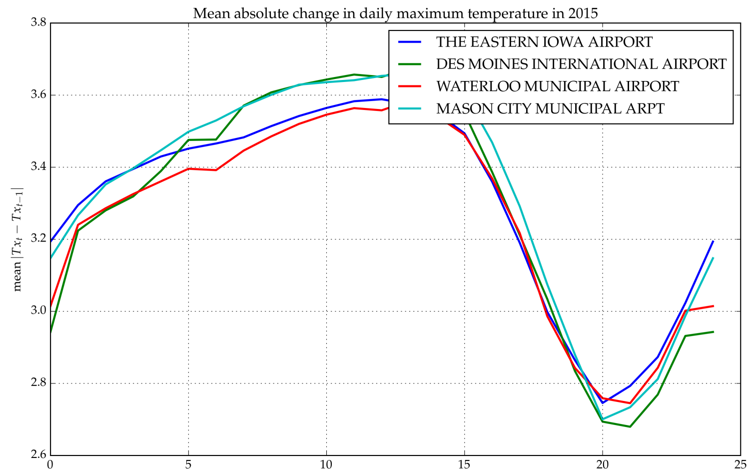


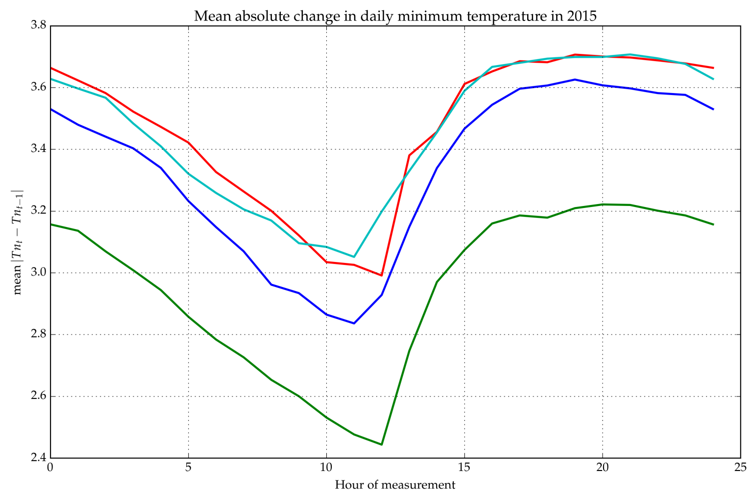
This subtle bias in the daily records can in turn bias long-term summary statistics that are of climatological interest. A measure as simple as the average daily maximum temperature for an entire year (2015) increases by over 1°C if the measurements are made at the warmest time of day 21:00 UTC rather than 14:00 UTC (see Figure X). Conversely, the average T_n is colder by over 1°C if T_n is measured at 10:00 UTC (the coldest time of day on average) rather than 17:00 UTC.

A climatologist studying weather variability might be interested in summary statistics such as the average absolute change in the daily temperature maxima and minima from one day to the next. The answer to that question too depends on the time of day at which the temperatures are recorded. Collecting the measurements at the hottest time of day means that the peaks on a warm day gets recorded twice, erasing the diurnal peaks of the following colder day, and hence the variability gets underestimated. We can see this in Figure X, where the respective variability estimates drop if the maxima get measured at the warmest time, or if the minima get measured at the coldest time.


Average daily maximum in 2015 as a function of the measurement hour
Average T_x
THE EASTERN IOWA AIRPORT
DES MOINES INTERNATIONAL AIRPORT
WATERLOO MUNICIPAL AIRPORT
MASON CITY MUNICIPAL ARPT


Average daily minimum in 2015 as a function of the measurement hour
Average T_n
Hour of measurement





1.2 Proposed solution

We have seen that the daily maxima and minima do not faithfully record each diurnal cycle's peak and trough. The peaks on a relatively cold day can get overwritten by temperatures at either end of the measurement window that properly belong to the previous or the next diurnal cycle. Troughs on relatively warm days can be similarly overwritten. Our goal is to undo this damage, and recover estimates of summary statistics, such as the average daily maximum temperature, that do not suffer from the consequent bias. We need to address the erasure of information caused by the measurement mechanism, and therefore view this as a missing data problem.

Taking the missing data perspective, we seek to impute the hourly temperatures that have been replaced by a maximum and minimum over a 24 hour period. To do so, we use information from two sources: the recorded daily temperature extremes at the station of interest, and also the hourly temperatures recorded at nearby meteorological stations. These hourly measurements are considered less reliable by climatologists, as they aren't as carefully documented, calibrated, and situated. The meterological stations are often in locations (like airports) where human activity will affect temperatures. Therefore, summary statistics extracted directly from those measurements would not be directly usable for climatology, as they could suffer from systematic bias. However, even if miscalibrated, the meterological data do contain valuable information about the hourly changes in temperatures on any given day. We therefore use them to inform the shape of the imputed temperature time-series at our location of interest, while we use the recorded temperature extrema to calibrate and constrain them.

2 Model Specification

1. start with a simple SE kernel in both space and time

$$k_{st}(s, s', t, t') = k_{time}(t, t') \times k_{space}(s, s') + k_{mean}(s, s')$$

2. observation model
    - not much to say… just clipping

3 Implementation

1. timeseries model
    - fitting hyperparameters
    - chunks
    - show variogram
2. spatiotemporal model
    - fitting hyperparameters
    - chunks
3. imputations
    - Stan
    - softmin and softmax
    - observation noise
    - reparametrization

4 Improving model

1. focused on timeseries model
    - kernel components
    - diurnal cycle
    - show improved variograms
2. spatiotemporal model
    - variograms and cross-variograms
    - trace evolution
        - product kernel
        - sum of products with variance 1
        - sum of products with free variance
    - for each model, report marginal likelihood, and predictive diagnostic in a table
    - discuss importance of getting uncertainty right

5 Analysis

- show imputations on interesting days
- show imputations can capture two possible explanations for a measurement
- discuss possibility of inferring measurement time