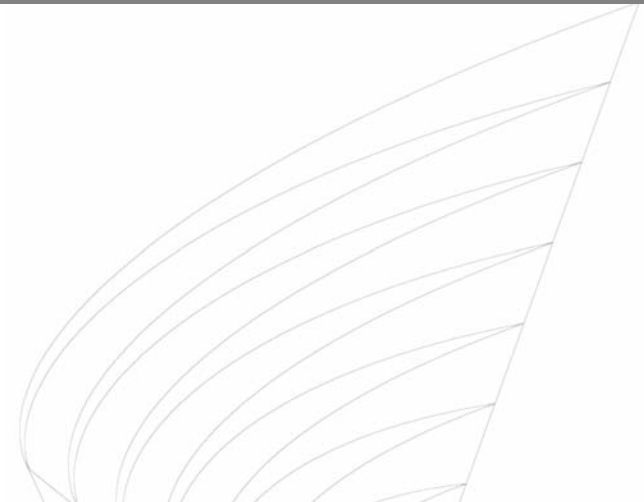




HELSINKI UNIVERSITY OF TECHNOLOGY
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More Quality Control for Weather Station Networks

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Contents

- Introduction
- The quality control motivation
- Some basic vocabulary
- Quality control overview
- Quality control details
- Further quality control problems
- From measurement quality control to network quality control



Introduction

- The quality control research made in Dada-project (1.6.2005-31.1.2007)
 - Dada = Development of Data Fusion and Diagnostics Methods in Weather Station Networks (<http://control.hut.fi/research/dada/>)
 - Dada includes also data fusion of multiple source weather measurements
 - The sequel: Pipo (Quality and fusion of surface weather stations and dual-polarization radar measurements)
- Collaboration between Helsinki University of Technology (TKK), Finnish Meteorological Institute (FMI) and Vaisala
- Dada is funded by Tekes and Vaisala



Quality Control Motivation

- Why quality control in weather station networks is just right now important?
 - A new generation of weather stations: cheaper and more accurate results → more dense measurements in spatial *and* temporal directions
 - New types of forecast products – all measurements used in the forecasting should be reliable with rapid quality control
- Number of measurements grows by decades
- Automated procedures needed for quick QC decisions



Quality Control Motivation

- Consider meso/synoptic scale measurement network difference:
 - If the average station spacing is decreased by factor 4-5, the number of measurement stations increases by factor 20
 - If the average sampling period decreases by a factor 12, from 1 hour to 5 minutes
- Number of measurements can easily grow approximately 200 times larger than before



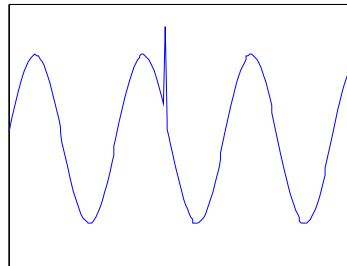
Quality Control Motivation

- In this presentation: quality control = fault detection (of meteorological measurements)
- From control engineering point of view, the fault diagnosis of meteorological measurement can be tedious
 - Unknown process
 - Time varying system (*e.g.* seasonal changes)
 - Geography dependent measurements (*e.g.* inland/sea)
- The first conclusions:
 - Adaptation needed
 - Traditional fault detection methods do not apply

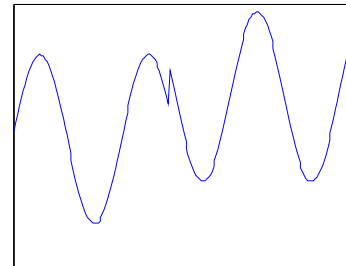


Some Basic Vocabulary

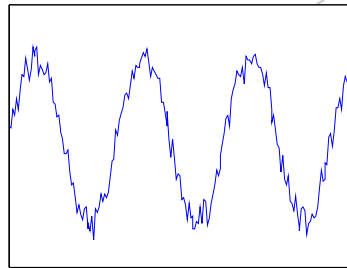
- A bit of vocabulary: some basic error types



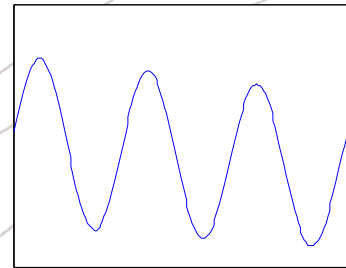
Spike



Bias



Noise



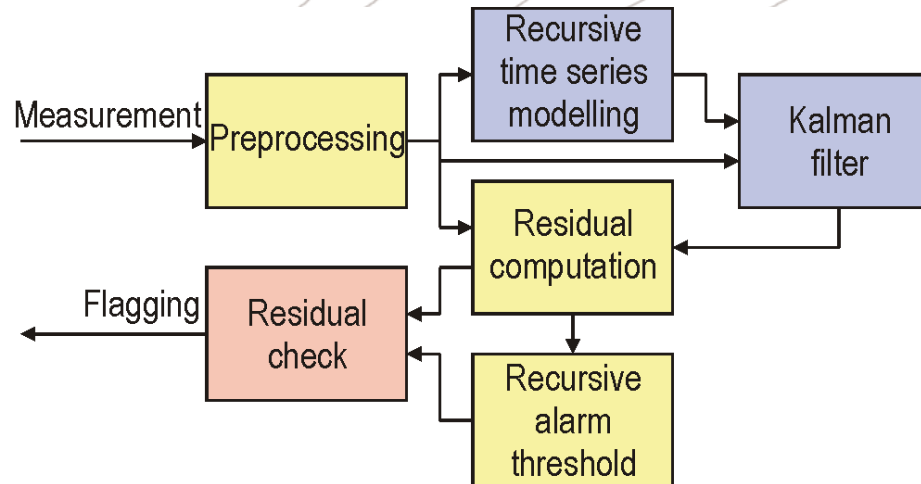
Drift

- The following fault detection method can detect the noise and spike errors



Noise Quality Control Overview

- The noise fault detection in general level is
 - Estimate a residual
 - Compare residual to the alarm thresholds
 - Update the residual estimation model and alarm threshold
- A more accurate block diagram:



Noise Quality Control Overview

- Advantages of the solution:
 - Adaptation to the seasonal changes
 - Applicable to different conditions due to the adaptation
 - The diurnal changes in the measurement statistics fairly easy to cope with
 - No need for a background field (from *e.g.* LAPS)
 - Applicable for a single station or a multiple station environment
 - Possibility to estimate a few missing measurements



Preprocessing

- The preprocessing consists of the flagging of the most obvious errors
- The preprocessing flagging is made based on step and consistency checks
- The preprocessing is essential, since large errors may bias the residual estimation of the actual fault detection



Modeling and Filtering

- Self-tuning modeling of the measurement behavior
 - Autoregressive time series model *i.e.* the new measurement is assumed to depend on the previous measurements
 - The model is updated by the recursive least squares method
- Filtering done by a Kalman filter
 - Kalman filter offers optimal linear estimation
 - Covariance matrices required by Kalman filter are also estimated by recursive methods



Residual Computation

- The idea is to filter the measurement and use the filtering residual to the fault detection
- The model applied in Kalman filter is modeled with a self-tuning recursive least squares estimation
 - The advantage: easy to implement for different measurements and robustness against the seasonal changes



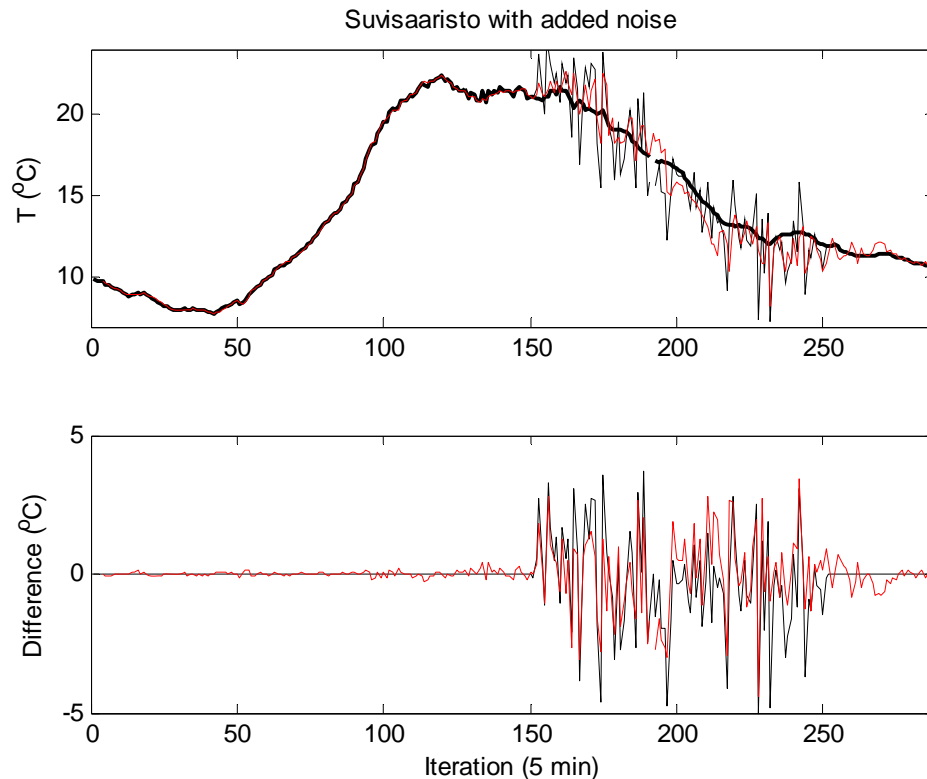
Measurement Flagging

- A measurement is flagged as erroneous, if the corresponding residual is larger than three (or four) times the standard deviation of the residual
 - 3σ - and 4σ -thresholds comes from the assumption of normally distributed residual
 - According to the theory, the 3σ -threshold corresponds to passing more than 99.5 % of measurements
 - Since the residual does not follow exactly the normal distribution, the 4σ -threshold should be used in the practice



Filtering Example

- An example of temperature filtering:



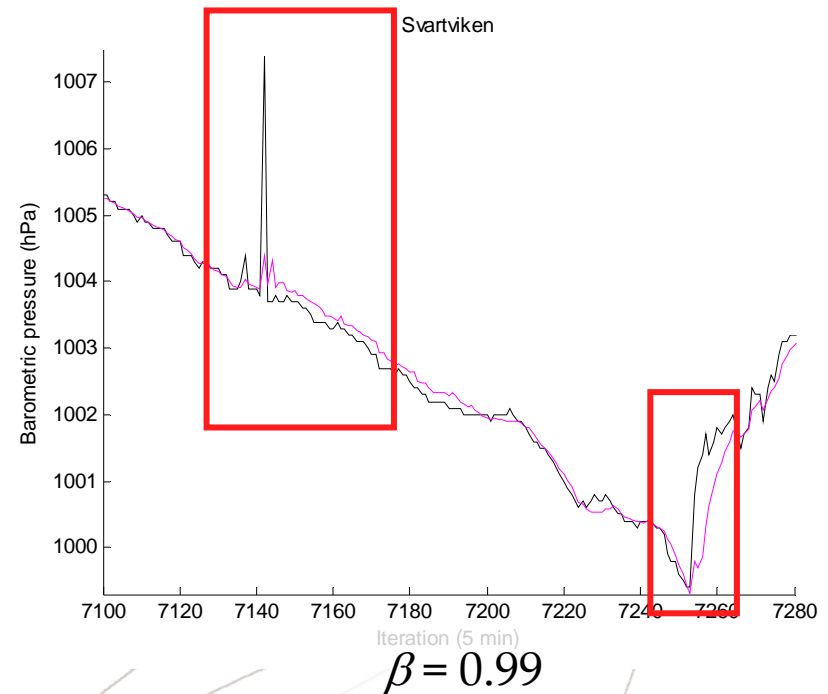
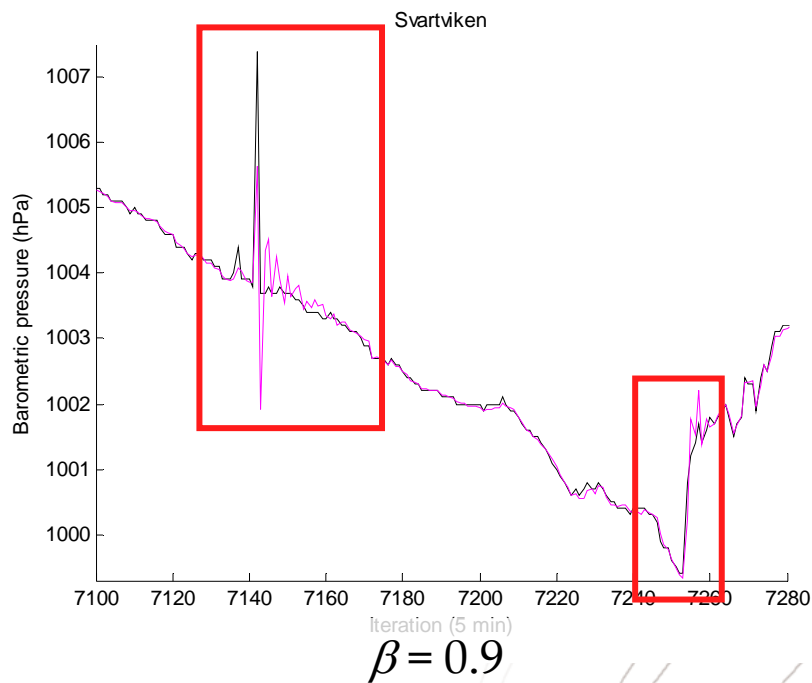
Thick black = measured temperature
 Thin black = temperature with added noise
 Red = estimated temperature

Black = the added noise
 Red = error of the estimated temperature



Another Filtering Example

- The difficulty of weather measurement filtering:



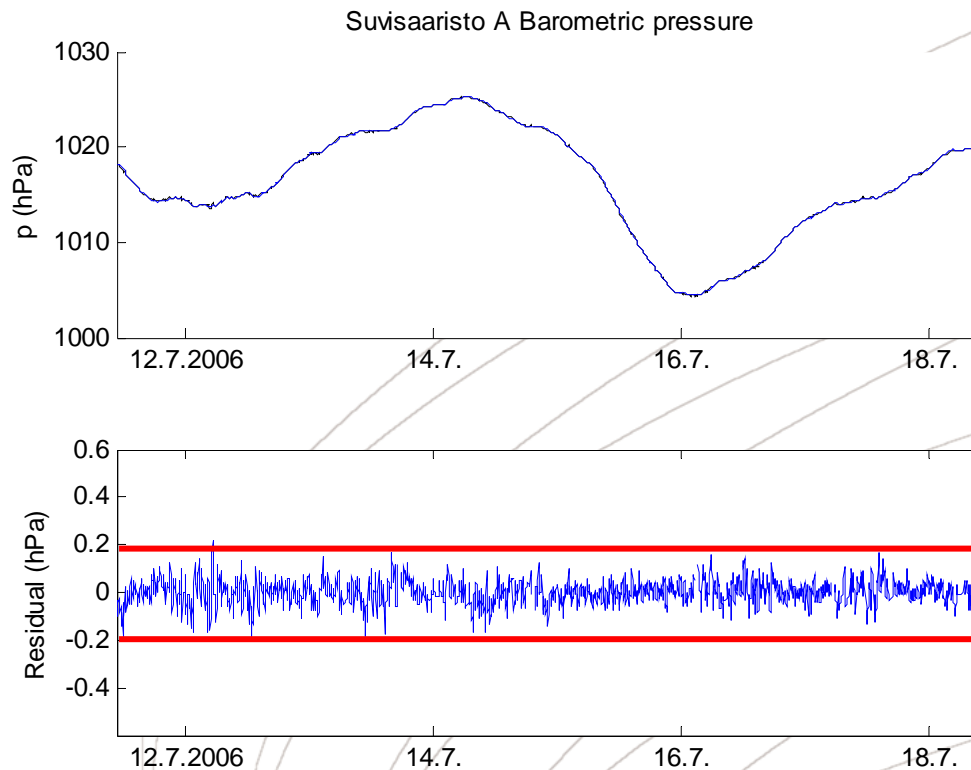
Black = measured barometric pressure

Purple = filtered barometric pressure



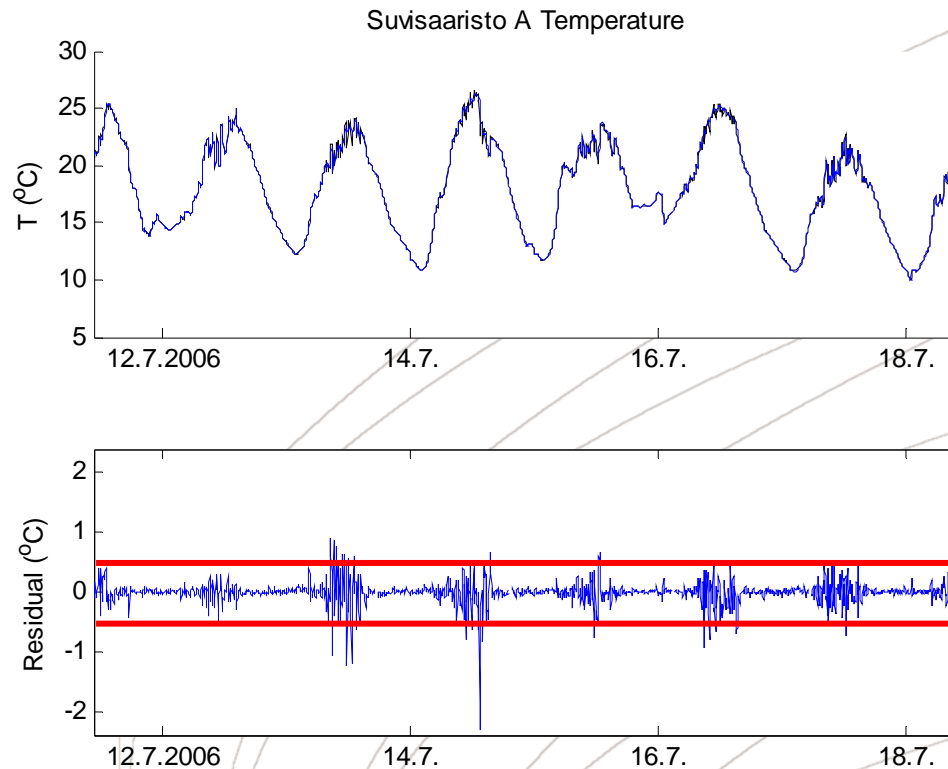
Residual Examples

- Suvisaaristo barometric pressure and its residual



Residual Examples

- Suvisaaristo temperature and its residual



Time-Dependent Alarm Thresholds

- Since the measurements are very much environment dependent, the alarm thresholds must be adaptive
- The variation of some meteorological measurements may have diurnal dependency
- The taken approach: estimate the residual variation based on the time of day



Alarm Thresholds: A Practical Recursive Version

- The recursive update of residual variance, and also the alarm threshold, looks like

$$\hat{\sigma}^2(k) = \lambda \hat{\sigma}^2(k) + (1 - \lambda)(x(k) - \hat{x}(k))^2$$

- Good for *e.g.* barometric pressure, which does not experience diurnal variance change

- The update rule for a measurement with diurnal variance change looks like

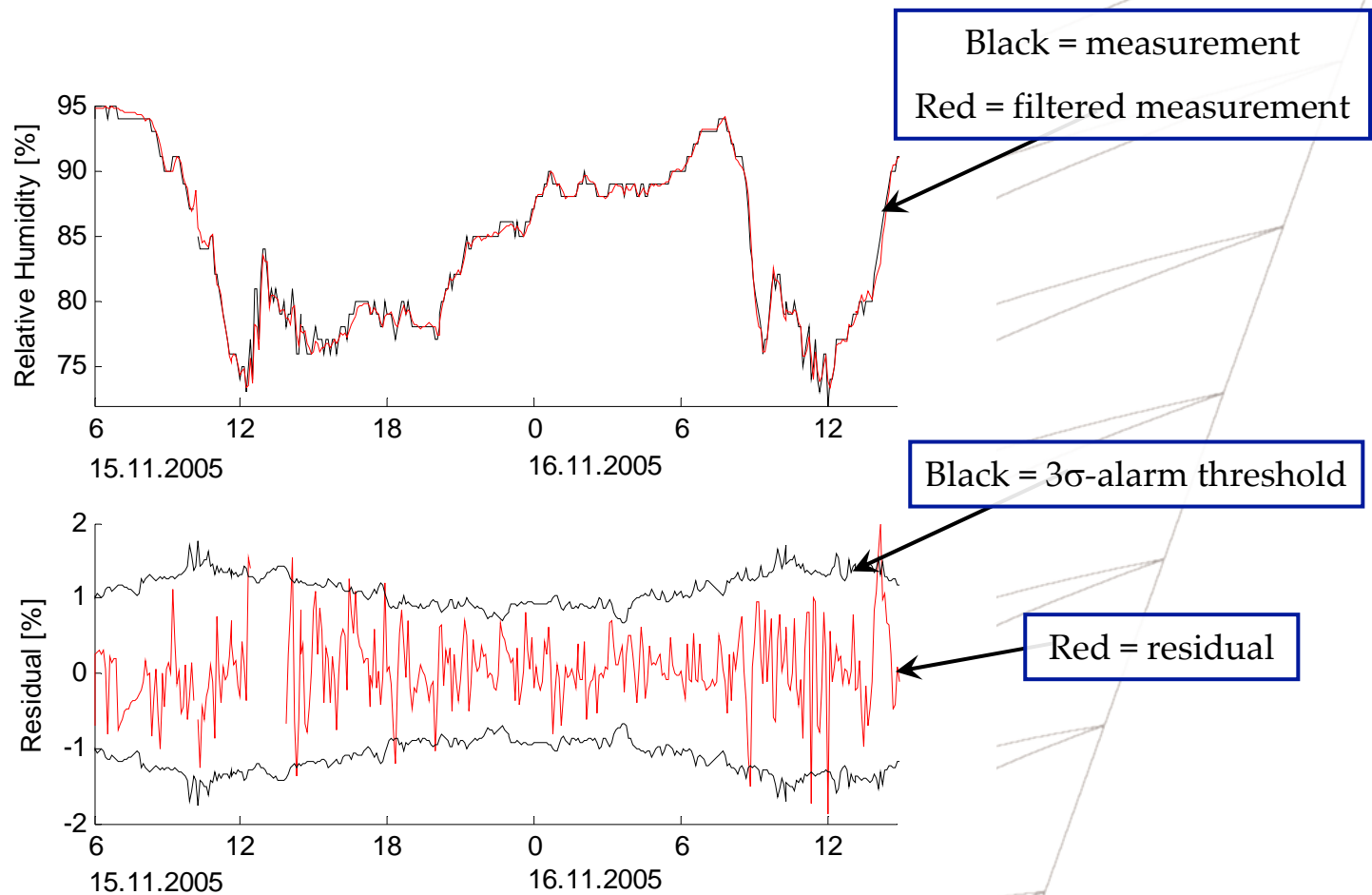
$$\hat{\sigma}^2(k) = \lambda \hat{\sigma}^2(k - 288) + (1 - \lambda)(x(k) - \hat{x}(k))^2$$

- Good for *e.g.* temperature and relative humidity, which variance depends strongly on the lighting conditions
- Additional temporal smoothing must be done



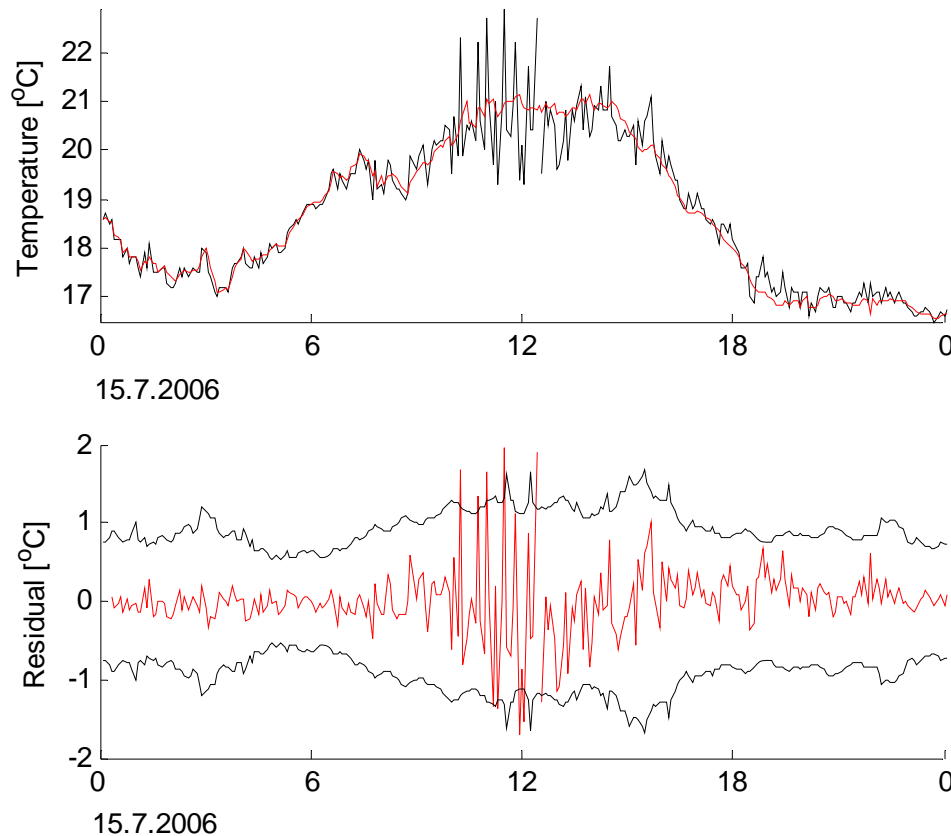
Residual Example

- An example of relative humidity measurement

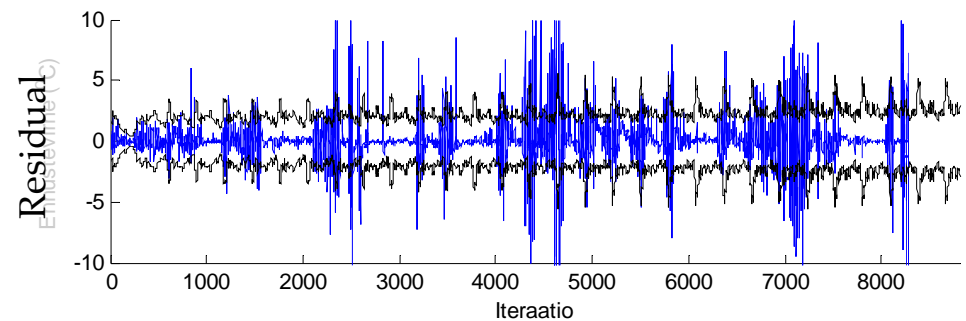
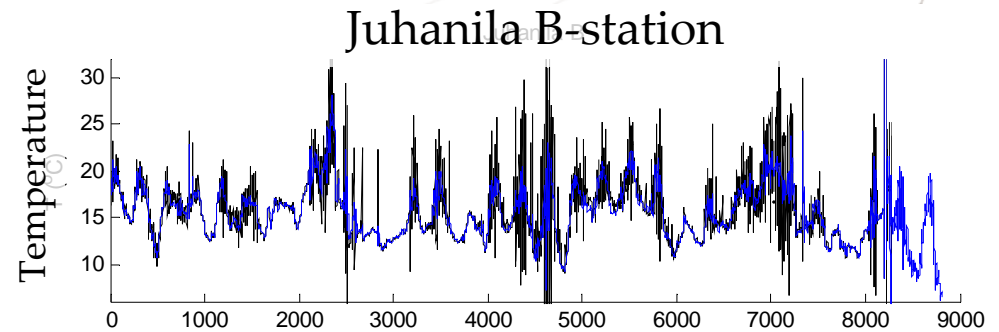
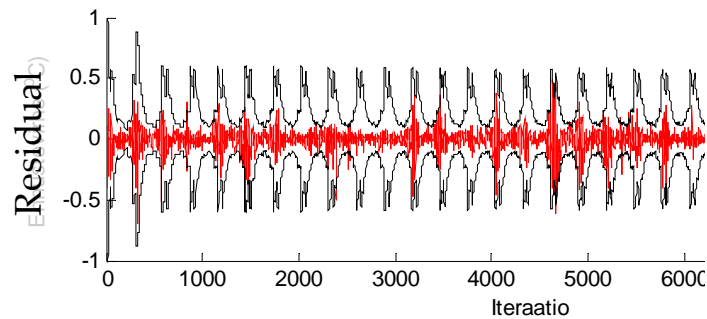
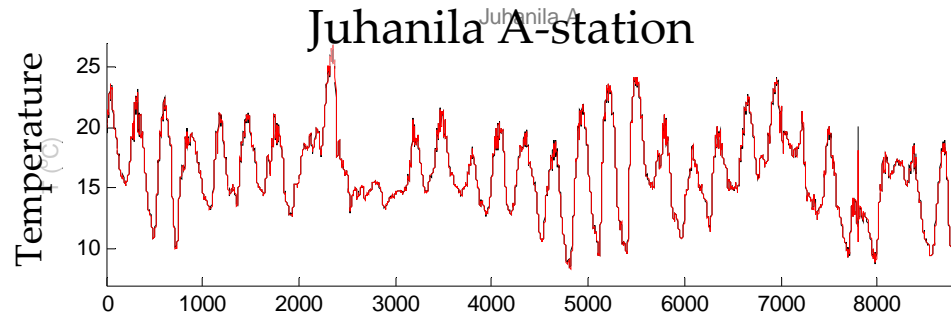


Residual Example

- An example on the temperature measurement with erroneous behavior



Residual Example: Two Stations



Juhanila stations August 2005

A-station: 2 m -level

B-station: 100 m -level



Further Quality Control Problems

- As mentioned earlier, the current fault detection works well in detecting spikes and noise
 - Fault/weather phenomena –separation is always an issue
- Drift detection is much more tedious task
 - Detection seems possible using either neighboring stations or nowcasted values
 - An exception: barometric pressure
- During heavy weather phenomena the measurements have special behavior that is not included in fault detection yet (*e.g.* wind, pressure and temperature in convection)
- Fault detection of non-continuous measurements: rain

→ Room for further QC work



From Measurement Quality Control to Measurement Network Performance

- For maintenance and forecasting purposes, knowing the measurement station performance is also essential
 - Additional information for the end user about the measurement quality
 - Maintenance operation planning
- In order to gain information about the network condition, descriptive performance indices about each station can be used
 - For example: availability, accuracy, reliability, estimability, influence



Descriptions of Measurement Network Performance

■ Short descriptions of performance indices :

- Availability = "are there missing measurements"
- Accuracy = "is the measurement accurate or not"
- Reliability = "can the measurement station be trusted"
- Estimability = "can the network compensate the measurement"
- Influence = "how the measurement is influencing the network performance"

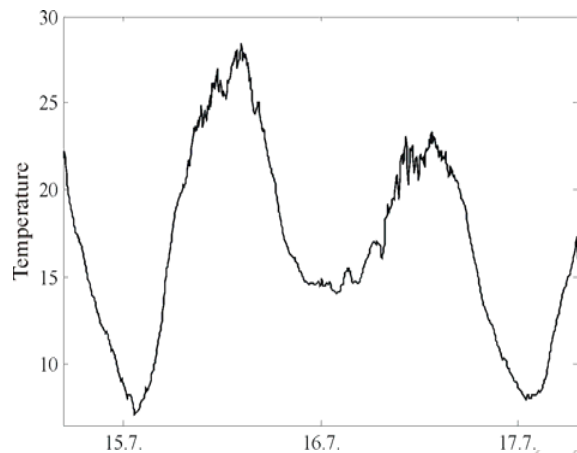
For data
users

For
maintenance

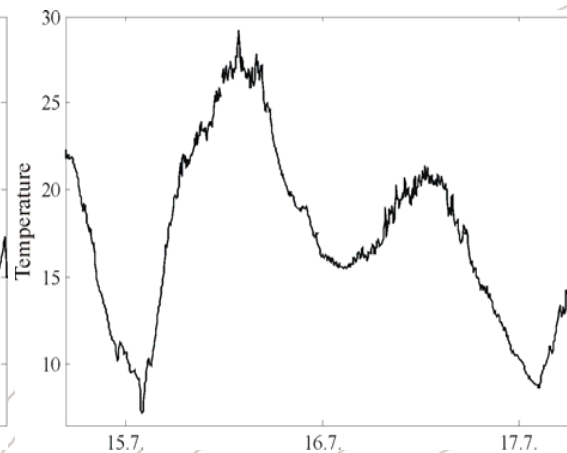


A Performance Index Example

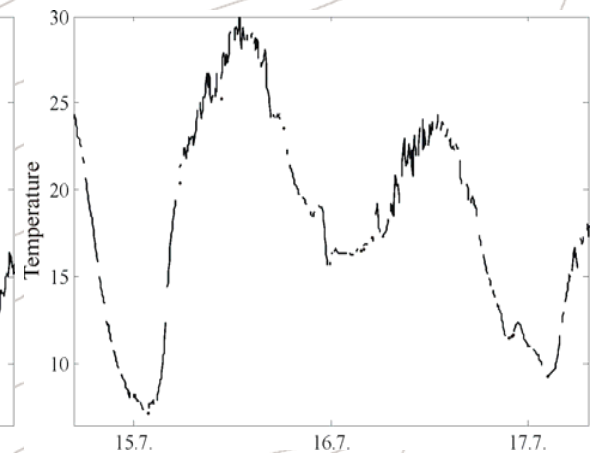
- Example temperature measurements:



Measurement OK



Low accuracy



Low availability



Conclusions

- Automatic quality control is a necessity when increasing the mesoscale measurement network size
- Traditional quality control is the starting point, the newer type algorithms can improve the results
- Using background field is not always a feasible assumption
- Quality control gives an opportunity to form new metadata to maintenance decisions

