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Control Engineering Laboratory

More Quality Control for Weather Station Networks

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Contents

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

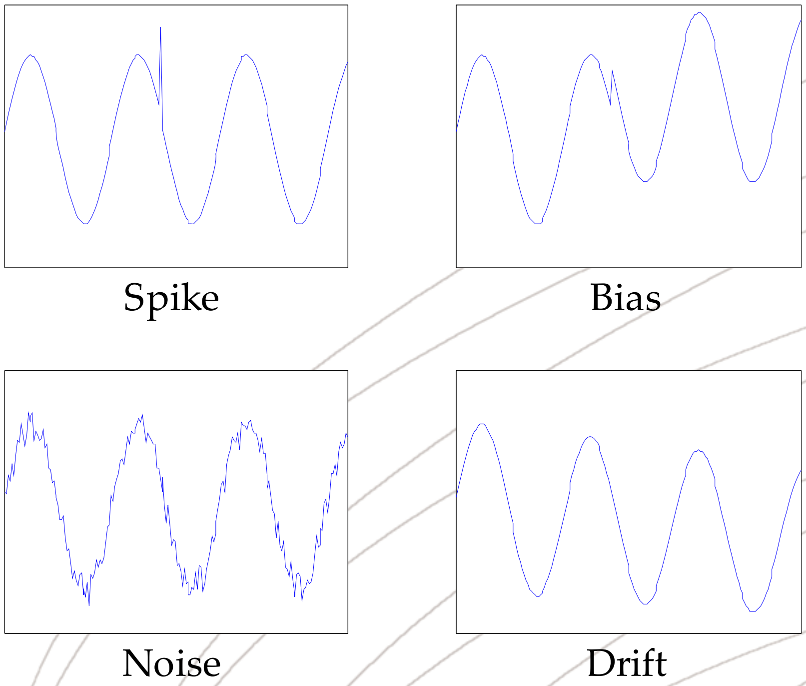
→ Number of measurements can easily grow approximately 200 times larger than before

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

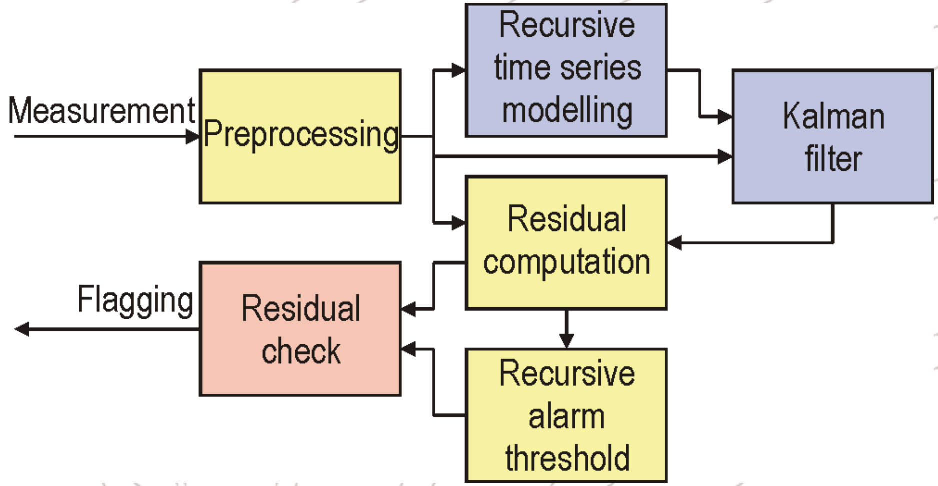
- A bit of vocabulary: some basic error types



- 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

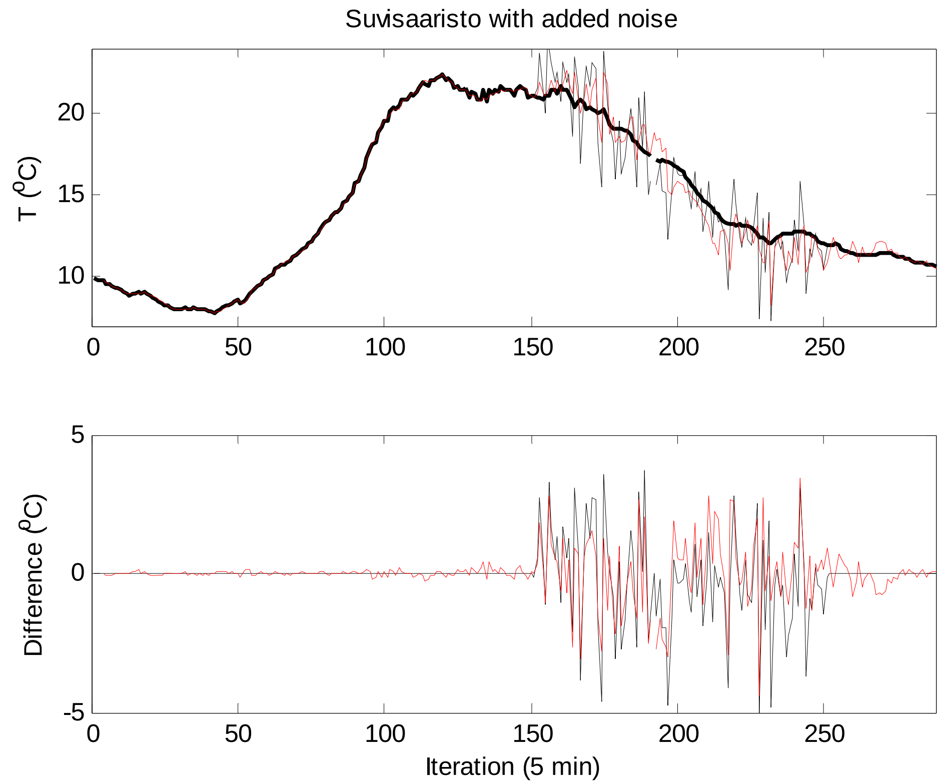
- The idea is to filter the measurement and use the filtering residual to the fault detection
- The model applied in Kalman filter is modeled with a self-tuning recursive least squares estimation
  - The advantage: easy to implement for different measurements and robustness against the seasonal changes

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

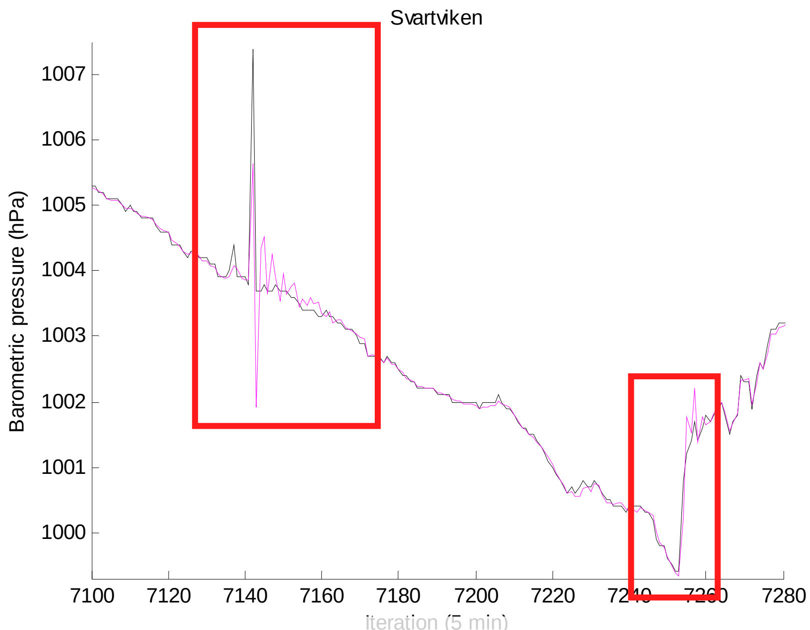
Red = estimated temperature

Black = the added noise

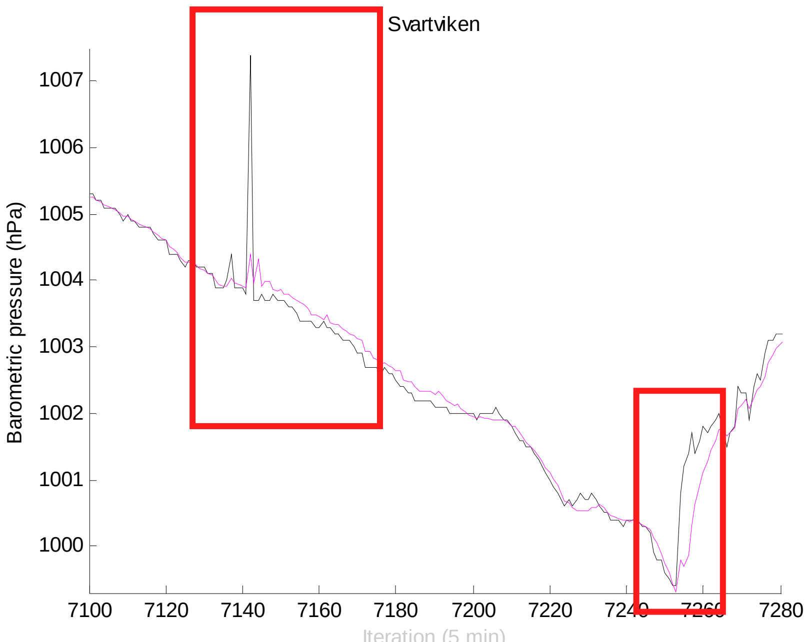
Red = error of the estimated temperature

Another Filtering Example

- The difficulty of weather measurement filtering:



$\beta = 0.9$



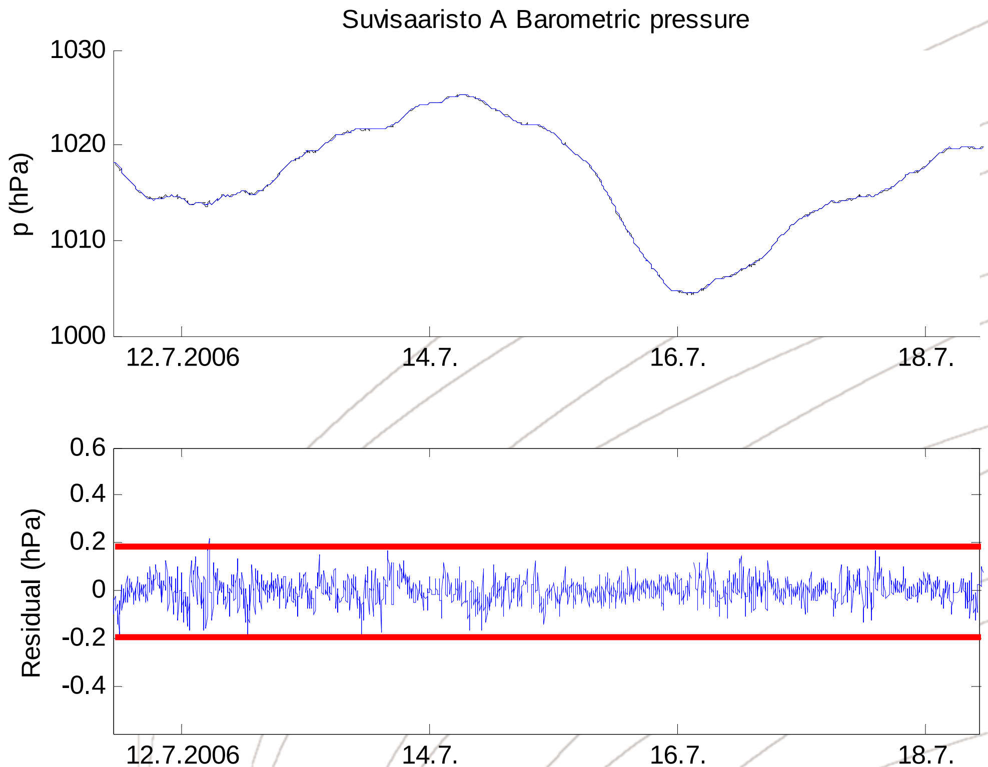
$\beta = 0.99$

Black = measured barometric pressure

Purple = filtered barometric pressure

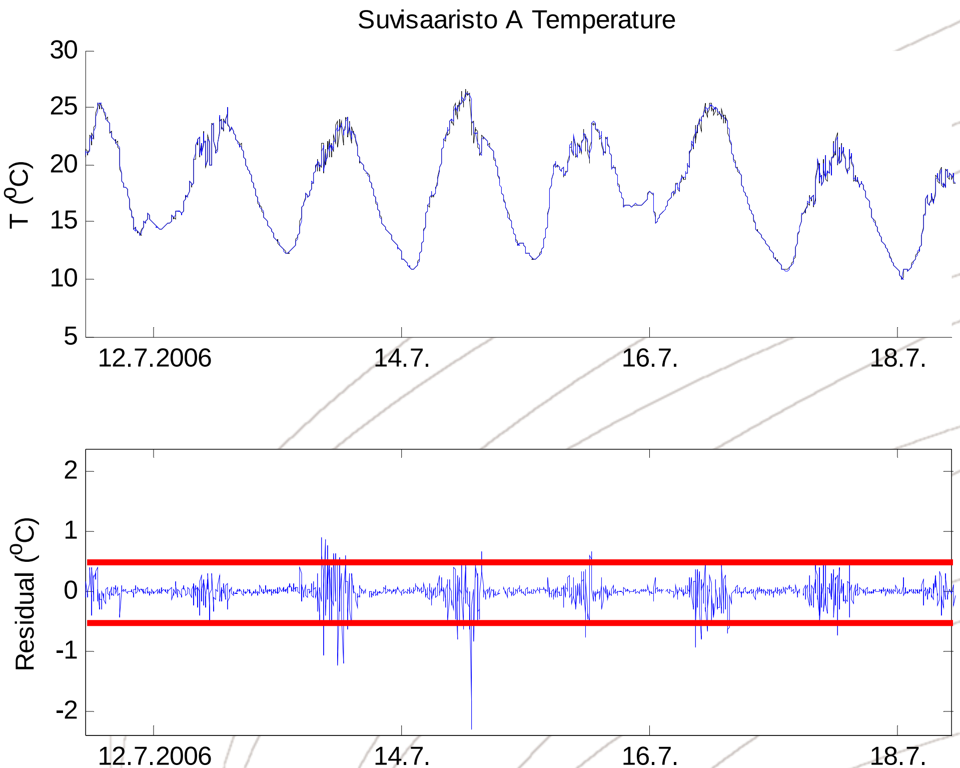
Residual Examples

- Suvisaaristo barometric pressure and its residual



Residual Examples

- Suvisaaristo temperature and its residual



Time-Dependent Alarm Thresholds

- Since the measurement 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

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

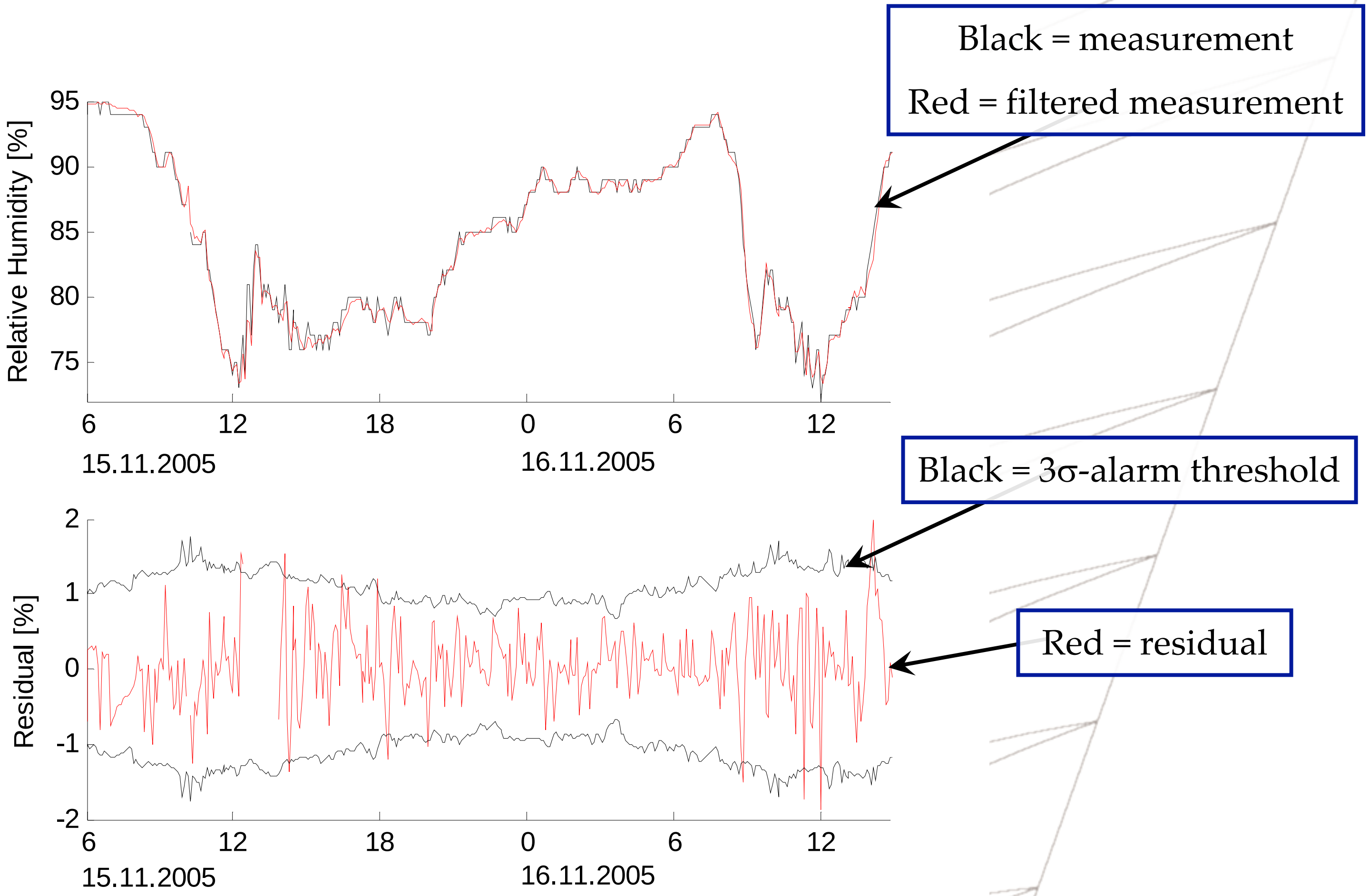
  - Good for *e.g.* barometric pressure, which does not experience diurnal variance change
- The update rule for a measurement with diurnal variance change looks like

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

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

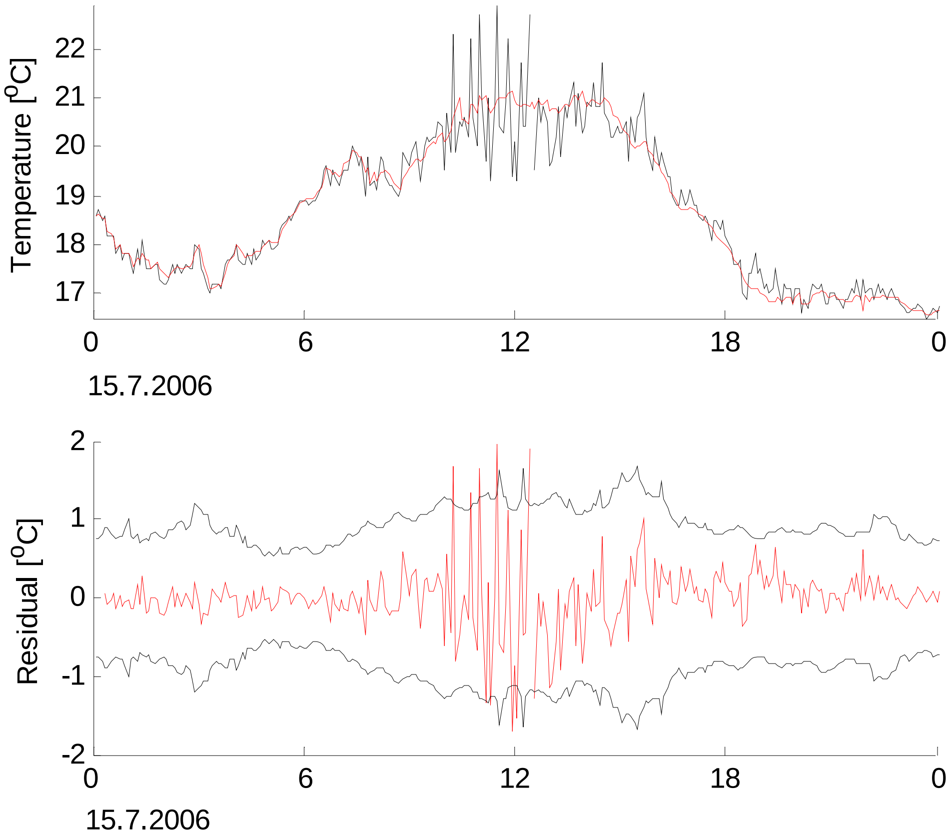
Residual Example

- An example of relative humidity measurement



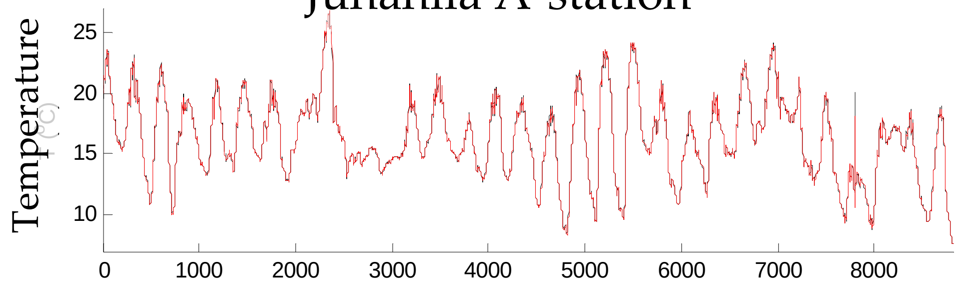
Residual Example

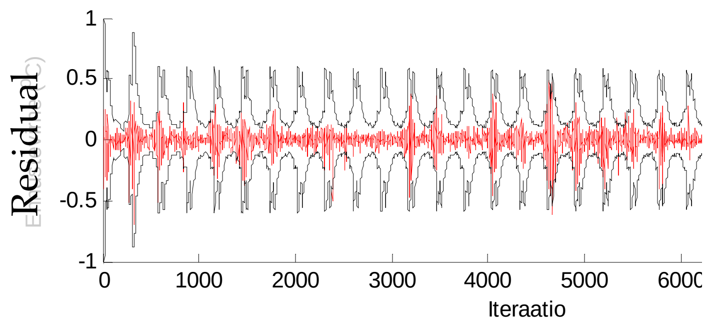
- An example on the temperature measurement with erroneous behavior



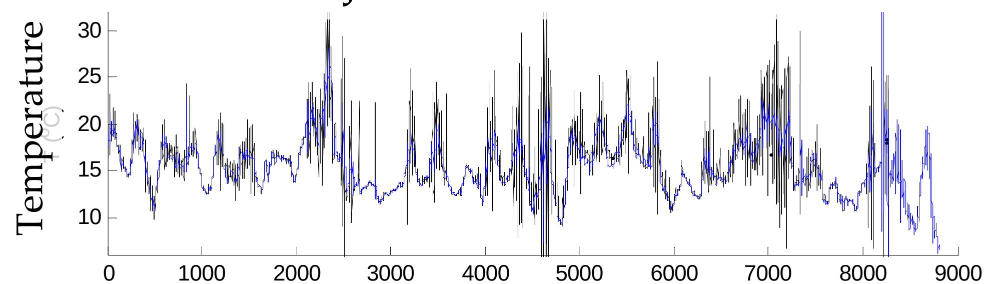
Residual Example: Two Stations

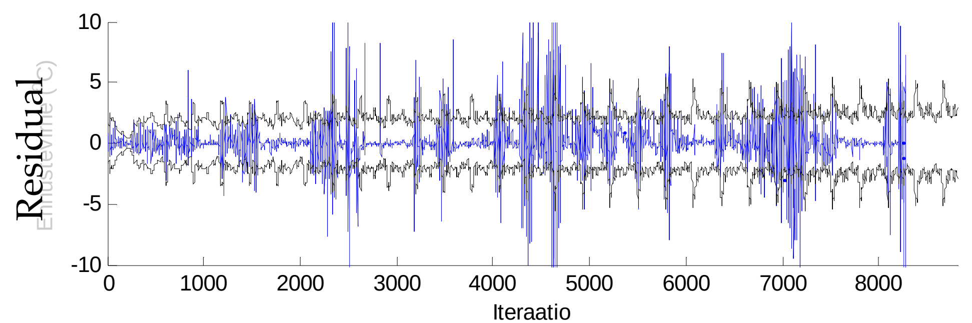
Juhanila A-station





Juhanila B-station





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

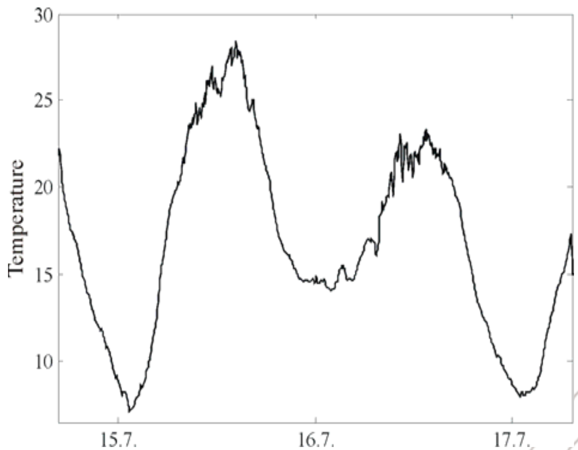
- Short descriptions of performance indices :
  - Availability = ”are there missing measurements”
  - Accuracy = ”is the measurement accurate or not”
  - Reliability = ”can the measurement station be trusted”
  - Estimability = ”can the network compensate the measurement”
  - Influence = ”how the measurement is influencing the network performance”

For data users

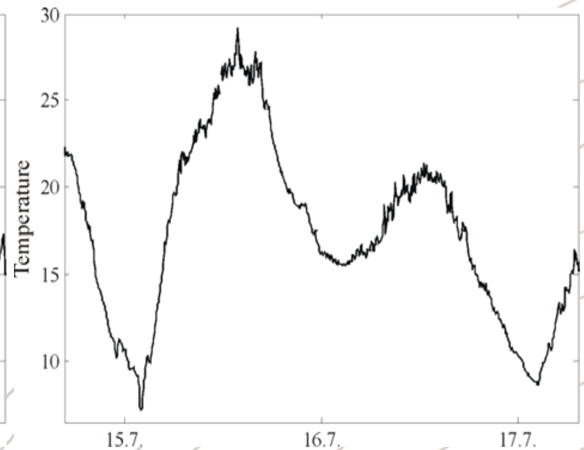
For maintenance

A Performance Index Example

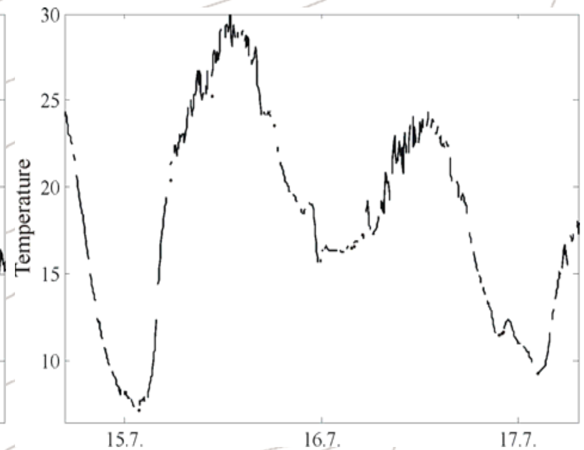
- Example temperature measurements:



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