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Extended information of product quality and their variability in paper board production using online measurement systems

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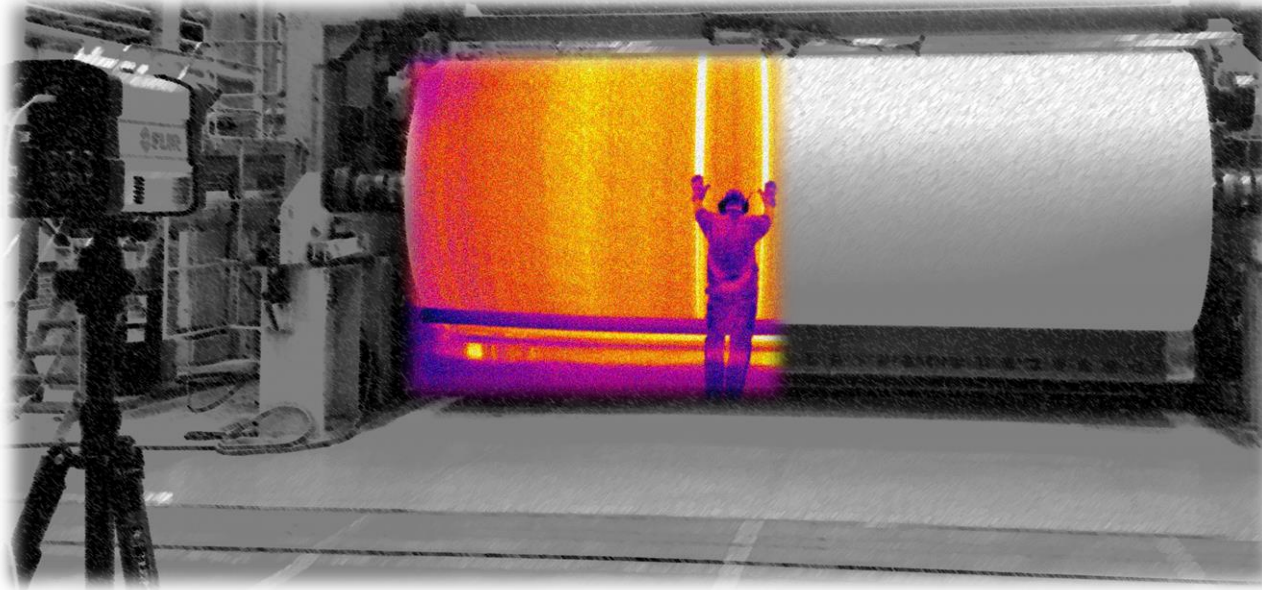


Acknowledgement

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 - StoraEnso



Making invisible information visible



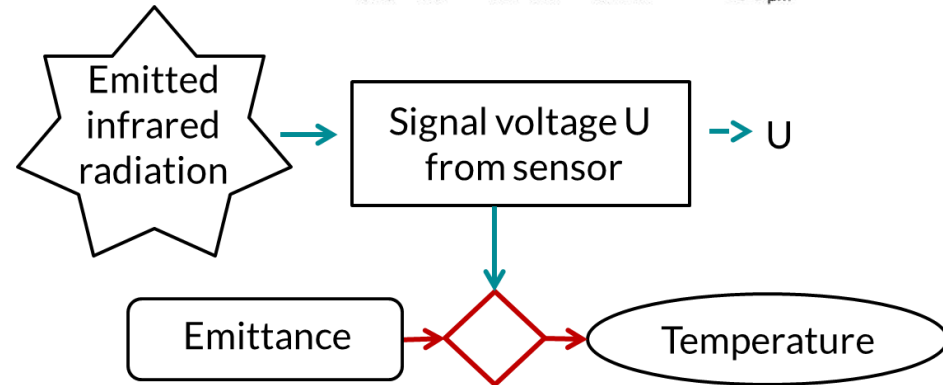
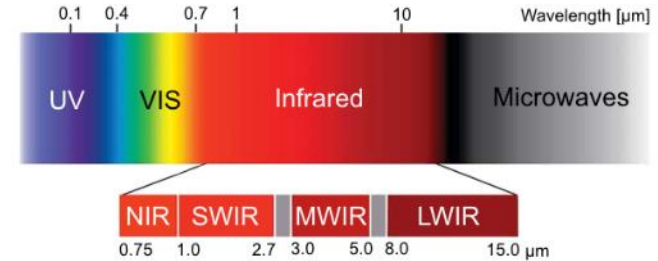
- Shorter time to operator action
- Increased performance stability and prediction
- Proactive machine maintenance
- Reduced product variations and less returns

From emitted radiation to temperature



Grammage or moisture

- More than one reason for non-uniform temperature distribution.
 - I.e. temperature cannot immediately be interpreted as a grammage variation, but will also be influenced by the amount of moisture present
- Need to de-couple moisture and basis weight when modelling

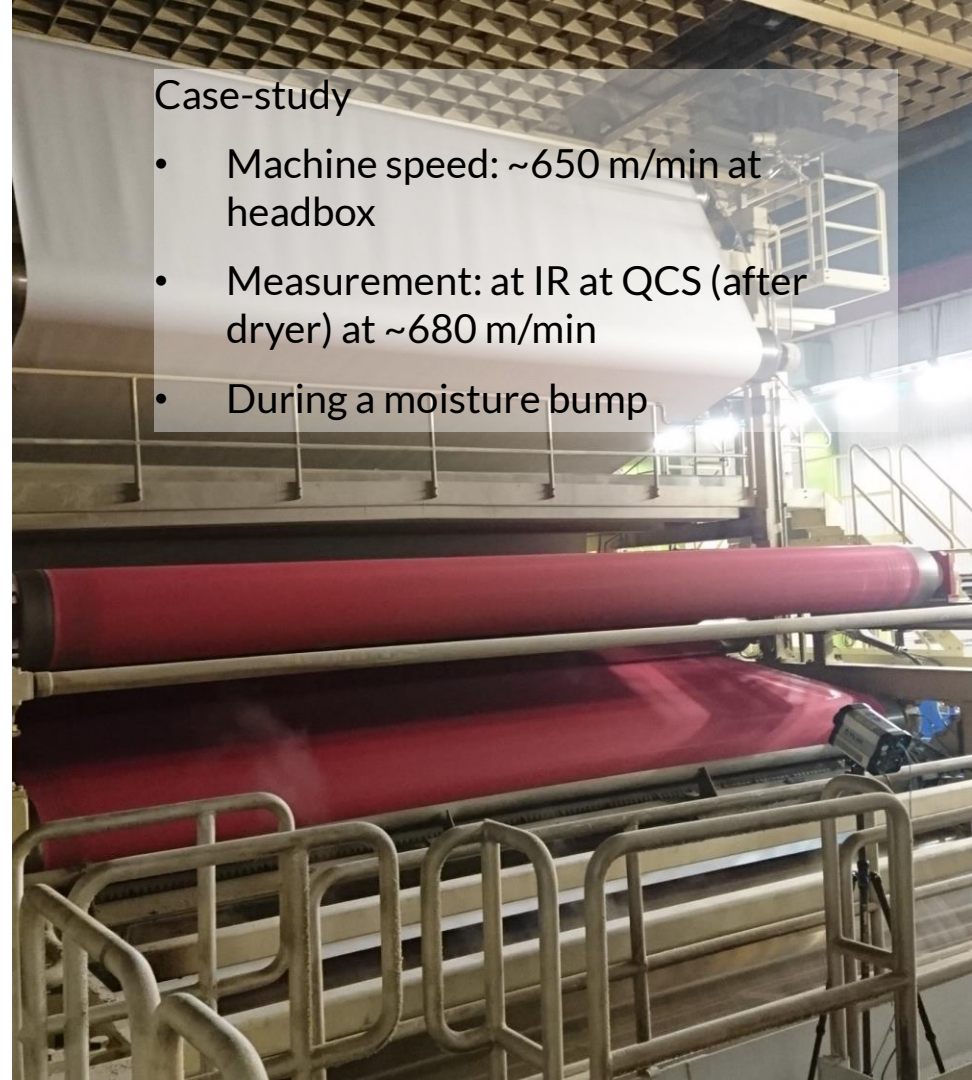


Mill trial

- Methodology developed at 6 different mills with varying conditions and infrastructure
- Collection of
 - WIS-images (grayscale CD strips of transmitted light)
 - QCS-data (point-wise moisture and basis weight, ~MD strip)
 - IR-film (area measurement of IR-emitance)
- IR is used to complement the data where measurements are not available over the complete area

Case-study

- Machine speed: ~650 m/min at headbox
- Measurement: at IR at QCS (after dryer) at ~680 m/min
- During a moisture bump



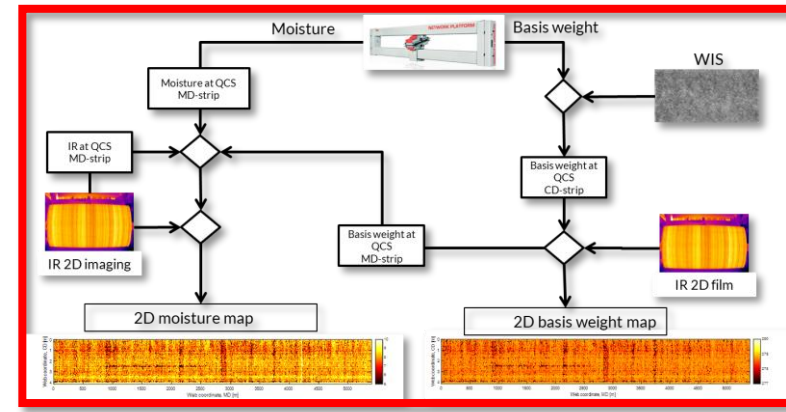
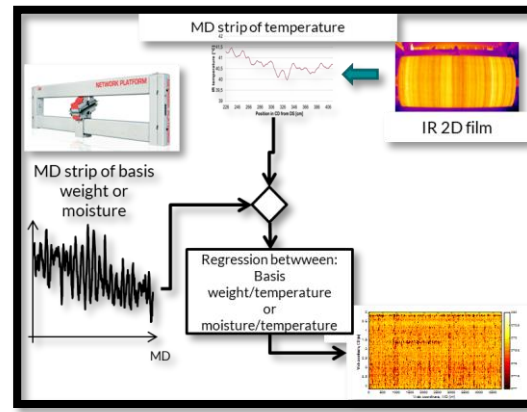
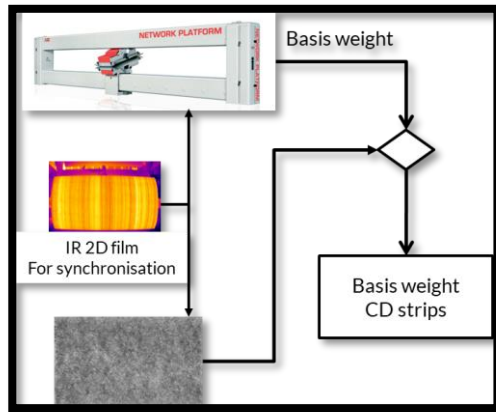
Three models in increasing complexity



Model 1: basis weight in CD-strips from QCS and WIS

Model 2, basis weight-OR moisture maps from IR and QCS

Model 3, basis weight and moisture maps from IR, QCS and WIS



IR-camera for synchronisation

On-line IR-camera and QCS

On-line IR-camera, QCS and WIS

IR+WIS

IR+QCS

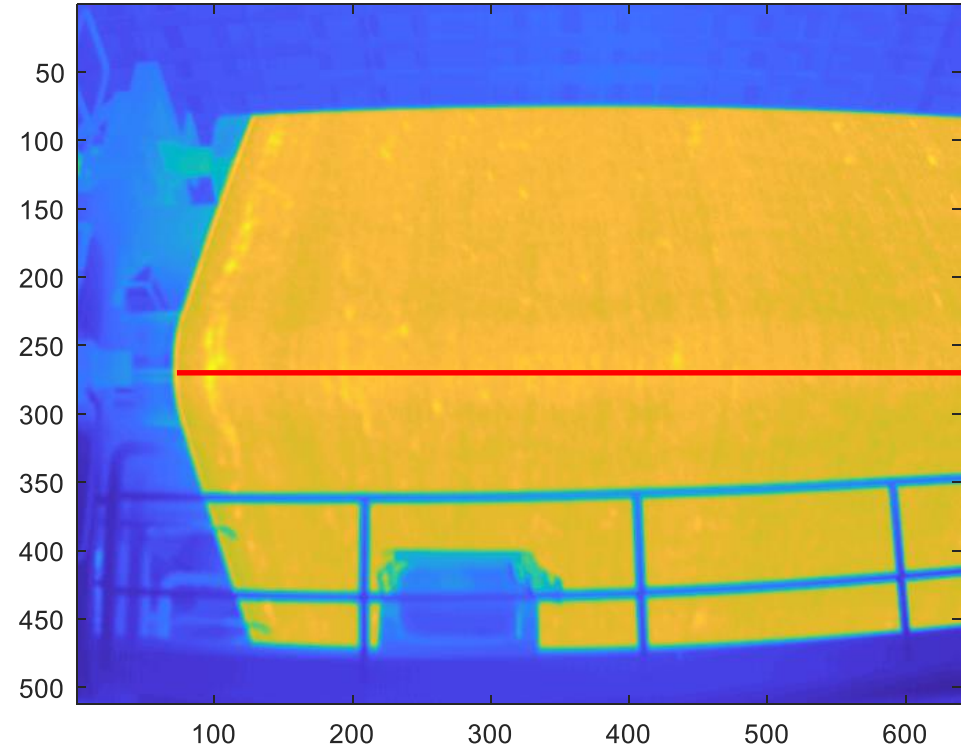
IR+QCS+WIS

Data set: IR

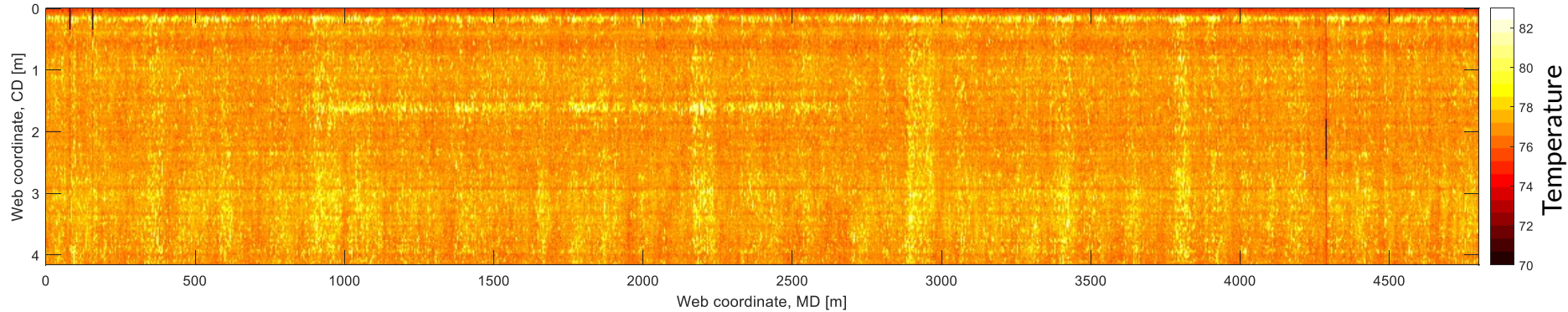


IR Analysis

- IR data processed in CD-strip (red line)
 - Process time: 3 min for 7 min IR-film
- Calibration of CD coordinates and scale
 - Note distortion from IR-lens and image depth can cause discrepancy in scale
- Data collection in 100 or 120 Hz



Data set: Temperature map



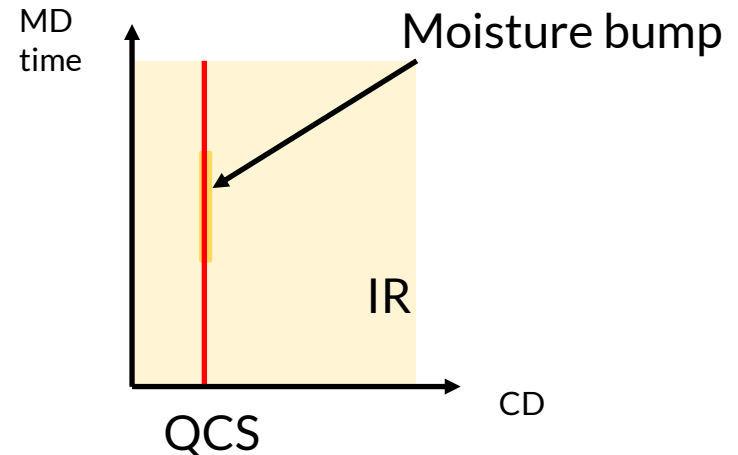
- Full resolution of IR-data overlapping QCS data set and complementary WIS
- Pixel size: 112.8 mm/pix in MD and 7.34mm/pix in CD
- 4.8 km board at 7.18 min production time

Data set: QCS



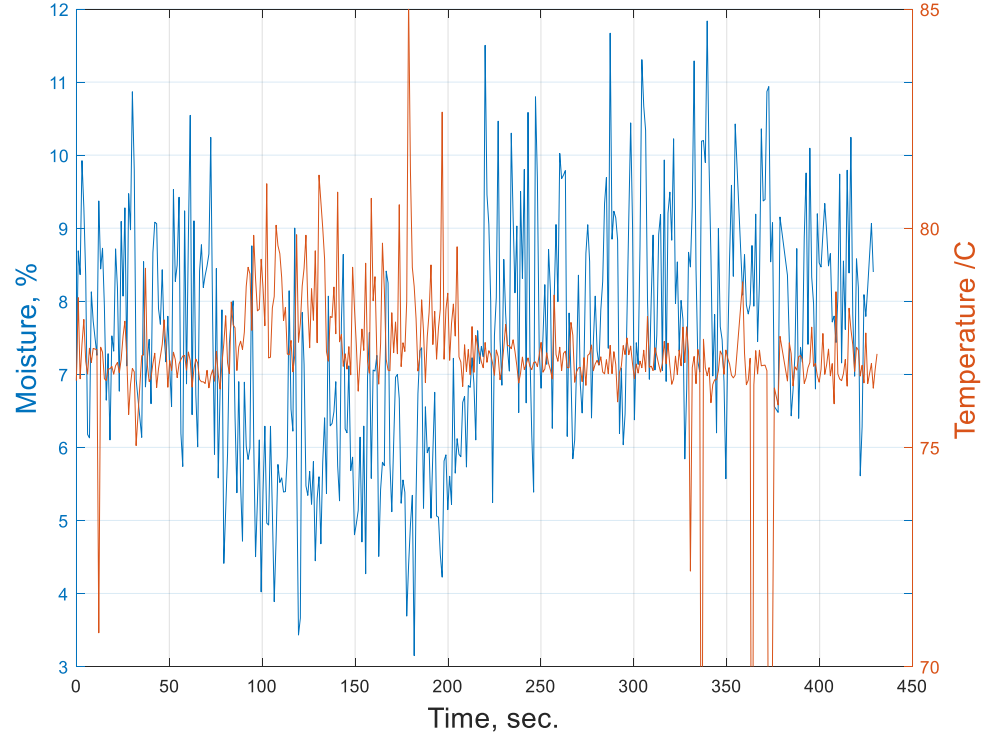
QCS analysis

- QCS-data (MD strip)
 - Moisture
 - Basis weight
- Moisture bump at stationary QCS used for synchronisation of lag, time and MD coordinate



Data set: Moisture and basis weight

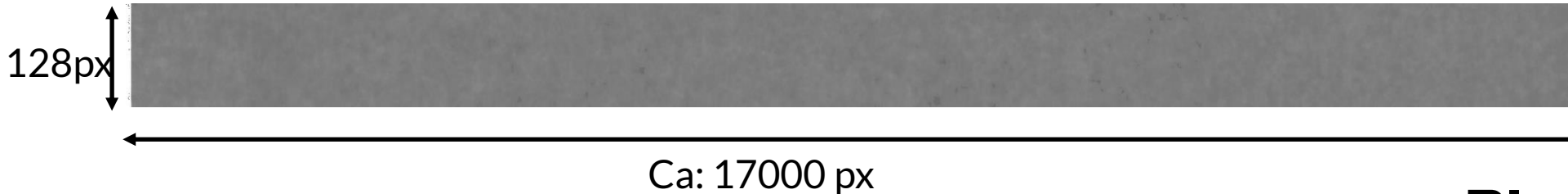
- Resolution 1000 pts/s
- Both moisture and basis weight
- Synchronized with IR-temperature at the QCS measurement position



Data set: WIS

WIS-information

- Matrix-system of complete machine width close to pope at very high resolution, but patch wise in MD
- Assumption: grayscale information of transmitted light approximately proportional to basis weight
- Positioned after coater in the machine
 - Note that the physical correlation between IR at the drier and WIS after coating is unknown and serves as a proof of concept in this case



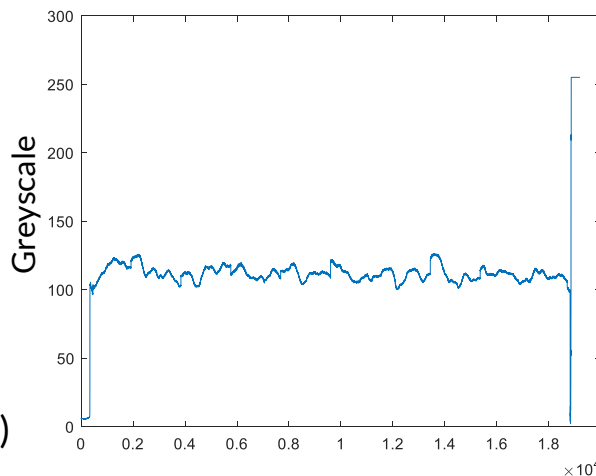
0.0045s production

WIS-data analysis

Some adaptations needed for WIS-data

- **Edge detection:** CD-coordinate
- **Image stitching:** image transitions adjusted in amplitude then according to the difference commutatively
- **Normalisation:** due to varying/unknown gain between cameras.
 - Preserves information between neighbouring pixels
 - However, large scale variations are lost IF there are unknown image overlaps

Synchronisation: very difficult without a proper marker (detectable on two systems)



Detected edge

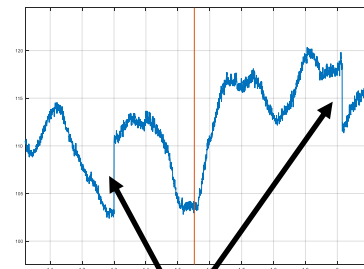
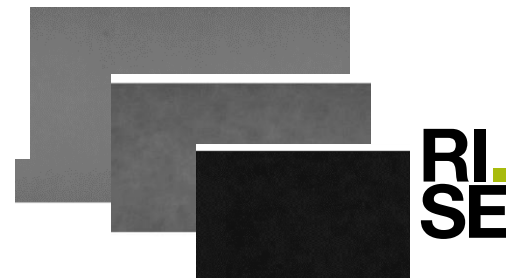
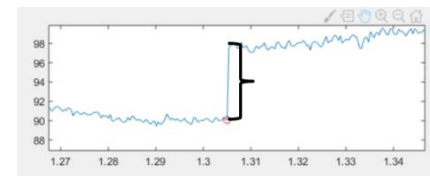
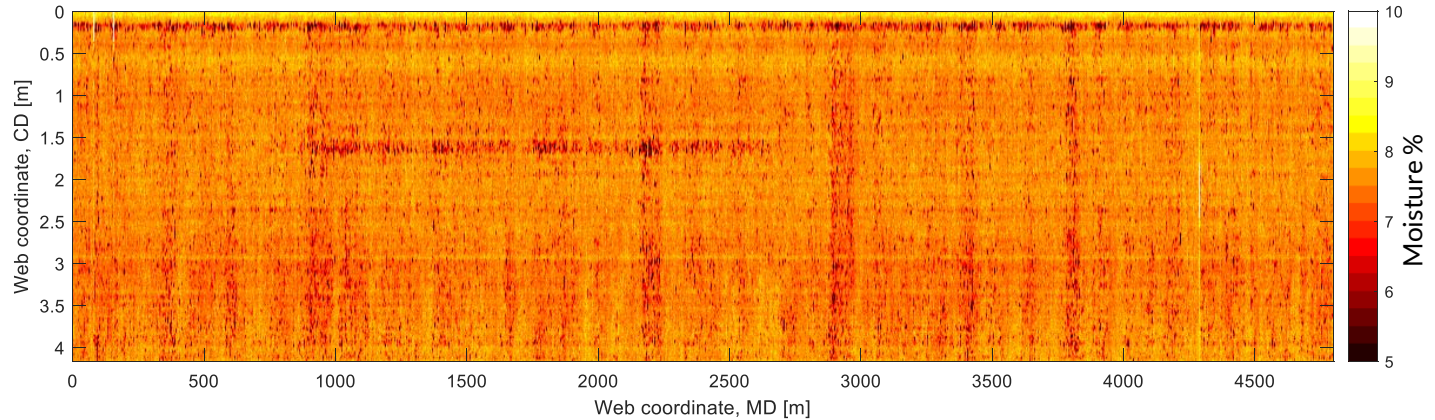


Image transition

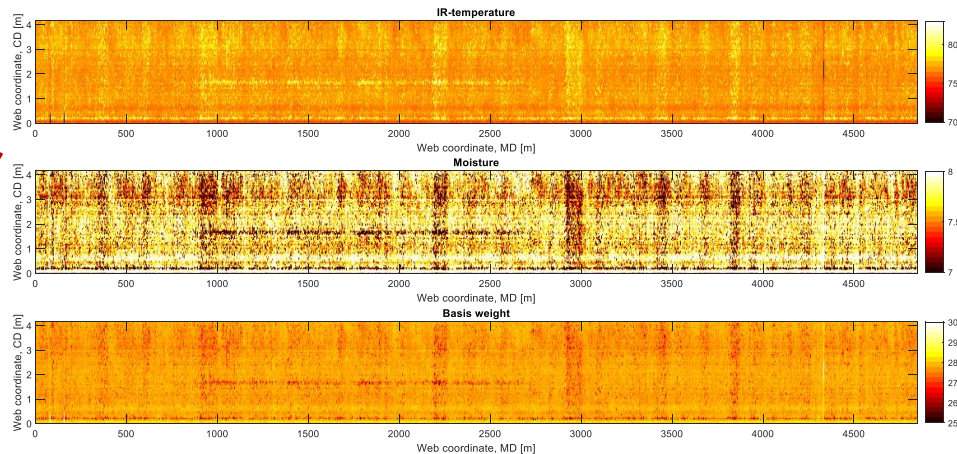
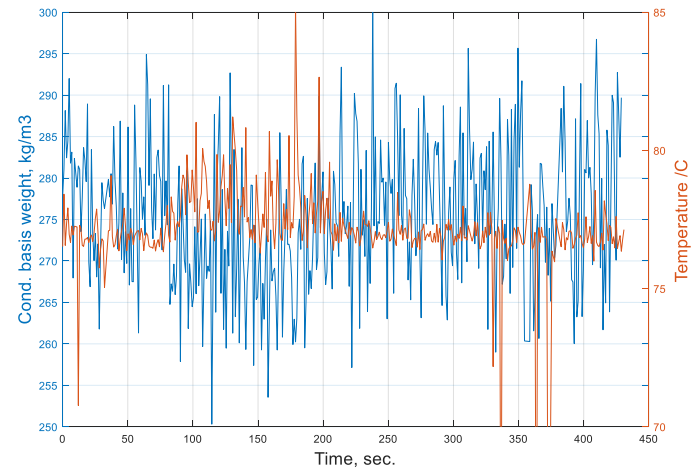
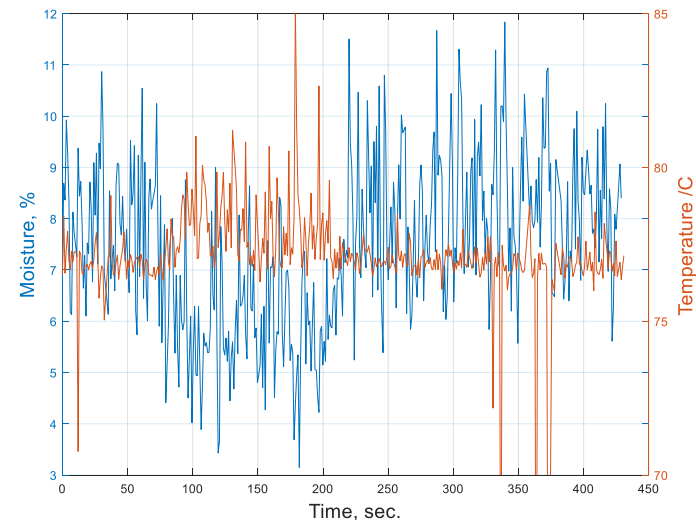


Modelling for extended information



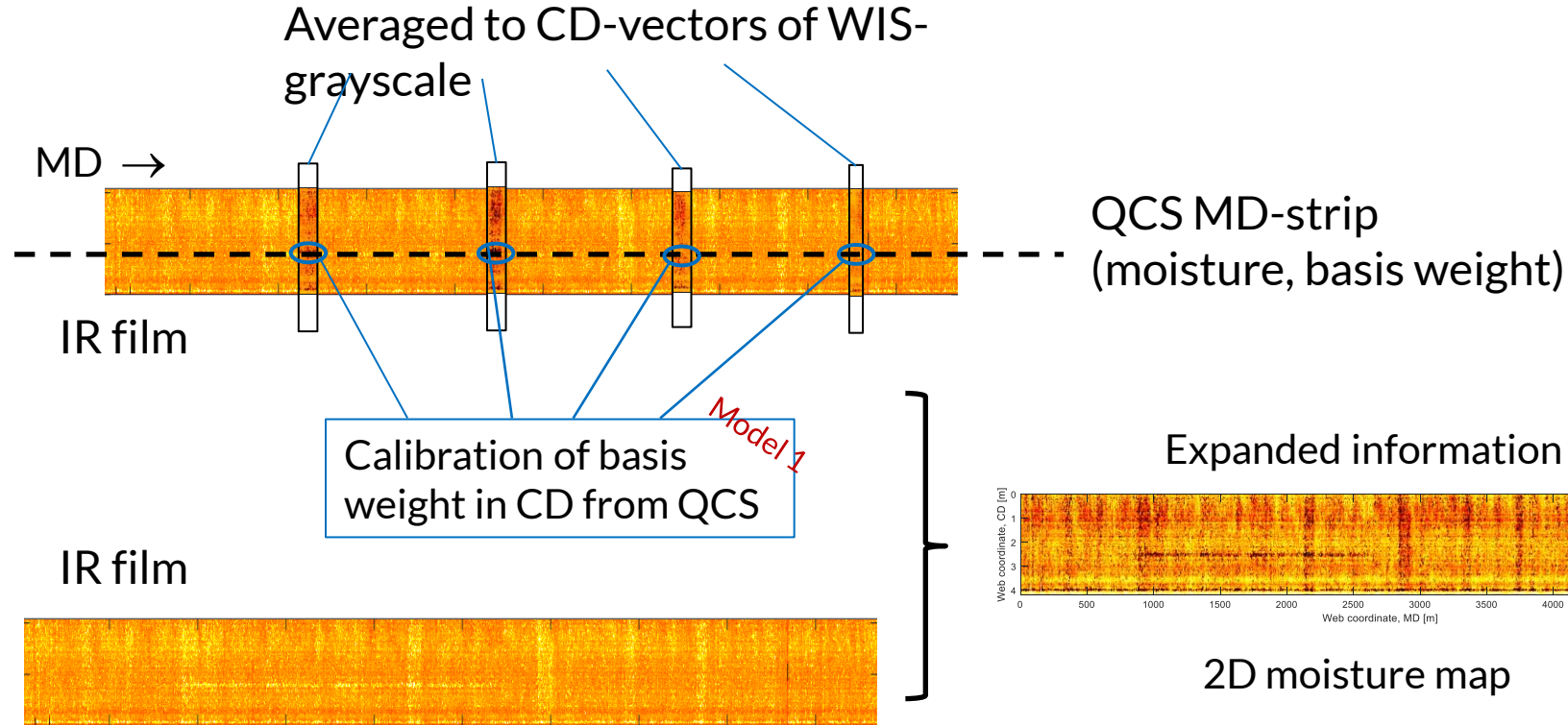
QCS and IR at ROI

- After synchronisation, and resampling to the same resolution
 - Full IR resolution: 100 pts/s
 - Full QCS resolution: 1000 pts/s
- Overlapping IR and QCS signal in about 450s
- Synchronised data used in a linear regression model for prediction of
 - Either moisture
 - or basis weight at the entire area



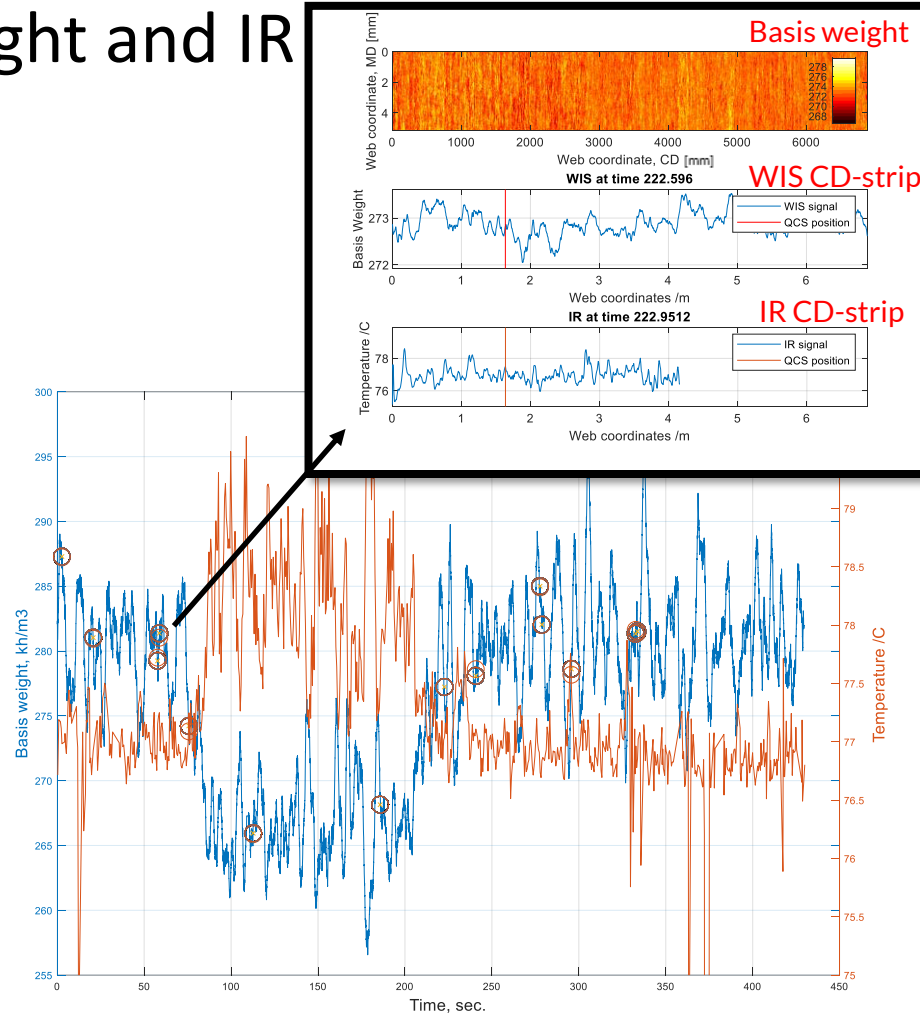
Model 2

2D map with calculated moisture content

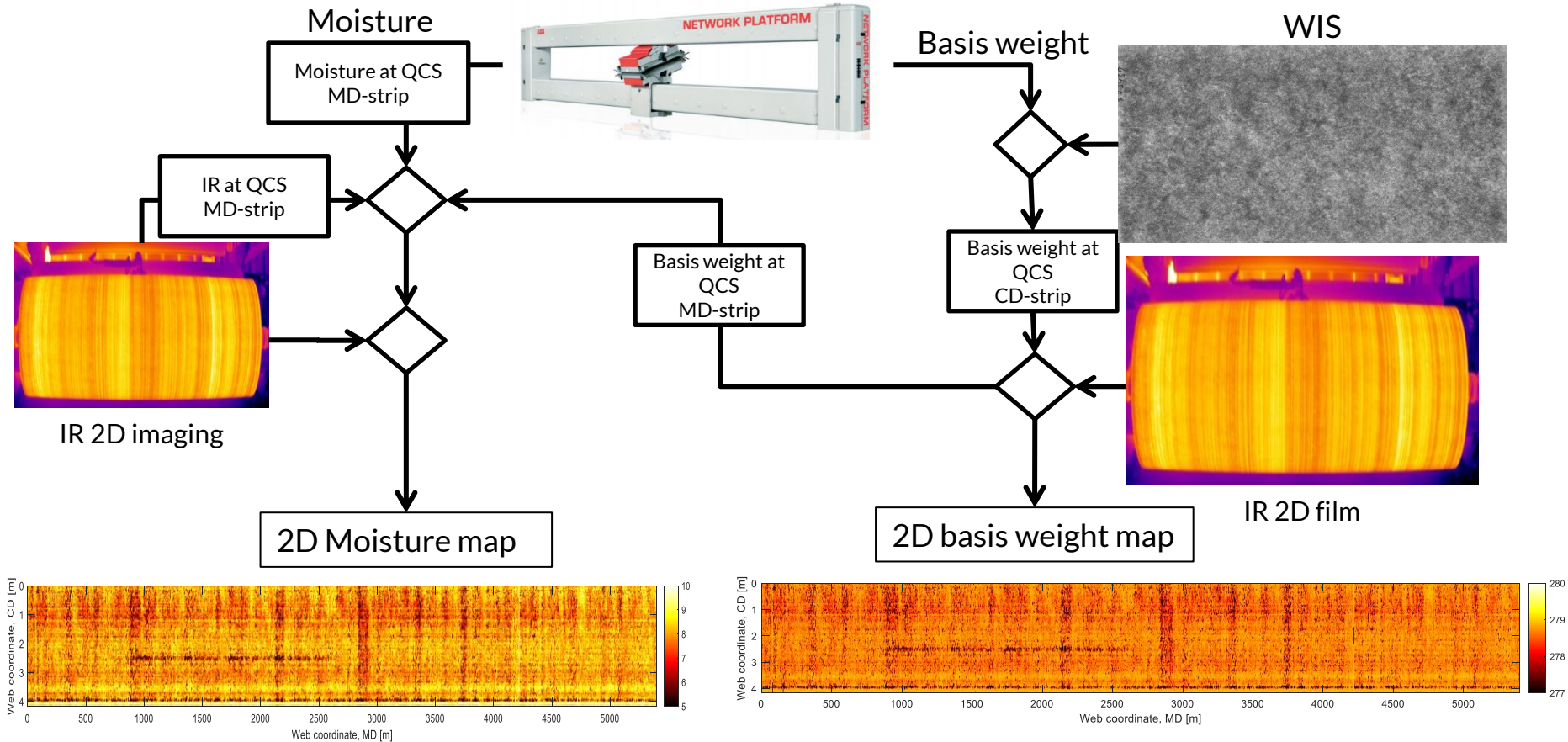


WIS-basis weight, QCS basis weight and IR

- **MD:** Moisture bump is clearly captured in both basis weight and moisture to temperature
- **CD:** Basis weight over CD (calibrated via QCS for each strip) collected as data to model
 - Parabolic model, $w(IR(CD, t_{WIS}))$ between basis weight CD-profiles for each WIS-image and IR in a least square sense (14 WIS vectors)
 - To decouple moisture and basis weight models

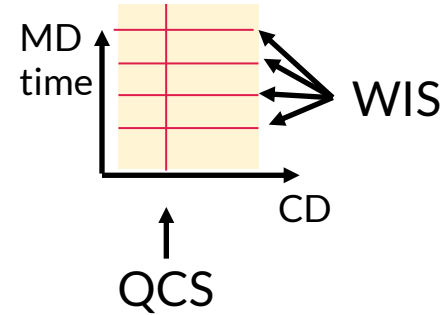


Basis weight and moisture map calculated from IR, WIS and QCS



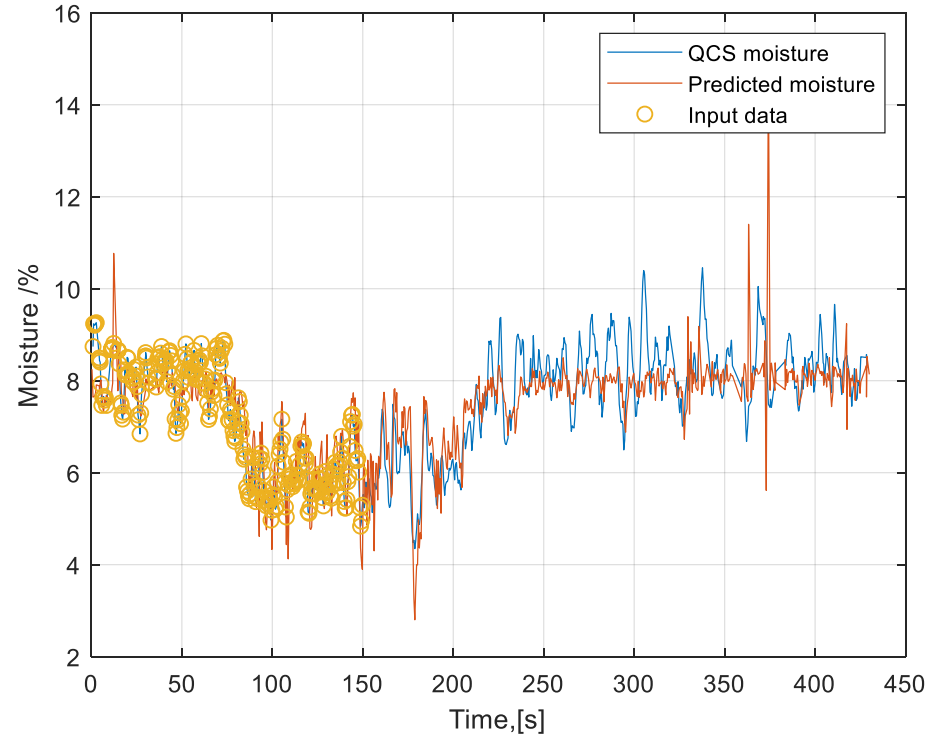
Model assumptions

- Correct synchronisation
- Gray scale variations in WIS at QCS position and time is assumed to correspond to the grammage variations measured by the QCS
 - and, WIS grayscale is linearly proportional to the basis weight in the same image
- Basis weight captured in 2 degree polynomial of the IR-temperature
- Moisture content is a function of this modelled basis weight, measured moisture content (at QCS) and IR-temperature in a multivariate least square regression



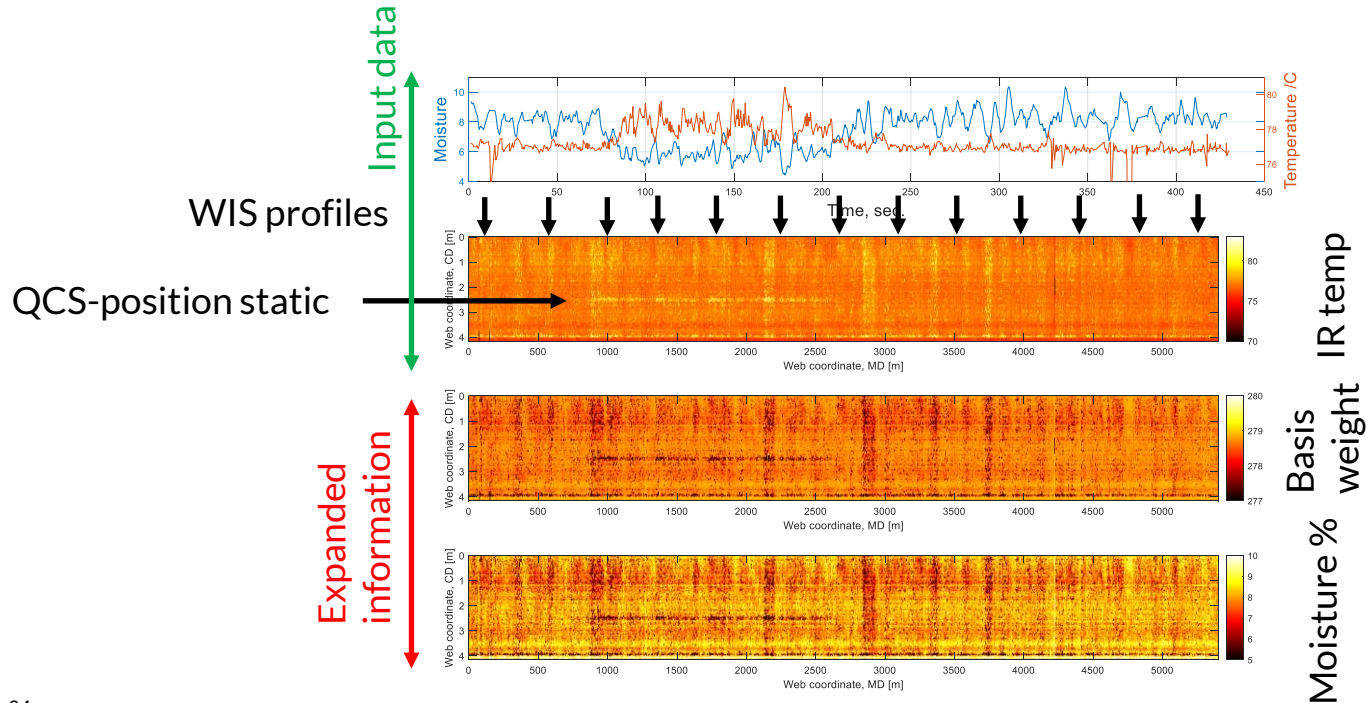
Granger causality test

- Simple test of predictability
- Here: 35% of the data used as input (marked yellow)
- Model prediction in orange compared to measurement (blue)
- Captures variations
 - Large scale (bump) very good
 - Small scale variations less so

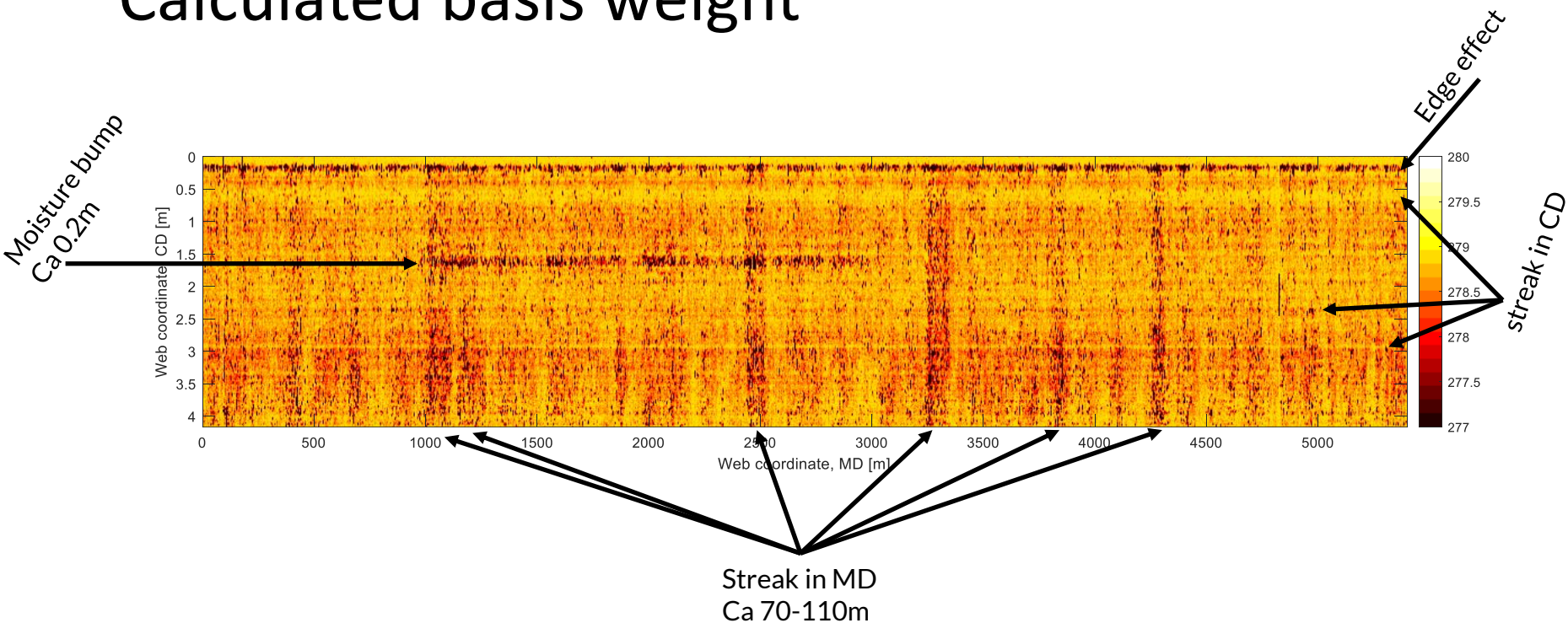


Results

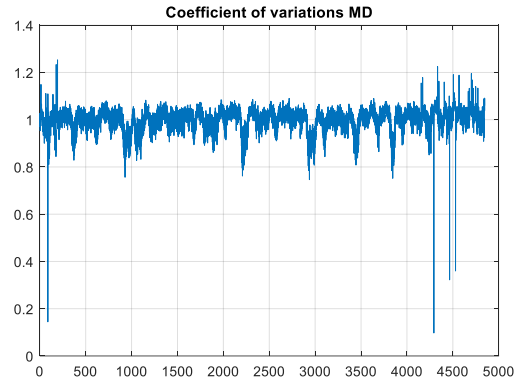
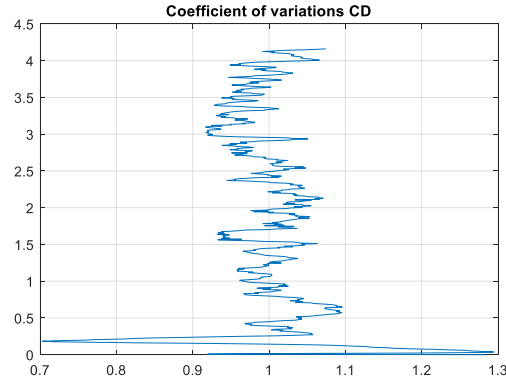
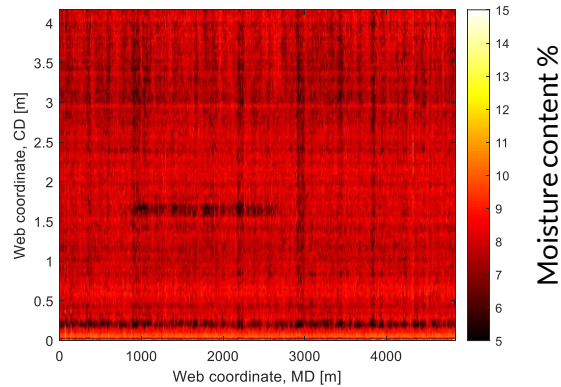
- Thus 2D-maps can be constructed based on QCS and WIS independently



Calculated basis weight



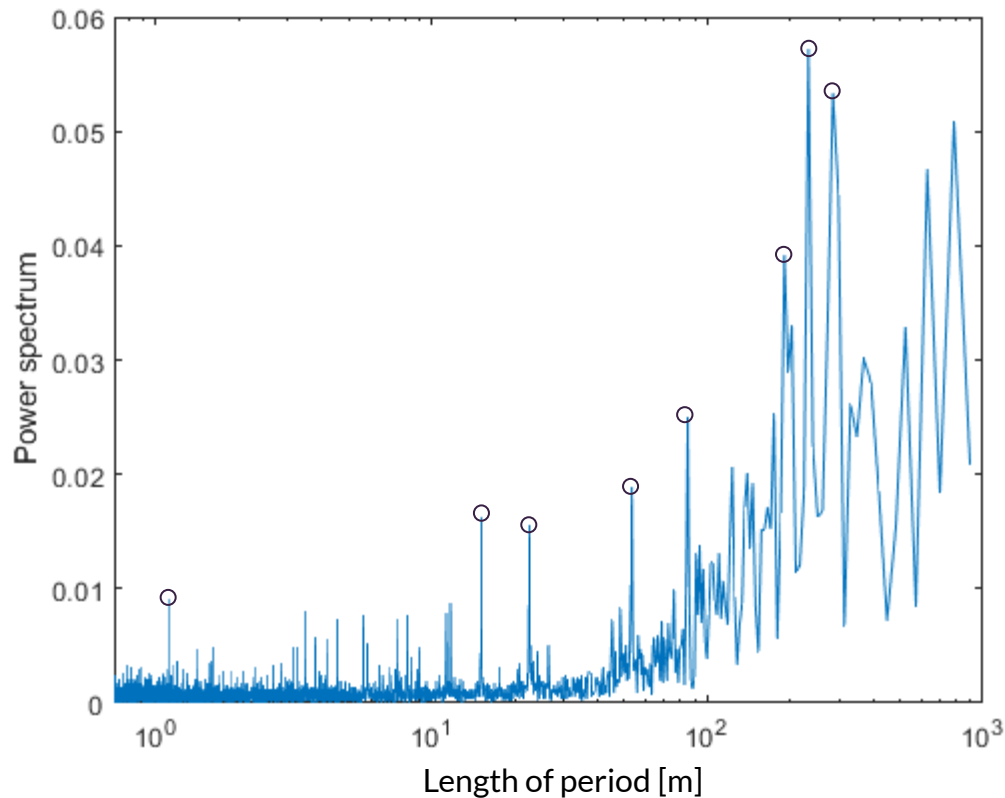
Predicted coefficient of variations - moisture



- Predicted moisture map, 5.5 km
- Variations can be identified in streaks (CD) or periodic disturbances (MD) within
 - a certain window
 - or complete production as example

Frequency analysis (FFT) MD-average, moisture content

- The frequency of variations can be determined by using discrete Fourier transform
- 285 \pm 15 m (25 s)
- 232 \pm 8 m (20 s)
- 190 \pm 6 m (17 s)
- 84.8 m (7,5 s)
- 53.2 m (4.7 s)
- 22.6 m (2.0 s)
- 15.1 m (1.3 s)
- 1.12 m (0.1 s)



Conclusions

- A methodology and practice has been developed to treat IR, WIS and QCS measurements in a model
- The method has been demonstrated in case studies (one presented here) and could in principle be used as a soft sensor, effectively extends information (using model predictions) to the whole production area
- The data was also shown in terms of property variations to demonstrate alternative data visualisation
- The developed methodology shows great promise to capture variations (both small and large)
- As errors in synchronisation and/or model assumptions are immediately detected in the correlation analysis the risk of false predictions are minimized

Note that there are a number of practical issues related to mill specific infrastructure and data structures that infers limitations on the ease of implementation, some of which has been discussed in this presentation



Thank you

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