Using nonlinear state space models for robust short-term forecasting of milk yield

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Overall modeling aim our SmartFarm project

- A lot prior work in PLF focuses on detection of individual problems: lameness, mastitis, ketosis
  - Requires a substantial dataset for supervised learning: hard to collect for rare conditions
  - Different problems can cause a similar response

- We decided to model normal behavior and yield of dairy cows using measured data combined with relevant system model
  - Short term forecast of what is expected to happen -> alert on anomalies
  - Give alarms on abnormal events.
- Pilot user interface to show alerts

Leverage from the EU 2014–2020
European Union
European Regional Development Fund

VTT

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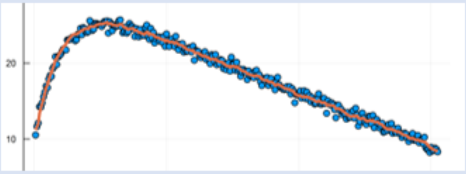
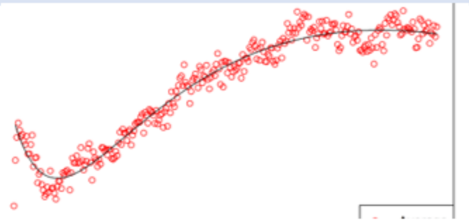
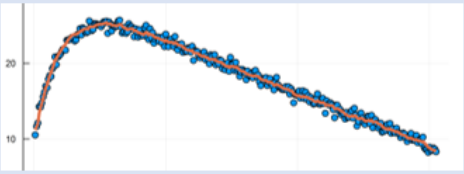
State space models

- State space models are used widely in animal science for state estimation of physiological and behavioural measurements.

- They provide a powerful tool to combine biological knowledge in the state equation combined with statistical methods for parameter estimation.

- In many applications the state equation can be nonlinear and the error distribution of observations can be non-Gaussian

Data sources and system models

Variable	Possible system model	
Milk yield	Wilmink function	
Daily lying time	Maselyne et al. 2017 + herd average	
Daily feeding time	Wilmink function + herd average	
Behavioral frequencis Feeding times / 24h Lying time / 24h	Constant mean model (Poisson distribution) + herd average	

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Particle filters

- Sequential Monte Carlo (SMC) method to estimate state space models that can't be estimated using traditional linear or linearized approaches.
  - Name particle first appeared in Kitagawa 1996
  - Work on parameter estimation more recent e.g. PMMH algorithm Andreiu et al (2010)
  - Used increasingly e.g. in economics and biology

- Requires more computational power than linear gaussian models and other non-linear methods such as EKF and UKF
  - A large number of particles can be needed to get repeatable results
  - Not necessarily an issue with current computers

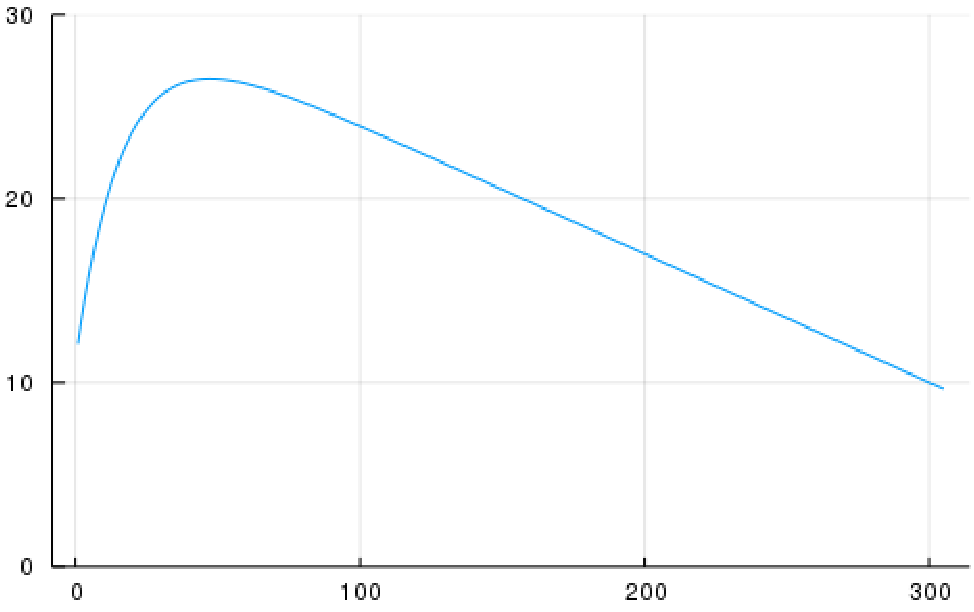
Step 1: Model milk yield and make a short term prediction

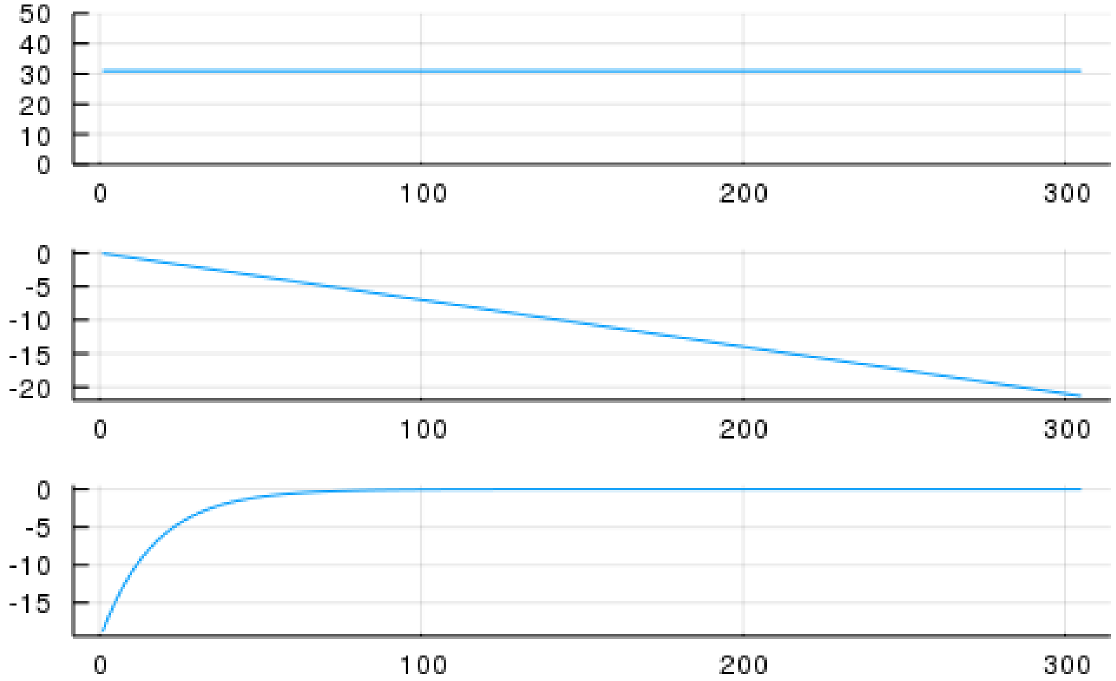
- Use Particle filters for modeling individual time series and estimate probability of "abnormal" values

- Short term forecasting 1-14 days forecasts and comparison to measured data

$$Yield = \beta_0 + \beta_1 t + \beta_0 + e^{kt}$$

$$Y_t = Y_{t-1} + \beta_1 \Delta t + \beta_2 e^{kt} \Delta t$$





Basic idea of particle filtering

- Simulation is used to estimate the parameters of a state space model

- Estimated parameters are represented by a "particles" -> data points

- "Particle Swarm" i.e. a group of datapoints represent different possible values for the parameters. e.g. 1000 particles can be used for estimation

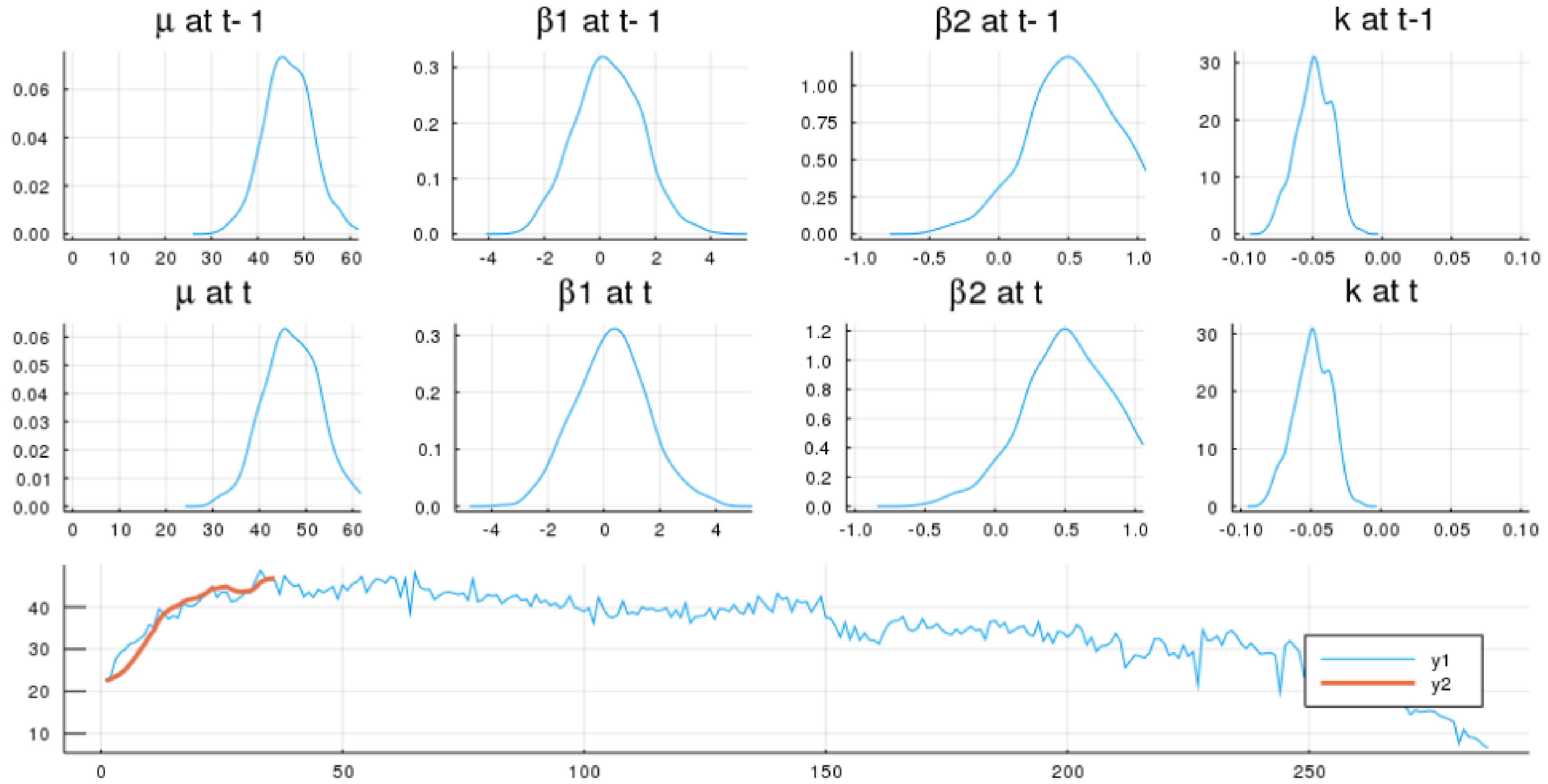
- Particles are initialized at some value using prior distribution
    - Particle values are updated to time t+1 using system equation and added simulation noise
    - Simulated values are compared to measured values -> calculate weights for each particle
    - State estimate are calculated as the weighted mean of particles

Particle filtering of milk yield data

System model:

$$\mu_t = \mu_{t-1} + \beta_1 \Delta t + \beta_2 e^{kt \cdot \Delta t}$$

Out[47]:



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Estimation and dataset

- Developed a Julia library for particle filtering

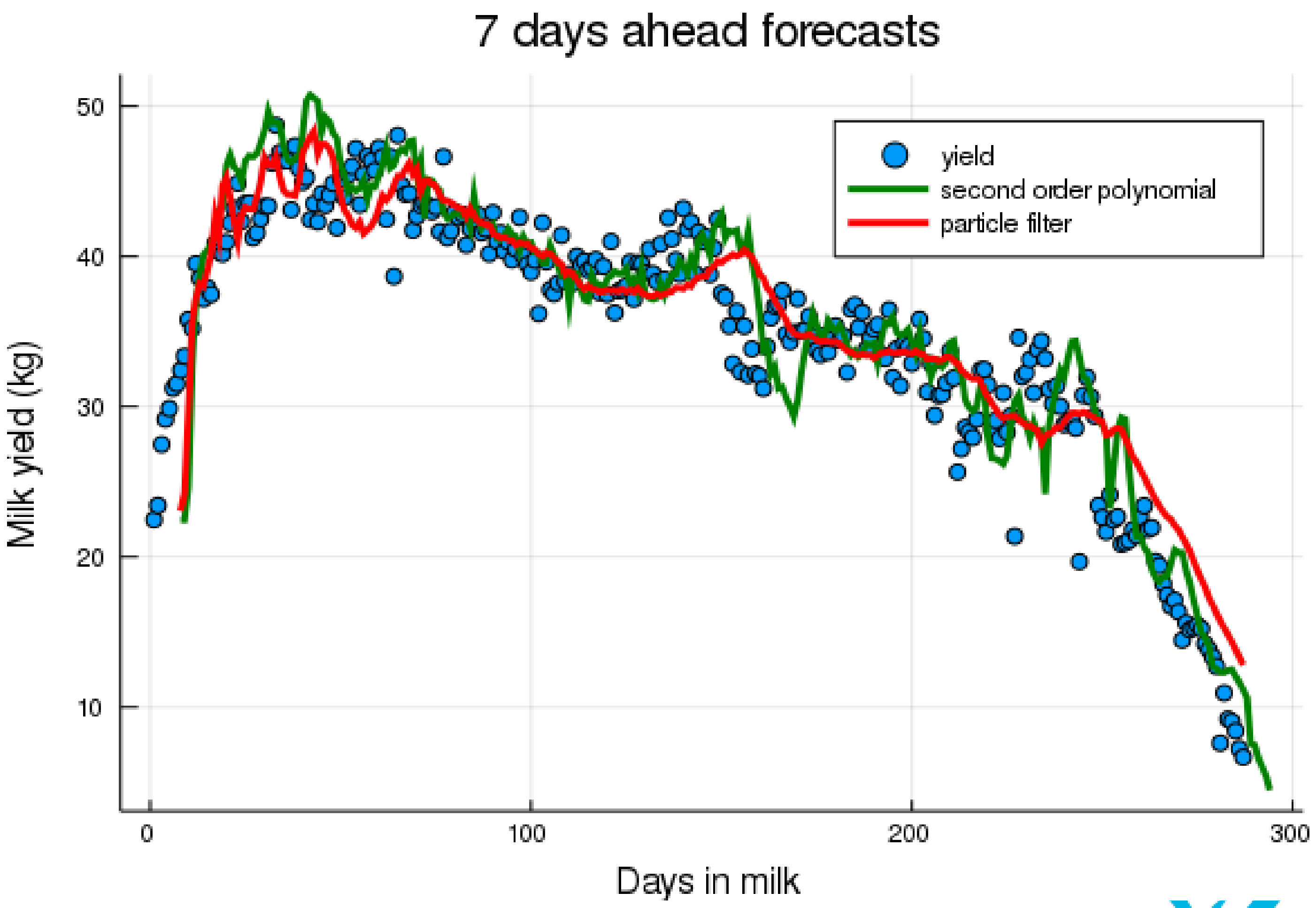
- Estimated model parameters: standard deviation of yield and model parameters using global optimizers in models with data from 800 lactations.

- Repeatable results obtained with 8000 particles

- Test 2 methods:
  - Maximum likelihood 1 step ahead filtering (ML textbook approach)
  - Minimize prediction error on 7 days ahead forecasting (MSE7)
- Test prediction on 530 lactations:

Results on optimization

- Average MSE for prediction: 31.5 ML and 28.17 MSE7
- The best method depends on the forecast horizon
- For disease detection it’s probably better to use separate model for acute and slowly developing conditions



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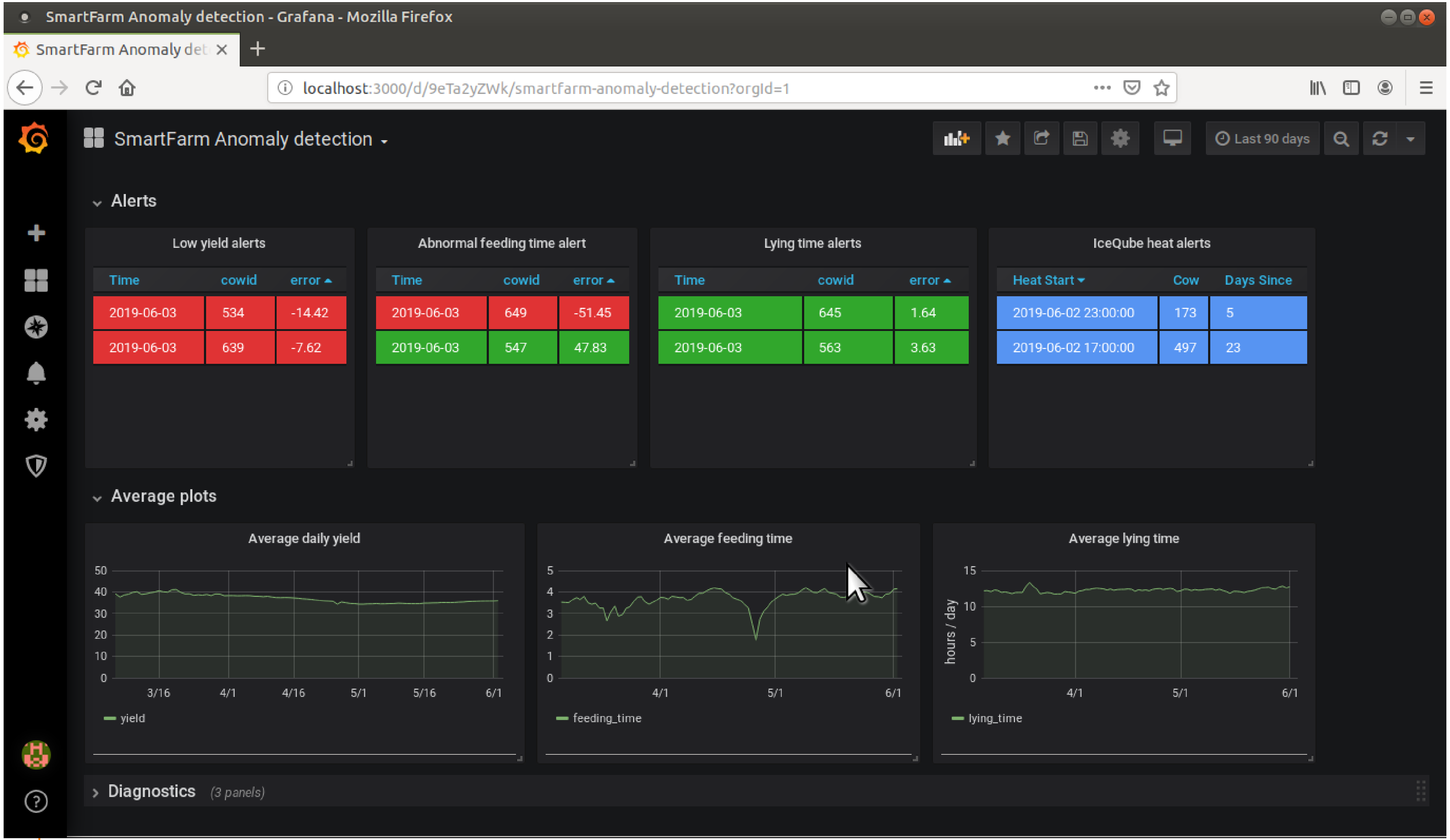
Real time alerts from the model



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Discussion

- The estimated model was very simple, but particle filtering allows much more complex models e.g. nonlinear predictors
  - We are not limited by not being able to estimate a specific model
  - You can directly interpret the parameters
- Computational cost is mainly an issue when optimizing the parameters (e.g. 48 CPU hours to optimize the Wilmink model -> 2hrs on 24 core task on a cluster (CSC – It center for science)

- **Anomaly detection approach** can be used when we have sensor data without reference data.
  - Requires assumptions/decisions on alert level
  - Needs data for validating alarm performance. We are working on it!

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See poster 61.09 by Rafael Muñoz-Tamayo