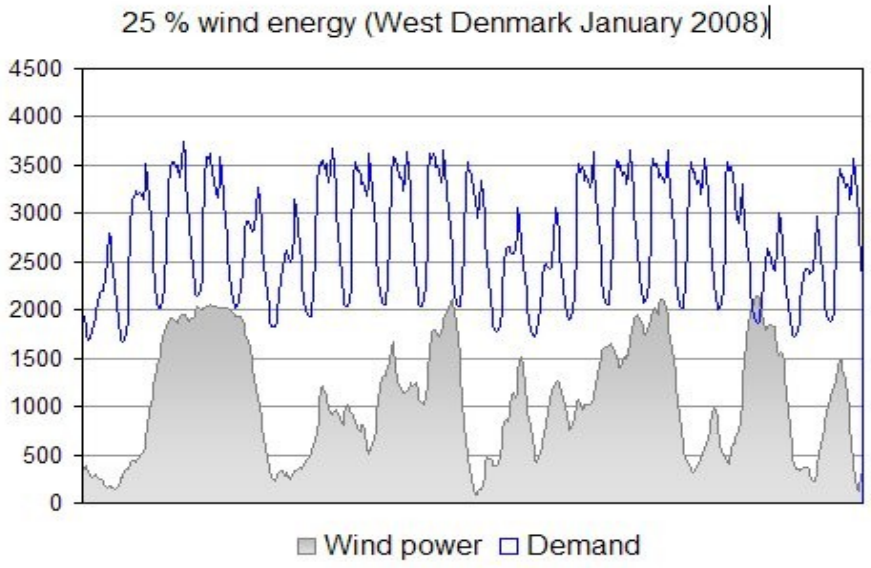
# Forecasting, Aggregation (and Control) for Future Electric Energy Systems

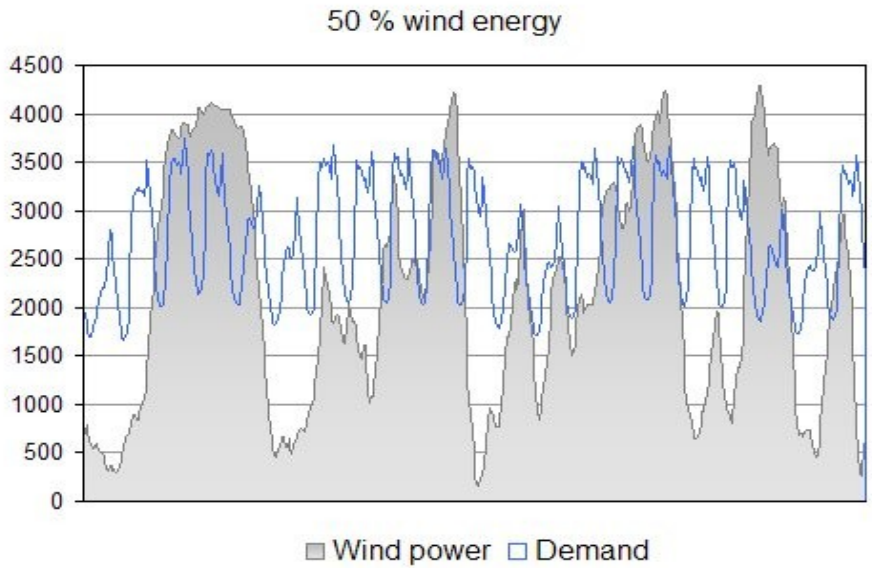
**Henrik Madsen**

# The Danish Wind Power Case

*.... balancing of the power system*

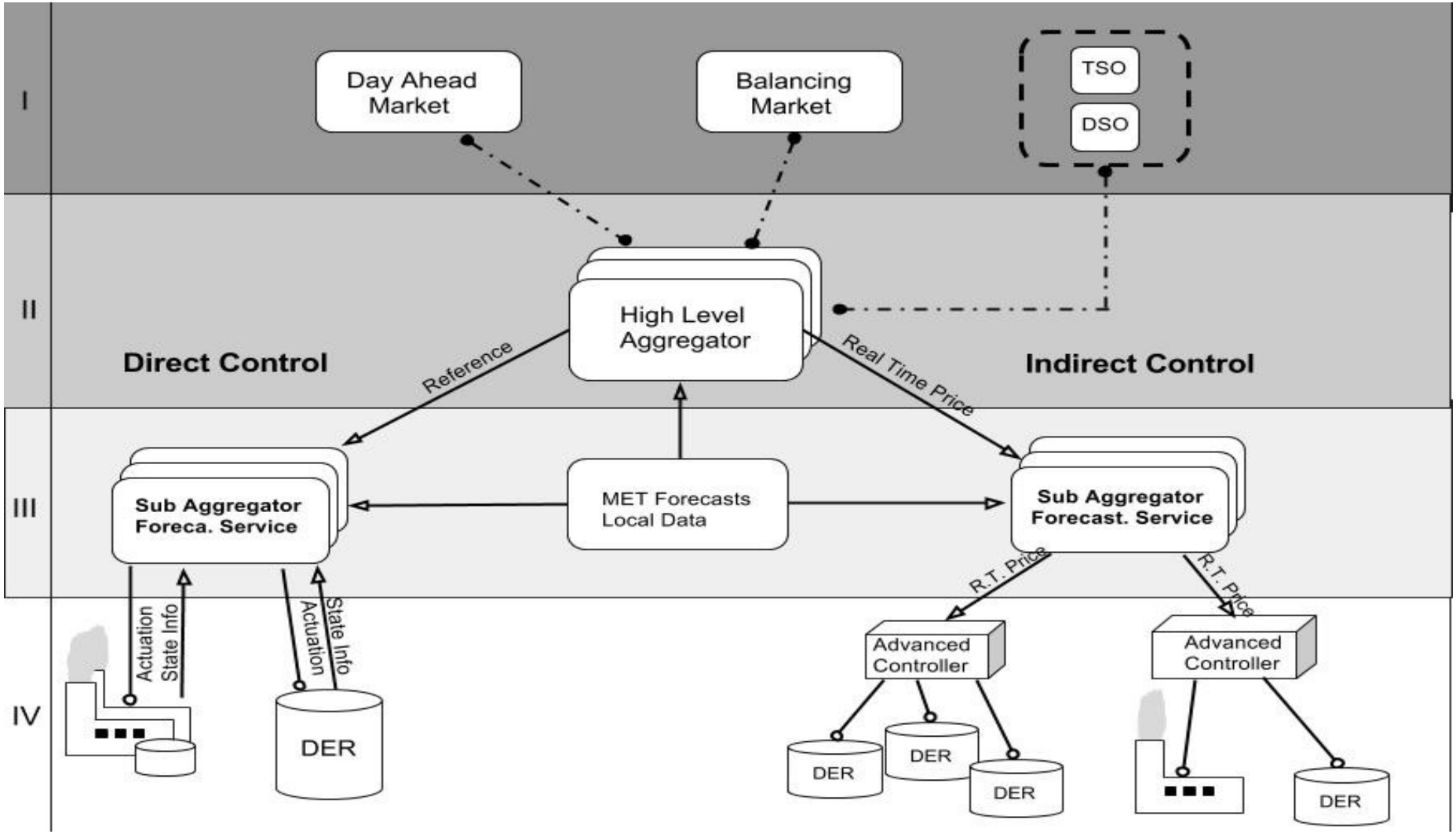



In 2008 wind power did cover the entire demand of electricity in200 hours (West DK)

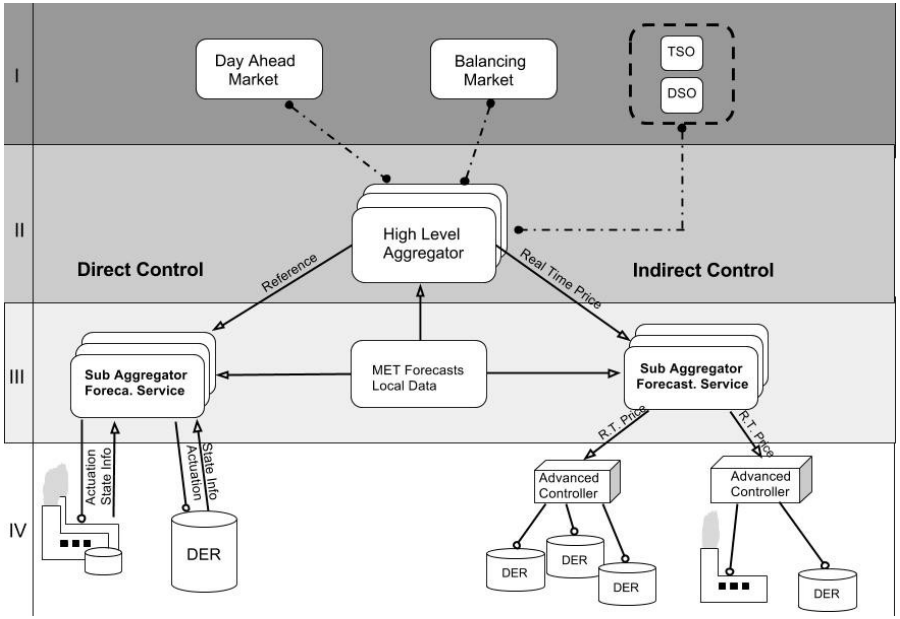



**In December 2013 and January 2014 more than 55 pct of electricity load was covered by wind power**. And for several days the wind power production was more than 120 pct of the power load

# Control/Opt. Principles

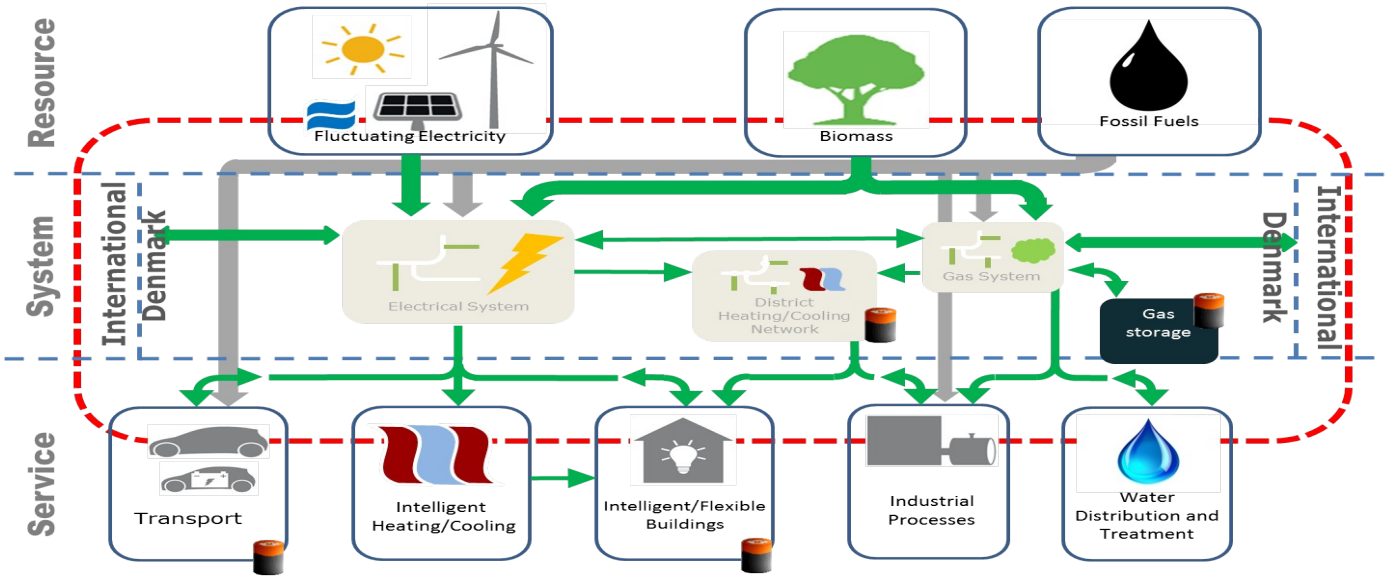


# Stoch. Control/Opt. Principles



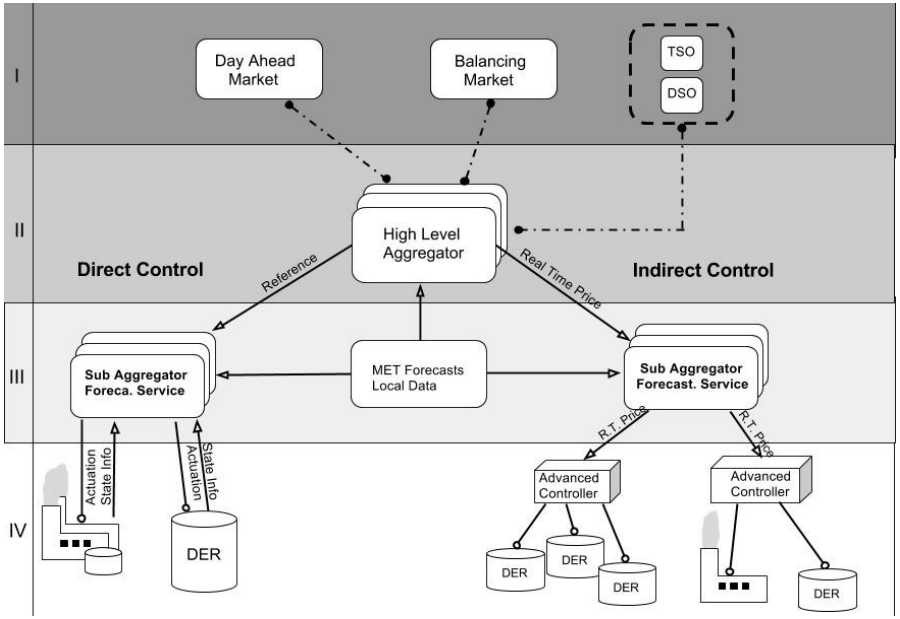

- **Day Ahead:**
  - Stoch. Programming based on scenarios
- **Direct Control:**
  - Actuator: Power
  - Cost: MV, LQG, GPC, ...
  - Two-way communication
  - Models for DERs are needed
  - Constraints for the DERs
  - Contracts on exceptions
- **Indirect Control:**
  - Actuator: Price
  - Cost: E-MPC, VaR-alike, ..
  - One-way communication
  - Models for DERs are not needed
  - Simple 'contracts'

# Example: Storage by Energy Systems Integration




- **Denmark (2014) : 45 pct of power load by renewables (> 100 pct at some days in January)**
- **(Virtual) storage principles:**
  - _ Buildings can provide storage up to, say, 5-12 hours ahead
  - _ District heating/cooling systems can provide storage up to 1-3 days ahead
  - _ Gas systems can provide seasonal storage

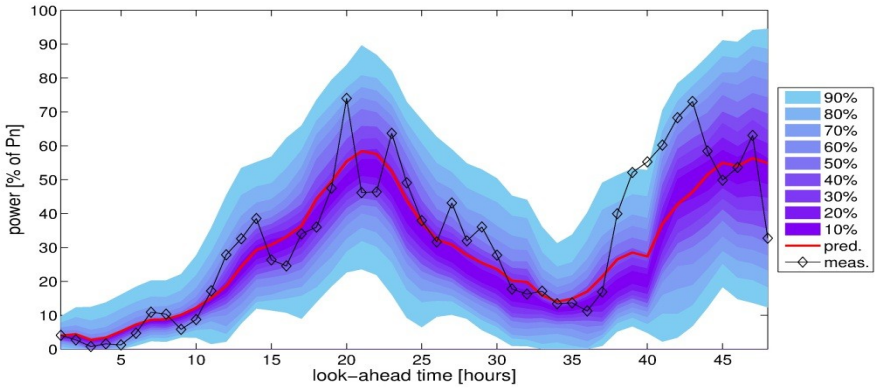
# Forecast requirements

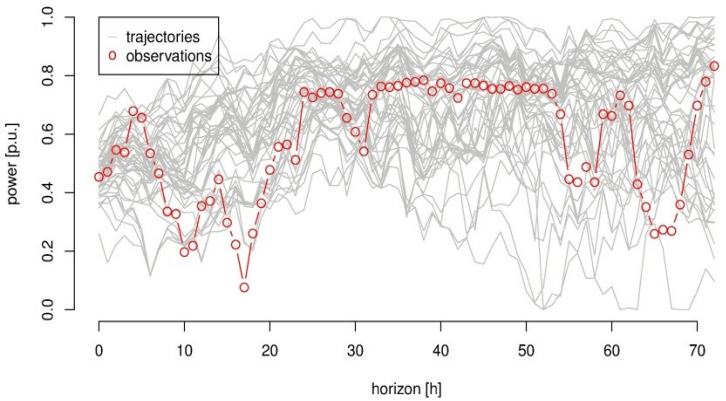



- **Day Ahead:**
  - Forecasts of loads
  - Forecasts of production (eg. Wind and Solar)
- **Direct Control:** .
  - Forecasts of states of DERs
  - Forecasts of flexibility
  - Forecasts of load
- **Indirect Control:**
  - Forecasts of prices
  - Forecasts of load.

# Which type of forecast to use?

- Point forecasts
- Conditional mean and covariances
- Conditional quantiles
- Conditional scenarios
- Conditional densities
- Stochastic differential equations



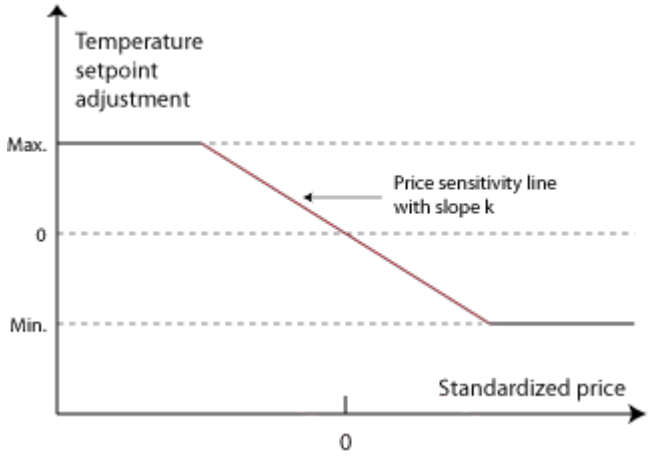



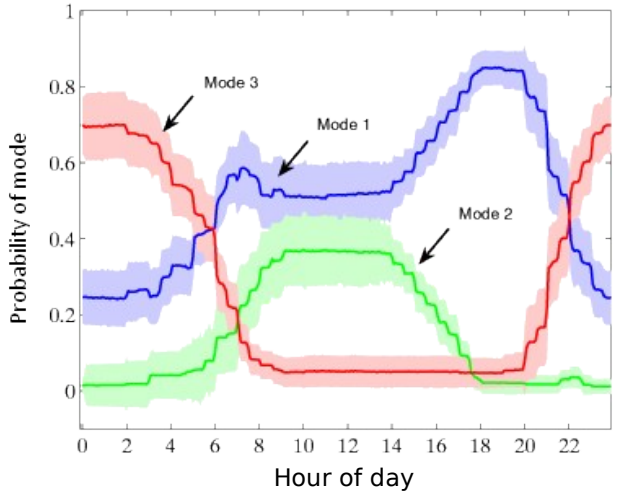
## Case study

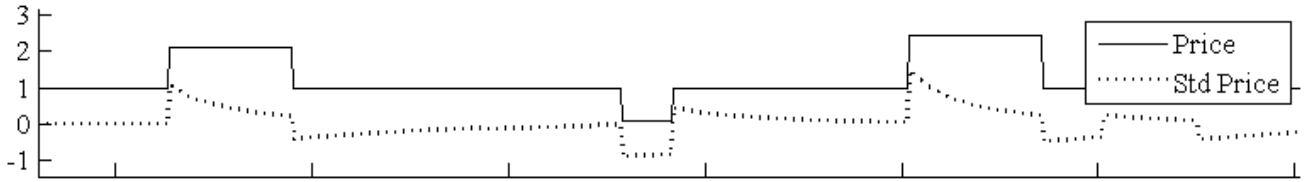
# Control of Power Consumption (DSM)

# Price responsivity

*Flexibility is activated by adjusting the temperature reference (setpoint)*



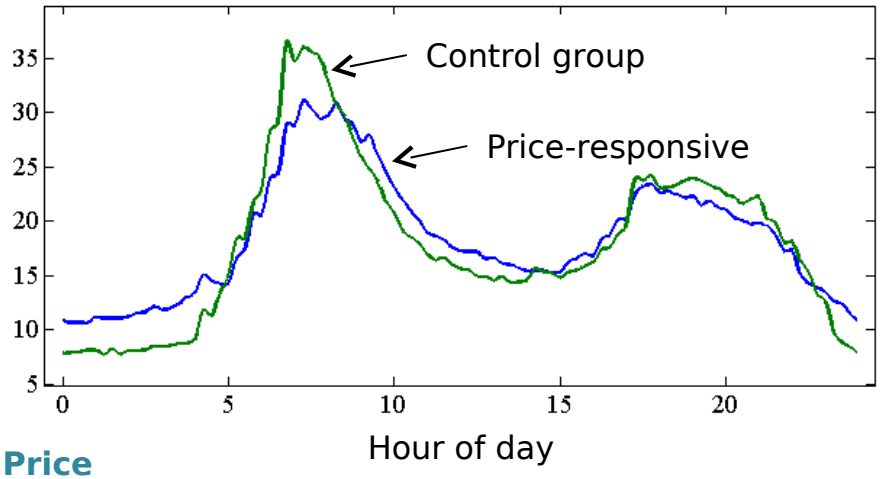




- **Standardized price** is the % of change from a price reference, computed as a mean of past prices with exponentially decaying weights.
- **Occupancy mode** contains a price sensitivity with its related comfort boundaries. 3 different modes of the household are identified (work, home, night).

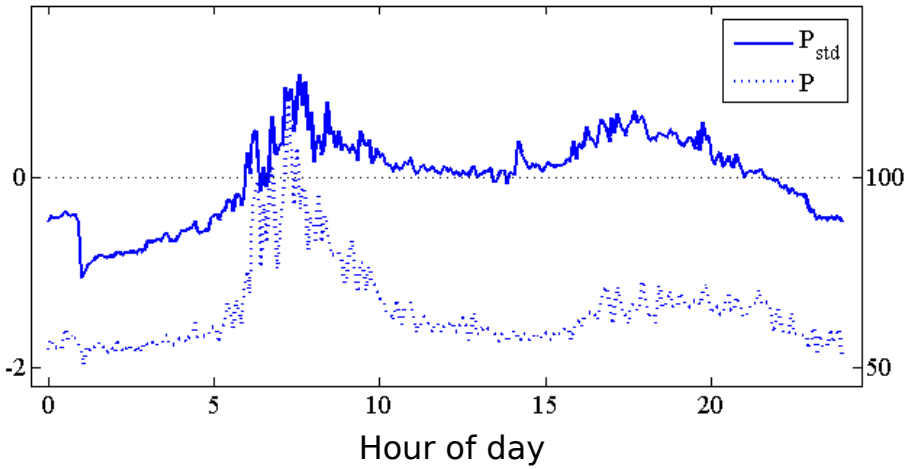
# Olympic Peninsula project

- Price-responsive and control group available for comparison
- Access to aggregated variables
  (mean, min, max and variance)
- Prices are the result of intersecting demand/supply curves in a shadow market
- Main flexibility source is heating/cooling

**Consumption**




**Price**

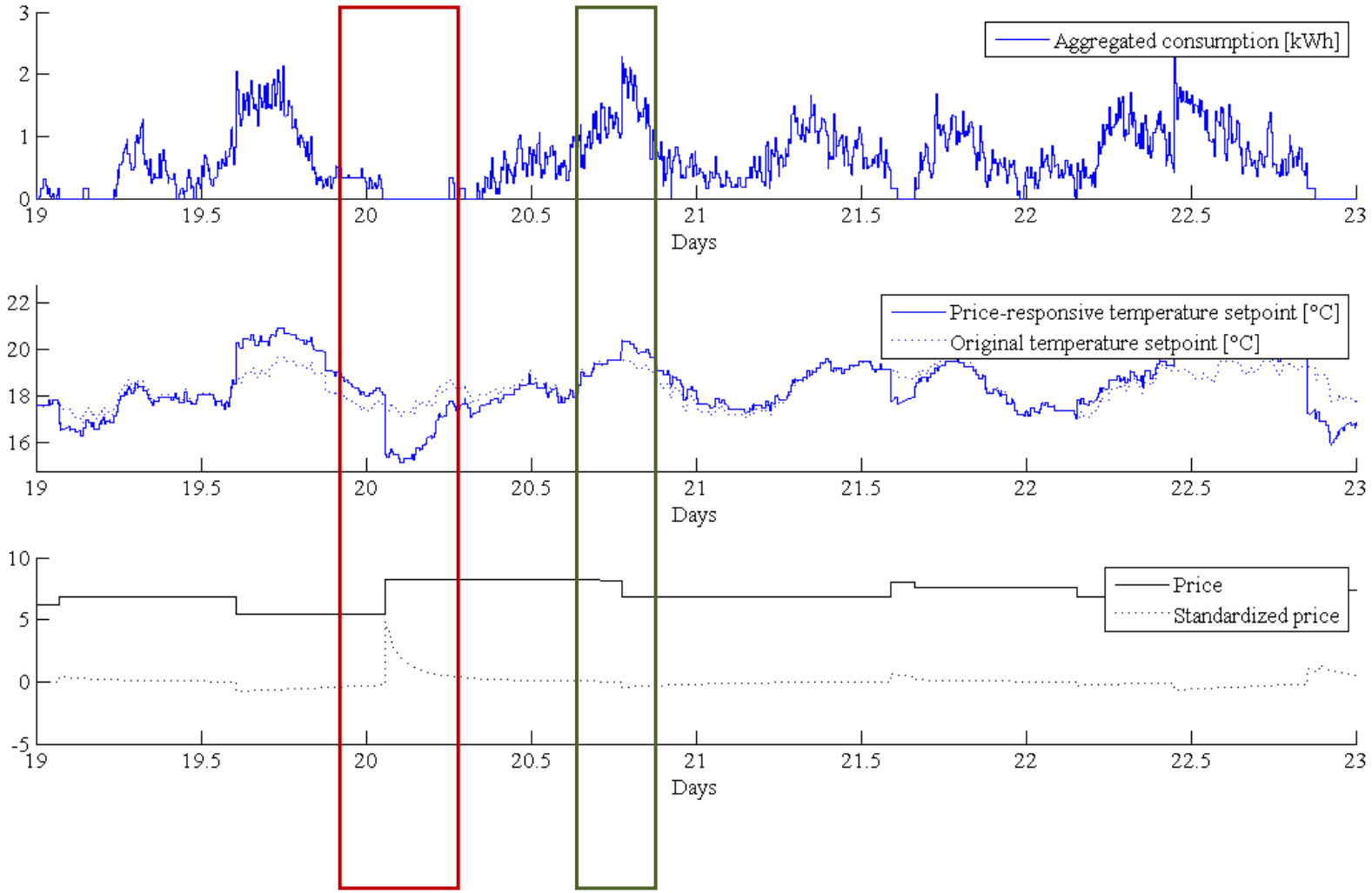


# Data from BPA

## Olympic Pensinsula project

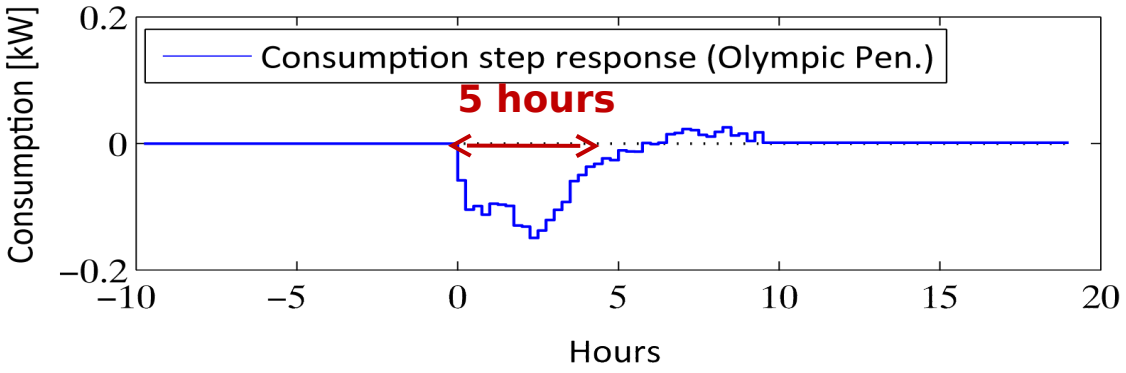
- 27 houses during one year
- Flexible appliances: HVAC, cloth dryers and water boilers
- 5-min prices, 15-min consumption
- Objective: limit max consumption

# Aggregation (over 20 houses)

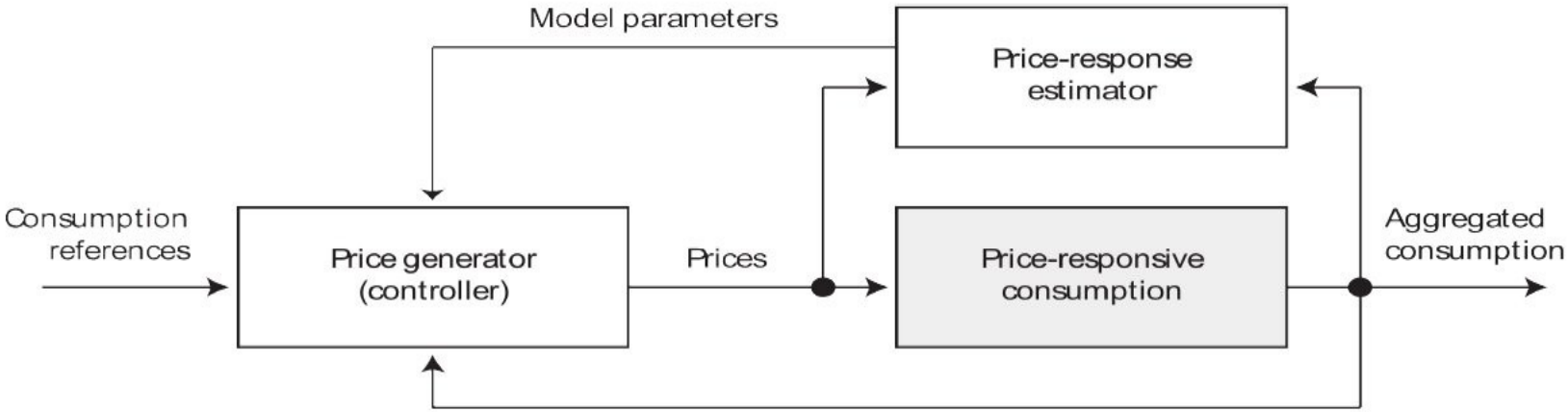


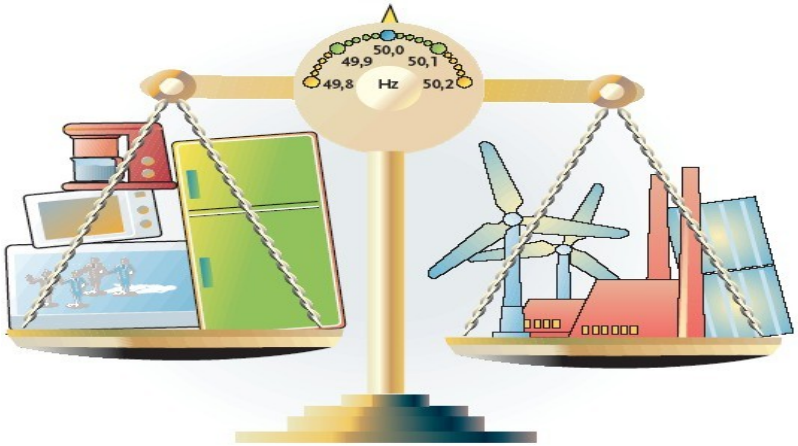
# Non-parametric Response on Price Step Change

## Olympic Peninsula



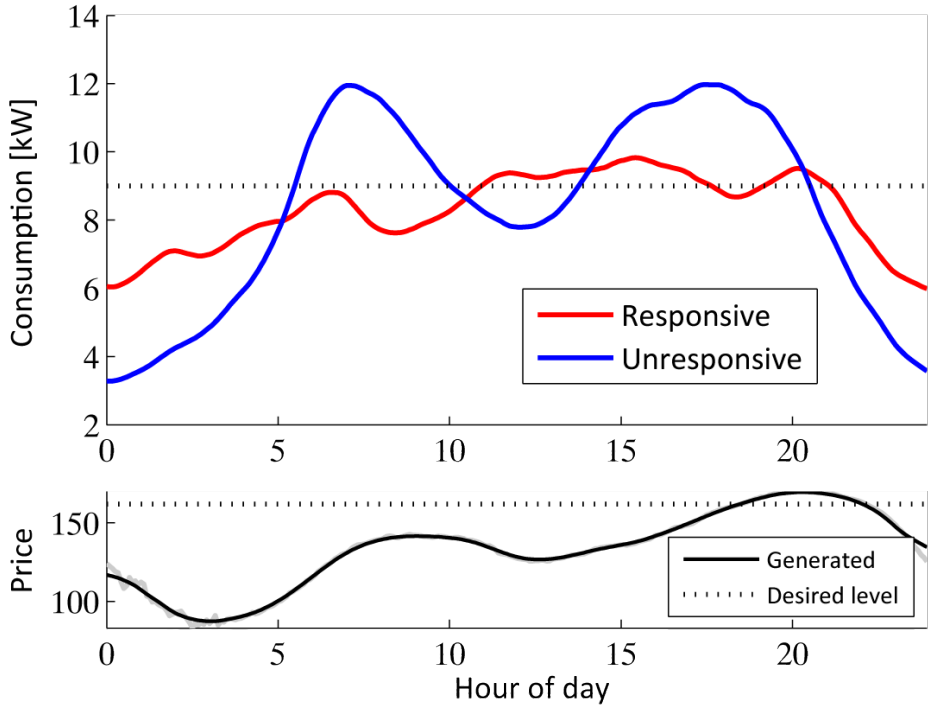
# Control of Power Consumption



# Control performance

- Considerable **reduction in peak consumption**
- Mean daily consumption shift



# Ongoing CITIES projects with a focus on DSM

- Temperature control in houses (Grundfos, ENFOR)
- HVAC systems (Grundfos, NREL)
- Supermarket cooling (Danfoss, UCD)
- Consumption in family houses (TI, ENFOR, ...)
- District heating networks (Cowi, ENFOR, Rambøll, DFF-EDB)
- Combined Heat and Power plants (Dong Energy)
- Heat Pumps in District Heating networks (HOFOR, Cowi, ENFOR)
- Rainfall Run-off Systems (DHI and Rambøll)
- Wastewater treatment plants (Krüger)
- .....

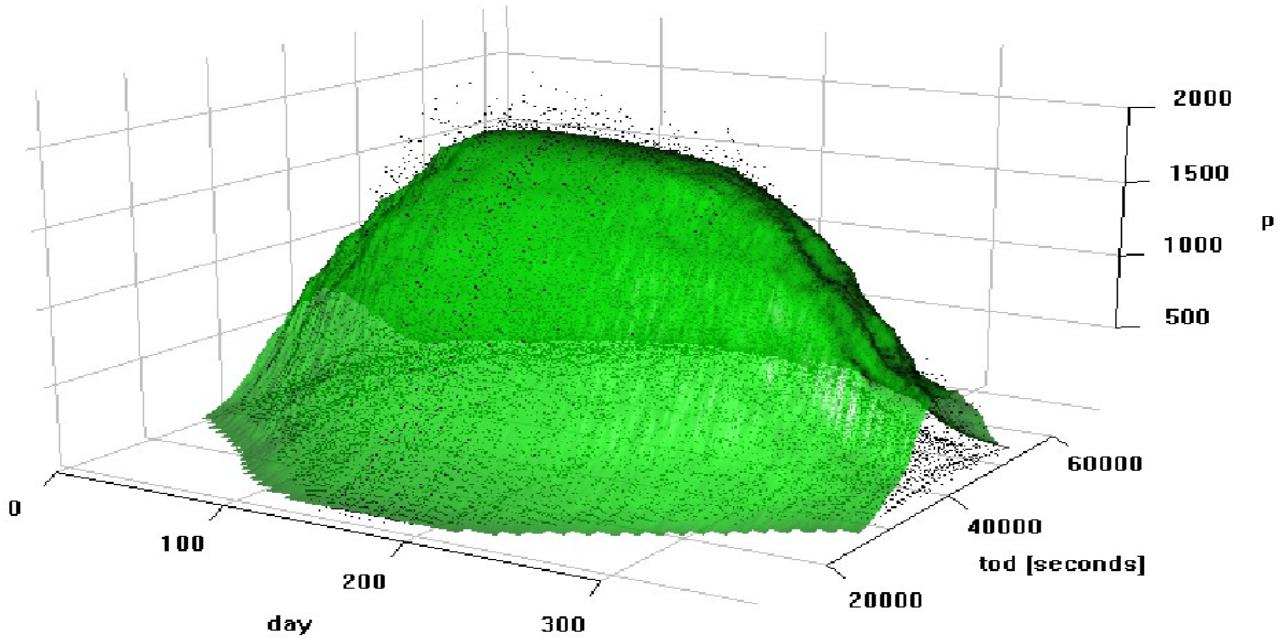
# Example

# Solar Power Forecasting

# Solar Power Forecasting

- Grid connected PV-systems mainly installed on rooftops
- Average of output from 21 PV systems in Brædstrup

# Method

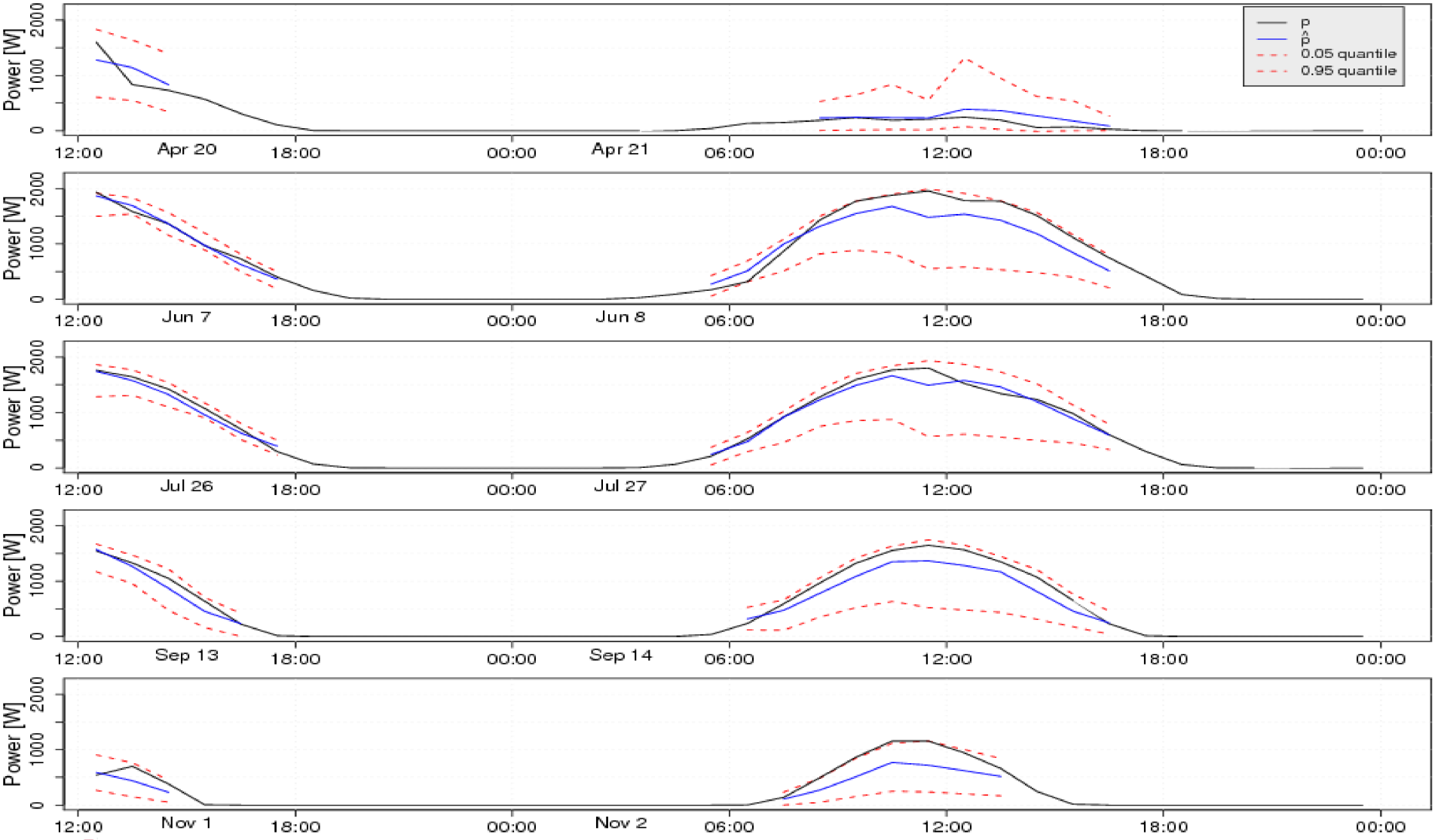



- Based on MET forecasts and online readings of output
- Two-step method:

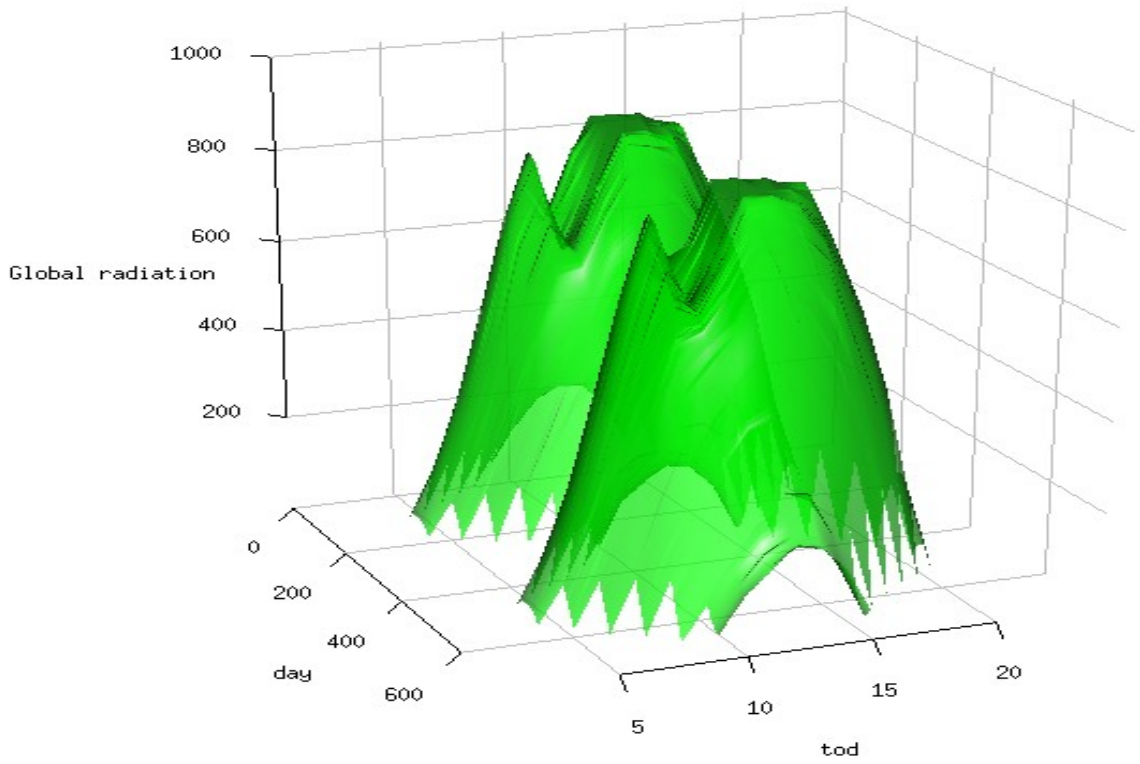
  1) Transformation to atmospheric transmittance with statistically clear sky (see above),

  2) A dynamic model + adaptive quantile regression.

# Example
# (quantile forecasts – up to 36h ahead)

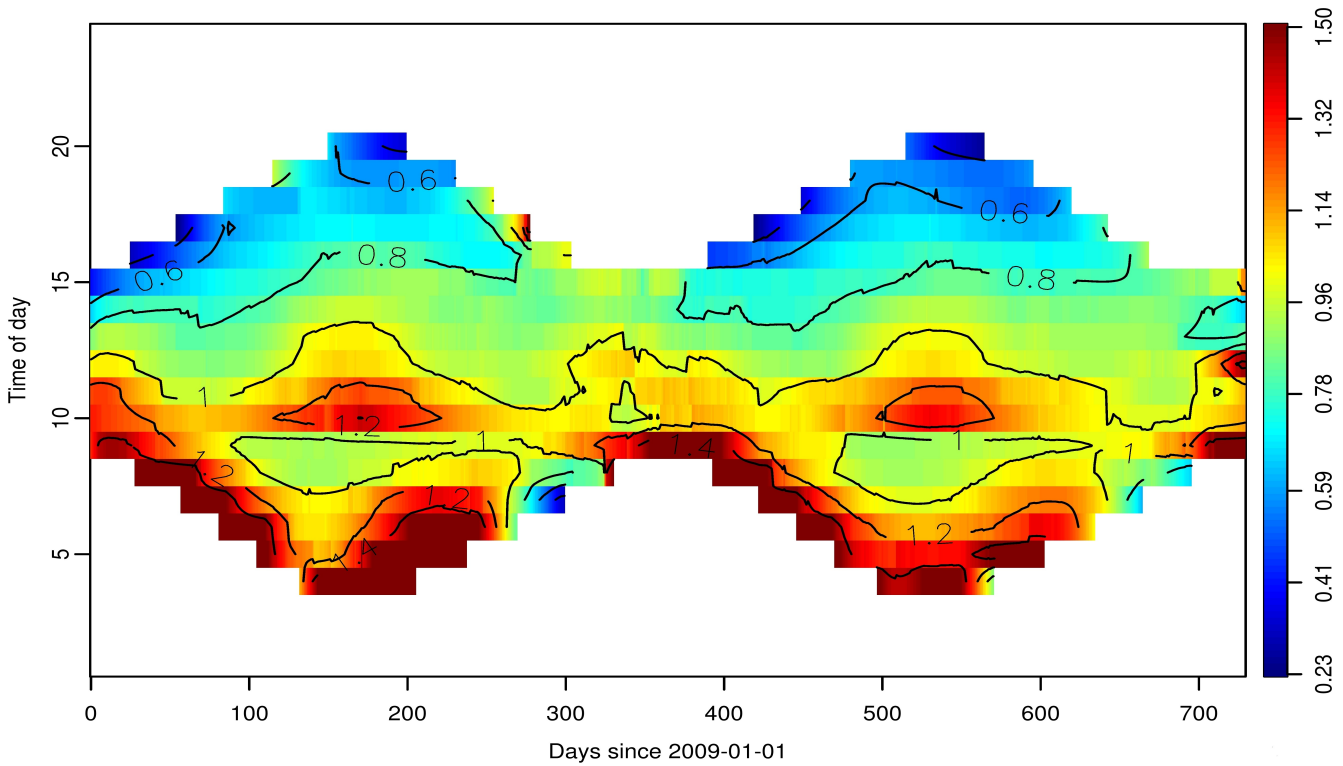


# Adaptive correction method



# Adaptive correction method

# Adaptive correction method (correction function)



# Adaptive correction method