PREDICTIVE CONTROL UNDER CLOUD PASSAGES OF A SOLAR TOWER PLANT WITH AN OPEN-VOLUMETRIC RECEIVER

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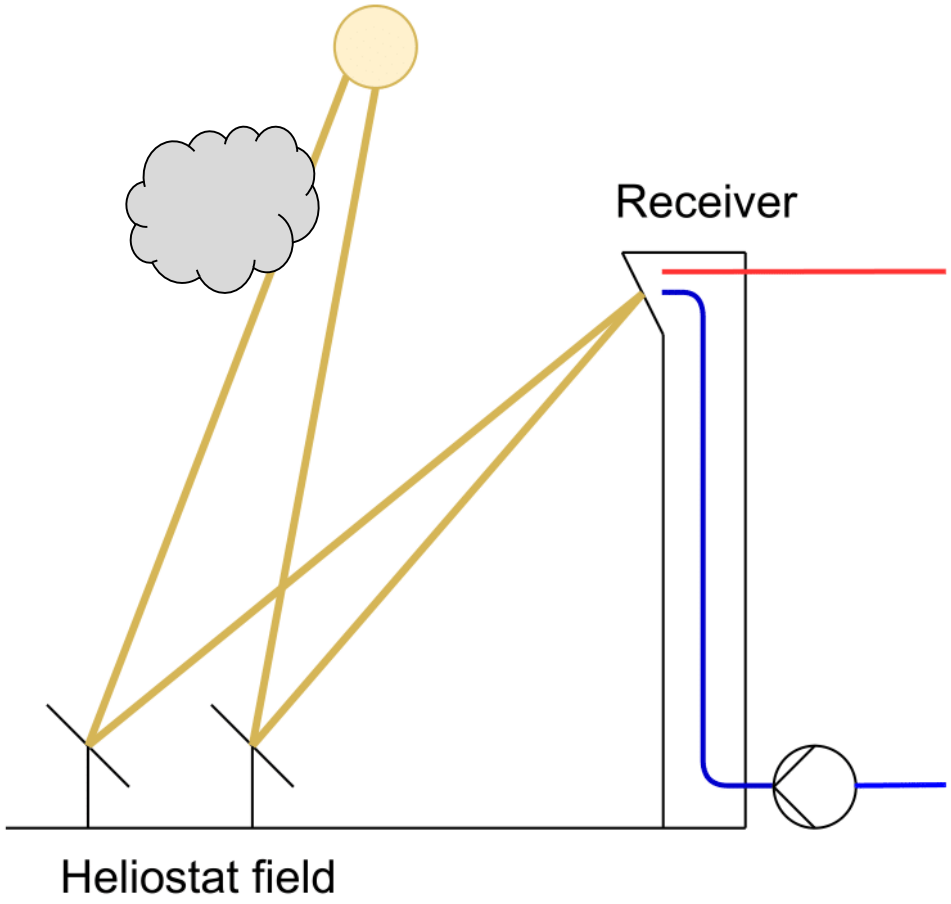
DLR

Problem - Cloud Passage

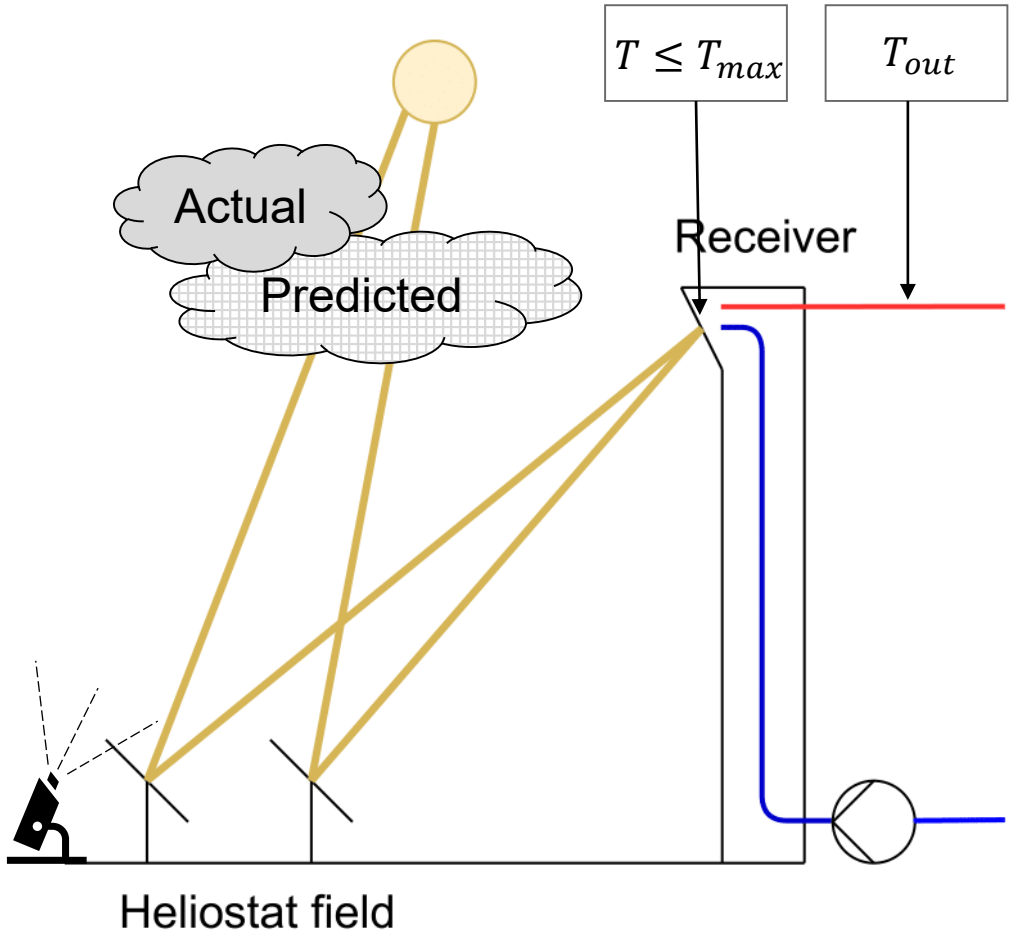
- Usually, a "cloud standby scenario" is set
  → Avoiding damage
- Problems:
  - The available solar energy is not fully utilized during cloud passage
    → Reduction of the efficiency
  - Colder heat transfer medium for downstream process
    → Reduction of the efficiency of the downstream processes
- Solution:
  - Control the mass flow and the heliostats during cloud passage to increase the efficiency

  → What about safety?

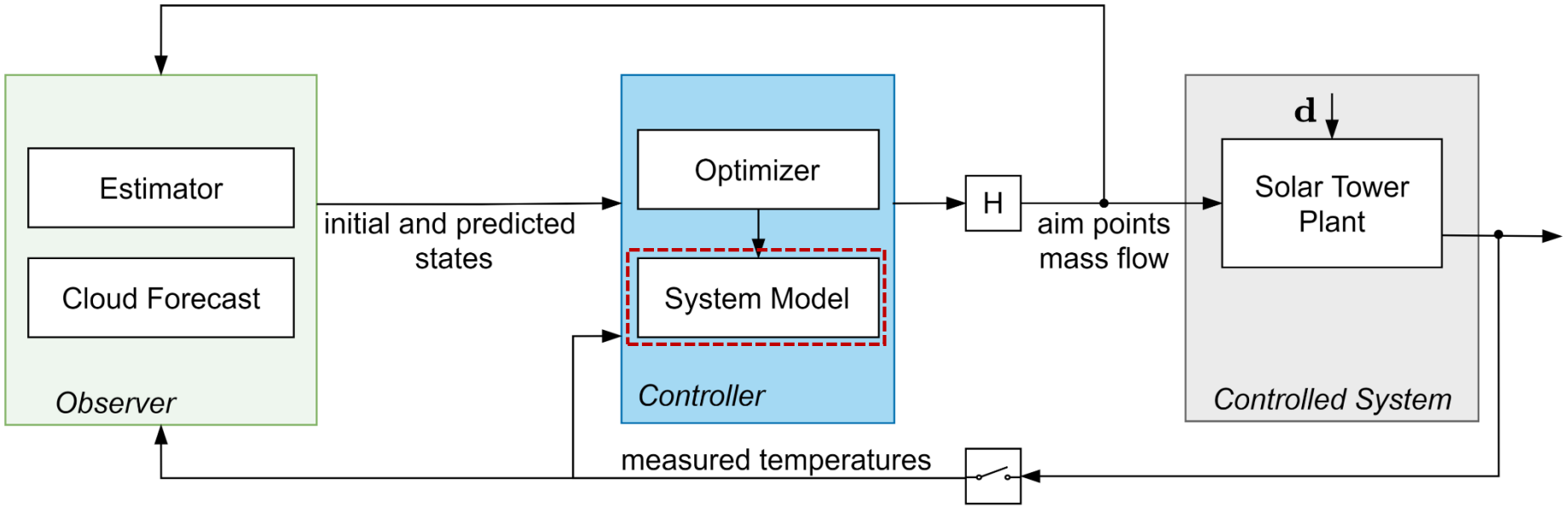


Objective

- Control of the air outlet temperature in compliance with the given temperature limits by manipulating the mass flow and heliostat aim points.
- Consider cloud forecasts.
- Analysis of the control performance under different cloud scenarios.
- Analysis of the robustness of the controller to uncertainties in cloud forecasting.



Approach: Model Predictive Controller



- Specifics of model predictive controller:
  - Possibility to include predictable disturbances/model states (e.g. cloud predictions)
  - Control of MIMO systems possible (e.g. mass flow and aim points)
  - Input and output variables as well as model states can be limited (e.g. surface temperatures)

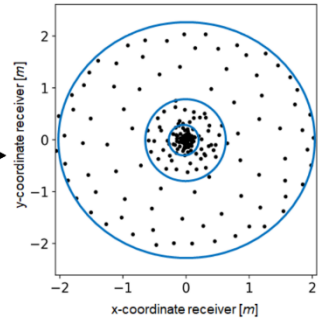
MODEL OF THE SOLAR TOWER JUELICH

Model for the MPC

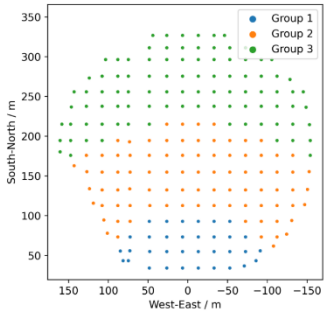
optical model

measurements

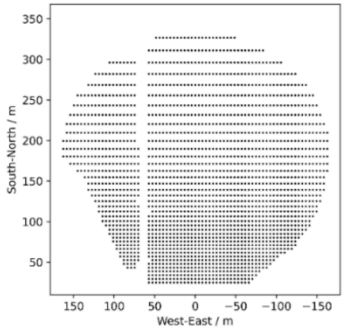
3 dispersion factors $\kappa_1, \kappa_2, \kappa_3$



Map to 3 groups

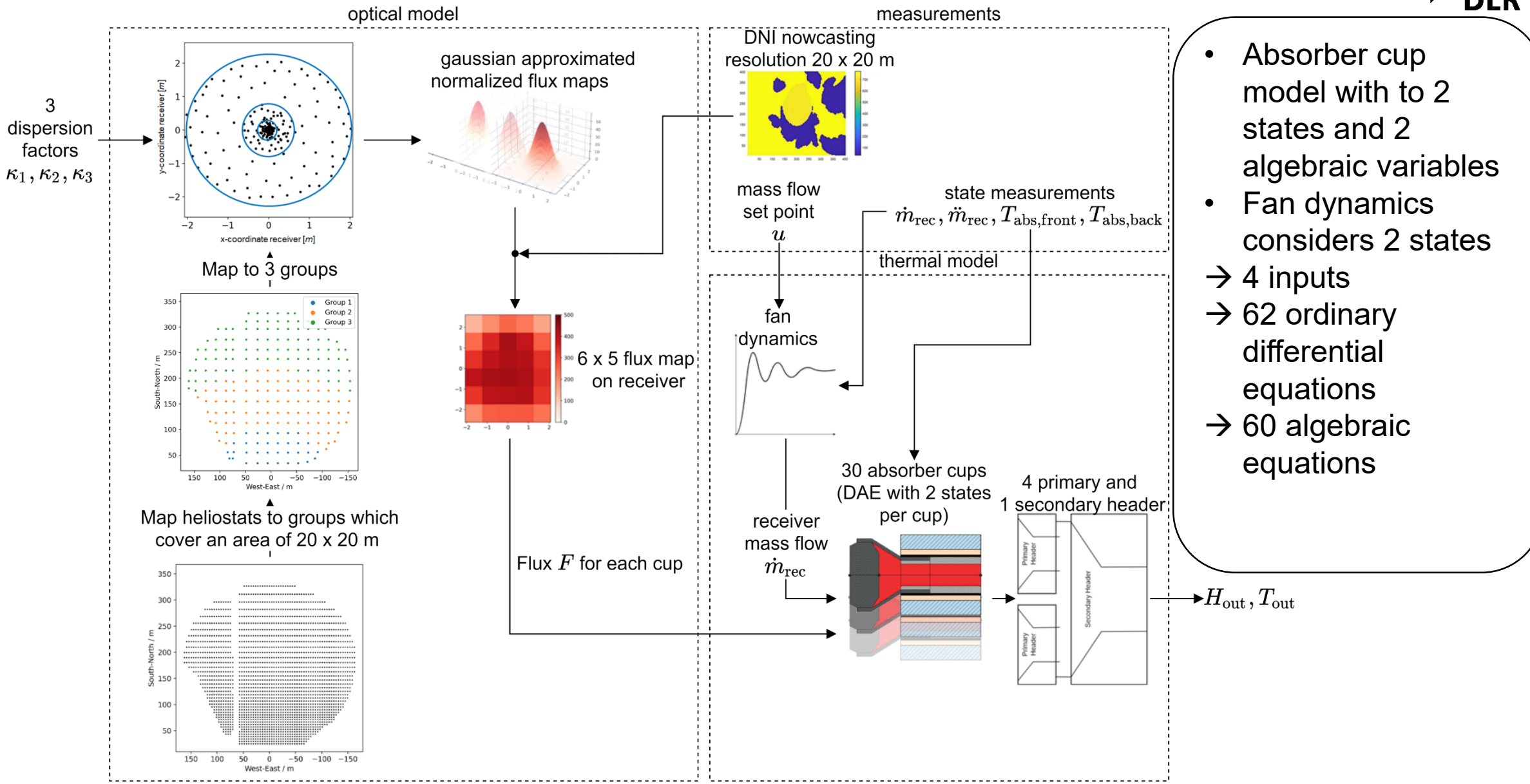


Map heliostats to groups which cover an area of 20 x 20 m



- Reducing to 3 dispersion factors by grouping and valve analogy from Garcia et al.
- Flux distribution by a superposition of Gaussian bells.
- Considering one critical cup out of 6x6 cups.

Model for the MPC



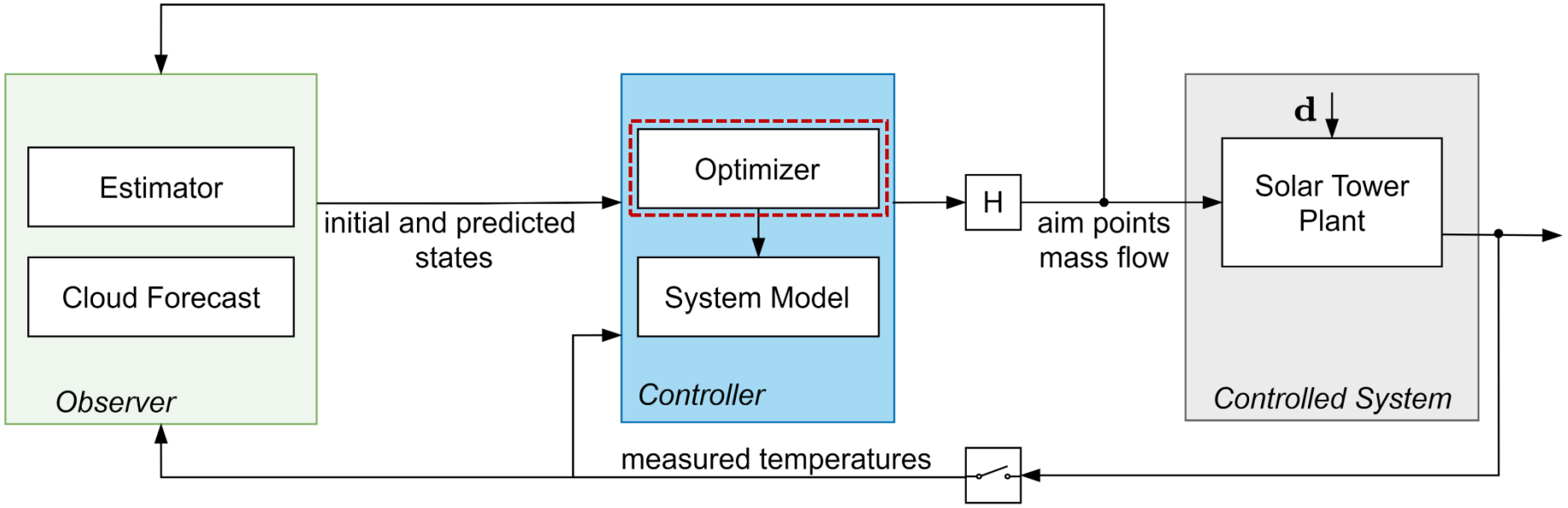
- Absorber cup model with to 2 states and 2 algebraic variables
- Fan dynamics considers 2 states

→ 4 inputs

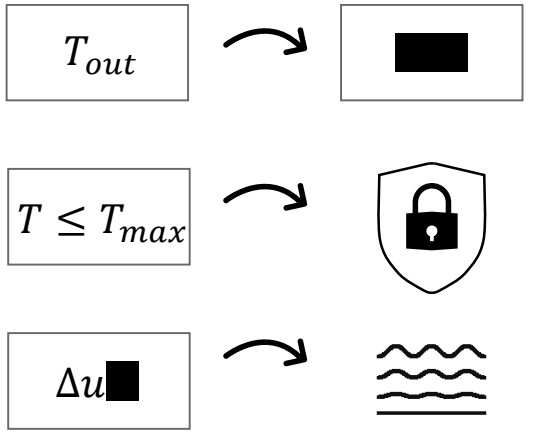
→ 62 ordinary differential equations

→ 60 algebraic equations

Optimizer



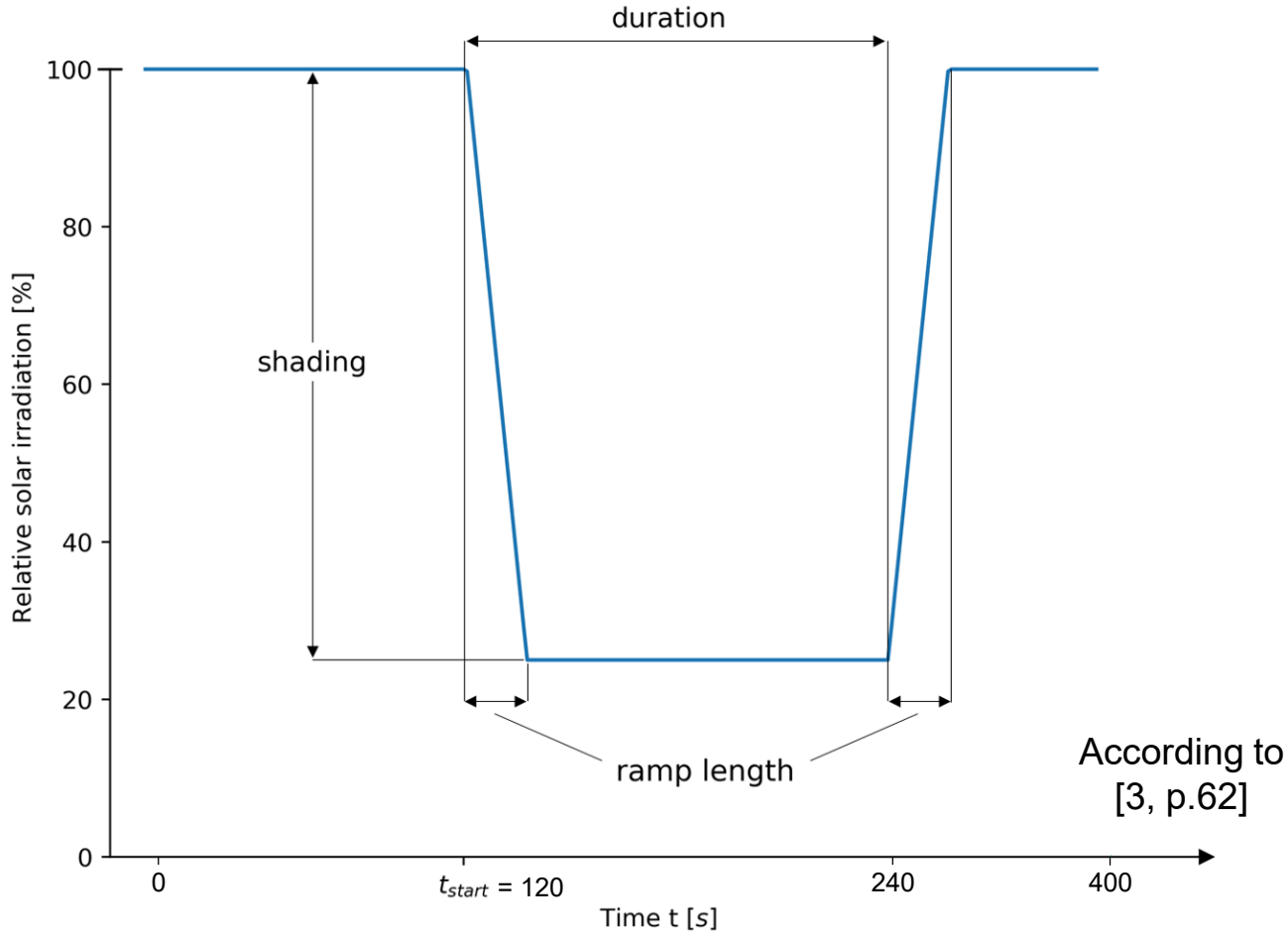
- Optimizer: IPOPT
- Objective function considers:
  - Deviation from set point temperature
  - Soft constraints for surface temperature
  - Rate term for manipulated variables
- Sample time: 10 s (3s for MPC, 3-6s heliostat movement)



RESULTS

Definition of Test Case 1

- Complete shading of the heliostat field.
- Shading duration: 120 seconds
- Cloud transmissivity: 0%, 25%, 50%, 75%,
- Cloud speed actual and predicted
  (Only influence on ramp length):
  15, 20, 25, 30 m/s

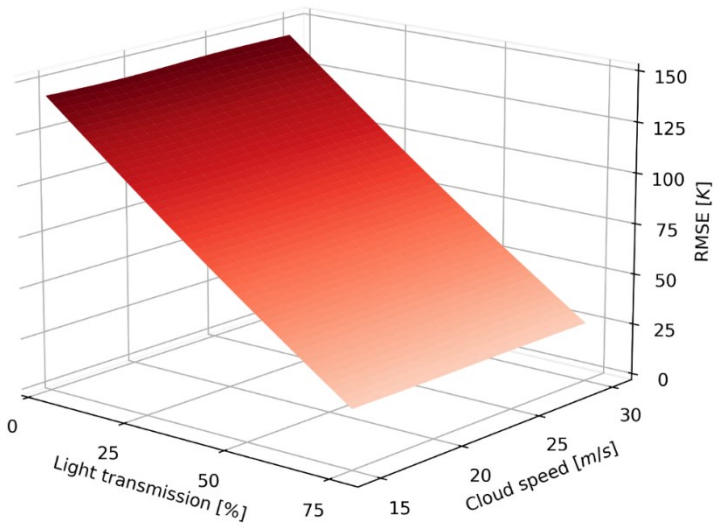


According to [3, p.62]

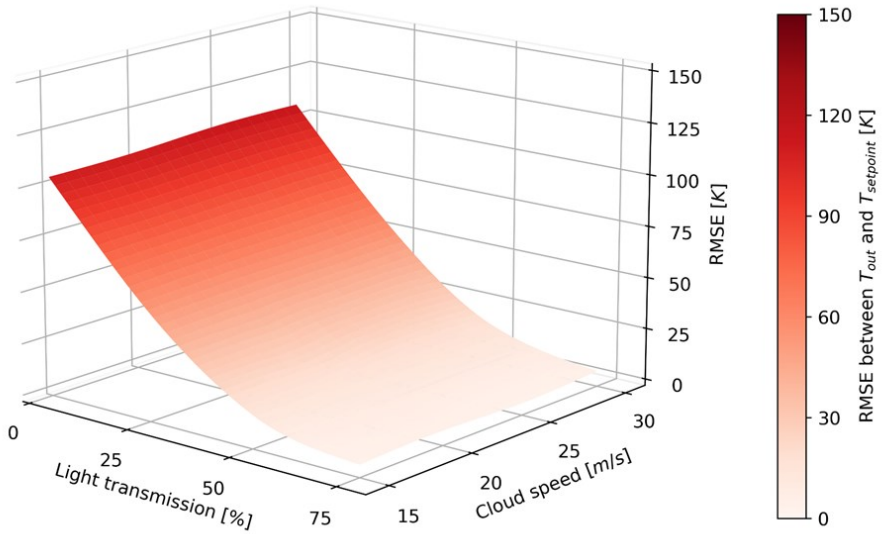
[3] T. Hirsch, "Dynamic system simulation and design of the separation system for direct solar evaporation in parabolic trough collectors", University of Stuttgart, 2005.

Test Case 1: Comparison of the Control Performance

Cloud standby



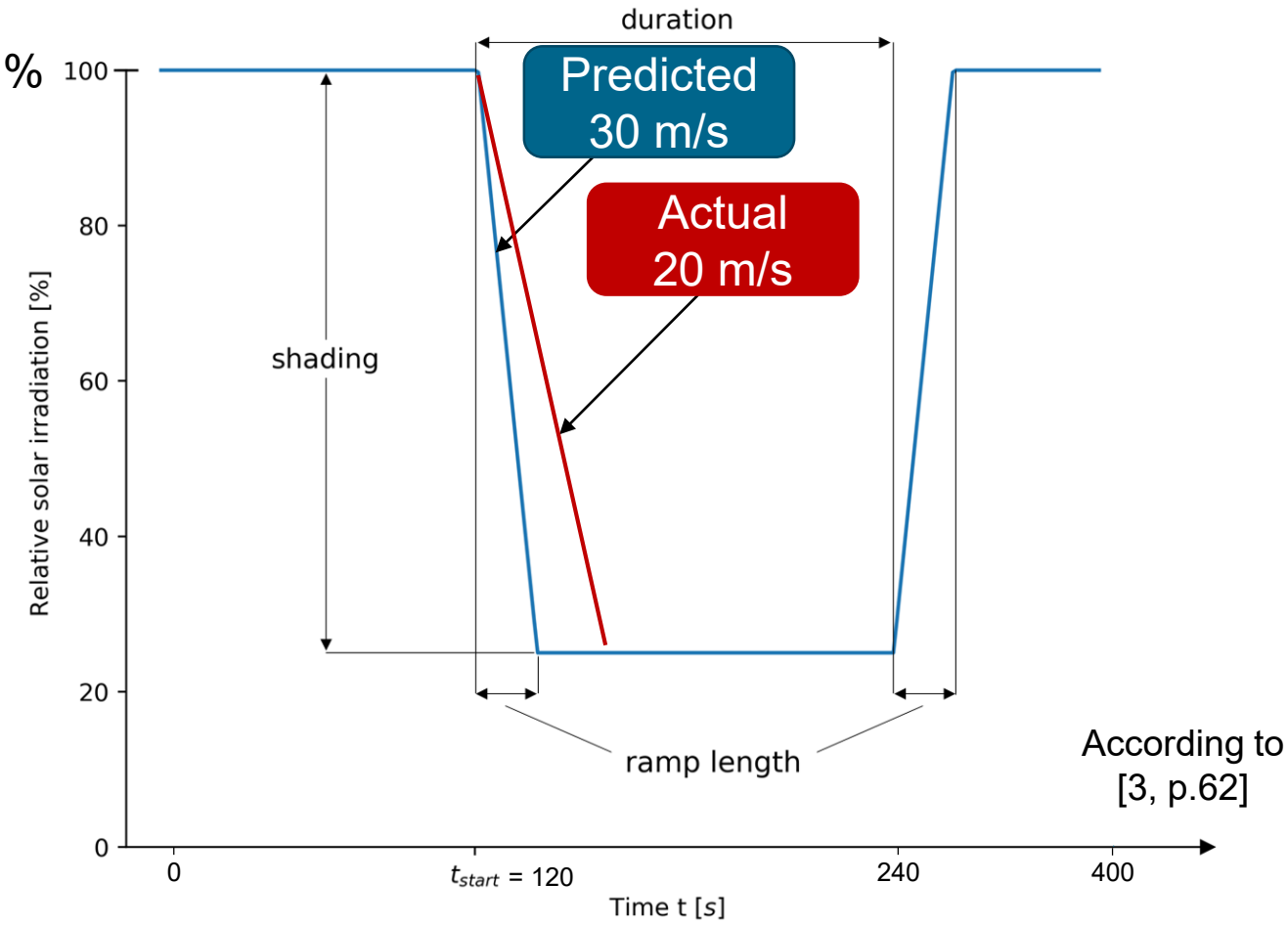
Regulation with deviation-free cloud forecast



→ RMSE hardly dependent on cloud velocity
→ Influence of the control particularly large with low shading
→ Up to 50 K or 86% lower RMSE

Definition of Test Case 2

- Complete shading of the heliostat field with 25 % transmissivity of the cloud.
- Shading duration: 120 seconds
- Cloud speed actual and predicted (Only influence on ramp length): 15, 20, 25, 30 m/s



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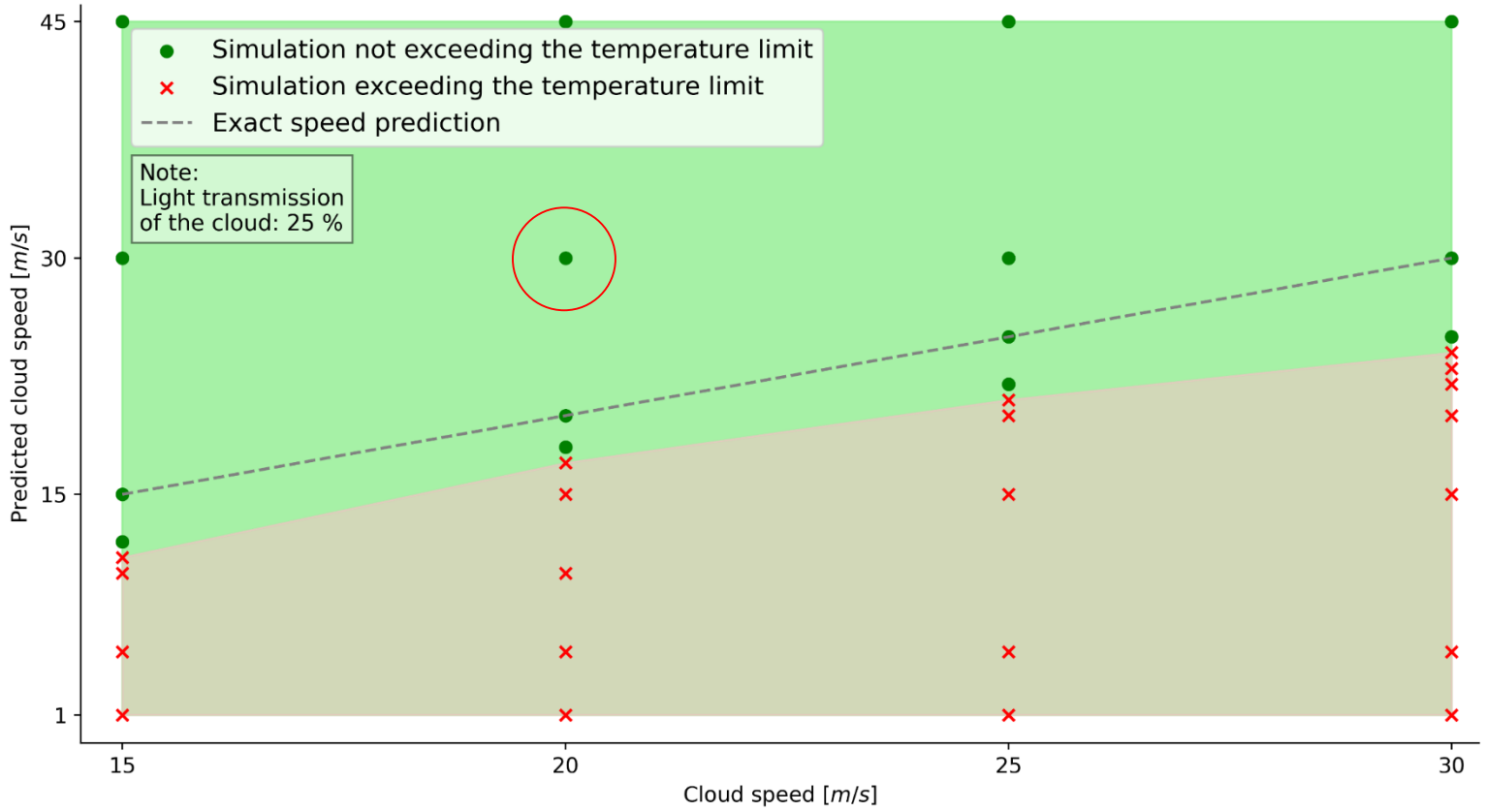
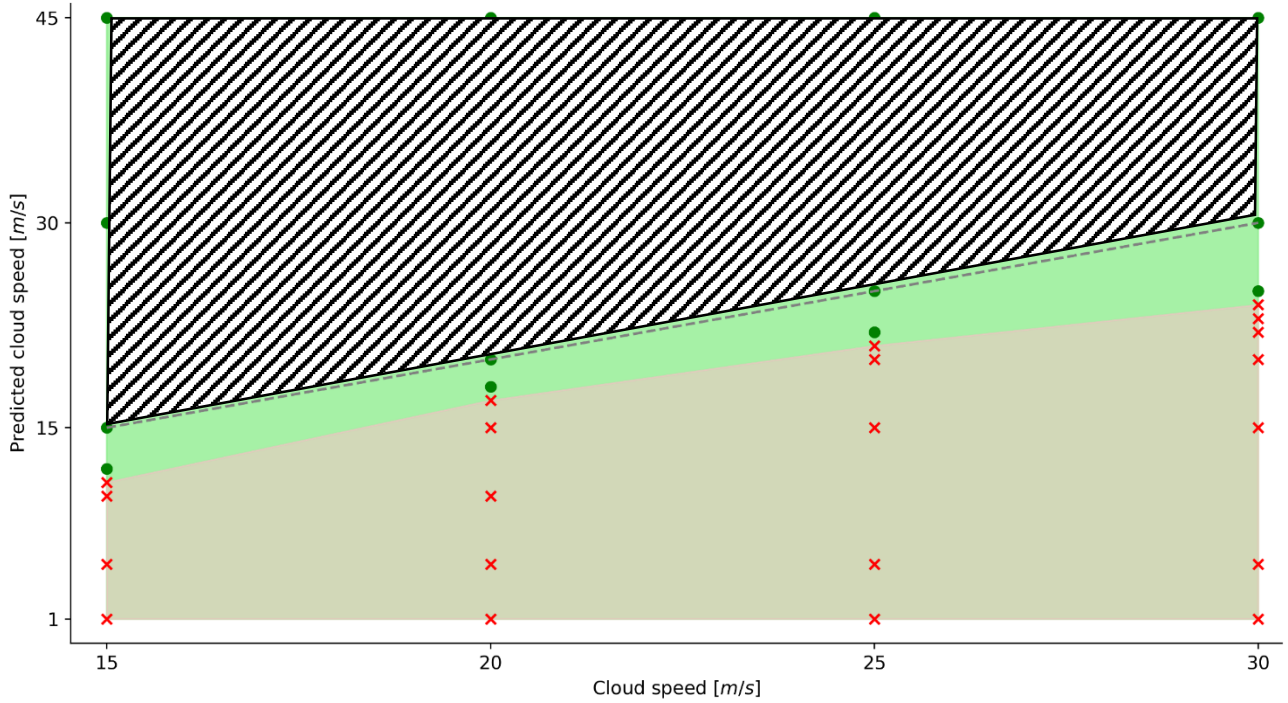
Test Case 2: Robustness against Uncertainties

- Analyzed the operational reliability of the power plant (limitation of the front temperature) with respect to forecast inaccuracies of cloud velocity



Robustness against Uncertainties in the Forecast

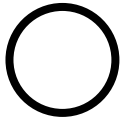
- If the cloud speed prediction is too slow, the heliostats are defocused too late
- The cloud speed prediction must not fall below the real value by more than -11%
- Faster cloud speed predictions are not problematic



Conclusion

- Designed a MPC including the system model for an open-volumetric receiver
- Objective:
  - Designed predictive control considering cloud predictions
  - Control of air outlet temperature meets given temperature limitations

    → Dependent on quality of cloud prediction



Thanks for your attention!

Topic:	Predictive Control under Cloud Passages of a Solar Tower Plant with an Open-Volumetric Receiver
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