Crash test for groundwater recharge models: The effect of model complexity and calibration period on recharge rate predictions

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Motivation

Groundwater Recharge (GR)

- GR is a key process for water resources management
- Modelers need to know how robust their simulations are, because…
  - ➢ the **model structure**,
  - ➢ the uncertainty in the **calibrated model parameters** and
  - ➢ the **calibration period**…might influence the predictions

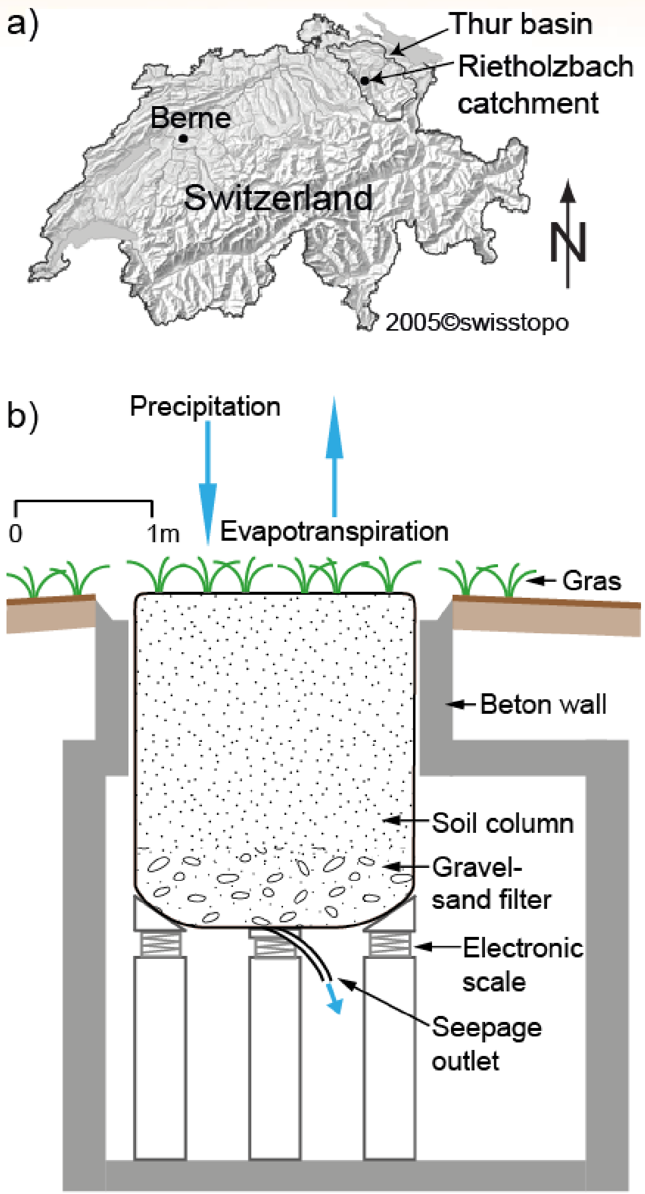
  - ➢ Uncertainty I: **Model structure and complexity**

- An implicit assumption is made that model parameters calibrated over historical periods are also valid for the predictions

  - ➢ Uncertainty II: **Non-Stationarity of calibrated model parameters**

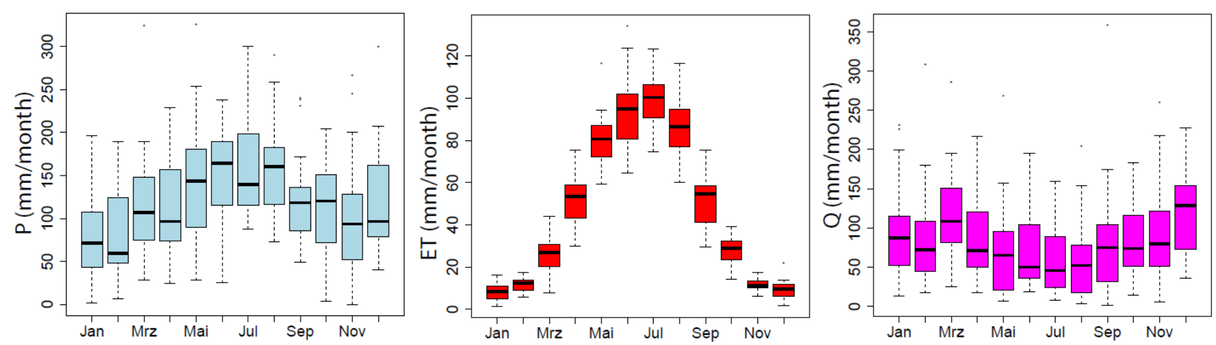
- **Operational testing is rarely done** – especially for GR models, because measuring GR is challenging

Study Area



- Pre-alpine head watershed north-eastern Switzerland
- Large free drainage weighting lysimeter (2.5 m deep, 2 m diameter) → unique data set (~32 y TS)
- Surface is covered with grass
- Groundwater table depths shallow
- Average annual values:

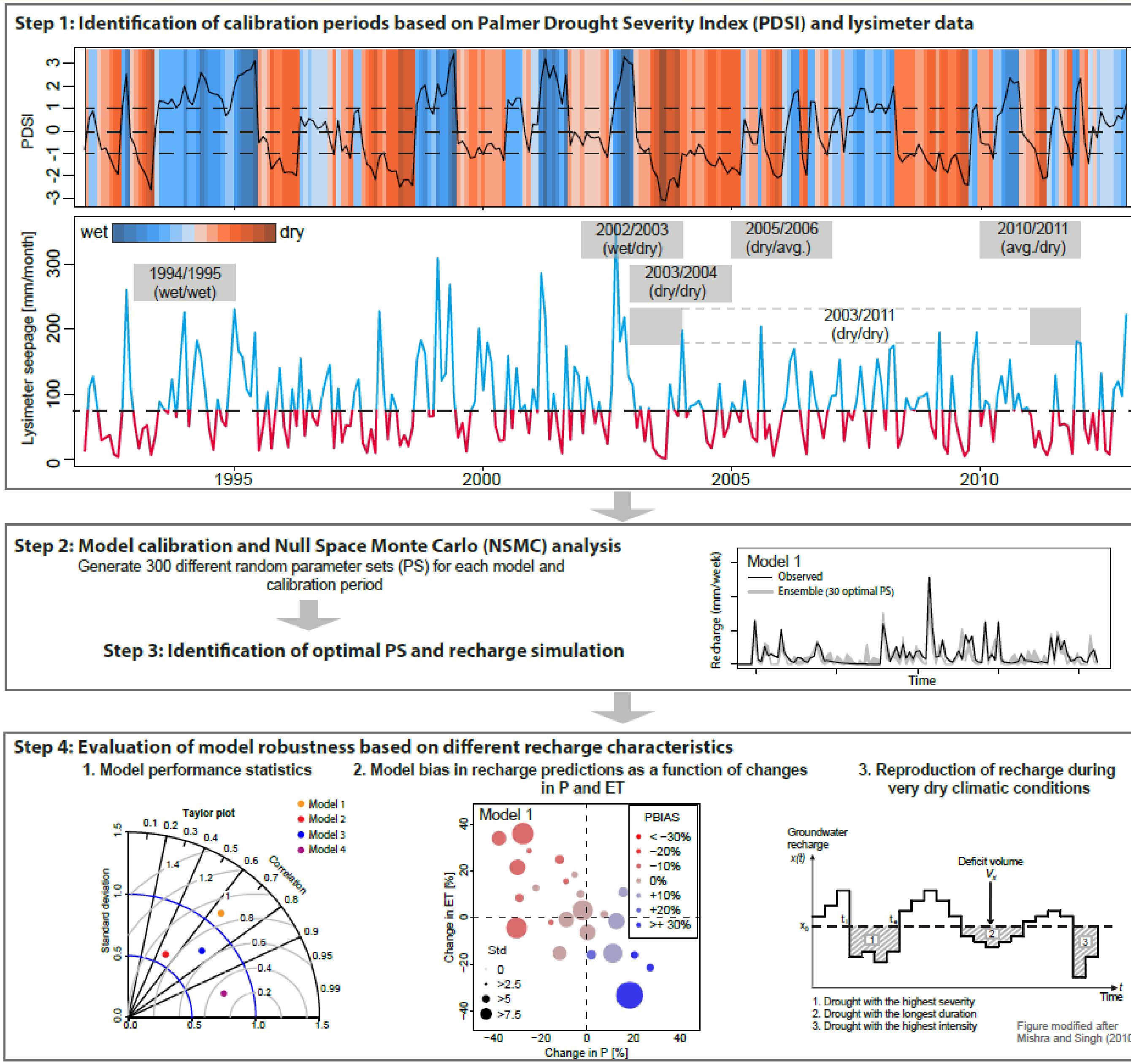
Precipitation	1473 mm/a
Actual evapotranspiration	560 mm/a



Methodology

Four Step Approach

- Identification of dissimilar calibration periods
- Constrained Monte Carlo Approach
- Simulations with optimal parameter sets
- Evaluation of model robustness



Models

Chosen Model Structures and Complexities + Degree-day snow model

i. Soil Water Balance Model **(FINCH, 14 parameters):**
- Simple daily water balance equation
- Predominately linear relationships between model parameters and outputs

ii. Lumped Parameter Bucket Model **(LUMPREM, 12 parameters):**
- Matrix and macropore flow are activated after specified delay times
- Soil moisture content in the column controls the recharge rate

iii. Physically-based Model **(HYDRUS 1D Homogenous, 16 parameters):**
- Richards equation
- Van Genuchten parameterisation
- Homogenous assumption

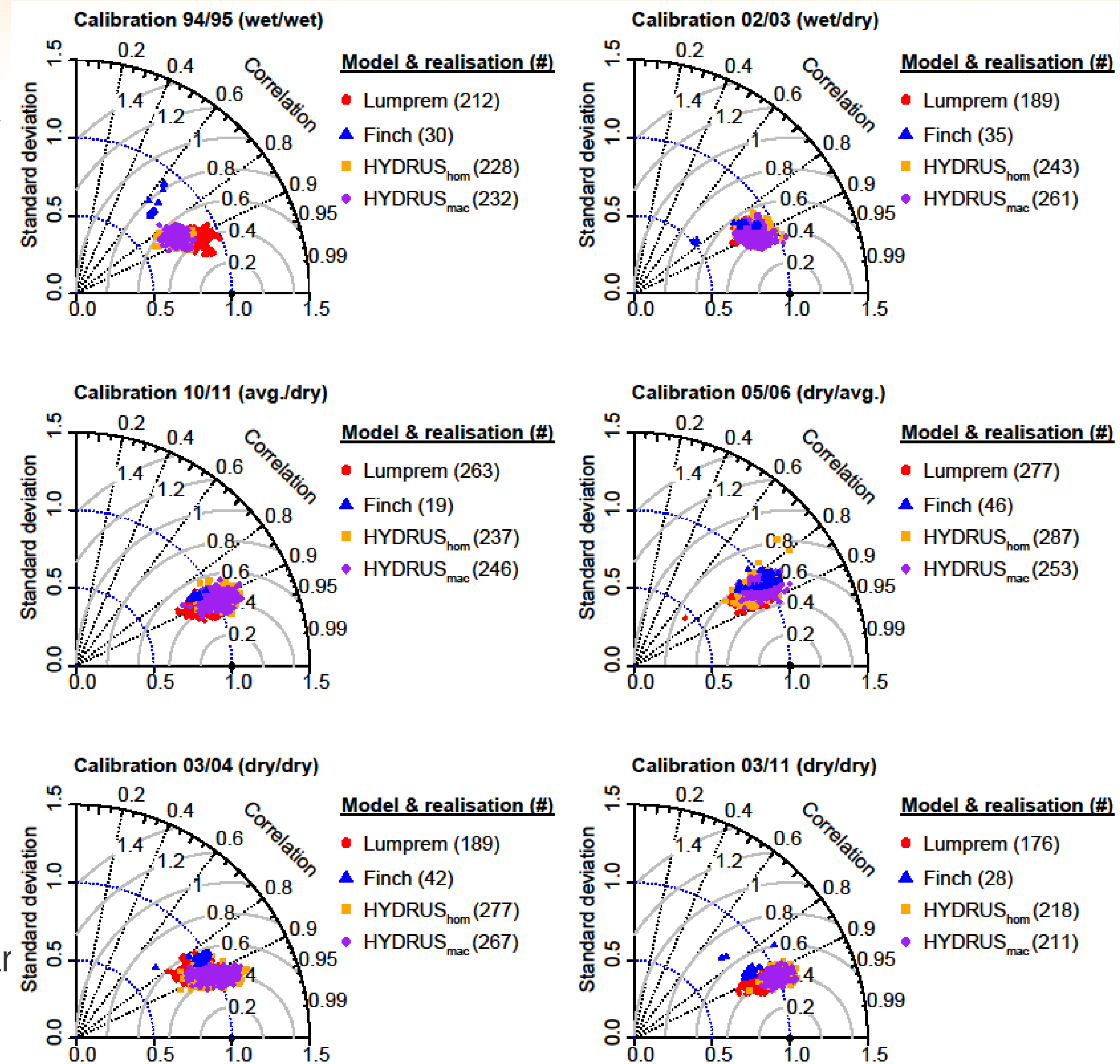
iv. Physically-based Model **(HYDRUS 1D Dual Porosity, 19 parameters):**
- Porous medium is divided into two overlapping soil domains

Increasing complexity

Results: Calibration

Taylor Plot

- The similarity between patterns is quantified by using their
  - Correlation
  - Their centred root mean square differences
  - Amplitude of their variations, represented by their standard deviations



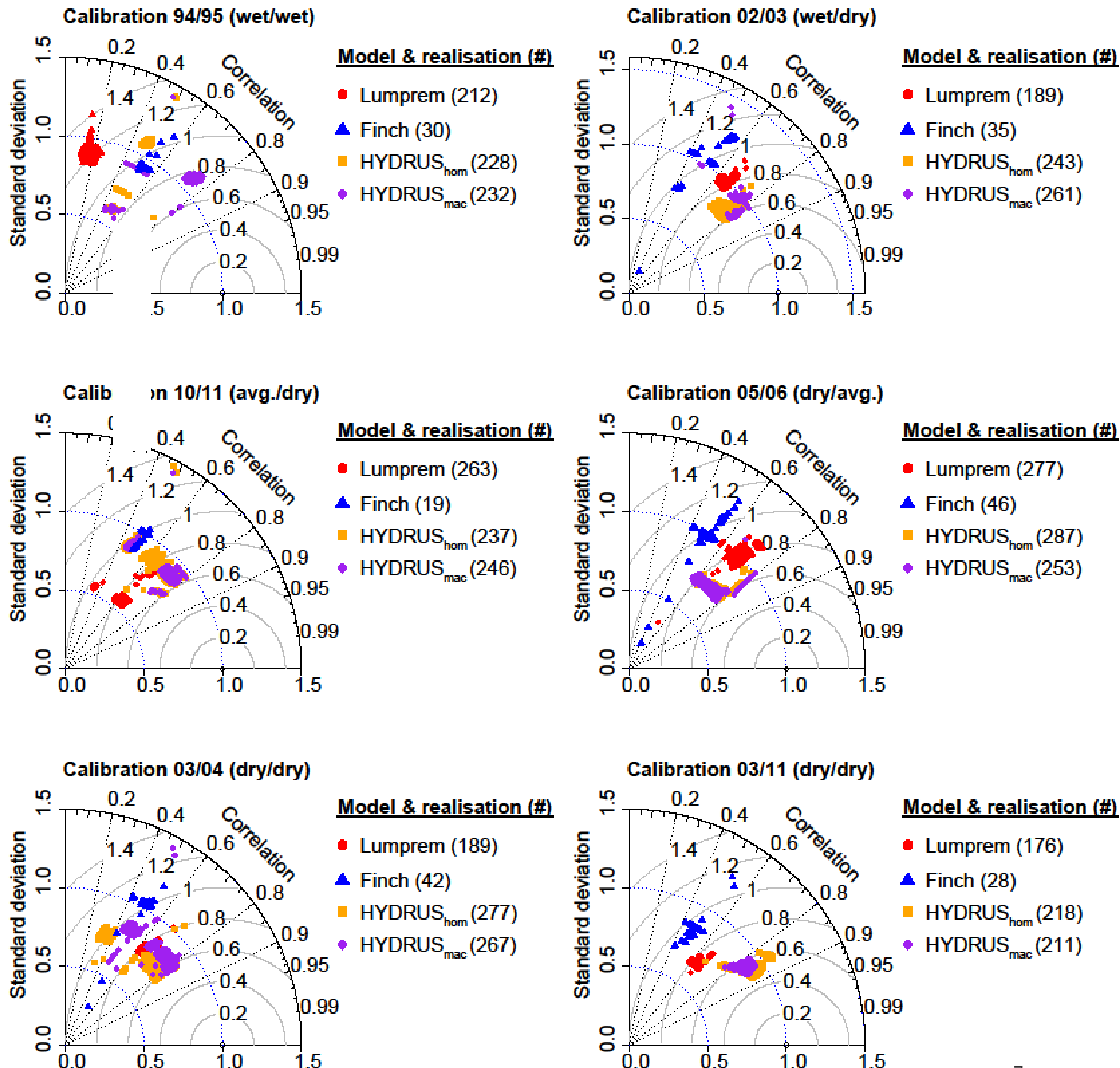
- Increasing model complexity; increasing number of acceptable parameter sets

- Model performance in calibration is quite similar under all calibration periods

Results: Validation

Taylor Plot

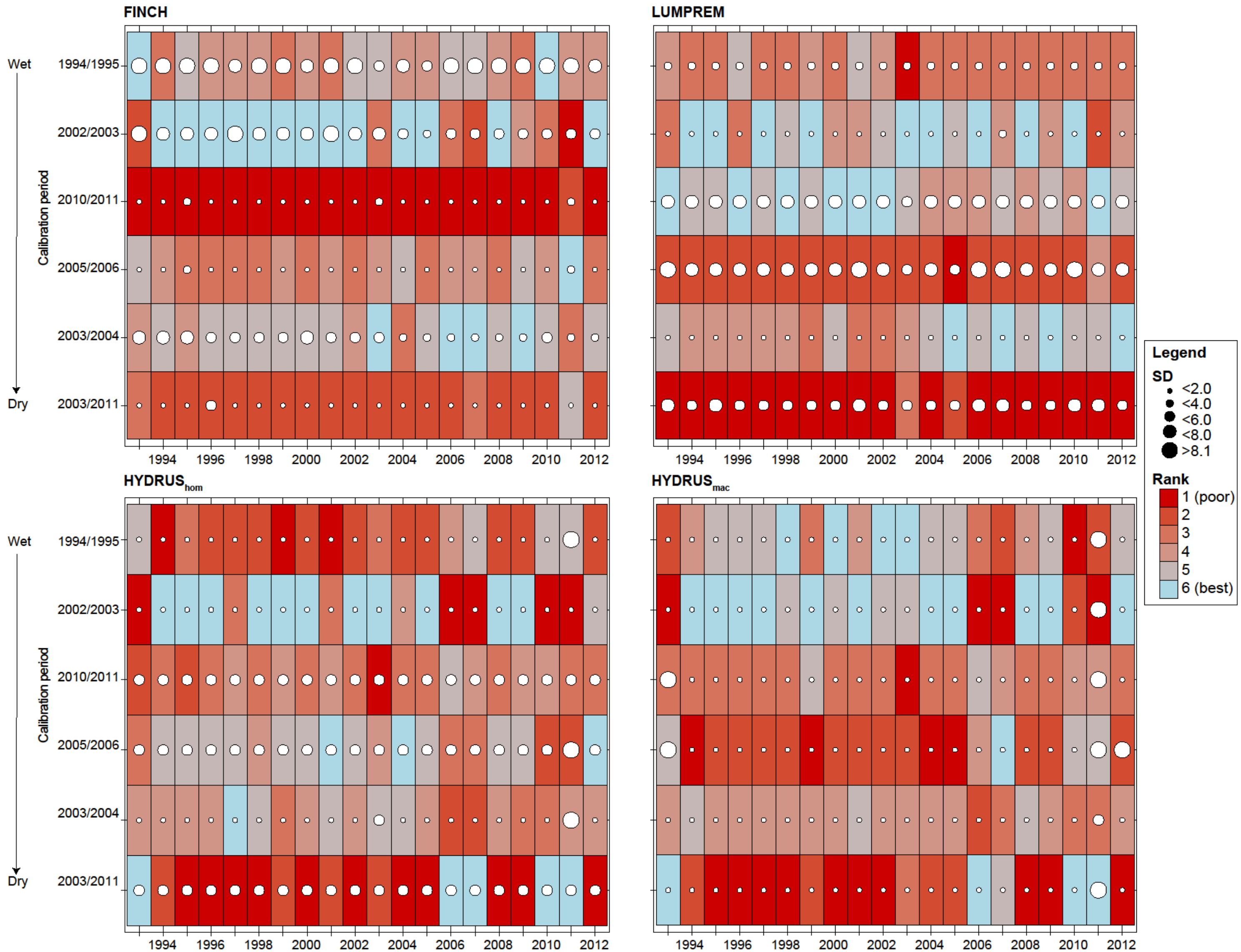
- Decreasing model performance
- The differences are a function of the chosen model complexity
- Uncertainty in model parameters is less pronounced than model structure
- Robustness of each individual model follows the degree of model complexity



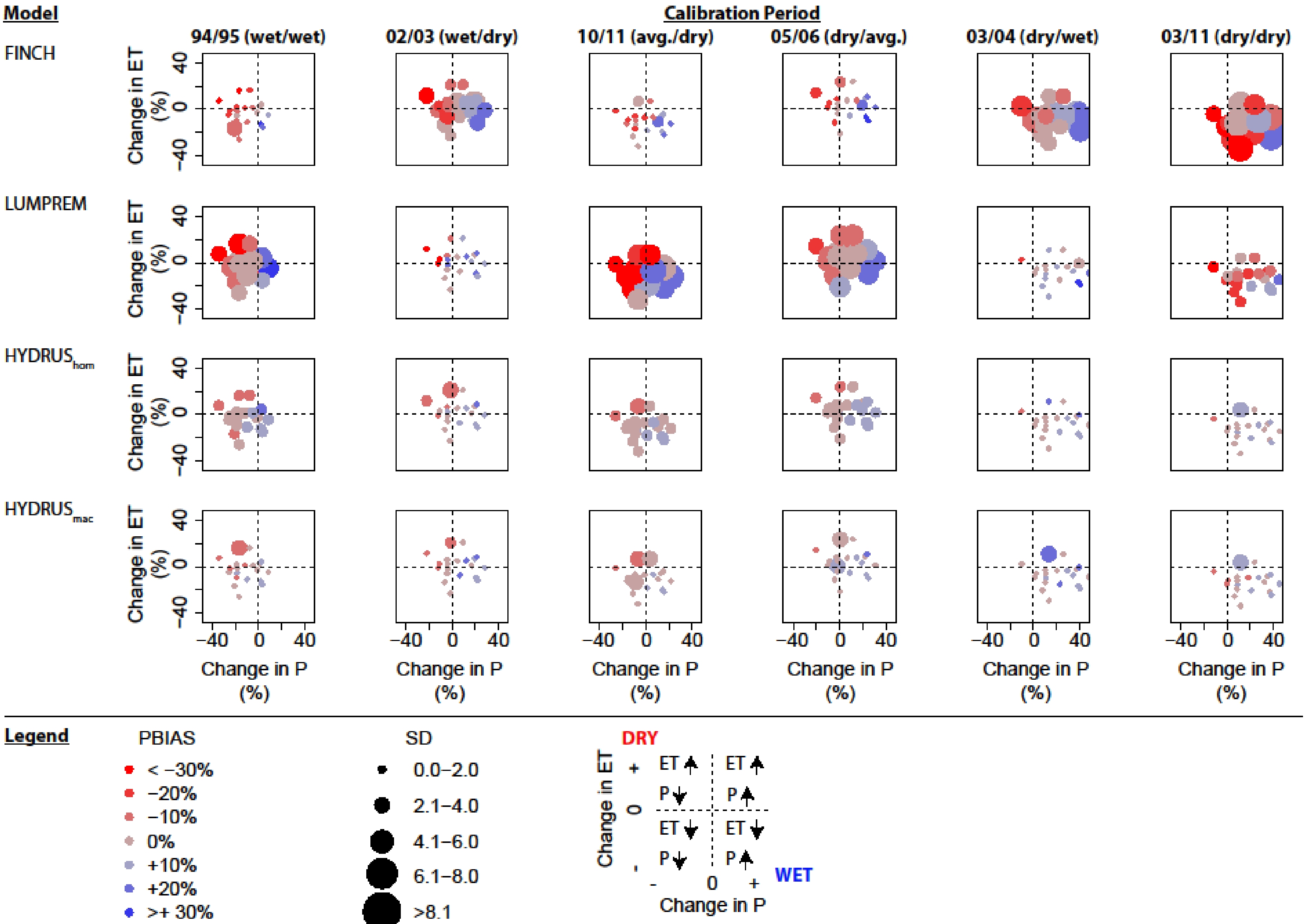
Sensitivity of recharge to the climate characteristics of the calibration period

Annual recharge patterns

- **Period dry/dry**: **Poor** model performance for all models
- Period **wet/dry:** **Best** model performance
- **No optimal calibration period**
- Model performance depends strongly on the **model complexity** and structure **rather** than on the **calibration period**



Sensitivity of recharge to the climate characteristics of the calibration period



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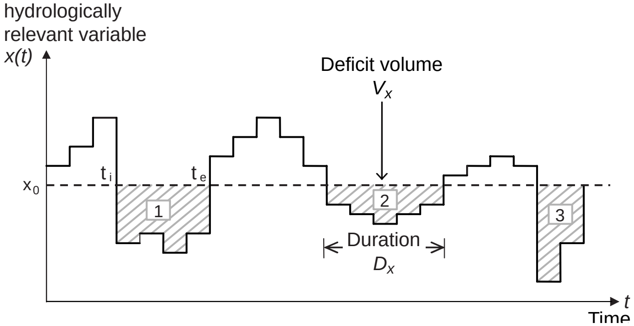
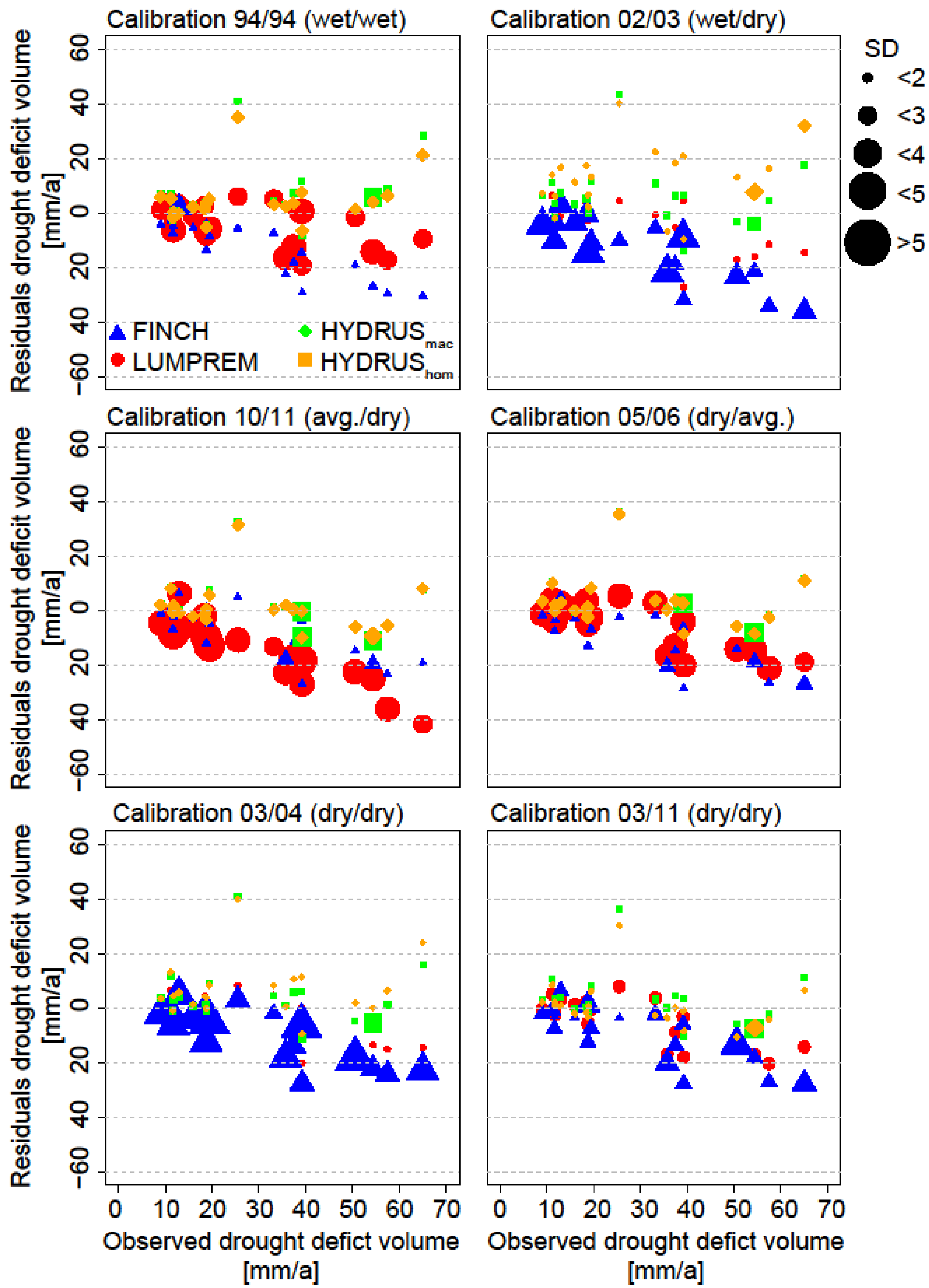
Impact on simulated recharge rates

Drought deficit volumes



Mishra and Singh (2010)

- Largest deviations for the drought years 2003, 2009 and 2011
- Differences are minor for observed volumes < 20 mm.
- Drought deficit volumes increase with decreasing model complexity
- Dry-Dry calibration most efficient to simulate droughts



Summary and Conclusions

- Acceptable model performance during the calibration will not ensure reliable predictions under dissimilar conditions
  - **BUT** differences are a function of the chosen model complexity

- Model structure becomes more important under **extremes or very contrasting climatic conditions**

- **Uncertainty in model parameters** is generally **less pronounced** than **model structure**
  - Elaborate calibration procedure does not automatically provide robust model parameters and accurate predictions

- **No optimal calibration period**
  - Model performance depends strongly on the **model complexity** and structure **rather** than on the **calibration period**
  - Wet calibration period → appears detrimental to simulate dry validation periods
  - Dry-Dry calibration most efficient to simulate droughts but for “average” or wet conditions the calibration period failed
  - Calibration period is less important for the physically based models

Results should raise the concern of model reliability when using simple models for extreme events or under dissimilar climatic conditions

Thank you for your attention

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Constrained Null Space Monte Carlo Simulation

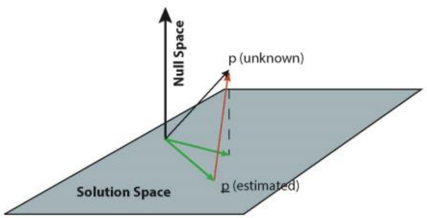
Approach: 2 steps are required:

- Calibrate base model
- Null Space Monte Carlo Procedure

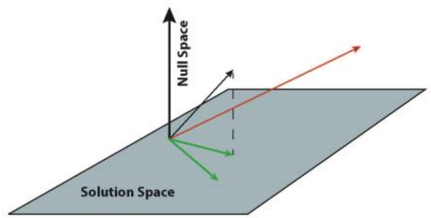
Advantages:

- Many different realizations are possible
- Parameter flexibility (reduce structural noise)
- Using pre-calculated sensitivities reduce computational effort
- SVD-Assist calibrate just the parameters in the solution space

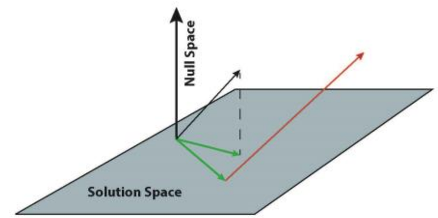
1. Calibrate the model



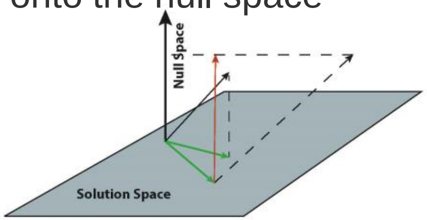
2. Generate parameter set: C(p)



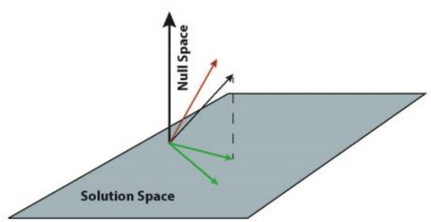
3. Take difference with calibrated model



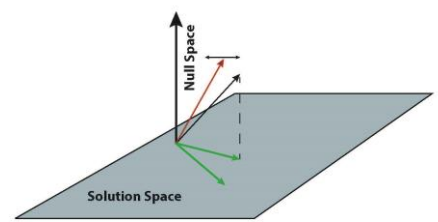
4. Project differences onto the null space



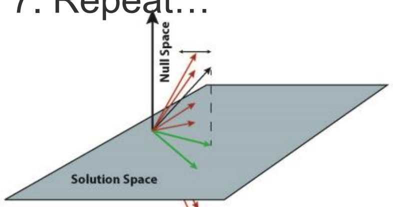
5.Add to calibrated field



6.Adjust solution space components



7. Repeat…



Modified after Doherty,Hunt and Tokin 2010 USGS Scientific Report

Constrained Null Space Monte Carlo Simulation

Approach:

Two steps are required

Advantages:

- Many different realizations are possible
- Parameter flexibility (reduce structural noise)
- Using pre-calculated sensitivities reduce computational effort
- SVD-Assist calibrates just the parameters in the solution space

Calibrate base model

PEST
1. Base model parameterization (Pilot Point approach)
2. Base parameter sensitivities (Jacobian matrix)
3. Tikhonov constrains

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PEST calibration output files

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Null Space Monte Carlo Procedure

Random parameter sets based on C(p)

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PNULPAR (Pest suite)
1. Calculate V2V2t and project differences between random parameters and the calibrated parameters onto the calibration null-space
2. Add projected differences to calibrated parameter values
3. “Almost calibrated” random parameter sets

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PEST
1. Re-calibration
2. SVD-Assist
3. Beopest (parallel computing)

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Evaluate predictive uncertainty

Modified after Doherty, Hunt and Tonkin 2010 USGS Scientific Report