# Model Data Fusion in Flood Prediction

**Thomas Pagano (Wang, Lan, Hapuarachchi, Toscas) May 10-12 2010, Cape Schanck**

**A water information R & D alliance between the Bureau of Meteorology and CSIRO's Water for a Healthy Country Flagship**

Australian Government
Bureau of Meteorology

Water Information
DATA › INFORMATION › INSIGHT

National Research FLAGSHIPS
Water for a Healthy Country
CSIRO

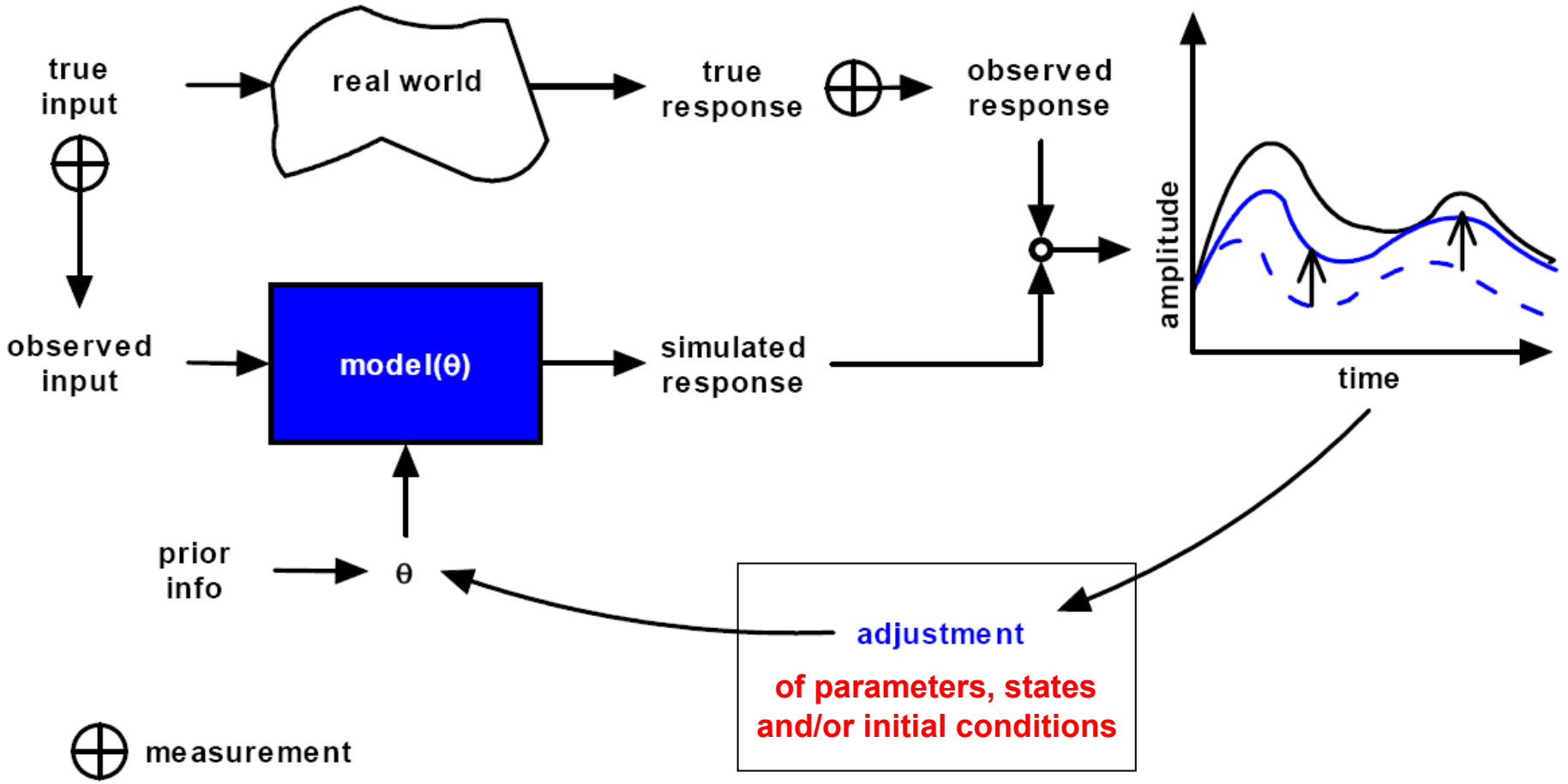
Photo credit 15/9/2008 Tony Gutierrez. Cattle in Hurricane Ike, High Island, Texas

# Outline

- Model calibration
- State updating
- Error correction

  Wirada activities
- Personal observations
- Open questions
- Future directions

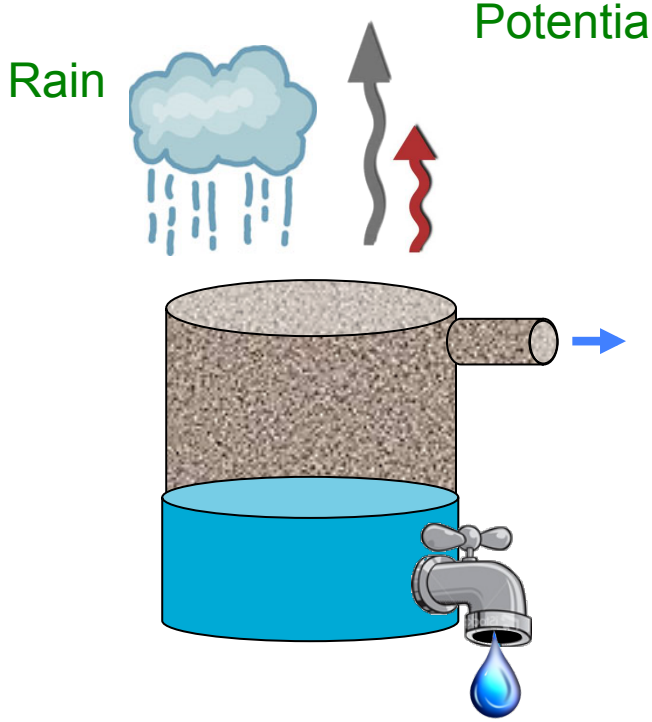
# Model data fusion




http://www.es.lancs.ac.uk/hfdg/uncertainty_workshop/PDF/Thorsten_Wagener.pdf

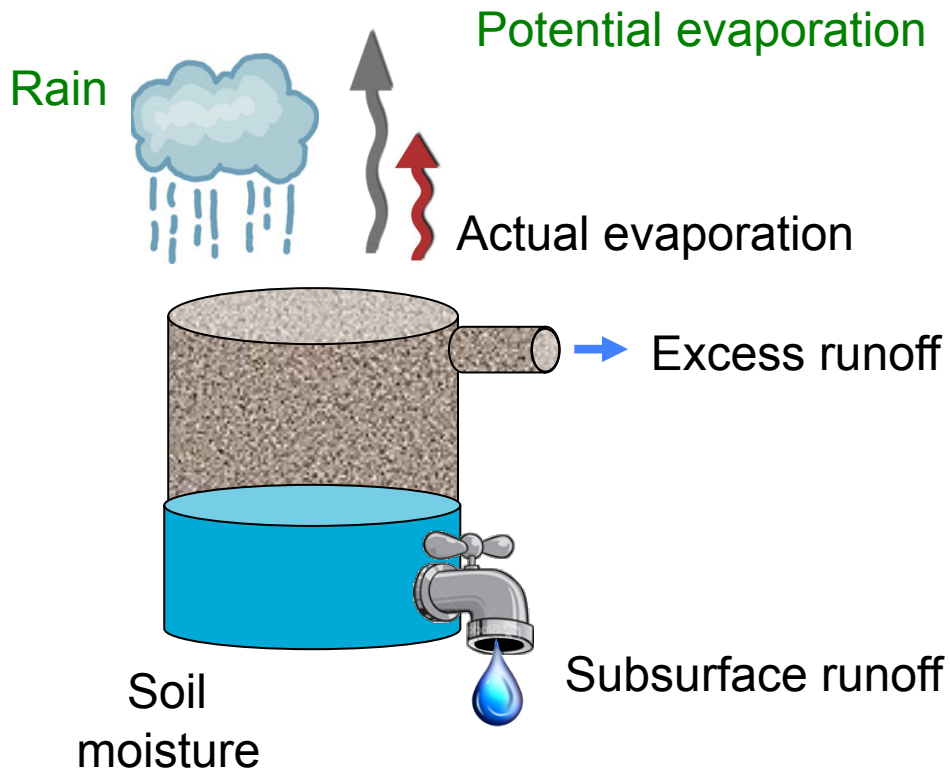
# Simple water balance model

Inputs, Parameters, Outputs

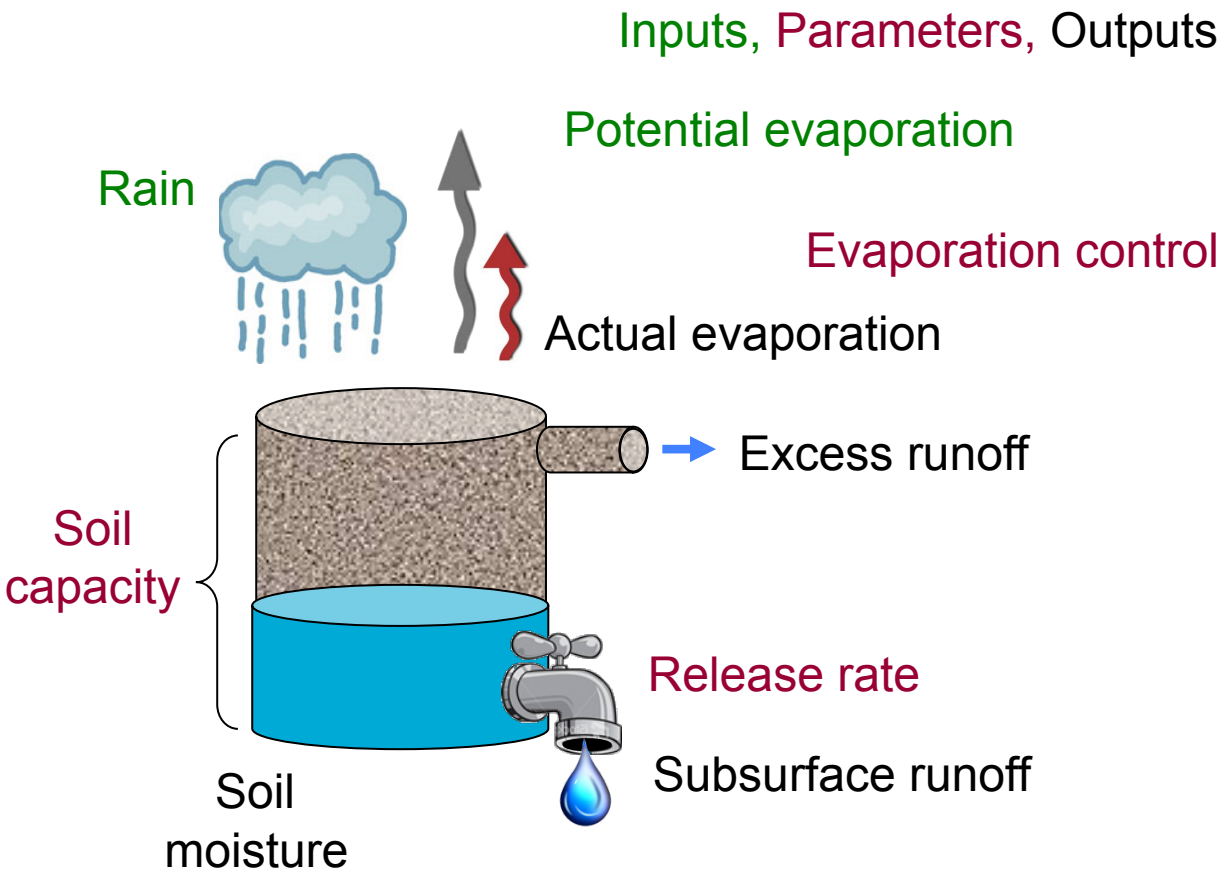


# Simple water balance model

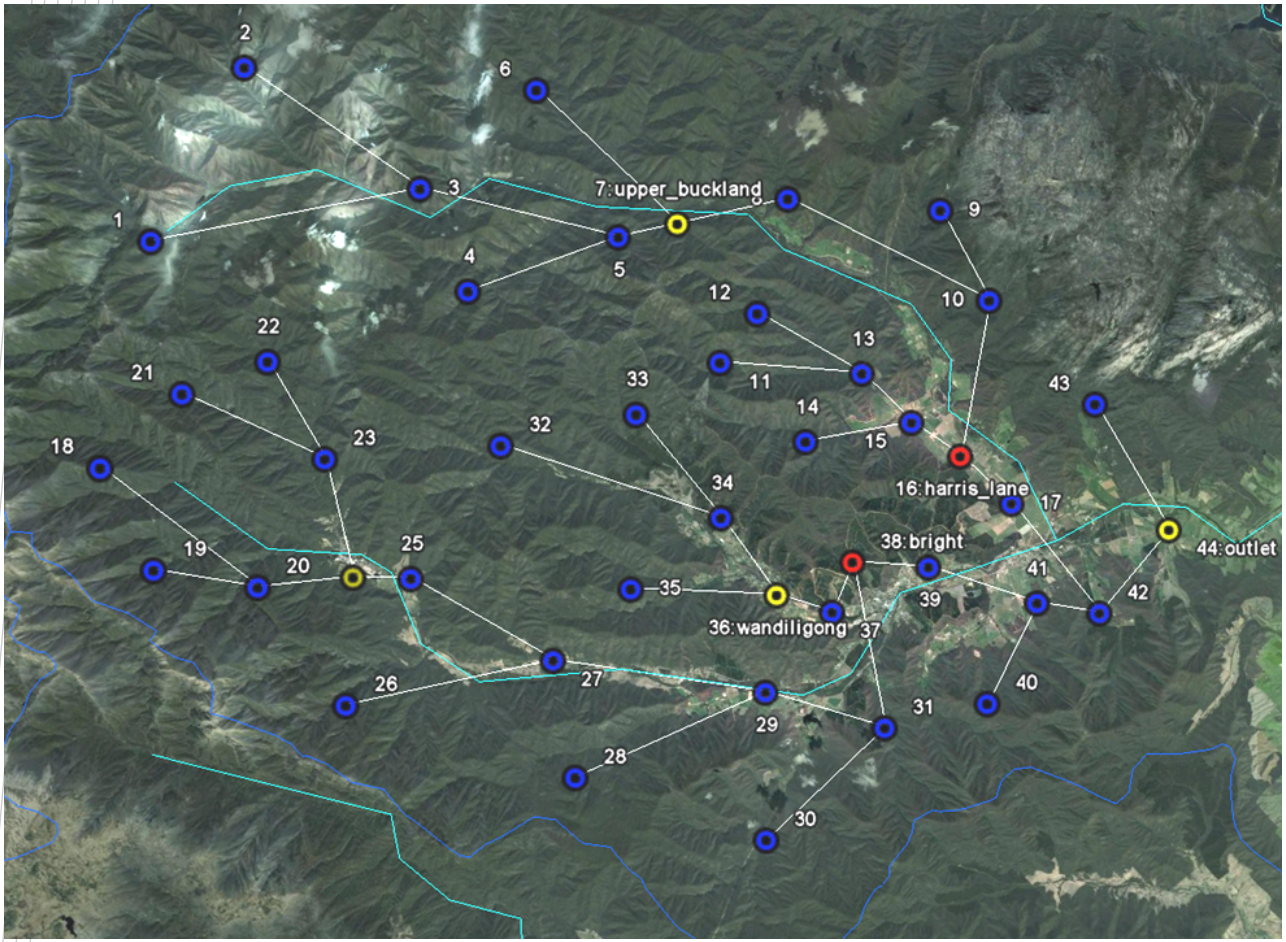
Inputs, Parameters, Outputs



# Simple water balance model



# Semi-distributed: Node link structure




**Ovens streamflow modelling network Links (white) and nodes: Physical, Print and Calibration**

**Parameters uniform above/between Calibration nodes**

# Typical modelling problem

**~100 spatial units (irregular gridcells) per catchment**

**~3-12 internal states per spatial unit**

**Streamflow observation at outlet**
**and ~0-10 upstream points**

**~5k-50k historical/~50 forecast timesteps**

**Simulation skill $r^2$=0.5-0.9**

**Initial condition and forcings ~equally important**

# Special challenges of flood forecasting

Realtime data quality/coverage is poor

Future forcings uncertain

Timesteps are short and “dynamic” processes active

Semi-distributed and seasonally varying processes

Data-to-product latency is O(minutes-hours)

Lives and property at stake

# SWIFT: Short-term Water Information Forecasting Tools


Time series (Rain, PET)

9 objective functions

Parameters

Ensemble forcings

Control Files

SWIFT

Automatic calibration

Hot-start initialization

Rainfall Runoff

AWBM

SimHyd

GR4J & 8 others

Routing

Muskingum

Catchment Routing

*State updating*

Adapters

Model states

Forecasts

Deterministic

Ensemble

*Error correction*

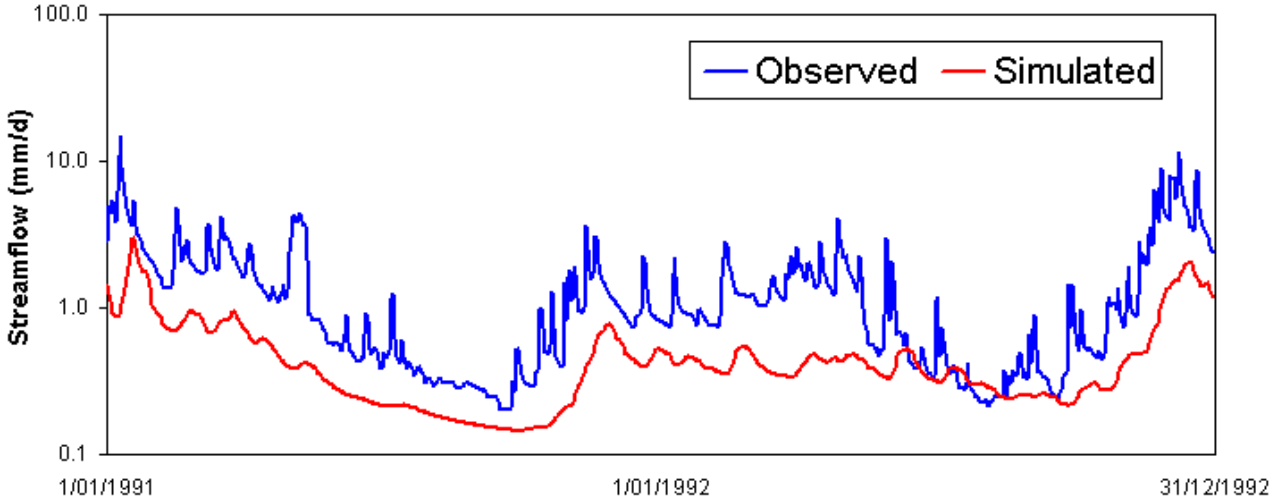
Australian Government Bureau of Meteorology

Water Information DATA › INFORMATION › INSIGHT

National Research FLAGSHIPS CSIRO

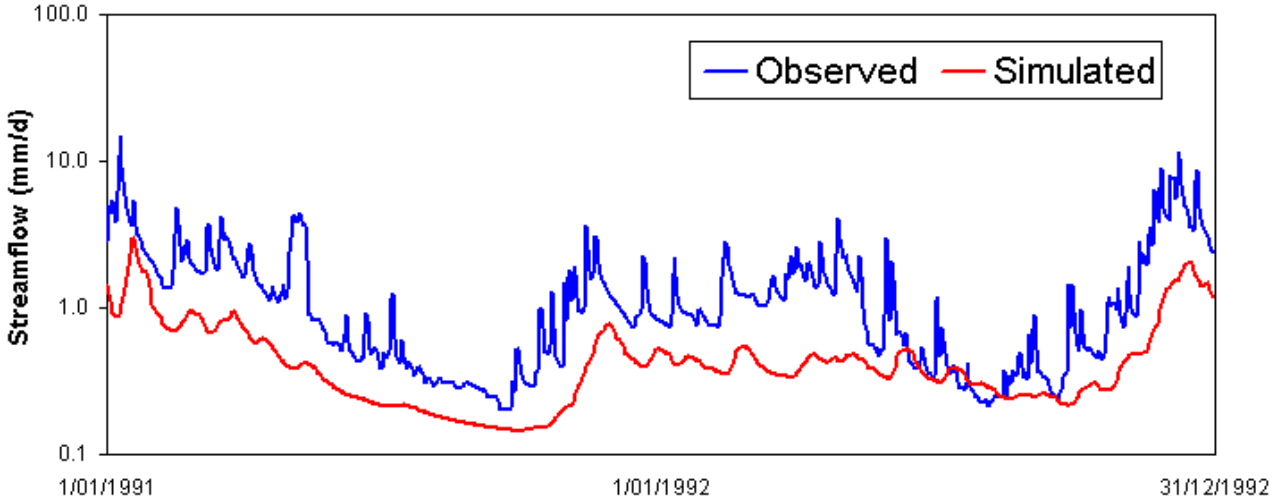
# Parameter calibration

We want a good fit between simulated and observed.



# Parameter calibration

We want a good fit between simulated and observed.



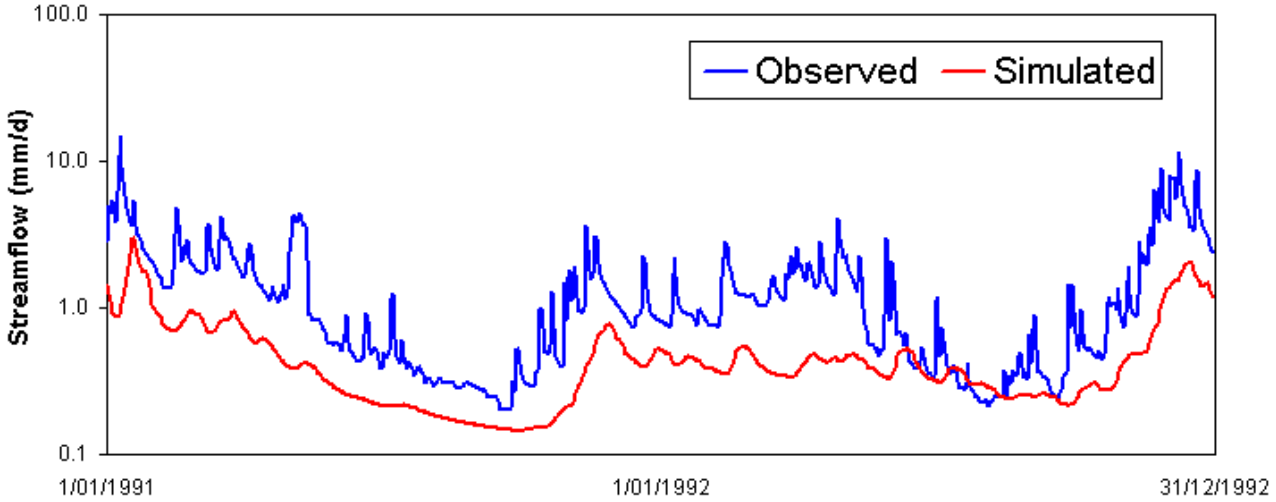

Define “good”… this is our “objective function” (OF)

e.g. Nash sutcliffe

$$1 - \frac{\text{Sum}((\text{Sim}-\text{Obs}))^2}{\text{Sum}((\text{Avg}-\text{Obs}))^2}$$

# Parameter calibration

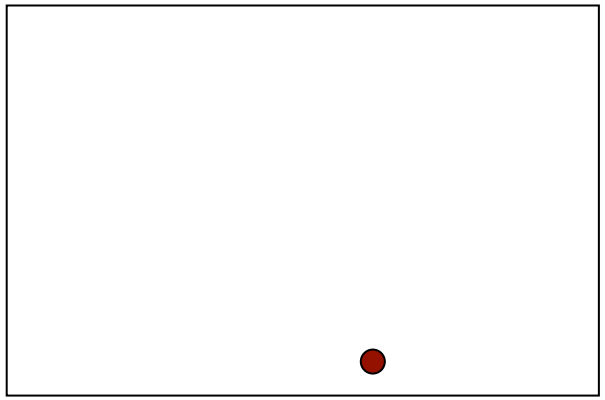
We want a good fit between simulated and observed.




Define "good"… this is our "objective function" (OF)
e.g. Nash sutcliffe

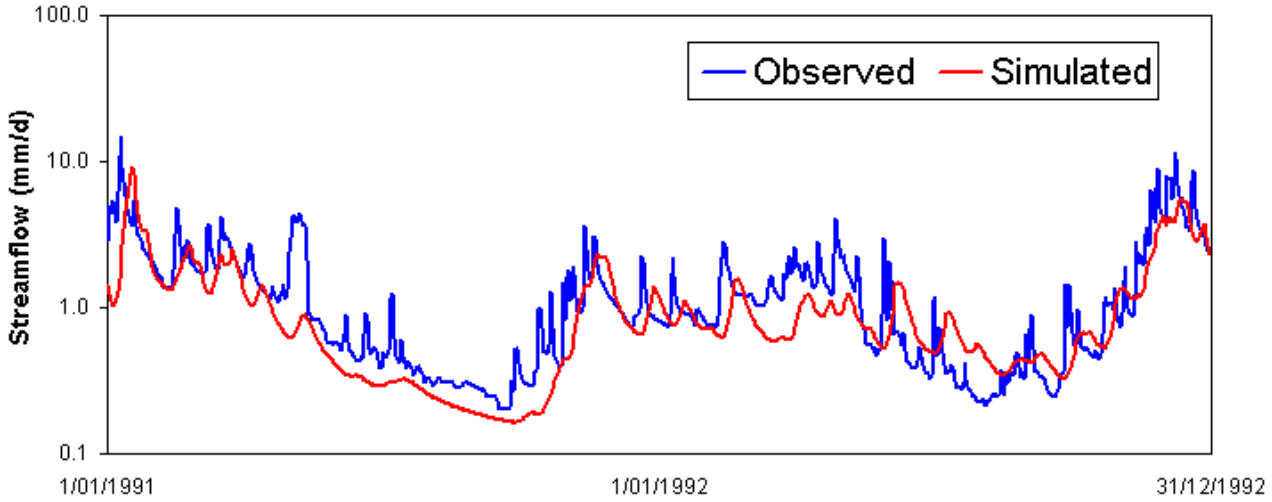
$$1 - \frac{\text{Sum}((\text{Sim}-\text{Obs}))^2}{\text{Sum}((\text{Avg}-\text{Obs}))^2}$$

Try parameter combinations, evaluate objective function



# Parameter calibration

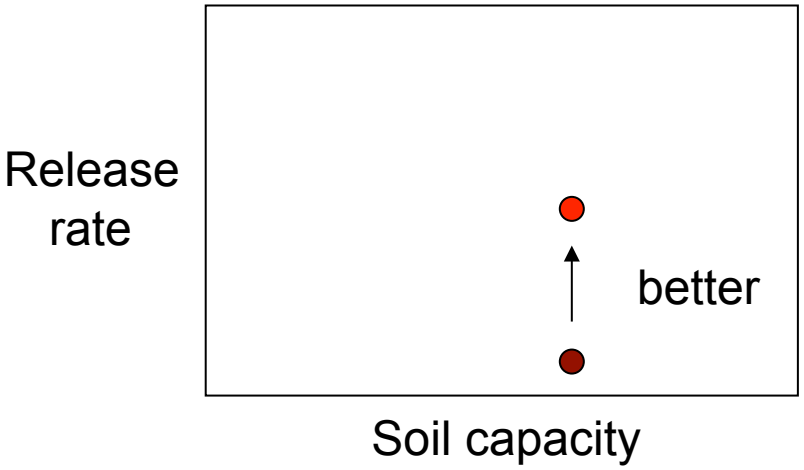
We want a good fit between simulated and observed.




Define "good"… this is our "objective function" (OF)
e.g. Nash sutcliffe

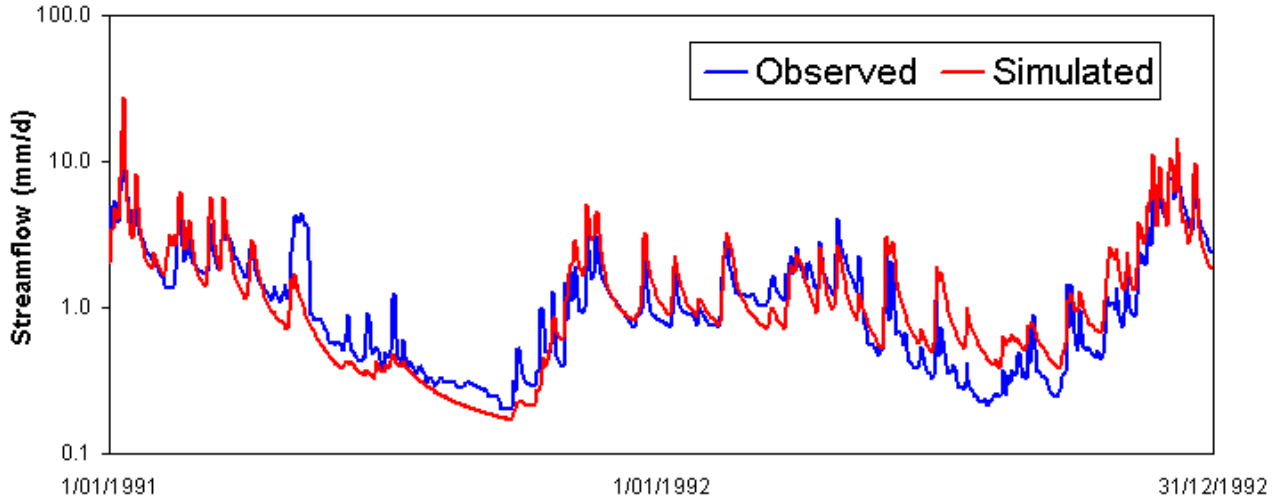
$$1 - \frac{\text{Sum}((\text{Sim}-\text{Obs}))^2}{\text{Sum}((\text{Avg}-\text{Obs}))^2}$$

Try parameter combinations, evaluate objective function



# Parameter calibration

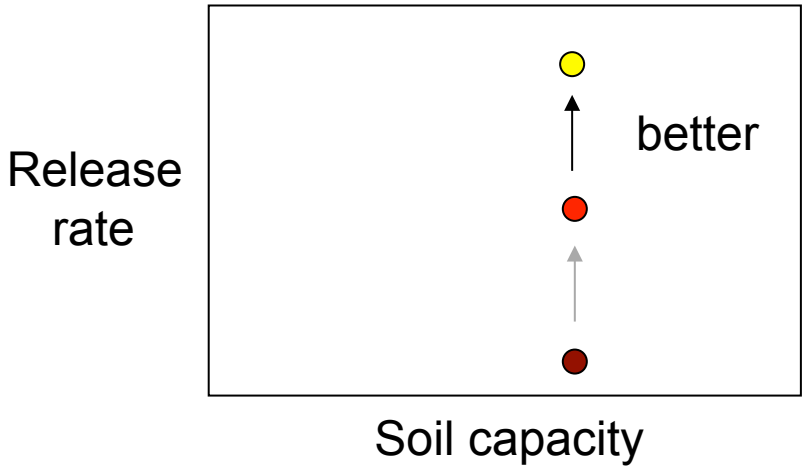
We want a good fit between simulated and observed.




Define "good"… this is our "objective function" (OF)
e.g. Nash sutcliffe

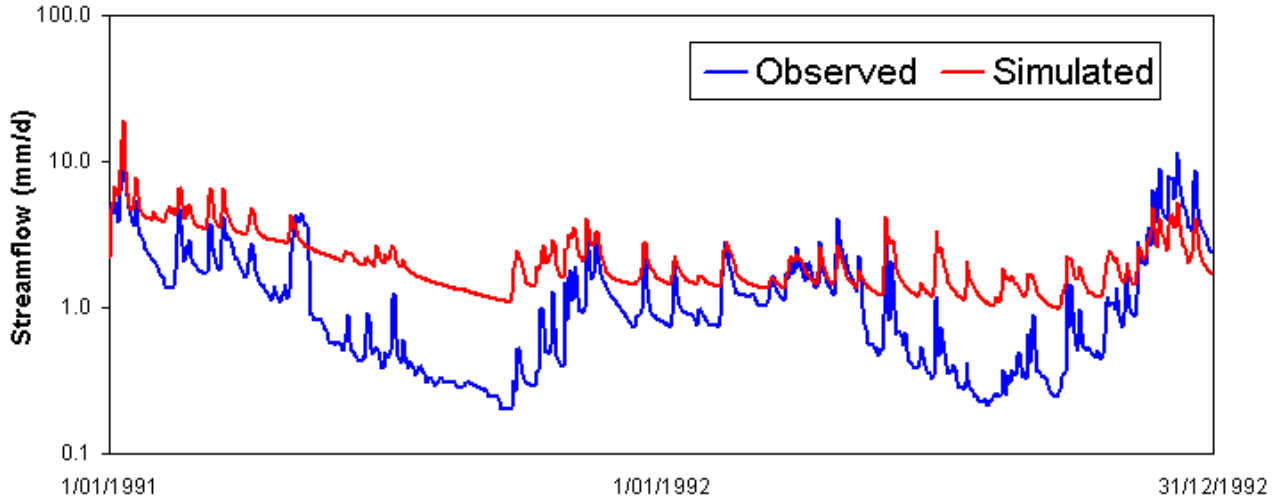
$$1 - \frac{\text{Sum}((\text{Sim}-\text{Obs}))^2}{\text{Sum}((\text{Avg}-\text{Obs}))^2}$$

Try parameter combinations, evaluate objective function



# Parameter calibration

We want a good fit between simulated and observed.



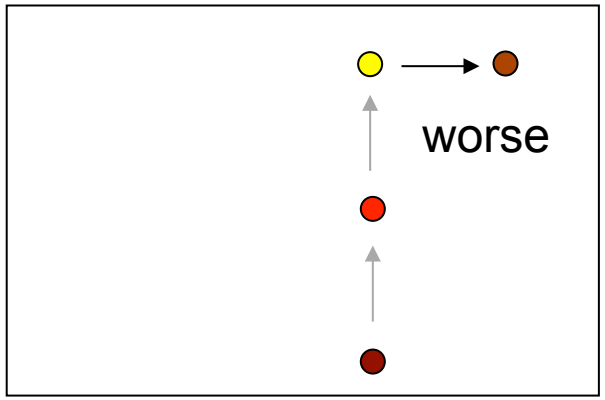

Define “good”… this is our “objective function” (OF)

e.g. Nash sutcliffe

$$1 - \frac{\text{Sum}((\text{Sim}-\text{Obs}))^2}{\text{Sum}((\text{Avg}-\text{Obs}))^2}$$

Try parameter combinations, evaluate objective function

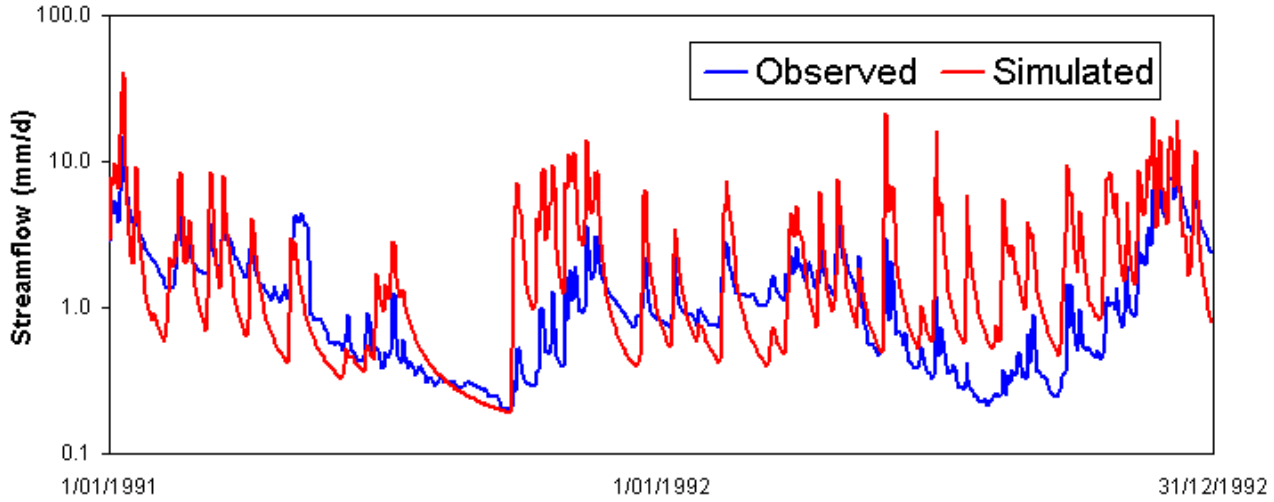
Release rate




Soil capacity

# Parameter calibration

We want a good fit between simulated and observed.



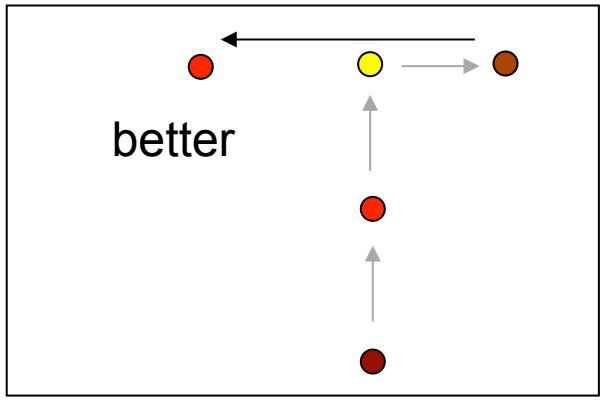

Define “good”… this is our “objective function” (OF)

e.g. Nash sutcliffe

$$1 - \frac{\text{Sum}((\text{Sim}-\text{Obs}))^2}{\text{Sum}((\text{Avg}-\text{Obs}))^2}$$

Try parameter combinations, evaluate objective function

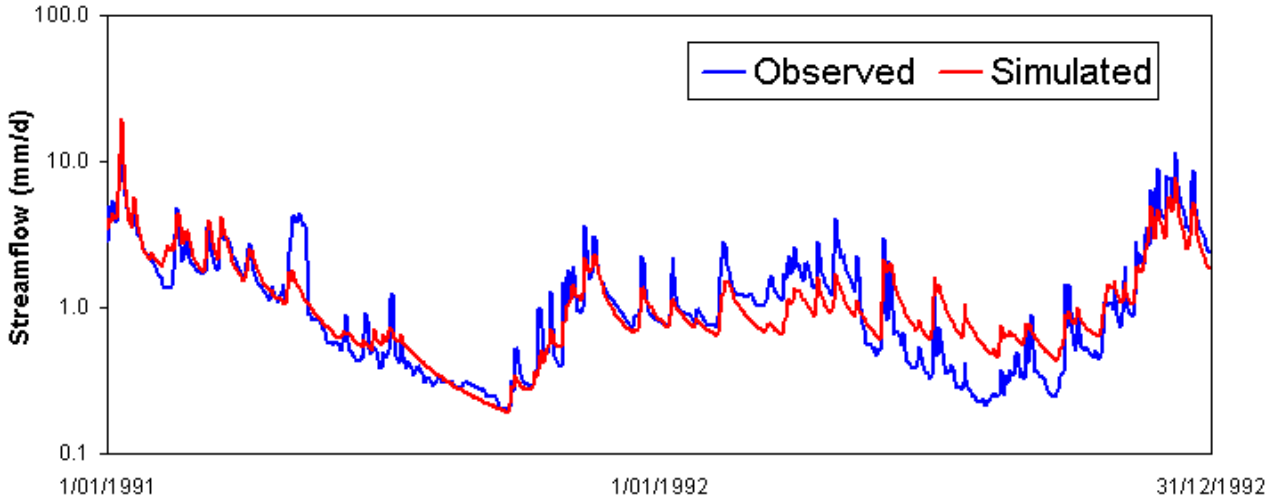
Release rate




Soil capacity

# Parameter calibration

We want a good fit between simulated and observed.



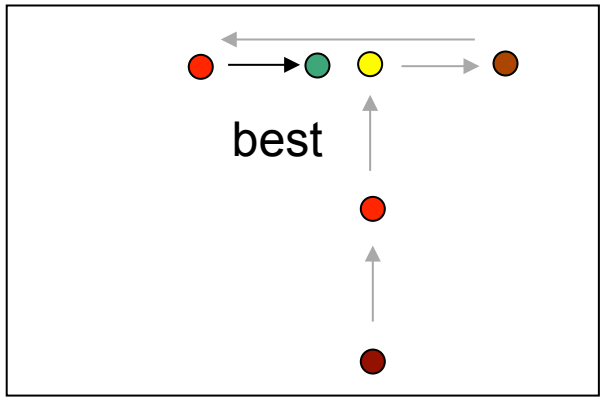

Define “good”… this is our “objective function” (OF)

e.g. Nash sutcliffe

$$1 - \frac{\text{Sum}((\text{Sim}-\text{Obs}))^2}{\text{Sum}((\text{Avg}-\text{Obs}))^2}$$

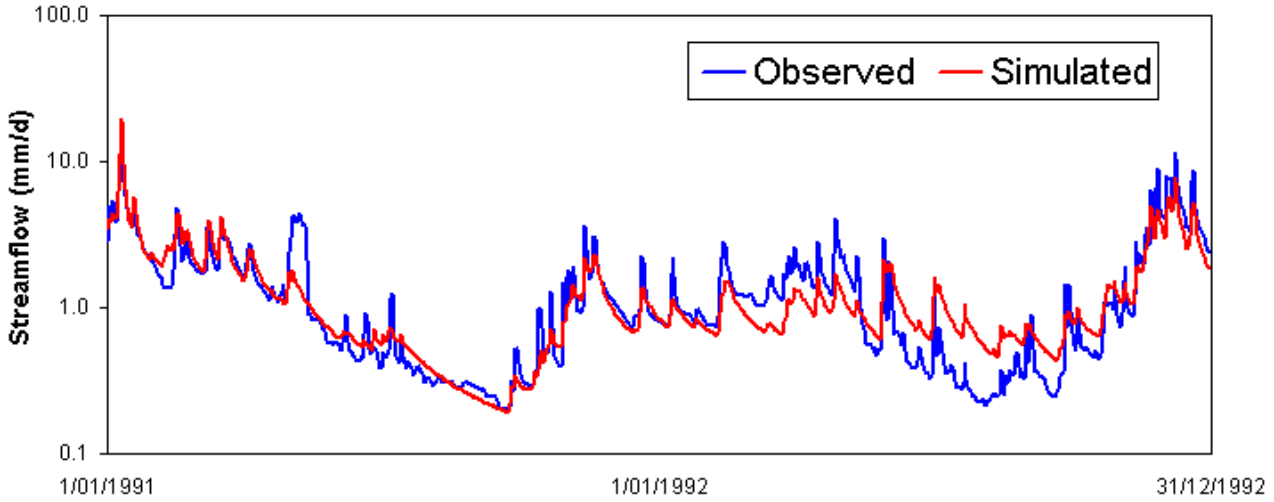
Try parameter combinations, evaluate objective function

Release rate



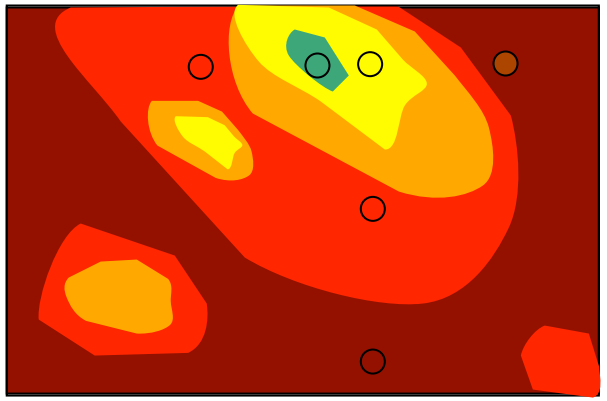

Soil capacity

# Parameter calibration



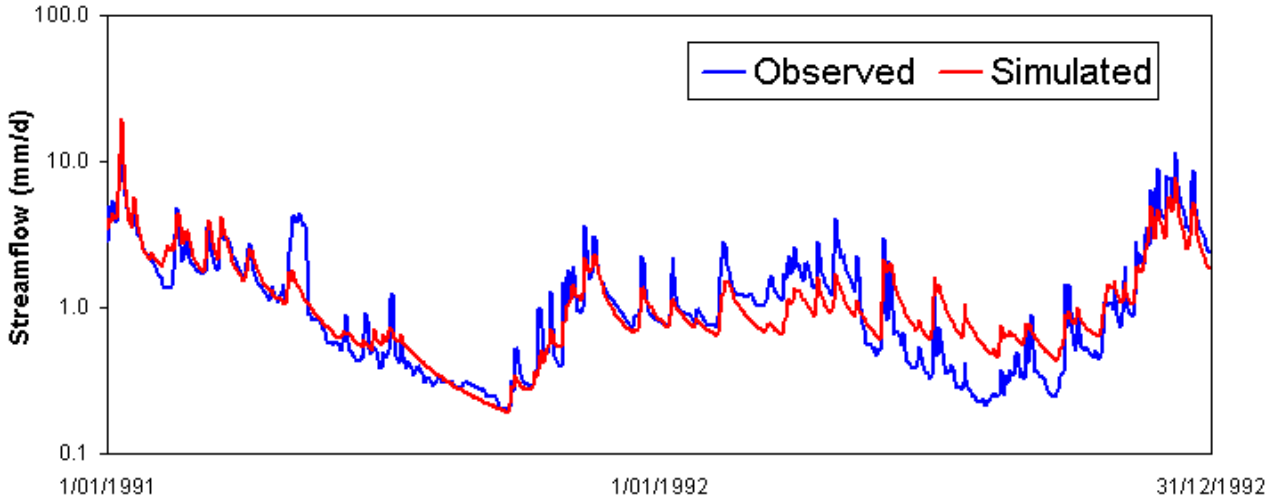

If you tried millions of combinations you could draw a “response surface”

Release rate



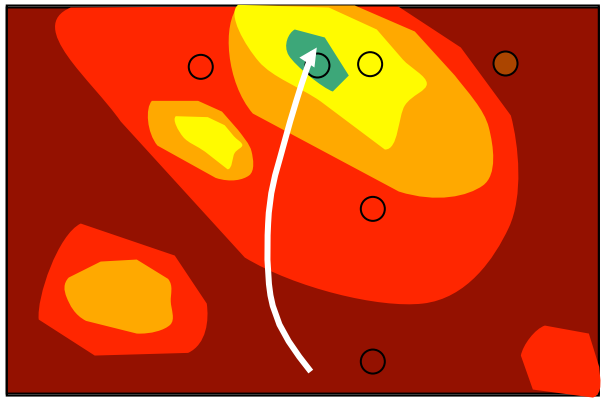
Soil capacity

# Parameter calibration

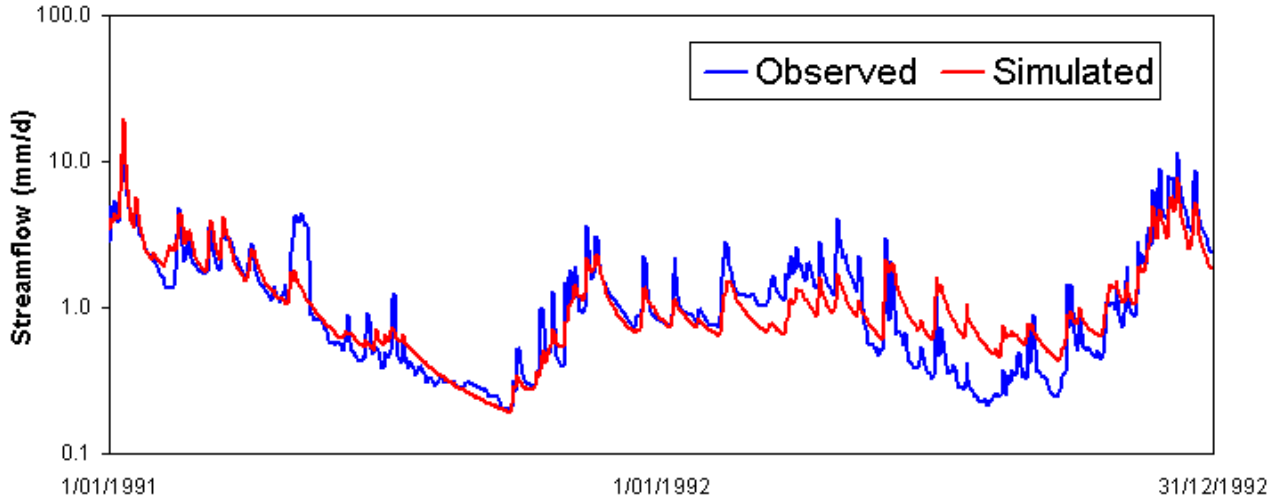



If you tried millions of combinations you could draw a “response surface”

Automatic calibration tries to find quickest path to “global optimum”



# Parameter calibration

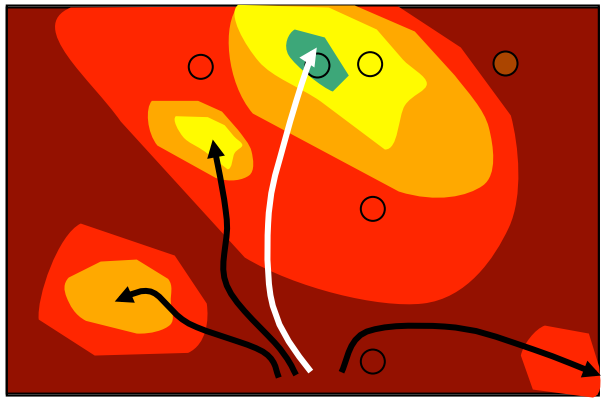



If you tried millions of combinations you could draw a “response surface”

Automatic calibration tries to find quickest path to “global optimum”

but can get trapped in “local optima” or give nonsense parameter values

Release rate



Soil capacity

# Automatic Parameter Estimation

Single objective global optimization: (1988-1994)
Genetic Algorithms, SCE, Simulated annealing, Particle Swarm

Multiple objective optimization: (1998-)
MOCOM, NSGA-II

Iterative calibration: (2001)
BARE

Monte Carlo/Metropolis: (2003)
MOSCEM

Combined optimization and assimilation: (2006)
SODA

Hybrid Automatic/Manual calibration: (2000-2006)
MACS, Boyle et al 2000

# Automatic Parameter Estimation

Single objective global optimization: (1988-1994)

Genetic Algorithms, SCE, Simulated annealing, Particle Swarm

Multiple objective optimization: (1998-)

MOCOM, NSGA-II

Iterative calibration: (2001)

BARE

Monte Carlo/Metropolis: (2003)

MOSCEM

Combined optimization and assimilation: (2006)

SODA

Hybrid Automatic/Manual calibration: (2000-2006)

MACS, Boyle et al 2000

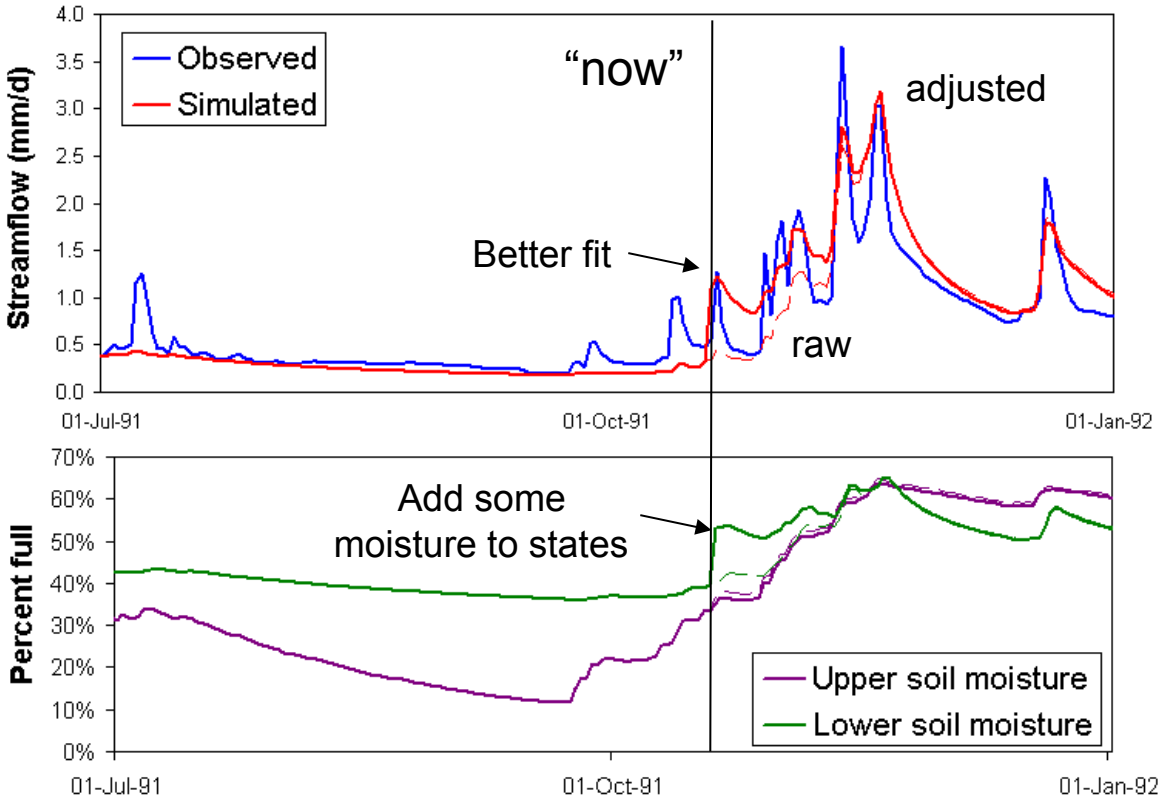
# WIRADA activities

## Parameter calibration:

Use Shuffled Complex Evolution with scalarized multiple objectives

How to use forecasters' subjective ideas for calibration objectives?

# State updating




What new state values will give best fit between recent simulated and observed?

# Main state updating techniques

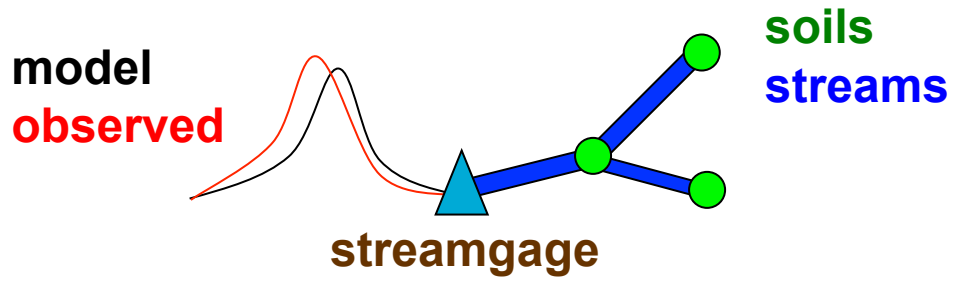
- Kalman Filter (~1980). Need modified model, computationally impractical.
- Ensemble Kalman Filter (~1994) Linear updating can be a problem.
- Variational (~2003) Needs adjoint model. Time invariant model covariance not a realistic assumption.
- Particle filter (~2006) States not updated, but rather their likelihoods.
- Assimilation of ancillary states (>2006). e.g. snow, soil moisture, leaf area index. Direct insertion rarely works, need history.

# WIRADA activities

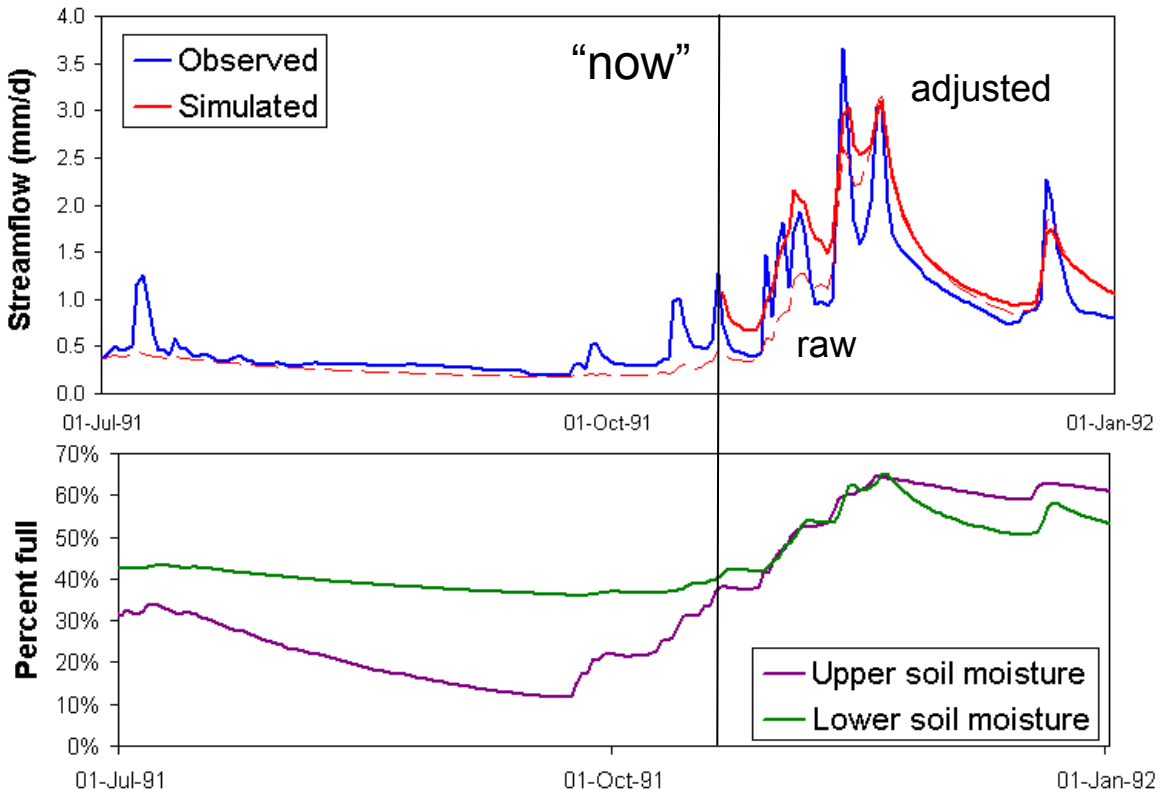
## State updating:

Have done EnKF and Particle filter for 1 spatially lumped catchment.
Skill for the 2 methods was about the same.

How to apply these in semi-distributed models with
time lag between rain and runoff?



# Error correction




How do you adjust the simulated streamflow into something that better matches observed?

Example:

Qadj = a * Qsim + b

Model states don't change

ARMA models common, Quantile mapping

DHI/MIKE has methods that considers timing errors (~1989) and state-updates and error-corrects simultaneously (2005)

# WIRADA activities

## Error correction:

Implementing DHI/MIKE 1989 method

Developing “dual timescale” error correction (e.g. 1 day+12 months)

# Personal reflections

**Operational practice is very basic**

- **Manual calibration**
- **Manual state updating**
- **“Matching” (direct use) of upstream observed streamflow**

**Current system transparent and works well with data of realtime quality**

- **Allows the use of “soft” information, expertise**

**Would operations accept highly formalized black box methods?**

**Even “optimal” methods have tunable parameters**

# Open questions

**How to work within streamflow forecasting's very non-linear, non-Gaussian space?**

**How to account for the lag between states and flow?**

**How to update semi-distributed model states?**

**How to merge the best of the automatic/objective and manual/subjective?**

# Future directions

## 1. Where do you want to be at the end of your project?

Develop and help implement operationally effective and practical model-data fusion techniques

## 2. Where should we be in 5 years?

How do you handle short-record datasets?

How to make and use retrospective forecasts?

How do we find the human-machine balance?

# Future directions

**3. Do other areas/fields affect us?**

**4. Who else would benefit from our work?**

Will hydrology and land surface modeling converge?

Seasonal hydro forecasting is relevant but simpler

Meteorology is often 5-10 yrs ahead of hydrology

**CSIRO Land and Water**
Thomas Pagano
Hydrologic Modeller

**Email:** Thomas.Pagano@csiro.au

# Thank you

## Contact Us

**Phone:** 1300 363 400 **or** +61 3 9545 2176
**Email:** Enquiries@csiro.au **Web:** www.csiro.au

Australian Government
Bureau of Meteorology

Water Information
DATA › INFORMATION › INSIGHT

National Research
FLAGSHIPS

CSIRO