Distributed modelling

CIE4431 – Hydrological Modelling

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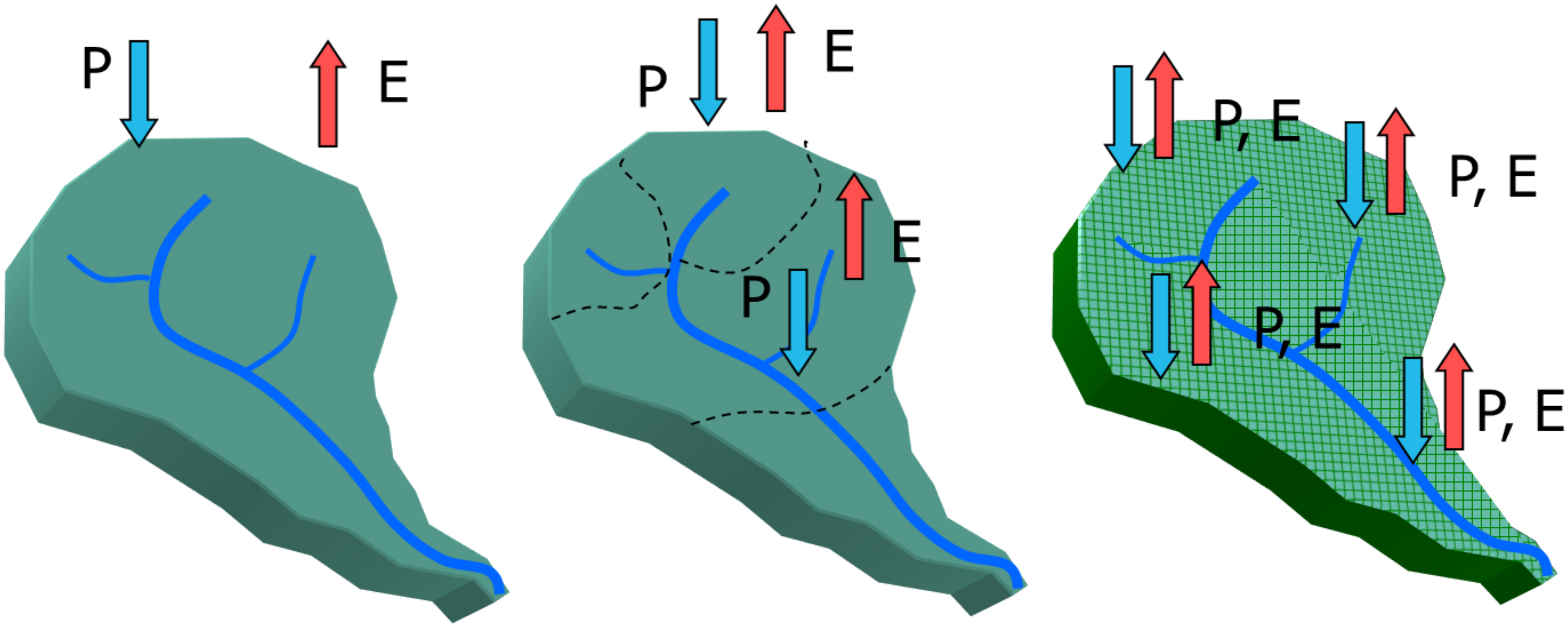
26 February 2016

Today’s Topics

- Why to use distributed models?
- What are distributed models?
- When and how to use distributed modelling?
- Data sources

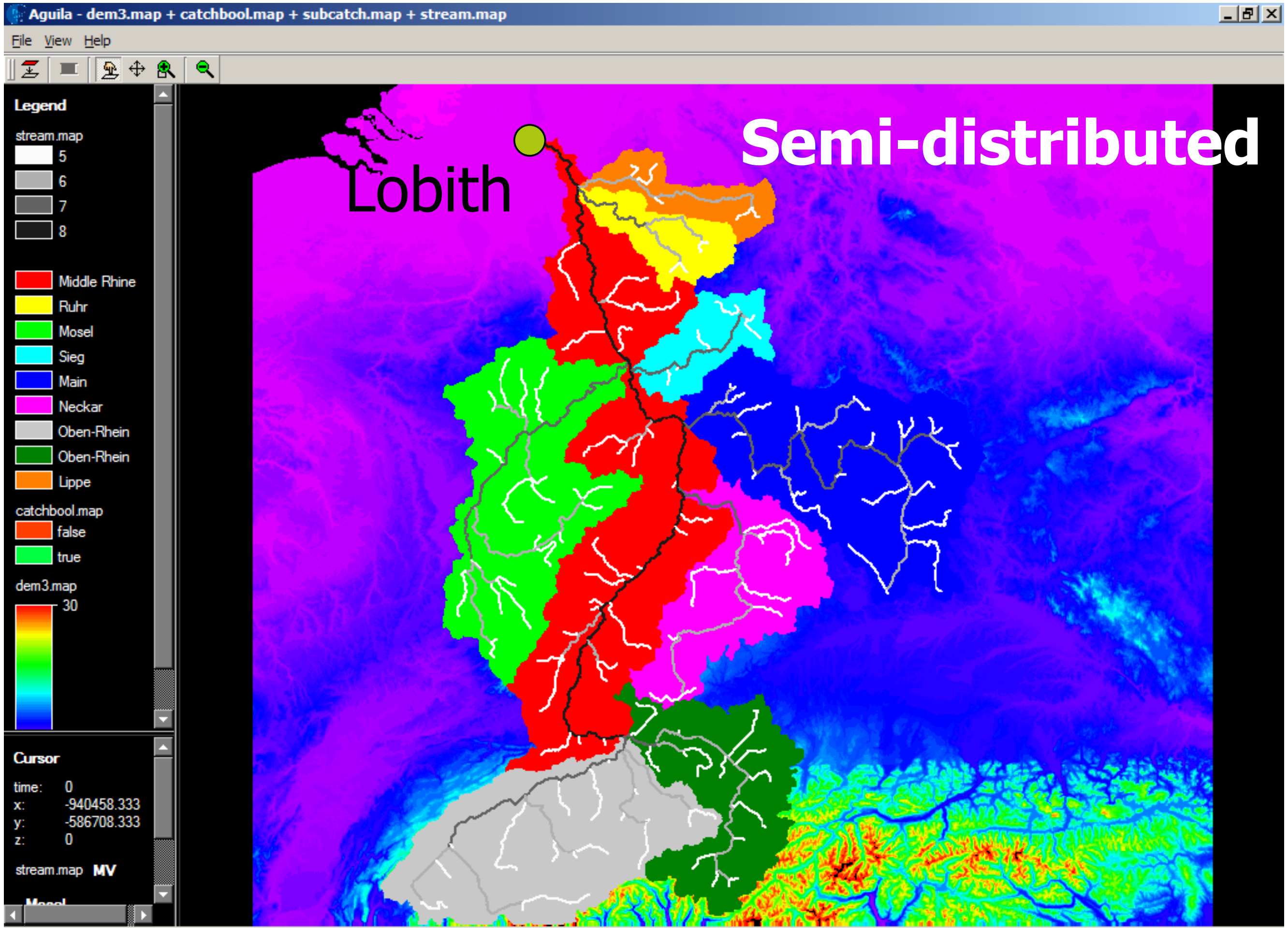
Introduction

lumped vs distributed



Introduction

lumped vs (semi) distributed



Introduction

Lumped

- Advantages
  - Fast
  - Easy to implement
- Disadvantages
  - only the outlet (discharge) behaviour or lumped over whole catchment
  - No internal info → no coupling with e.g. soil erosion or vegetation models
  - Loss of information on spatial distribution

Introduction

Fully distributed

- Advantages
  - Include distributed data sources (e.g. rainfall)
  - Include distributed scenarios (e.g. land use change)
  - Interpret distributed results (e.g. local erosion potential, vegetation changes, include local pollution sources)

- Disadvantages
  - Slower
  - Equifinality (i.e. distribution of parameters often causes confusion and not necessarily a better model)

Introduction

Semi-distributed

- Advantages
  - Include distributed data sources (e.g. one rain gauge per sub-catchment)
  - Fast
- Disadvantages
  - Little internal info
  - Equifinality

Introduction

Reasons to model distributed

- Distributed data available, so why not use it?
  - Drivers
  - Land use
- Known variability in hydrological processes
- Evaluate water balance in specific sub-domains
- We have a certain question that can only be answered with a distributed model:
  - …
  - …

Introduction

Reasons to model distributed

But, be careful!

- Extra information can be 'fake'
  - How good is your distributed input data?
  - Can you test your results?

- Equifinality

What are distributed models?

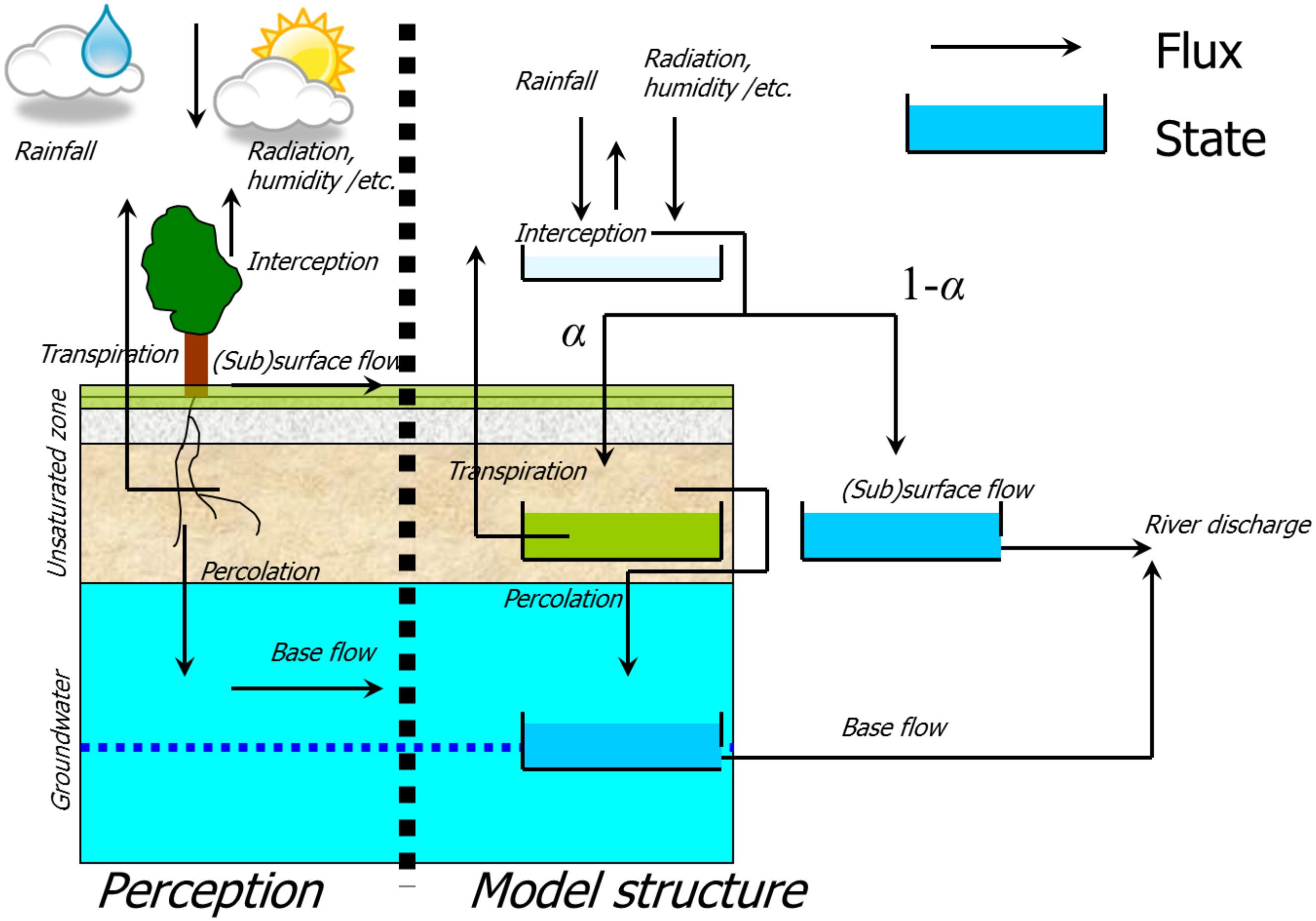
"*Distributed refers to any selection of model structure, parameters or data which is not considered representative for the entire catchment*"

What do they consist of?

- A (conceptual or physical) model for the water balance
  - input: rainfall, potential evaporation;
  - output: evaporation, river discharge, etc.
- Often some form of (river) routing

What are distributed models?

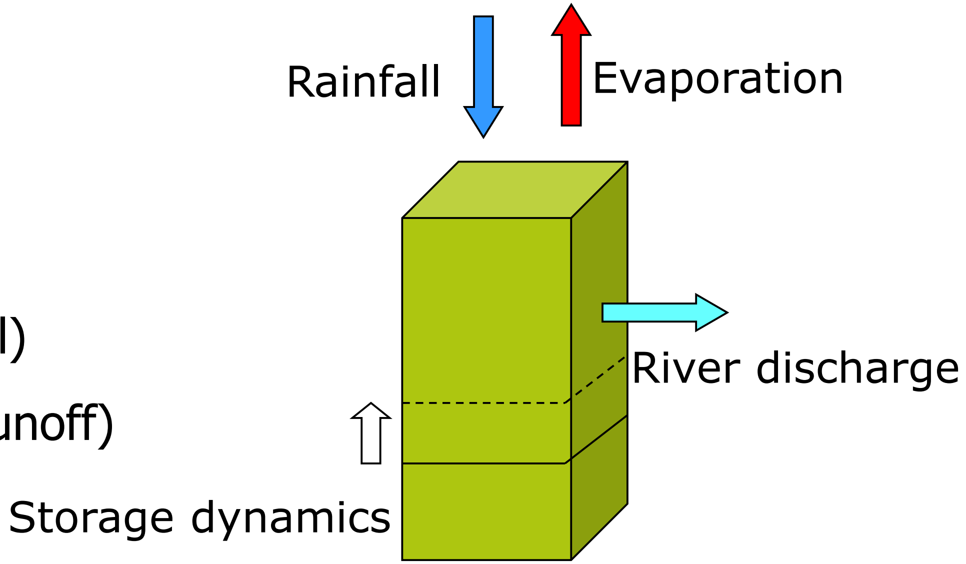
Water balance model



What are distributed models?

Water balance model

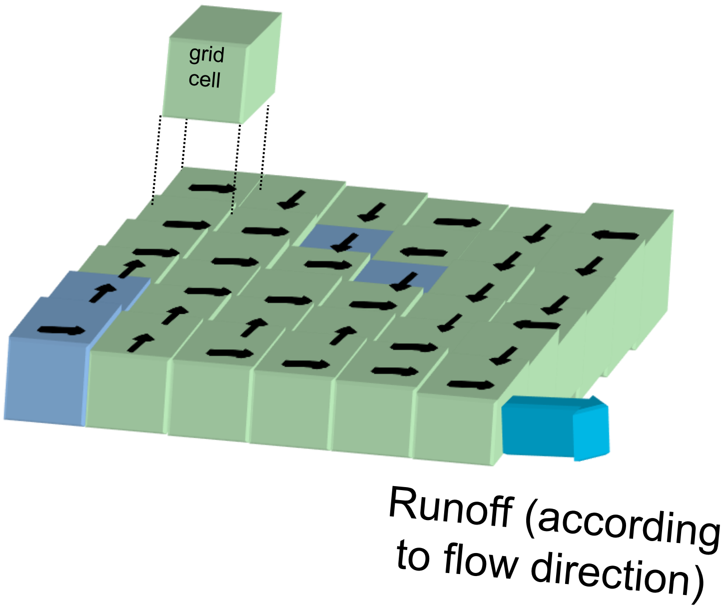
- Each cell has:
  - Input (e.g. rainfall)
  - State variables (e.g. soil moisture, groundwater level)
  - Output (e.g. evaporation, runoff)

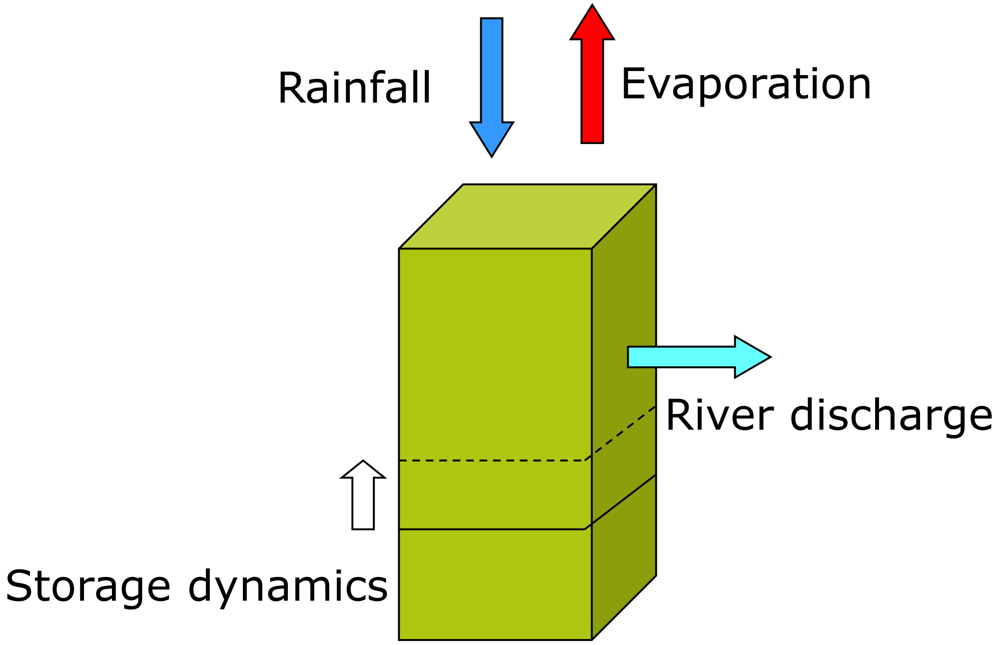


- Groundwater outflow goes straight to the river?
- What to do with the runoff?

What are distributed models?

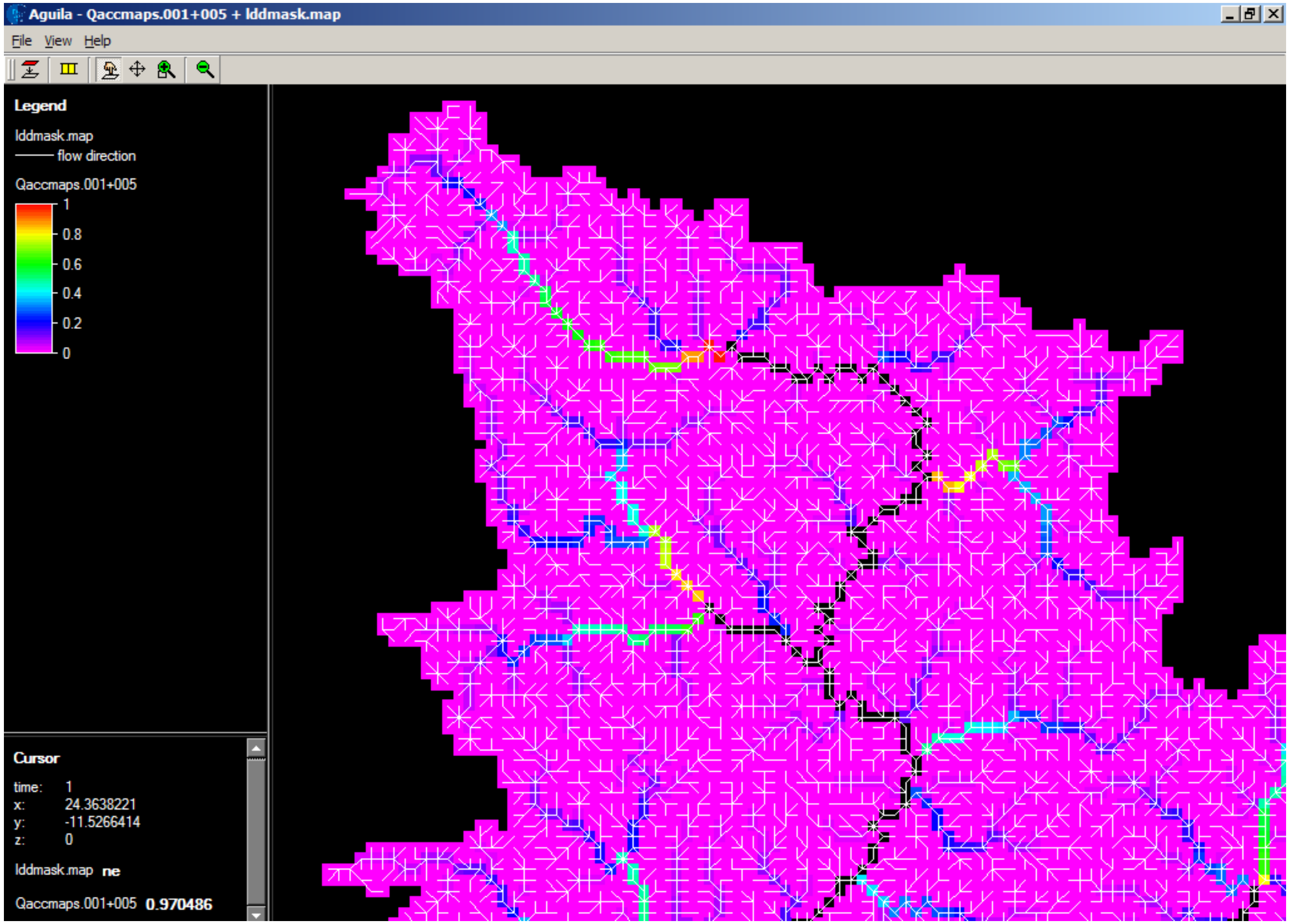
Water balance model





What are distributed models?

Routing



What are distributed models?

Routing

- Runoff moves horizontally over the drainage network
- Transport in a cell without storage consideration is:

$$Q_i = \sum_{n=0}^{n=i} Q_n$$

where

n :	location of upstream cell
i :	location cell under computation
$n = 0$:	the location of a water divide

What are distributed models?

Routing

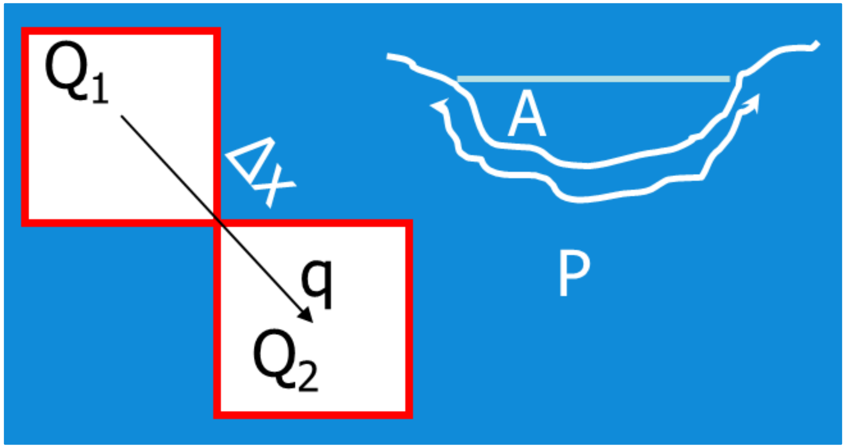
Taking into account that there is channel storage

- Kinematic wave approximations

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$

$$Q = A\frac{1}{n}R^{2/3}i^{1/2}$$

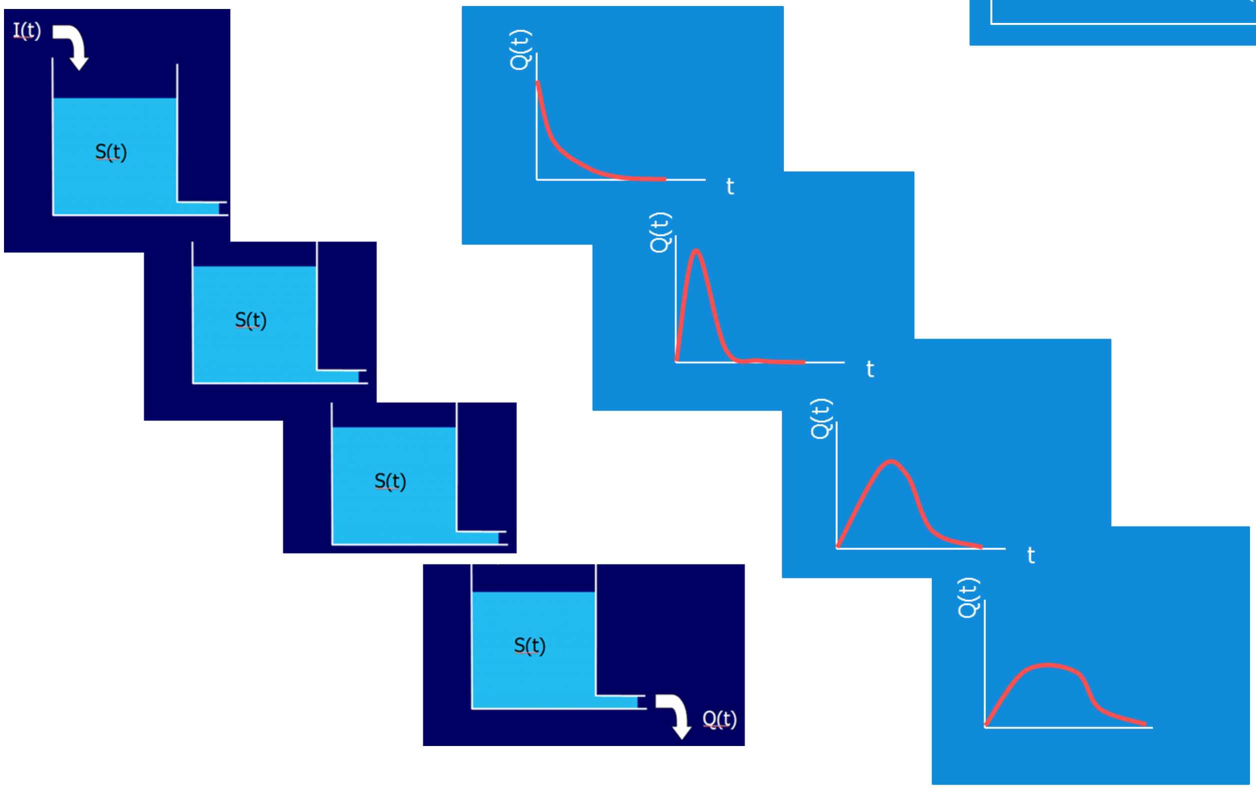
$$A = \left(\frac{nP^{2/3}}{i^{1/2}}Q\right)^{3/5}$$



What are distributed models?

Routing

$$Q(t) = \frac{1}{K}\left(\frac{t}{K}\right)^{n-1}\frac{1}{(n-1)!}e^{-t/K}$$



What are distributed models?

Semi-distributed modelling

(Fully-)distributed: grid with usually equal cell-sizes

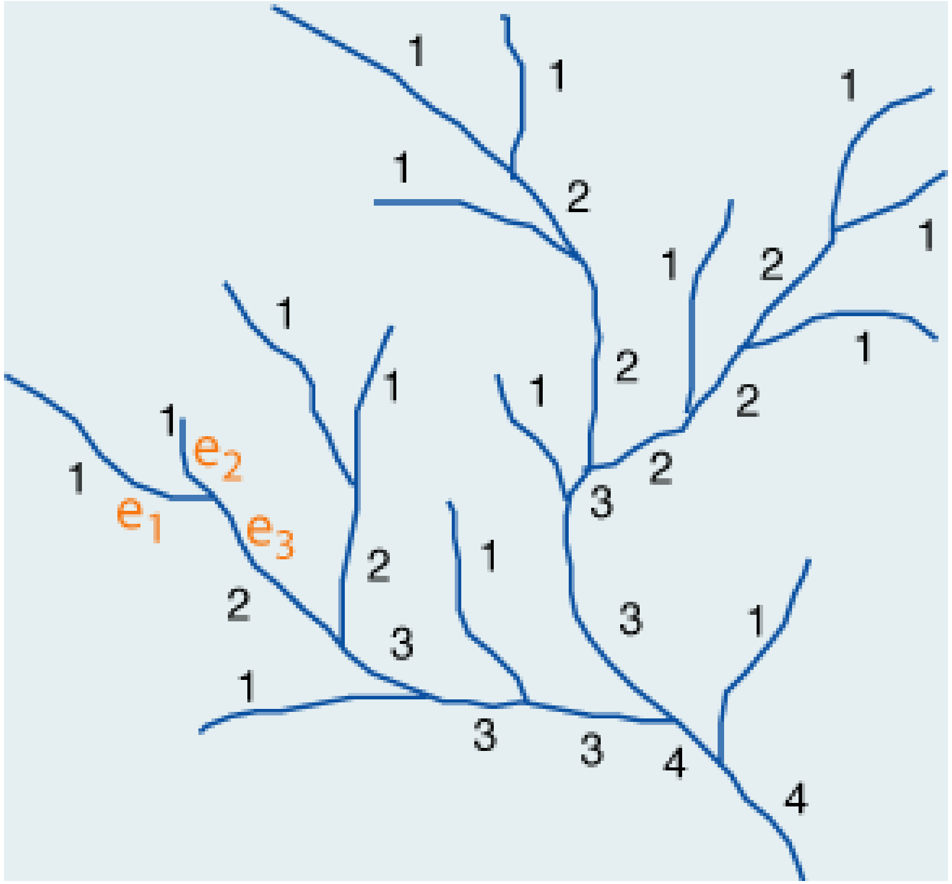
- Gridded rainfall data

Semi-distributed: aggregation of grid-cells in spatial units e.g.:

- Location of runoff gauges
- According to Strahler order river network
- Hydrotope analysis (in between semi-distributed and distributed)
    - Similar landscape elements
    - Similar land use elements
    - Similar ecosystem elements

Semi-distributed modelling

Strahler order

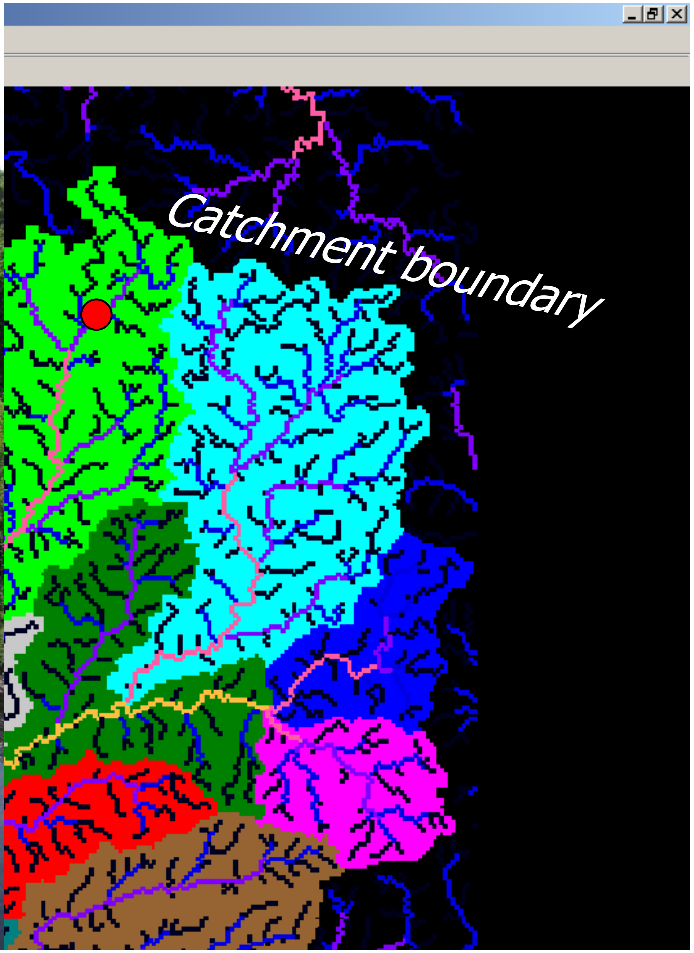


Semi-distributed modelling

Example: Kabompo, strahler threshold?

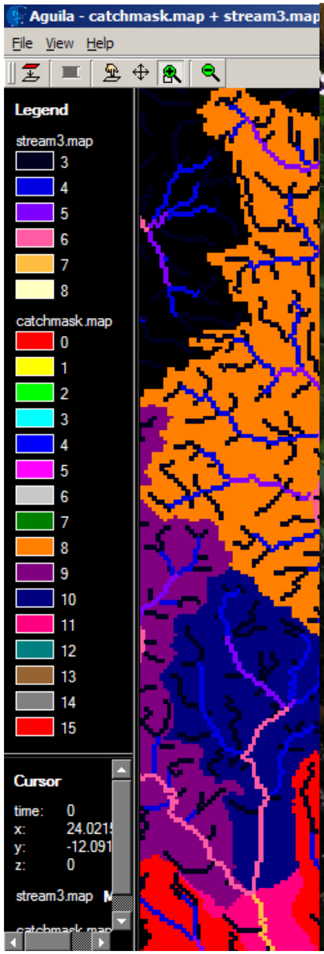
Semi-distributed modelling

Example: Kabompo, strahler threshold?



Semi-distributed modelling

Example: Kabompo, strahler threshold?



Semi-distributed modelling

Hydrological response units

- Areas (classes) of assumed similar hydrological behaviour
- Remotely sensed/distributed data for delineation
- Expert judgment or field examinations recommended
- Also known as:
  - Landscape units
  - Hydrotopes
  - Representative watersheds
  - Classes
  - Etc…

Hydrological response units

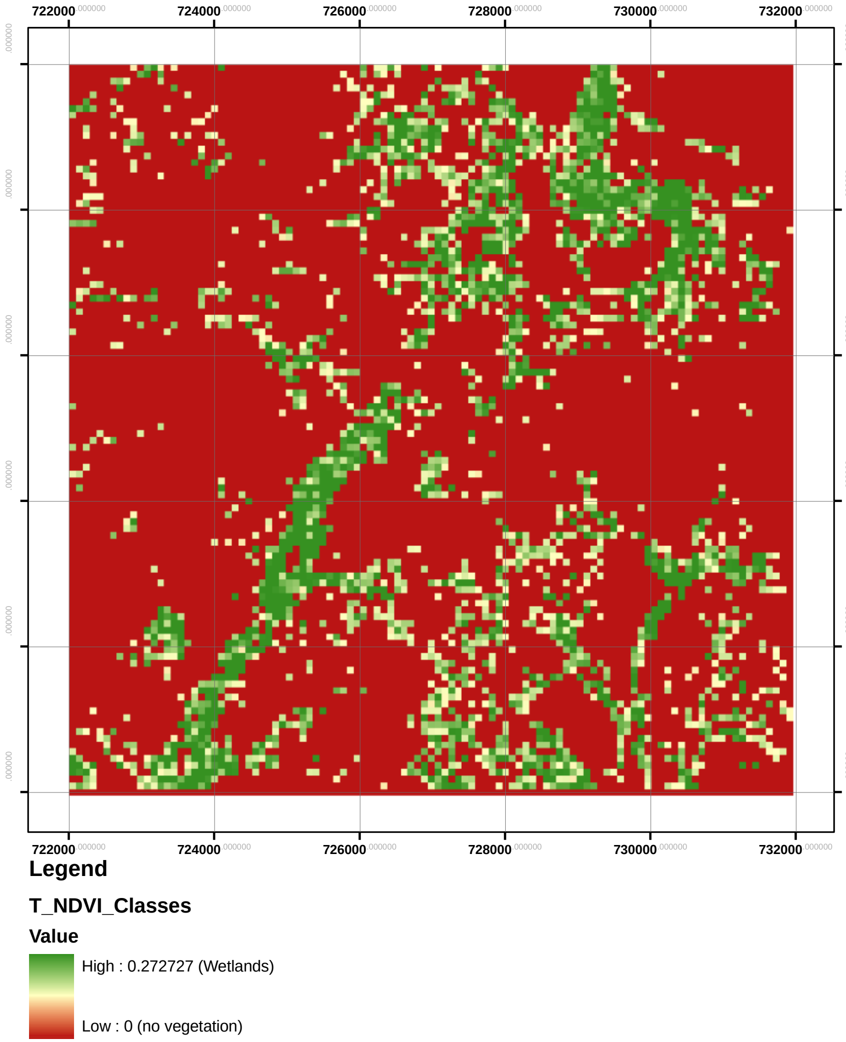
Example Volta basin

Hydrological response units

LandSAT imagery

- Use thresholds to derive the classes
- Normalized Difference Vegetation Index (NDVI)
- Logical expression:

  If NDVI > 0.05, wetland

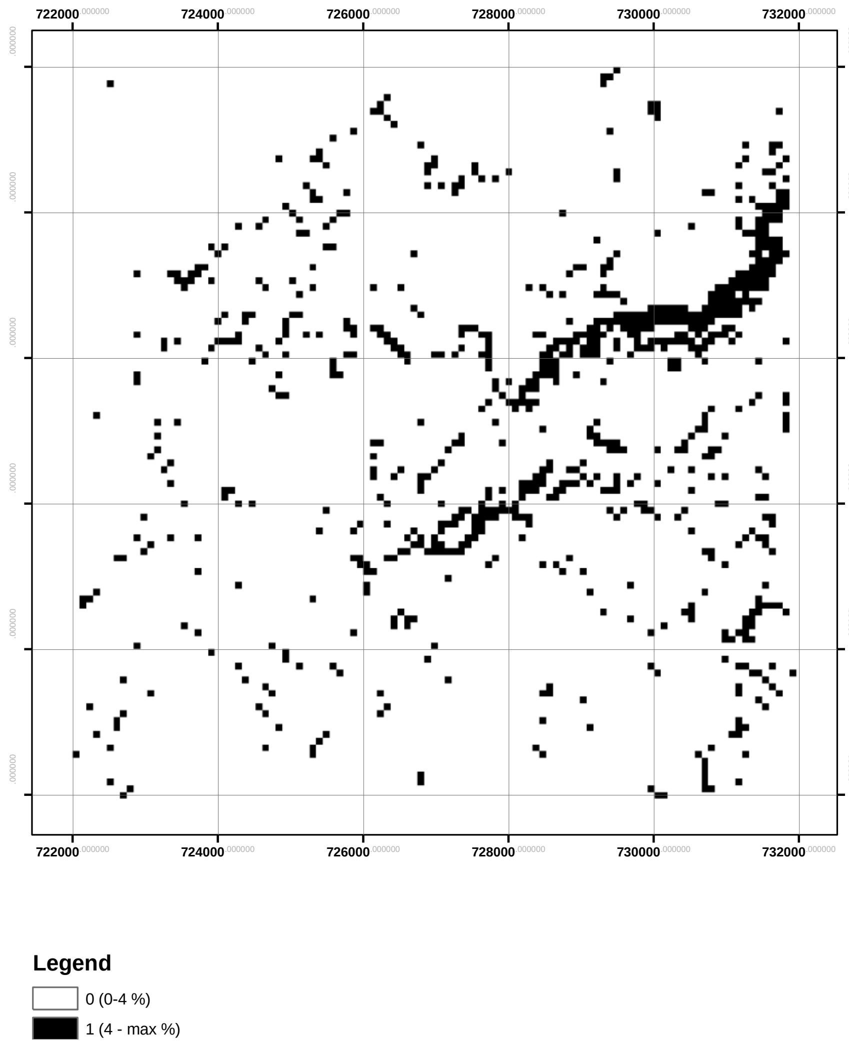


Hydrological response units

DEM: slopes

- Use thresholds to derive the classes
- Slope of topography
- Logical expression:

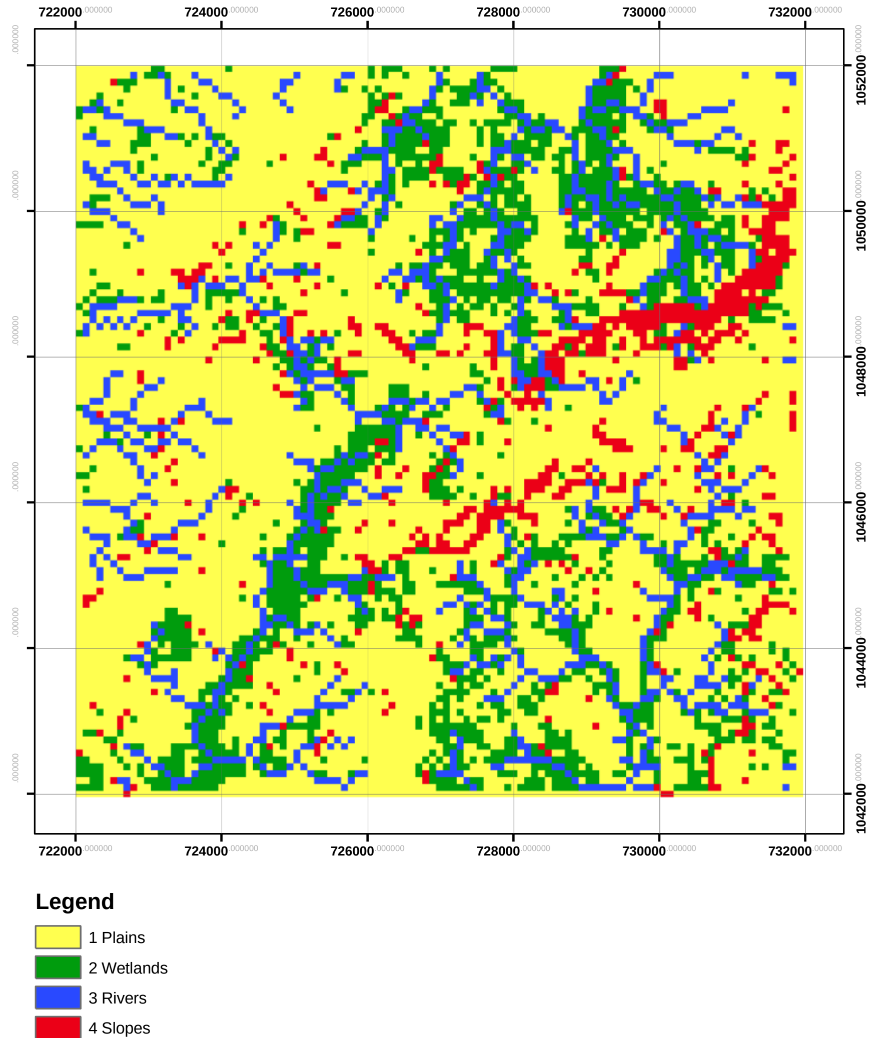
  If slope > 0.04, hill



Hydrological response units

Classification

1. Plains (DEM)
2. Wetlands (NDVI)
3. Rivers (runoff)
4. Slopes (DEM)



How and when to use distributed modelling?

To start with

- Investigate what information you have available
- Decide what is suitable to distribute and to what extend
  - Data availability
  - Which processes are you interested in?
  - Area extent
- Use the right tools:
  - Computational time
  - Programming language/framework
  - Existing models

How and when to use distributed modelling?

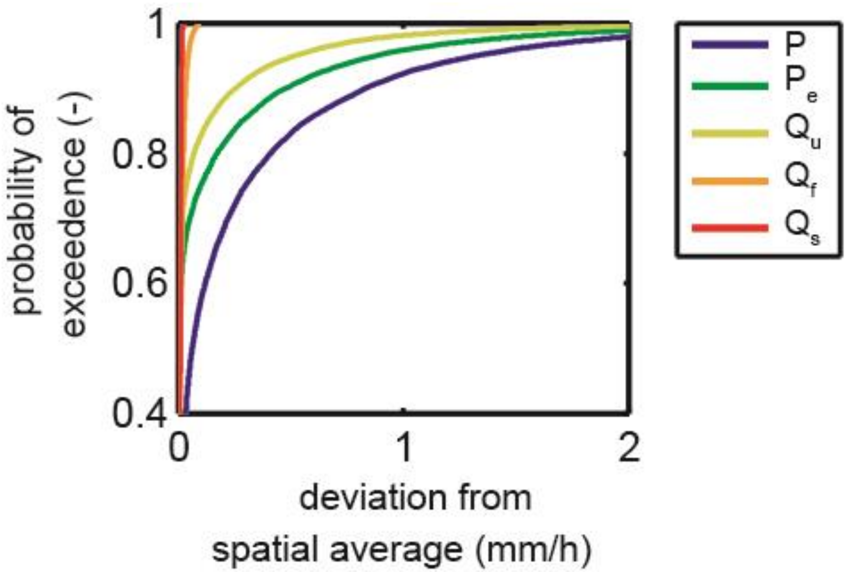
Possibilities

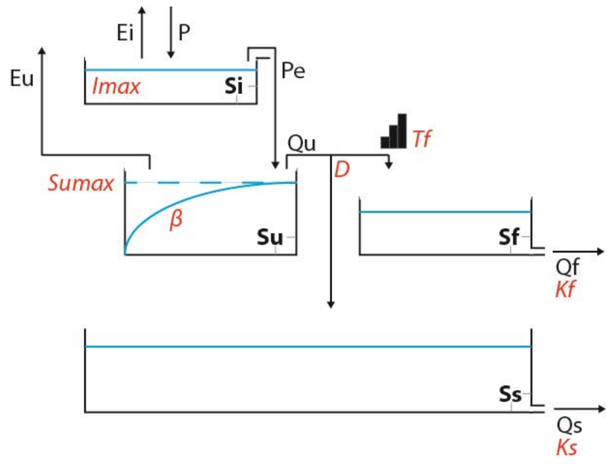
- Distribution of input data
- Distribution of model
    - Distribution of parameters
    - Distribution of model structure

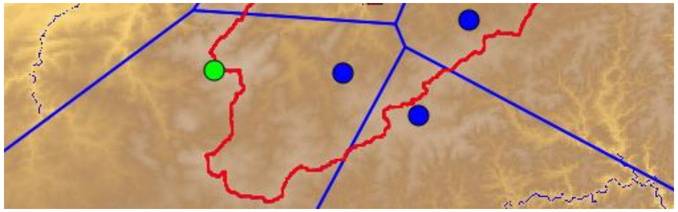
	Lumped model	Distributed model
Lumped data	Most simple	
Distributed data		Most complex

Distribution of input data

- Data availability main issue
- Heterogeneity of rainfall
- Filtering in heterogeneity by model

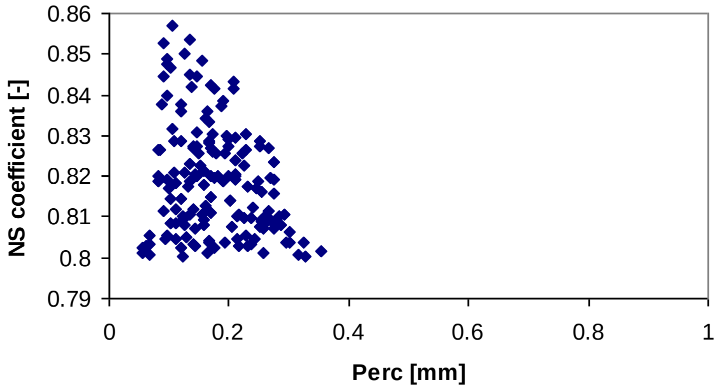


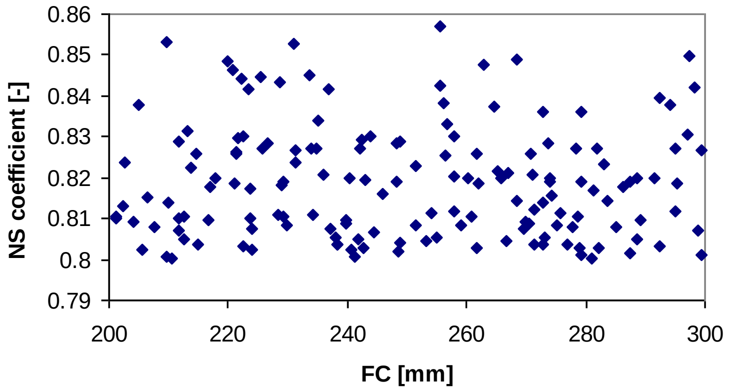




Distribution of parameters

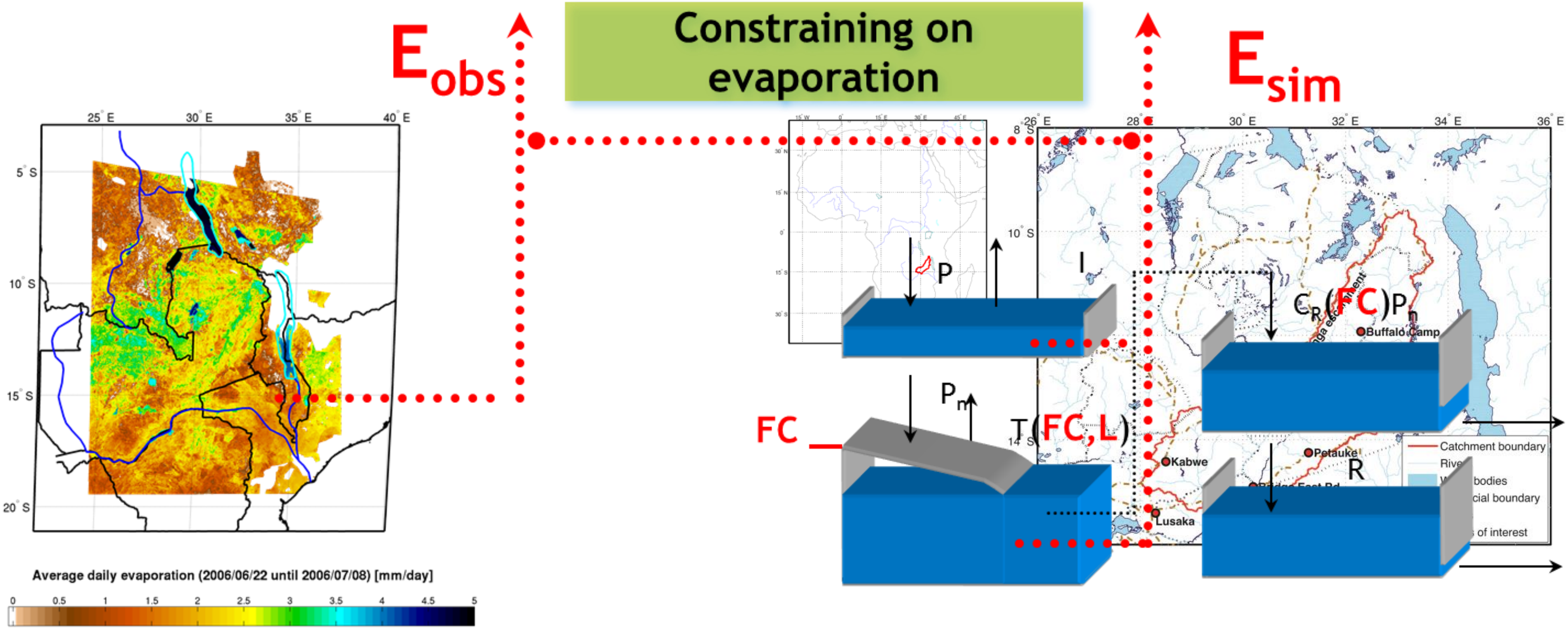
- Often combined with distribution of input data
- Not all parameters distributed
  - Landuse often suitable
  - Make sure you can justify your distribution





Distribution of parameters

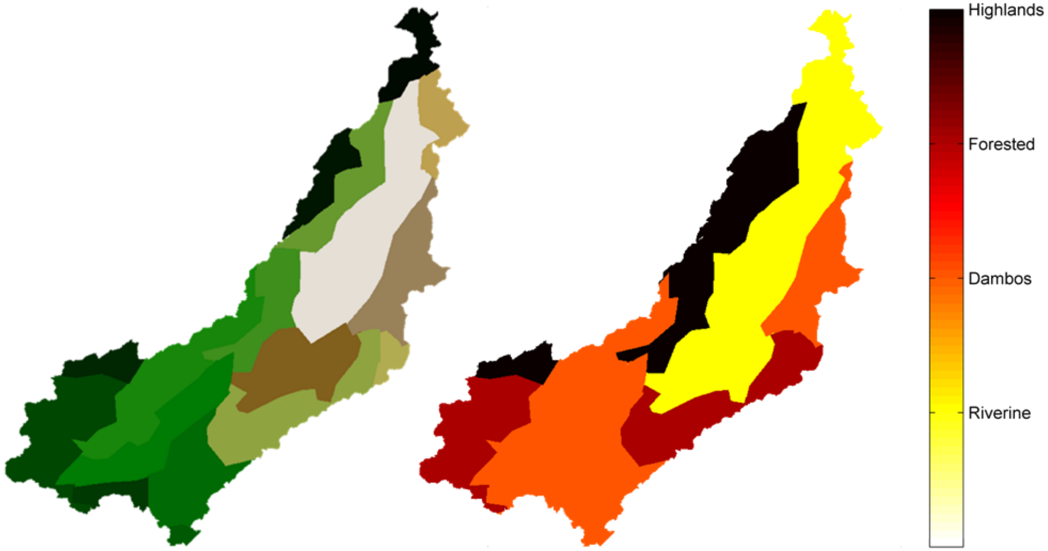
Example Luangwa: constraining on evaporation



Winsemius et. al, HESS, 2008

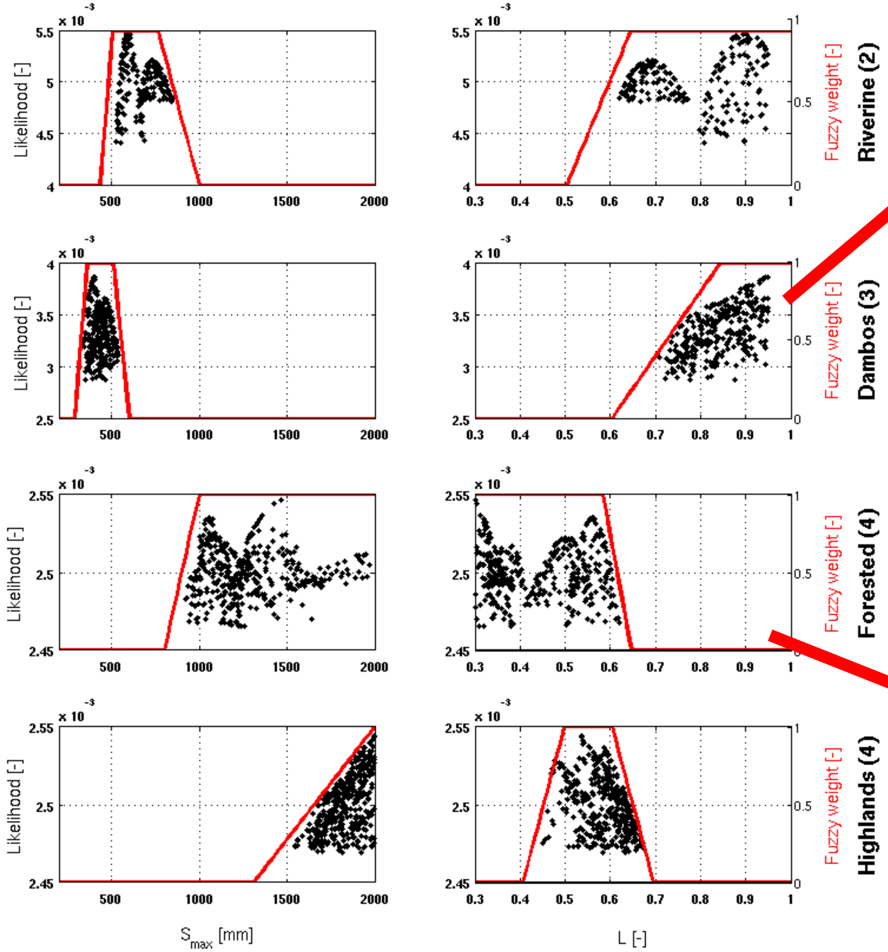
Distribution of parameters

Example Luangwa: methodology



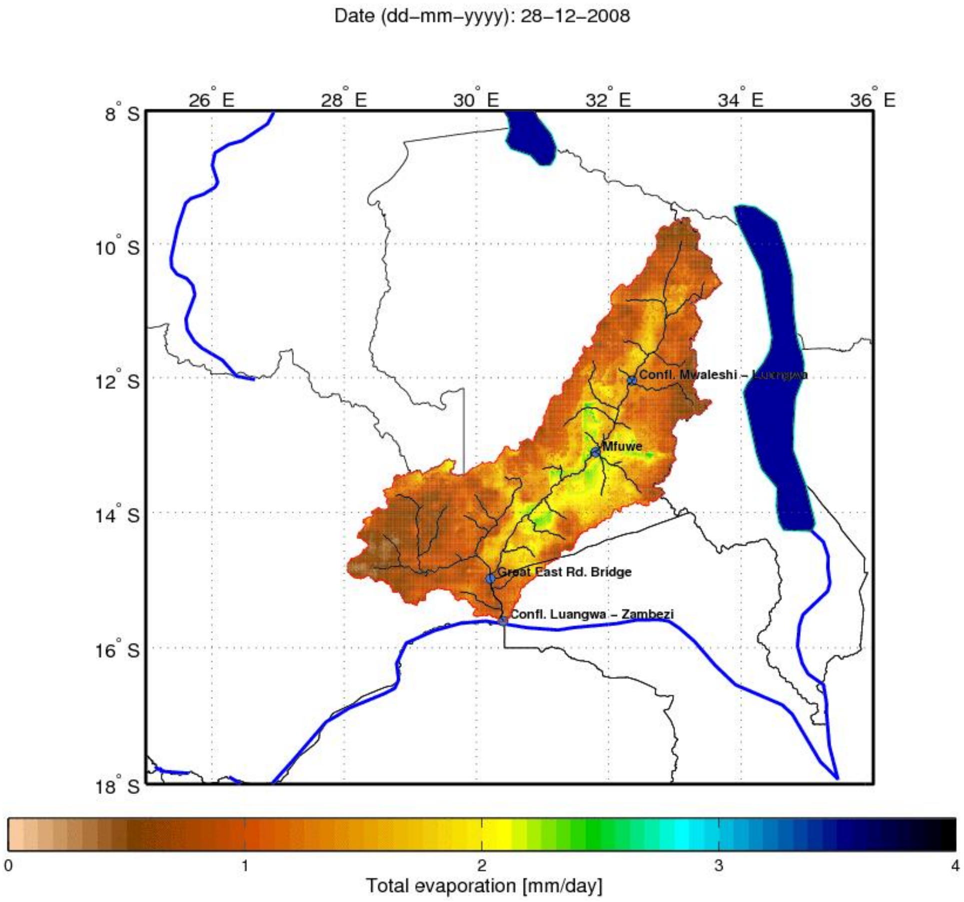
Distribution of parameters

Example Luangwa: Results



Distribution of parameters

Example Luangwa: distributed responses

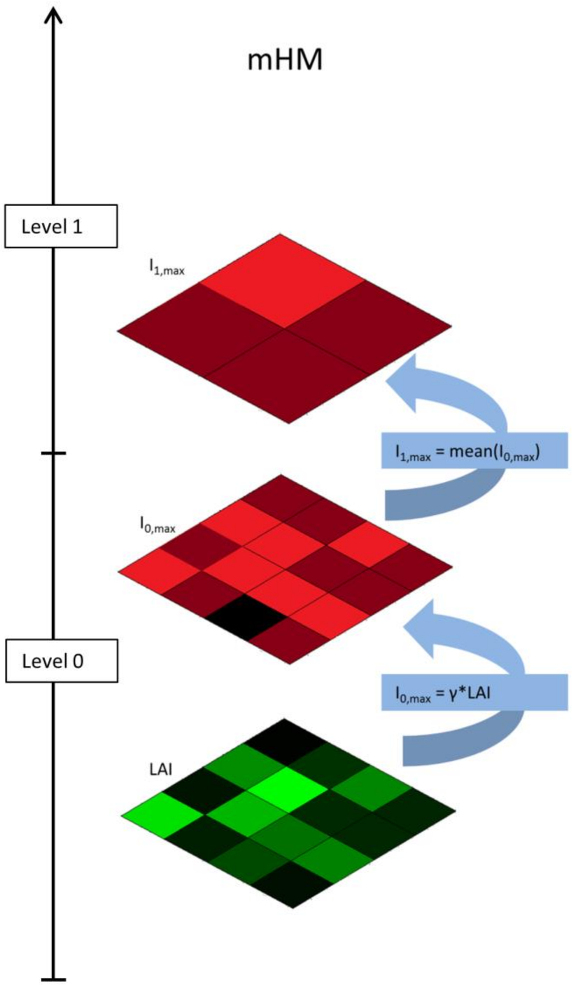


Distribution of parameters

Equifinality

How to limit equifinality in distributed models?

- Transfer function methods:
    - Lookup tables or functions to link model parameters with soil types, land cover classes



Distribution of parameters

Equifinality

How to limit equifinality in distributed models?

- Transfer function methods:
  - Lookup tables or functions to link model parameters with soil types, land cover classes
- Use constraints

Parameter constraints:

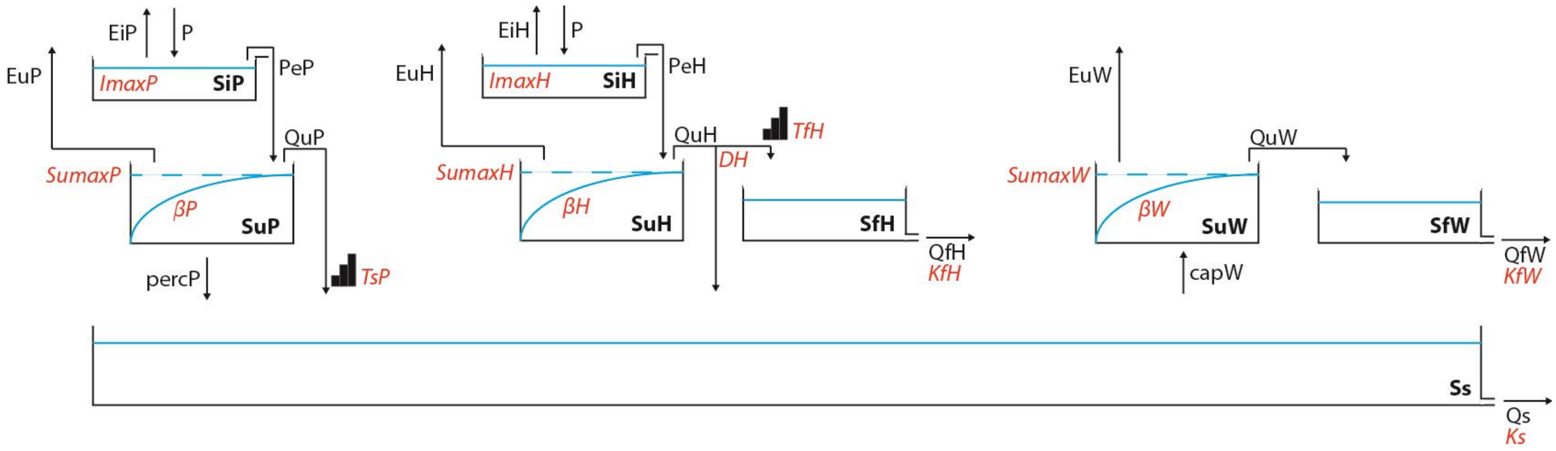
$I_{max, grass} < I_{max, forest}$
$Su_{max, wetland} < Su_{max, plateau}$

Process constraints:

$Q_{dry, fast, hillslope} < Q_{dry, fast, wetland}$
$Q_{dry, fast, hillslope} < Q_{dry, fast, wetland}$

Distribution of model structure

Parallel modelling



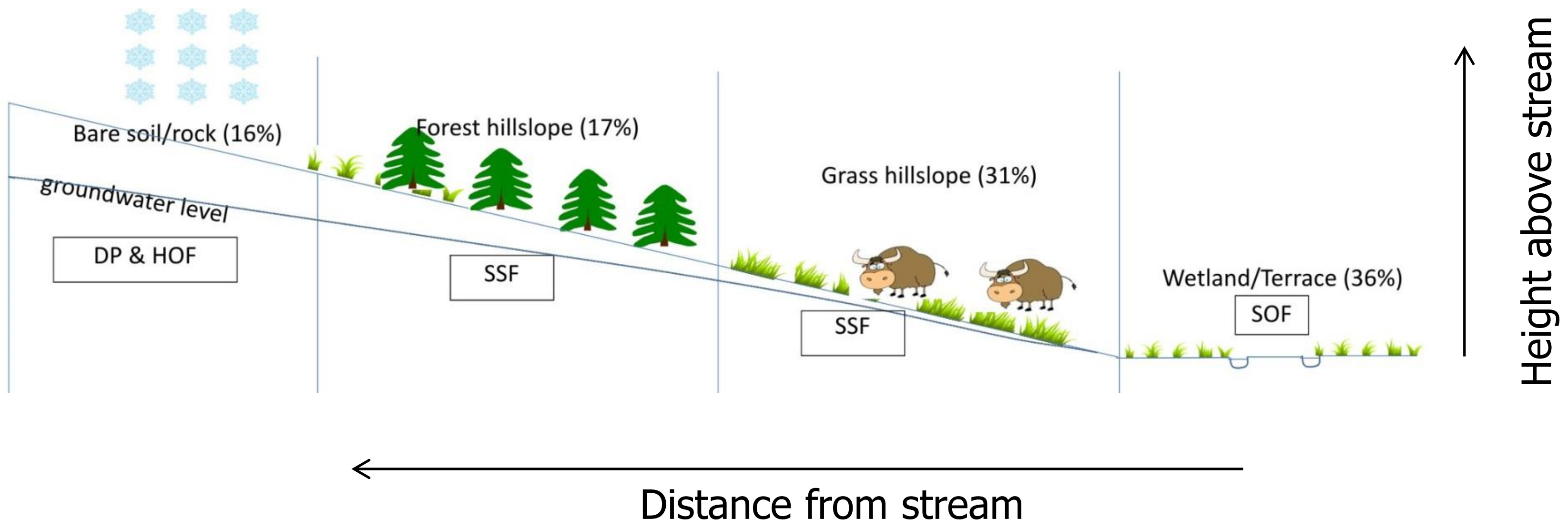
Distribution of model structure

Parallel modelling

- Classification required
  - Topography
  - Land use
  - Subsurface
- Only dominant runoff processes for a each class
- Processes occur simultaneously
- Limited connections between neighbouring classes
  - Possible connection via groundwater reservoir

Distribution of model structure

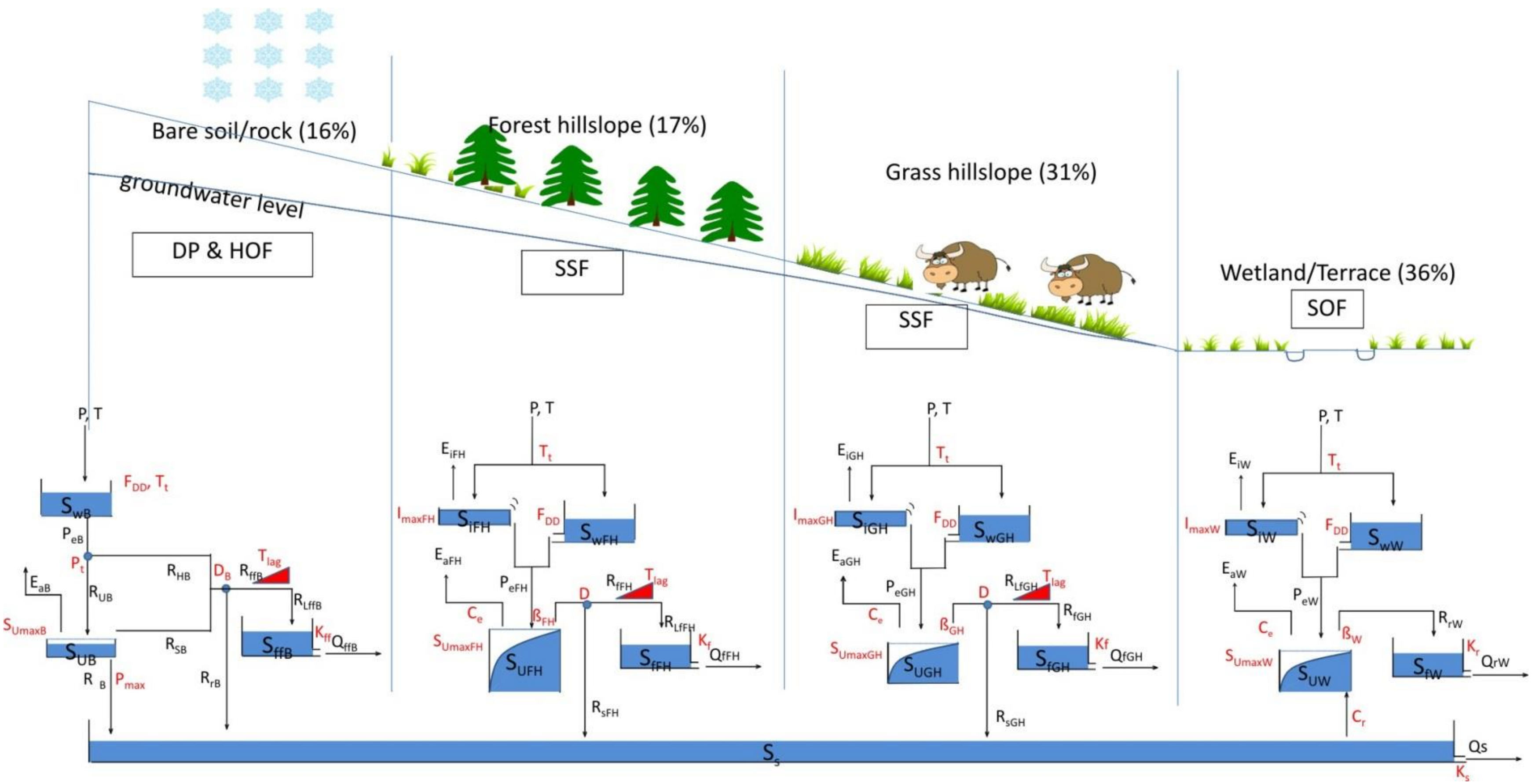
Parallel modelling: FLEX-Topo



Gao, HESS, 2014

Distribution of model structure

Parallel modelling: FLEX-Topo



Distribution of model structure

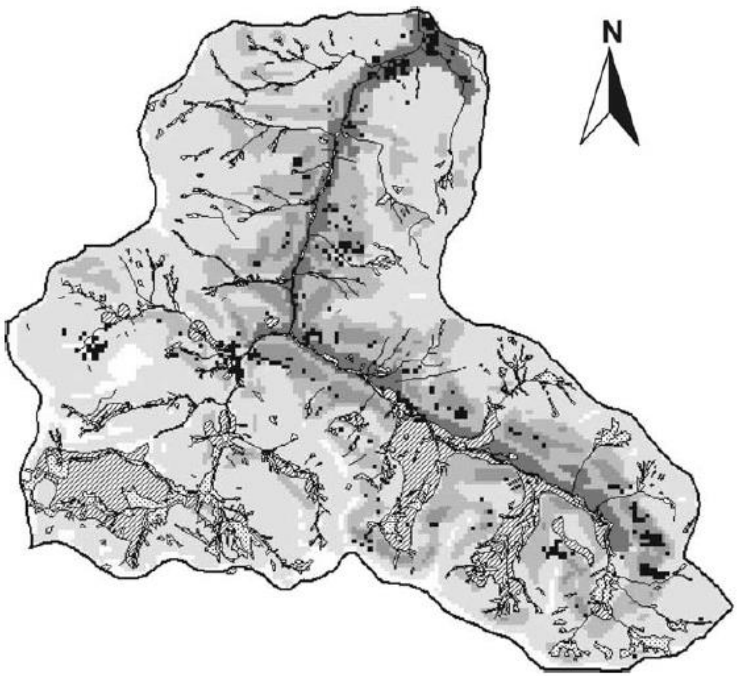
Parallel modelling

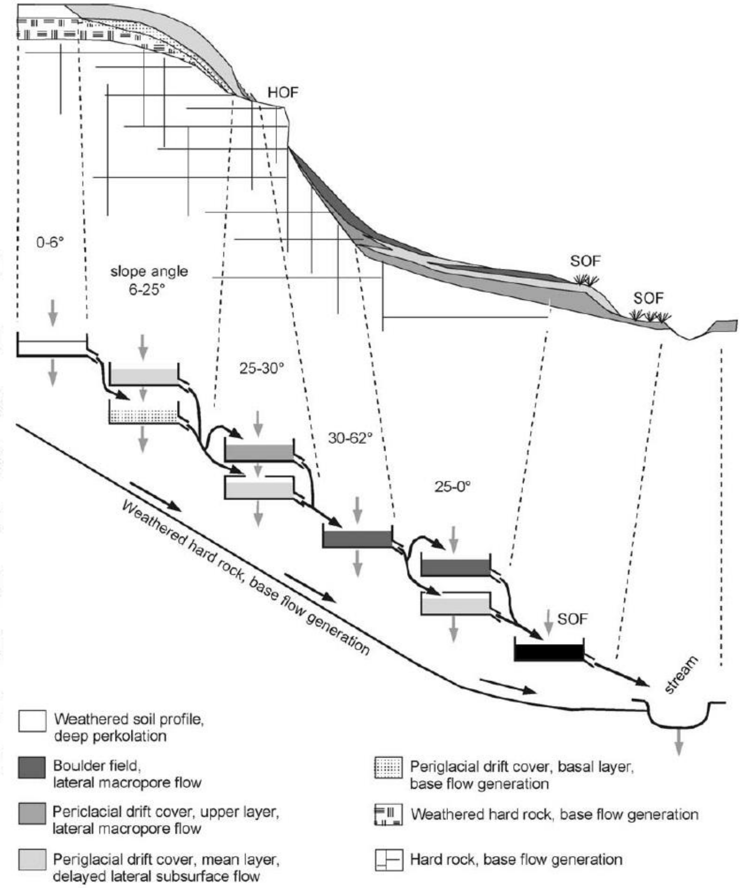
- Assumptions
  - Which processes are dominant
  - Boundaries of hydrotopes
- Testing is difficult
  - No measurements at appropriate scale
  - Extra data sources required
  - Internal realism checks
    - Transferability
- Constraining based on expert knowledge can help

Distribution of model structure

Example testing with tracer data

$$Q = k \times S \times (1 + \tan\beta/\tan\beta(\text{mean}))$$

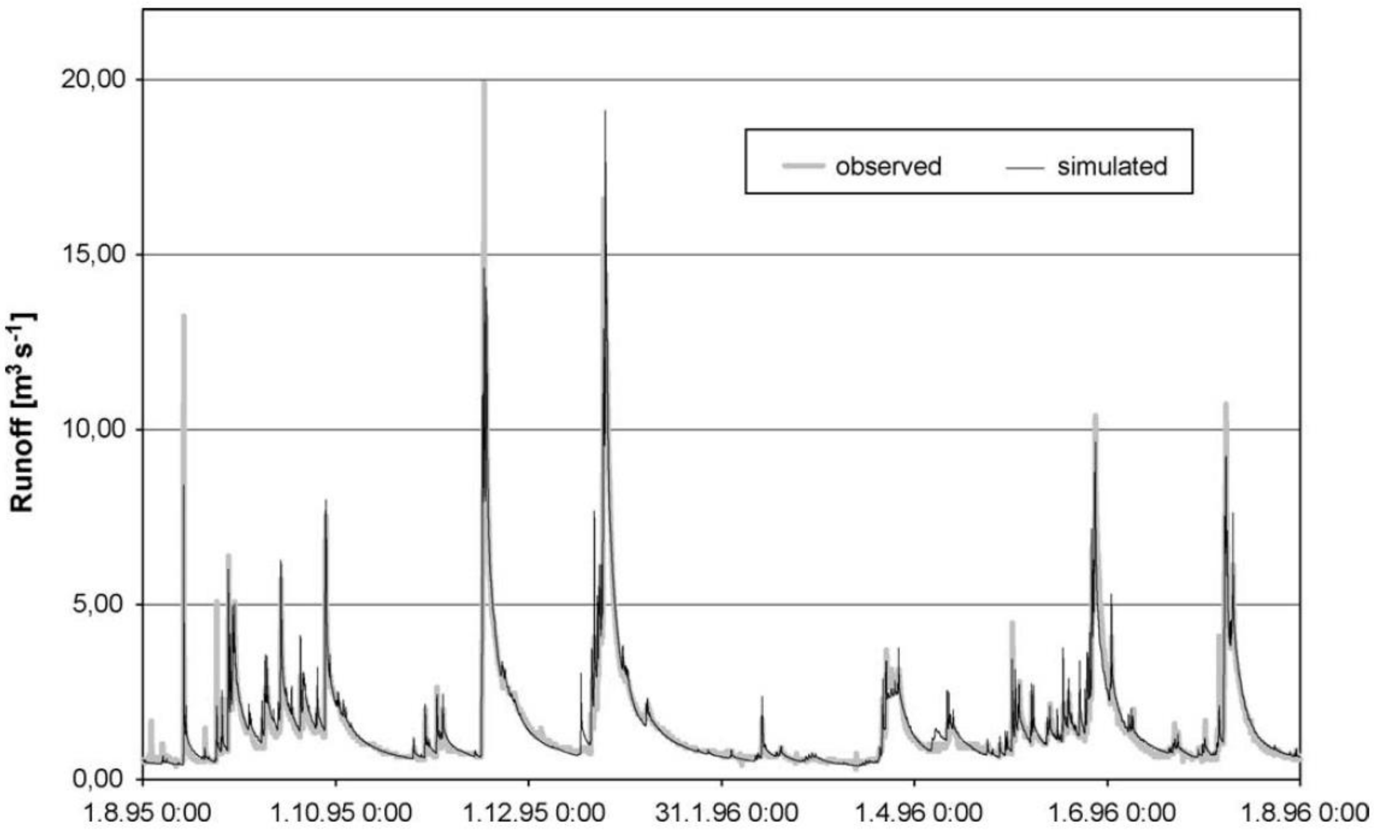




Uhlenbrook et. al, JoH, 2004

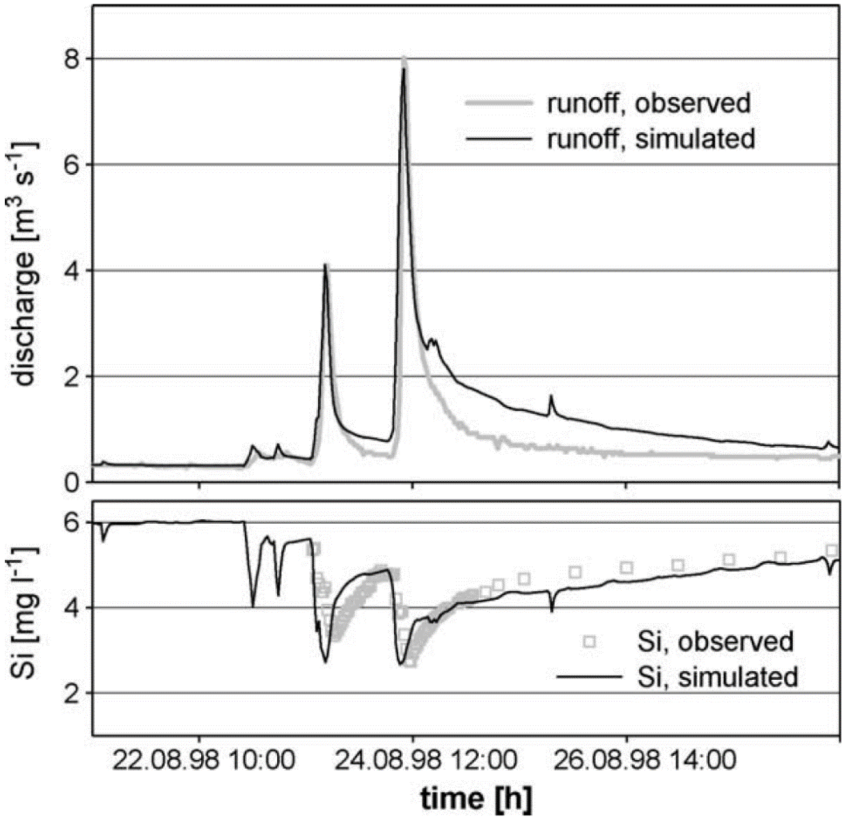
Distribution of model structure

Example testing with tracer data



Distribution of model structure

Example testing with tracer data



$$\mathrm{Si}_{\mathrm{conc}} = Q_{\mathrm{sim}}^{-1} \times \sum (\mathrm{Si}_{\text{runoff-comp}} \times Q_{\text{runoff-comp}})$$

Data sources

Introduction

- History: from point to grid → geo-statistical interpolation, e.g.
  - Thiessen polygons (nearest neighbour)
  - Kriging (co-variance matrix approach)
  - Inverse distance weighted
  - See also: lecture notes hydrological measurements
- General problem: by interpolating, you loose (local) extremes

Data sources

Introduction

Now:

Remote sensors on satellites provide new data:

… to used distributed input data,

… to help estimating parameters,

… to support distributed models.

Data sources

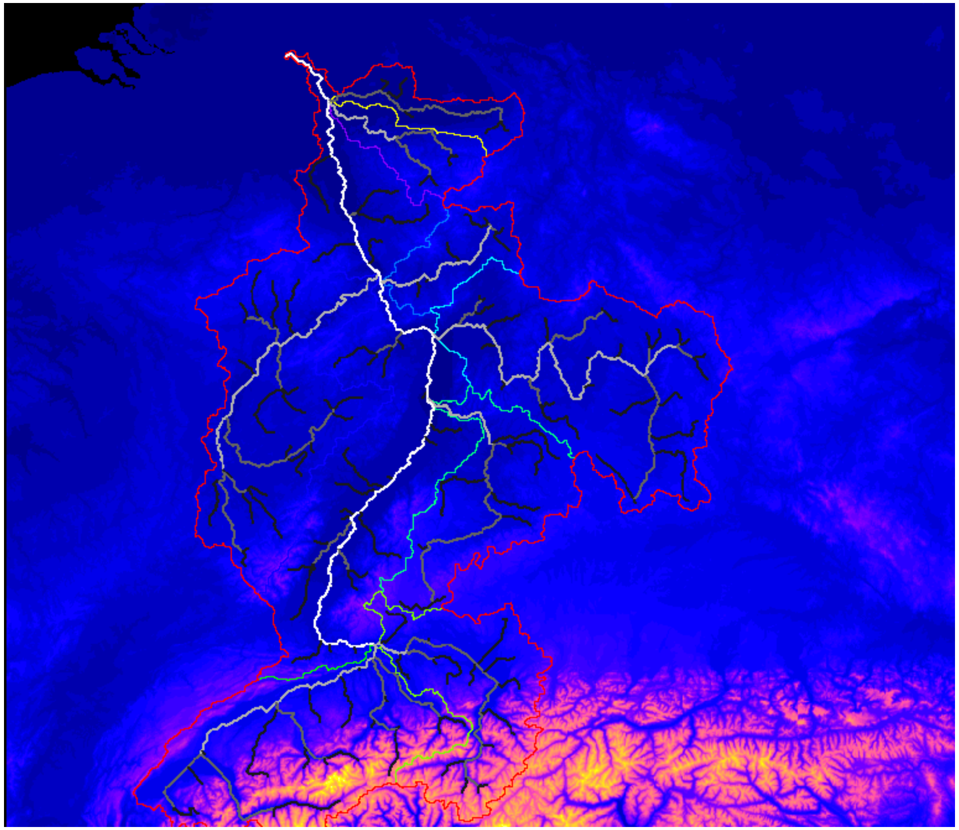
Elevation

- Hydrosheds

http://hydrosheds.cr.usgs.gov/dataavail.php

Usage:

- Slopes
- HAND
- Drain direction
- Catchment delineation

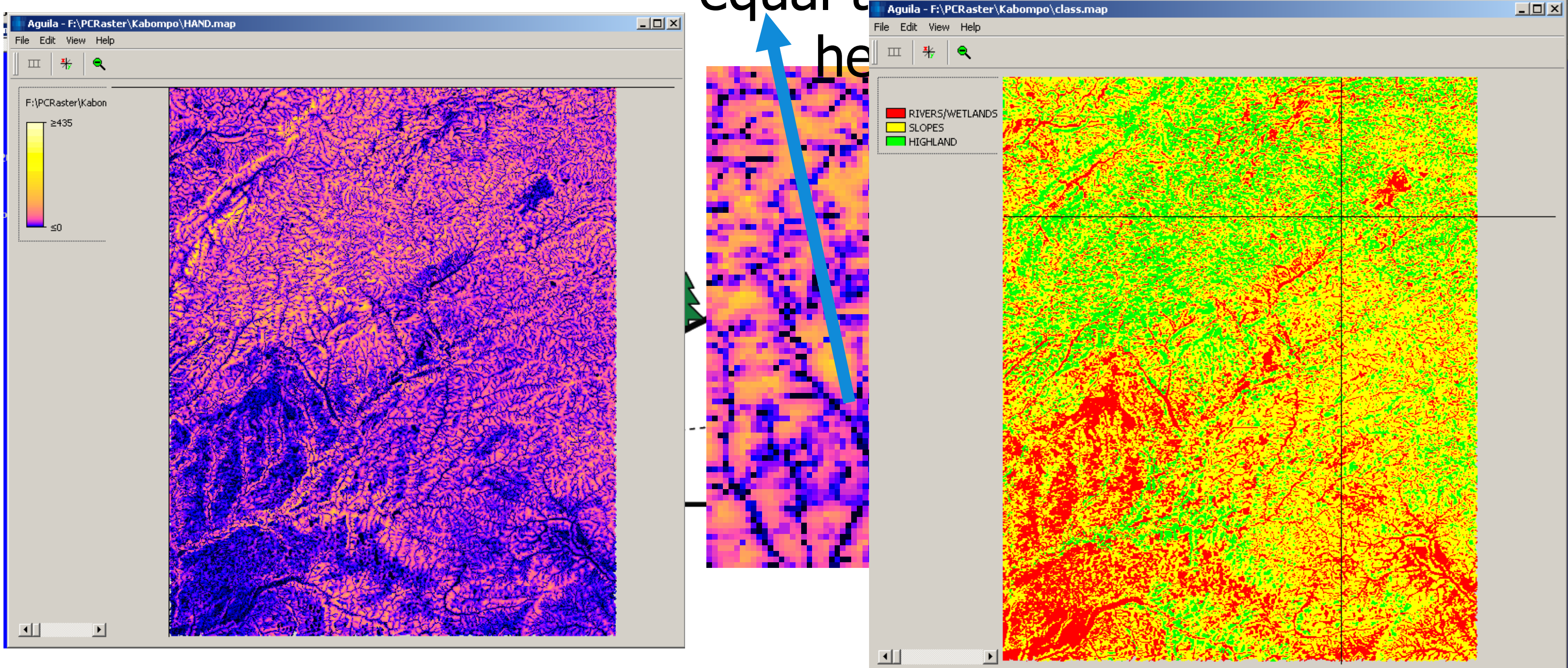


Data sources

HAND (Height Above Nearest Drain)

height almost equal to stream

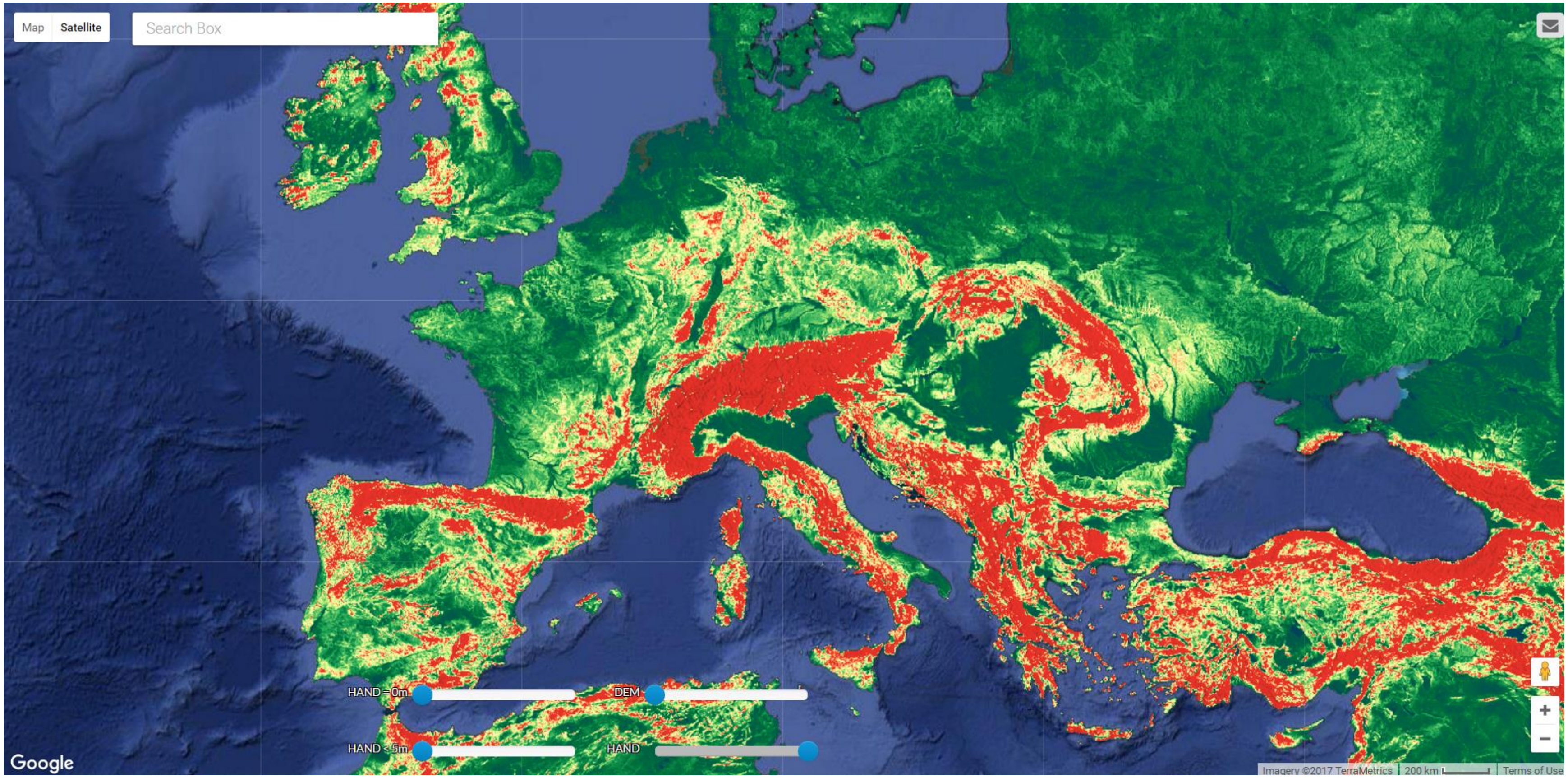
large height difference



Data sources

HAND (Height Above Nearest Drain)

http://global-hand.appspot.com/



Data sources

Rainfall

- Many rainfall products available
  - Eobs (0.25x0.25 º, daily, for Europe, KNMI data centre)

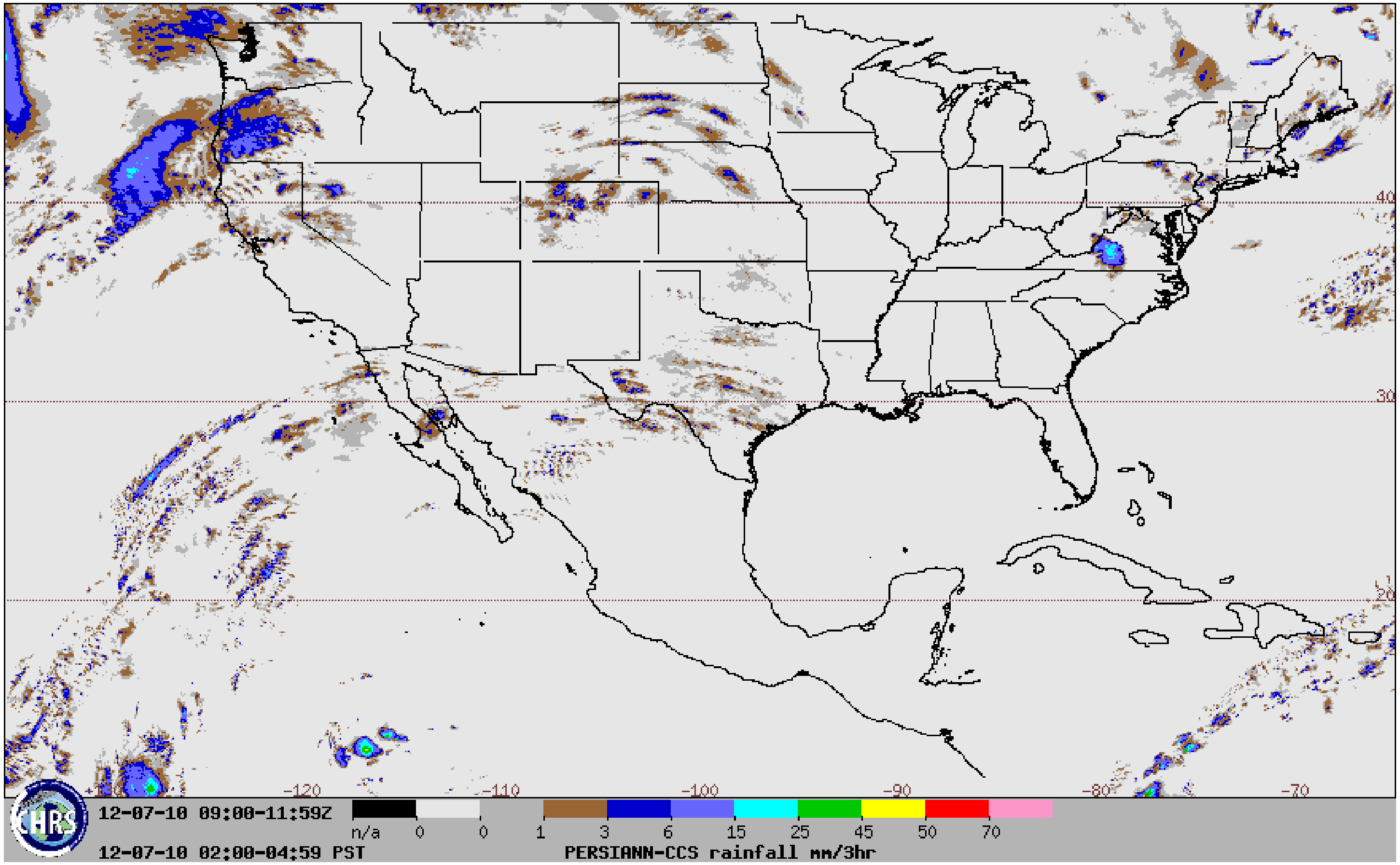
  http://www.ecad.eu/download/ensembles/ensembles.php
  - Tropical Rainfall Measuring Mission (TRMM, ~25x25 km, 3-hourly)

  http://pmm.nasa.gov/TRMM
  - GPM (since 2014)

  http://pmm.nasa.gov/data-access/downloads/gpm
  - GSMaP (~10x10 km, 1-hourly)
  - FEWS RFE 2.0 (10x10 km, daily)
  - PERSIANN CCS (4x4 km, 30-min**!!**)

Data sources

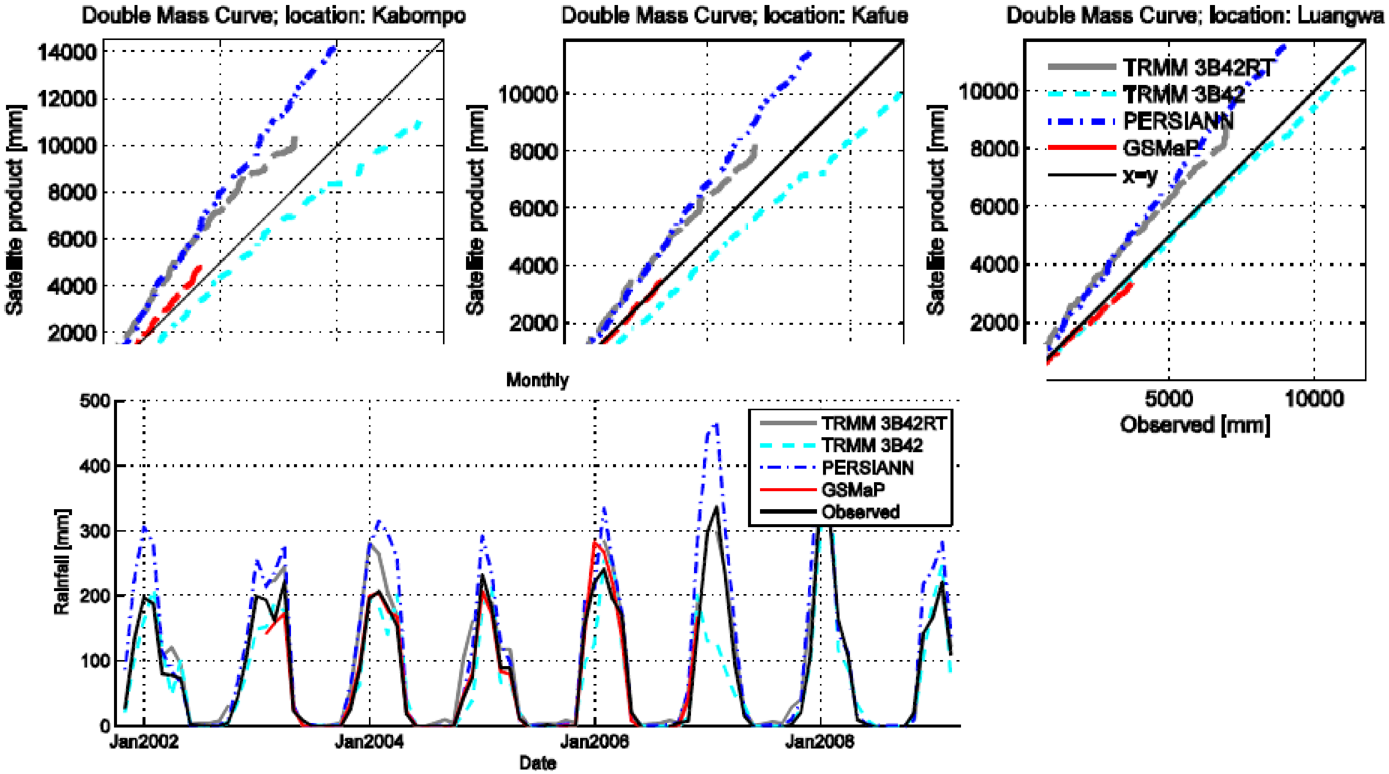
Rainfall



Data sources

Rainfall

Validation and bias-correction is often required!!



Data sources

Land cover

- Globcover

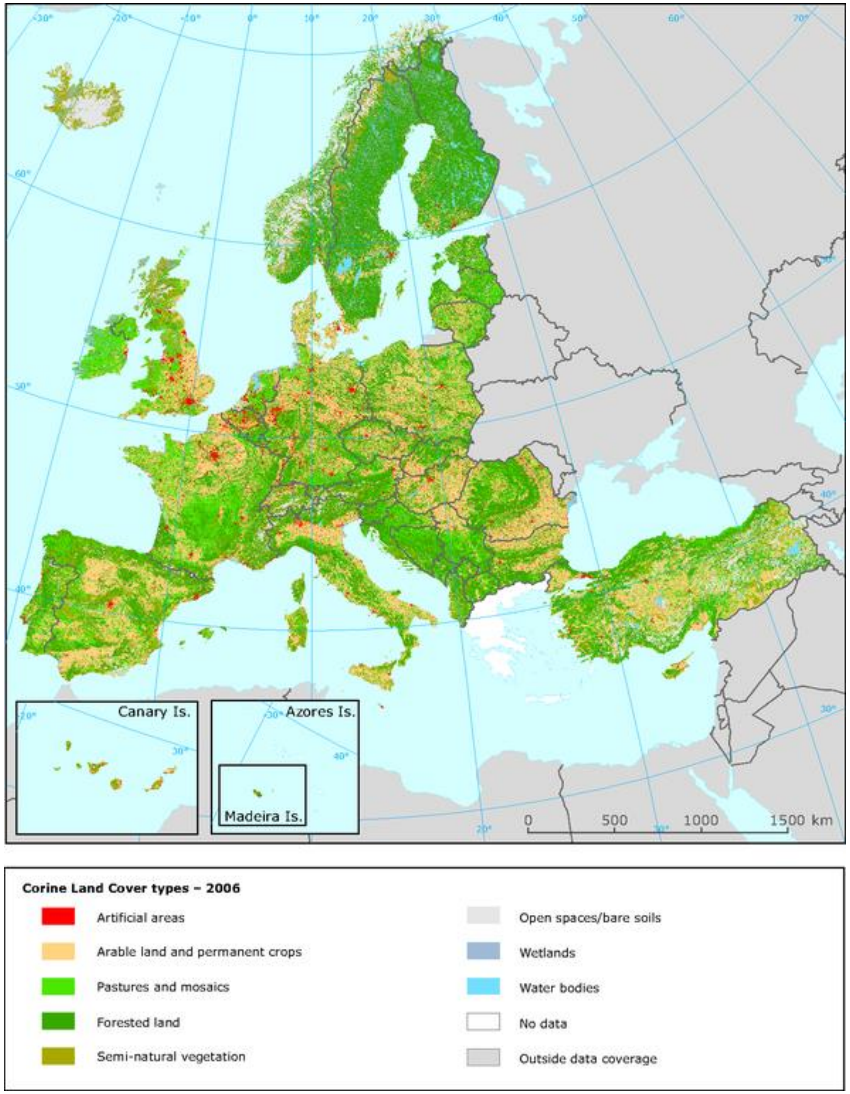
http://due.esrin.esa.int/page_globcover.php

- Corine

http://www.eea.europa.eu/data-and-maps/figures/corine-land-cover-types-2006

Usage:

- Delineation of response units
- Estimation of parameters



Data sources

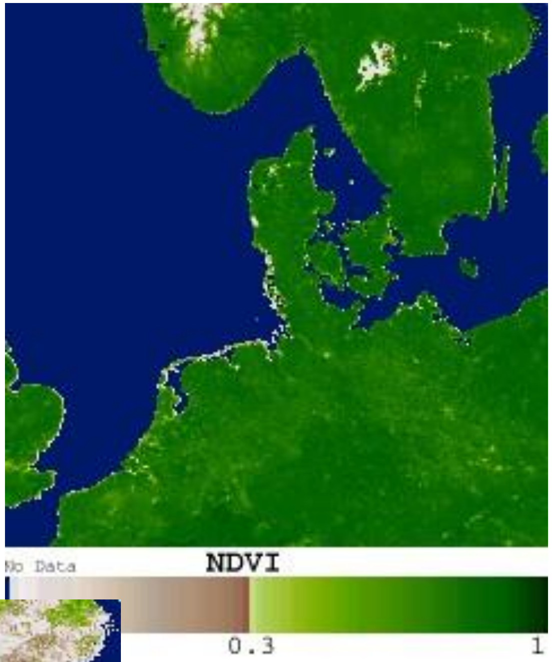
NDVI

- 'Greenness' of the area

http://e4ftl01.cr.usgs.gov/MOLT/MOD13A1.005/

Usage:

- Proxy for transpiration
- Constraining of model
- Delineation response units

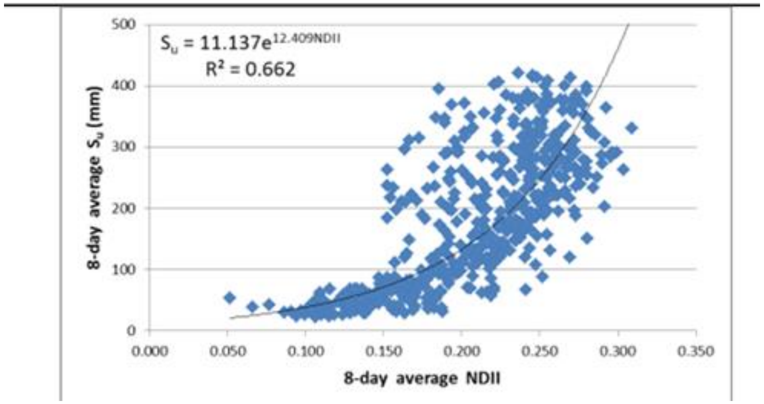


Data sources

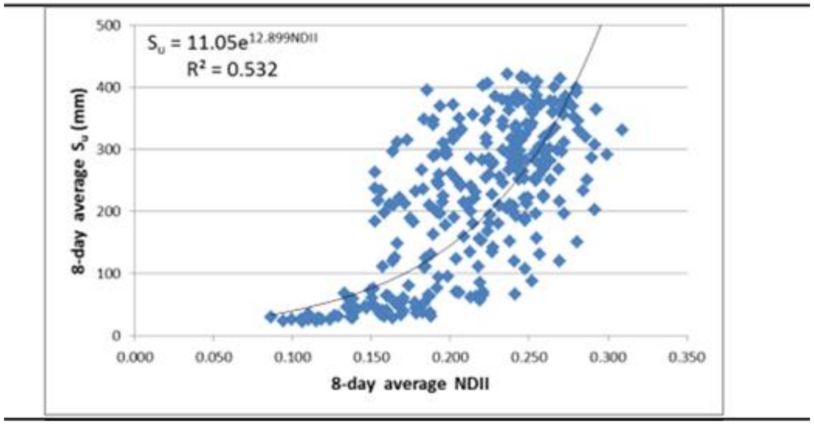
NDII

- Correlation with soil moisture

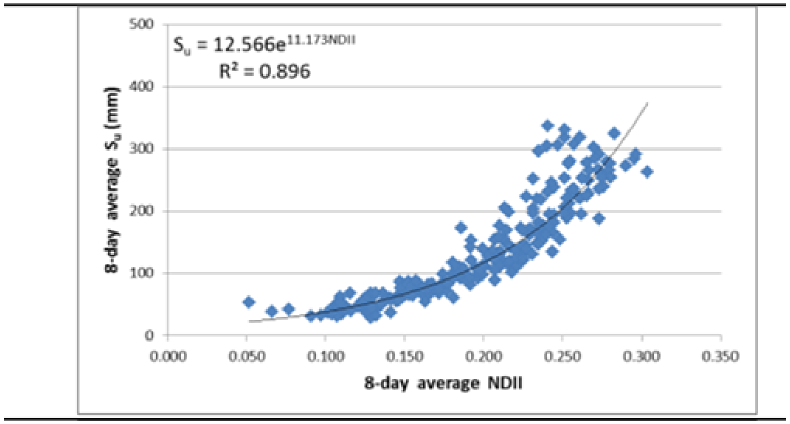
Annual



Wet Season



Dry Season



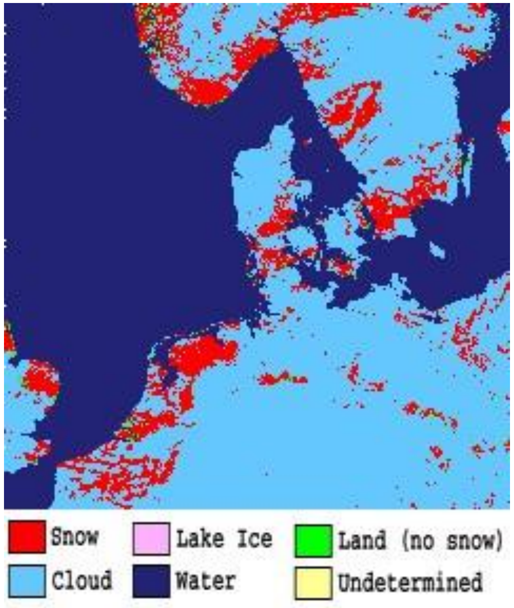
Sriwongsitanon, N., et al., HESSD, 2015.

Data sources

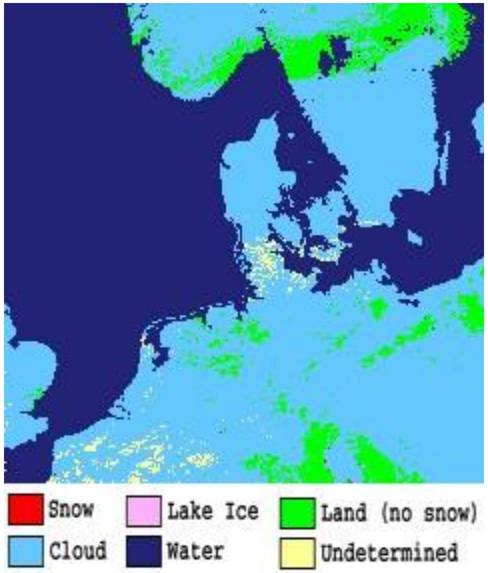
Snow products

- Modis snow

ftp://n5eil01u.ecs.nsidc.org/SAN/MOST/MOD10A1.005



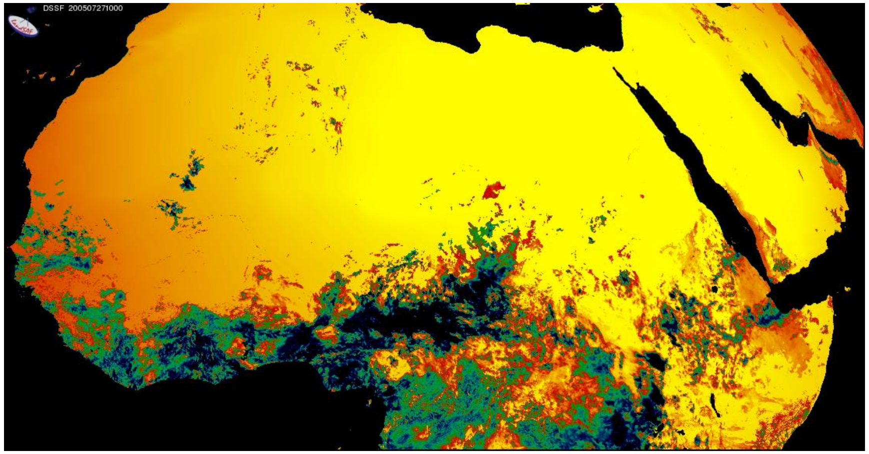
- Check for snow modelling



Data sources

Evaporation products

- Mod16 evaporation
- http://www.ntsg.umt.edu/project/mod16
- LSA-SAF evaporation
- https://landsaf.ipma.pt/;jsessionid=117534FA19A153B092CC5E1EBBCDF747
- GLEAM
- http://www.gleam.eu/#datasets
- SEBAL



- Forcing data
- Calibration data

Data sources

Searching for data…

- CUASHI

http://data.cuahsi.org/

- SWITCH-ON

http://tl-243.xtr.deltares.nl/byod/#/map

- GEOSS Portal

http://www.geoportal.org/web/guest/geo_home_stp

Data sources

How to use

- Provide input (e.g. rainfall, (potential) evaporation)
- Constrain model structures and parameterization
- Mitigating the 'equifinality problem' by incorporating the spatially distributed data in a performance criterium

Exercises

Literature exercise:
Write a review

HESS Opinions: The complementary merits of top-down and bottom-up modelling philosophies in hydrology

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Abstract. In hydrology, the two somewhat competing modelling philosophies of bottom-up and top-down approaches are the basis of most process-based models. Differing mostly (1) in their respective degree of detail in resolving the modelling domain and (2) in their respective degree of explicitly treating conservation laws, these two philosophies suffer from similar limitations. Nevertheless, a better understanding of their respective basis (i.e. micro-scale vs. macro-scale) as well as their respective short comings bears the potential of identifying the complementary value of the two philosophies for improving our models. In this manuscript we analyse several frequently communicated beliefs and assumptions to identify, discuss and emphasize the functional similarity of the two modelling philosophies. We argue that deficiencies in model applications largely do not depend on the modelling philosophy but rather on the way a model is implemented. Based on the premises that top-down models can be implemented at any desired degree of detail and that any type of model remains to some degree conceptual we argue that a convergence of the two modelling strategies may hold some value for progressing the development of hydrological models.