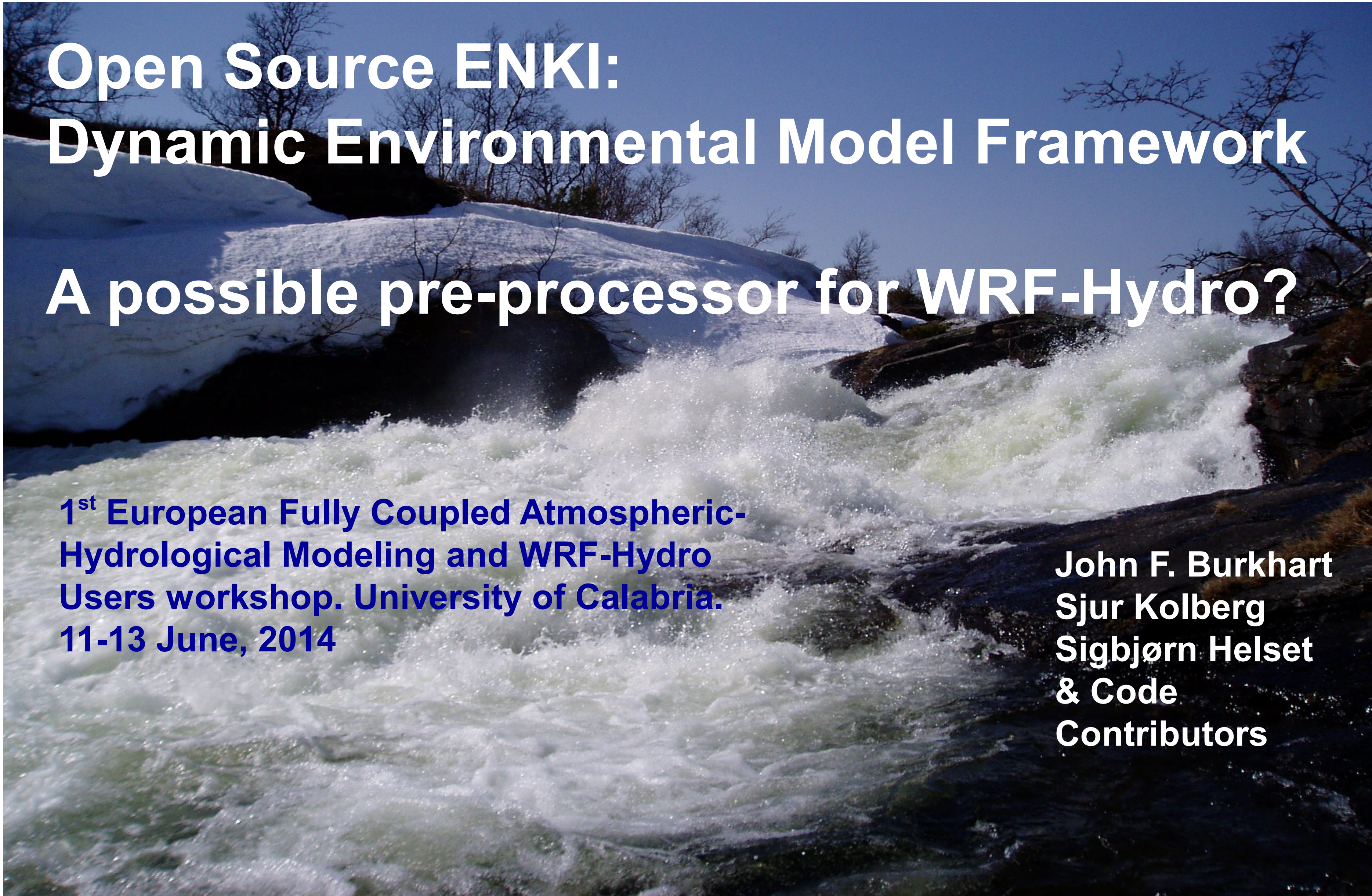


Open Source ENKI: Dynamic Environmental Model Framework

A possible pre-processor for WRF-Hydro?

1st European Fully Coupled Atmospheric-Hydrological Modeling and WRF-Hydro Users workshop. University of Calabria.
11-13 June, 2014

John F. Burkhart
Sjur Kolberg
Sigbjørn Helset
& Code Contributors

Overview

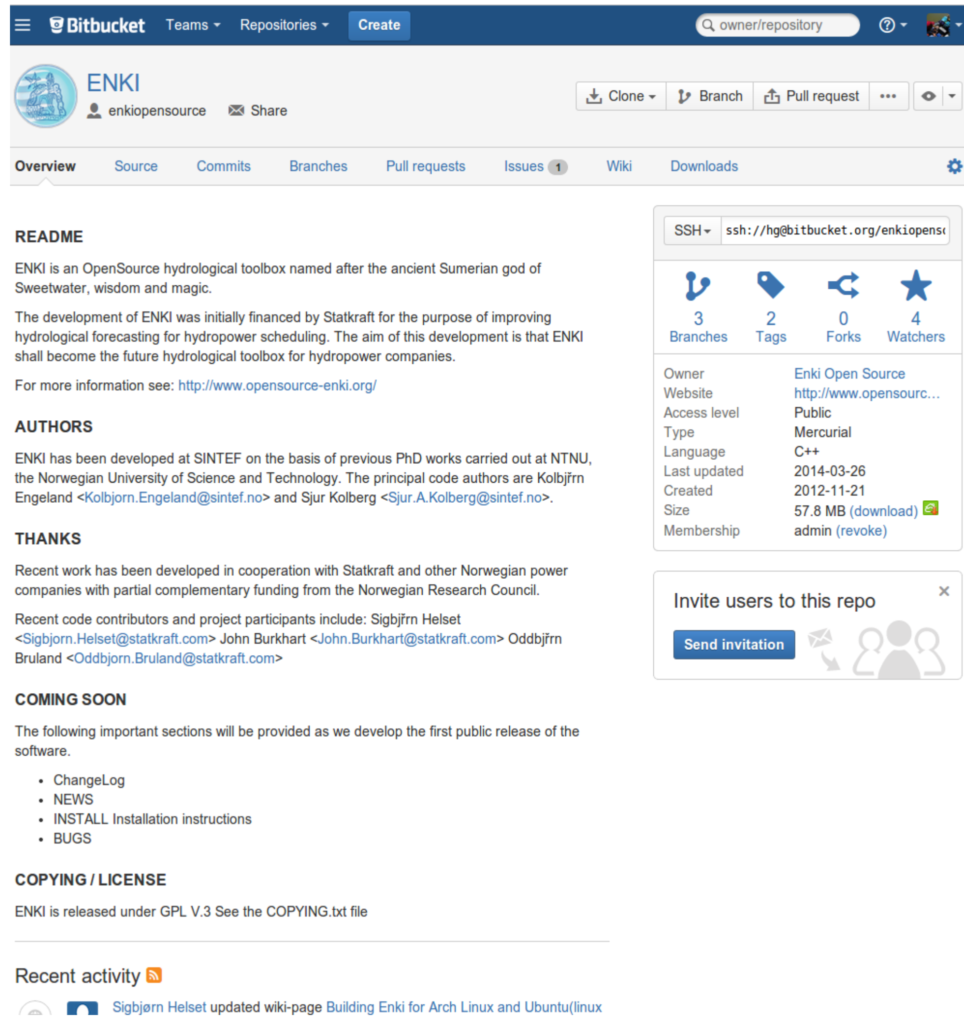
- Energy Management in practice
- Overview of the ENKI Hydrologic Modeling Framework
- ENKI as a prototyping framework for WRF-Hydro

What is ENKI?

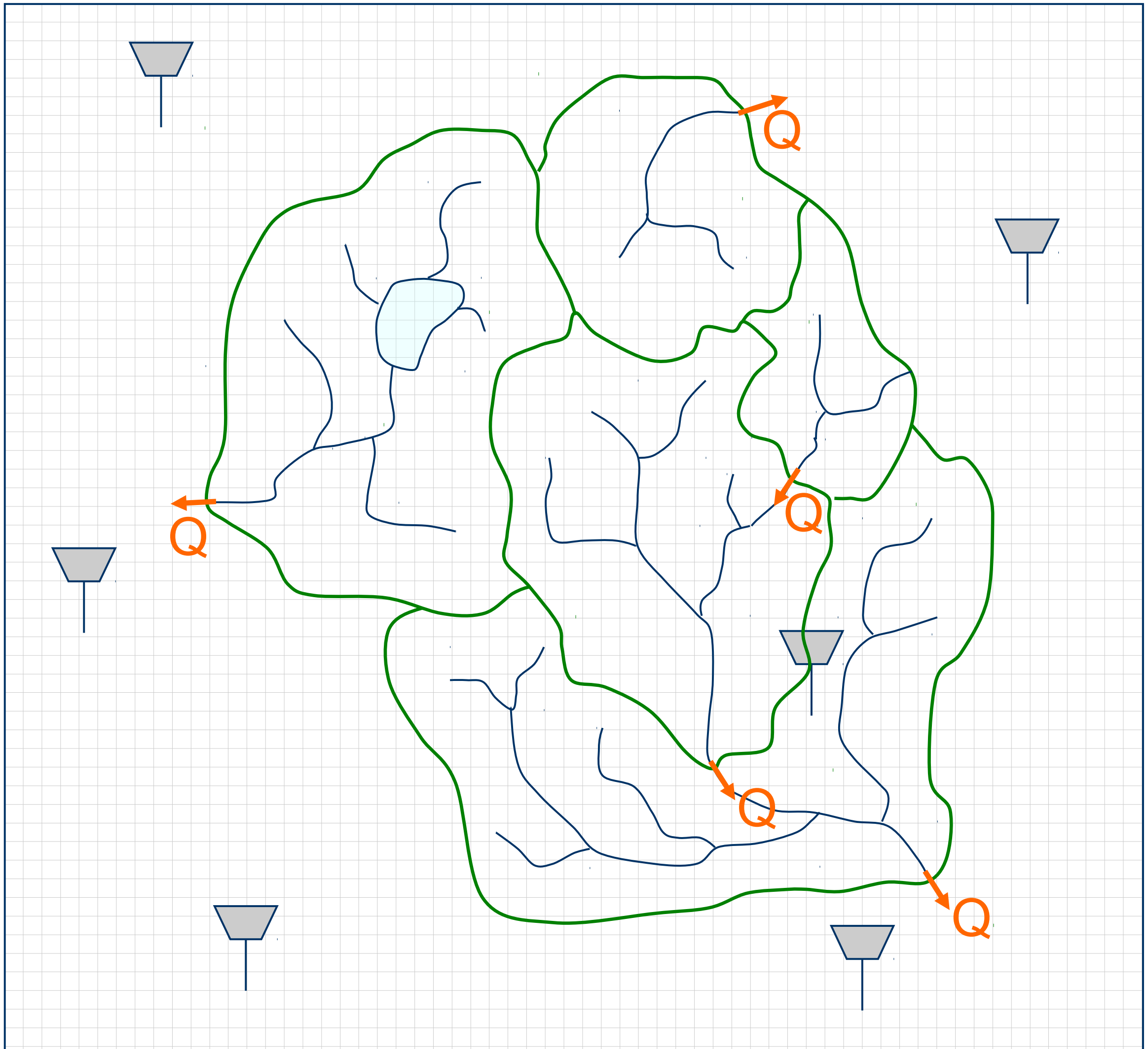
- Software framework for model building and evaluation
- Extension and re-writing of PINE (Rinde, 1994-97), financed by Statkraft
- Simulation of temporal processes in spatial variables
- Primary application: Distributed hydrologic models
- Now: Open Source project under operationalisation
- Sumerian deity for sweet water, wisdom and magic

The Hydrologic Modeling Framework: ENKI

- Main objects are the **model** and the **region**
- A **region** is a set of static and dynamic GIS data
- A **model** is an ordered set of subroutines
- The subroutine variables are linked to the region's GIS data.
- It's Open Source and easily available (bitbucket)
- Linux and Python Porting are underway!

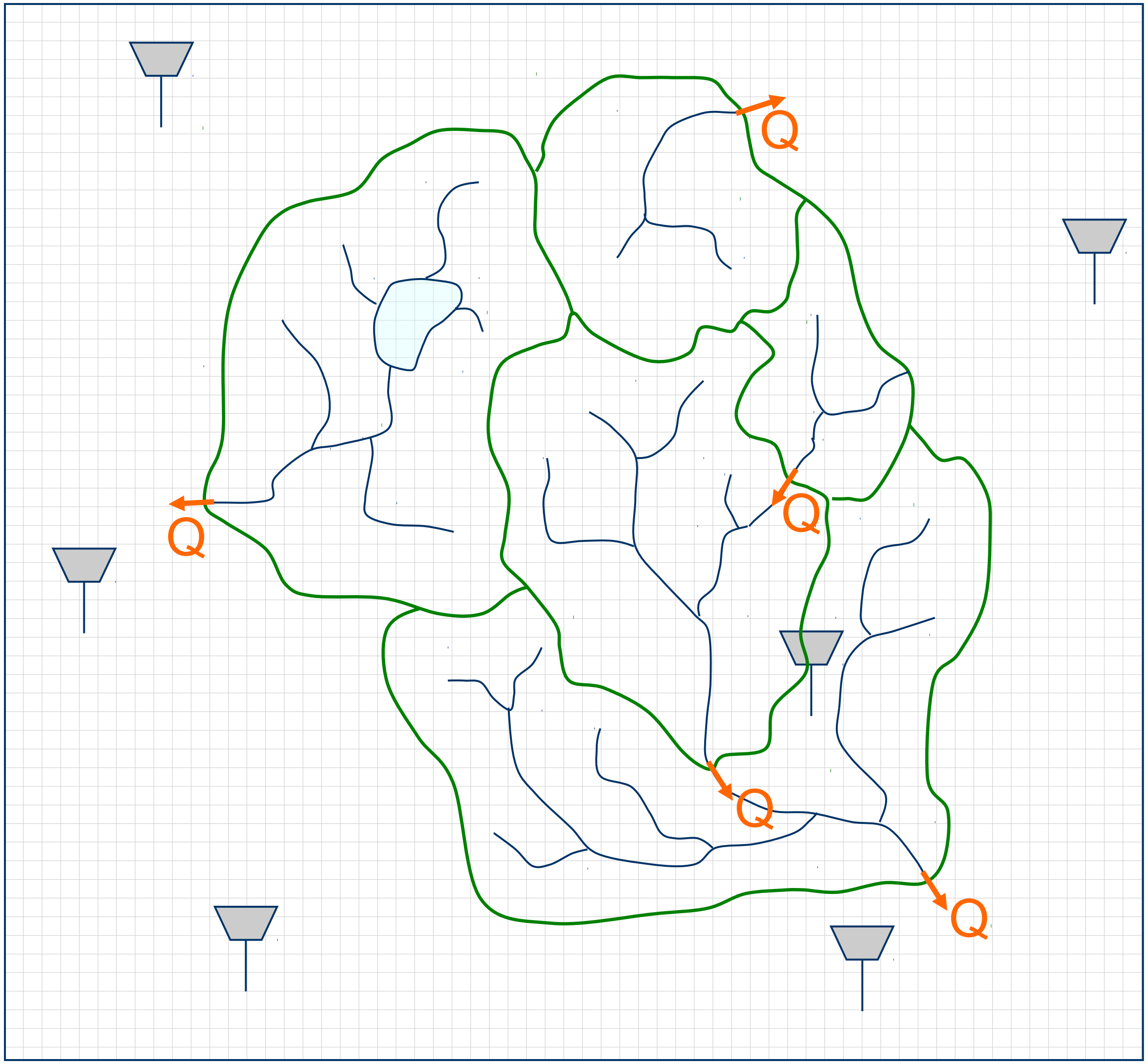


Distributed models and regional simulation



- One regional ENKI setup replaces many HBV models
- Common setup of input data using GIS tools
- Easy input of:
  - Weather radar
  - Satellite data
  - Gridded met forecasts.
- The catchment is no longer the primary unit for
  - Simulation
  - Calibration

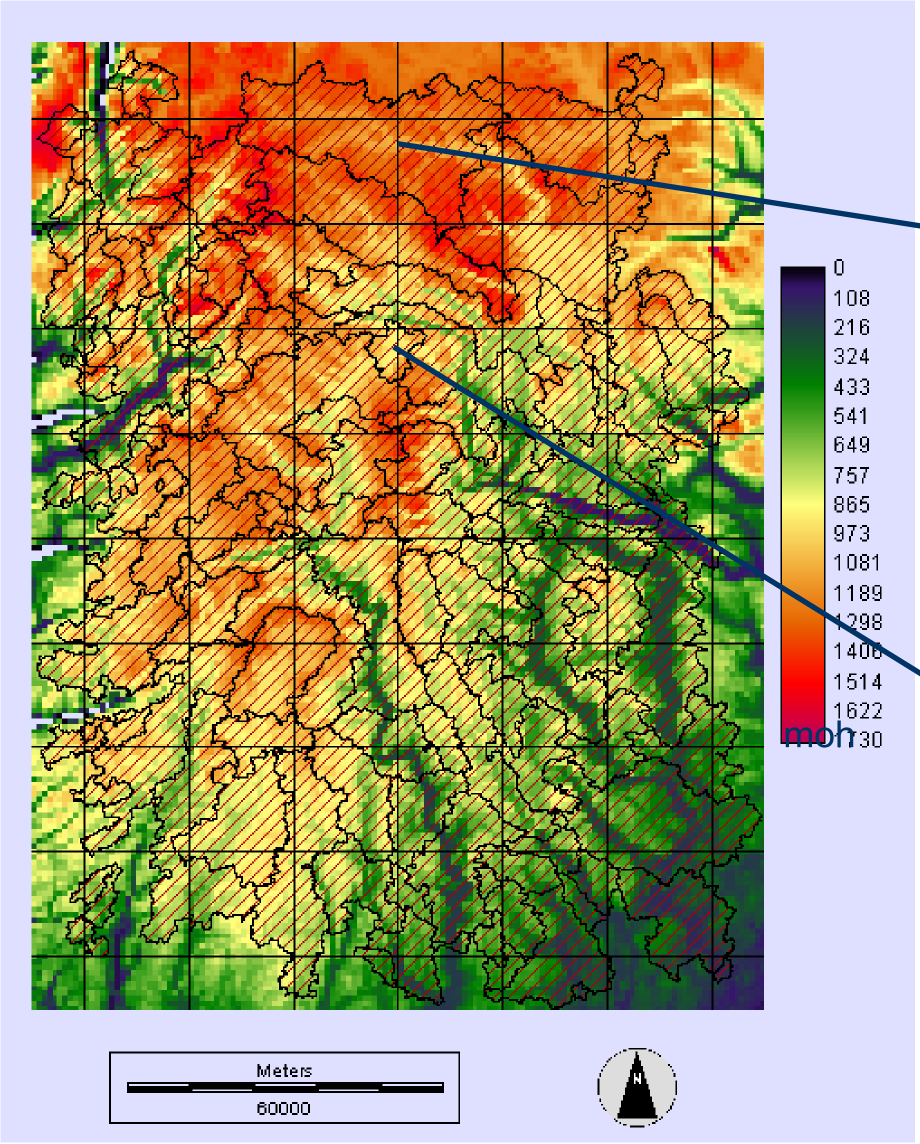
Distributed models

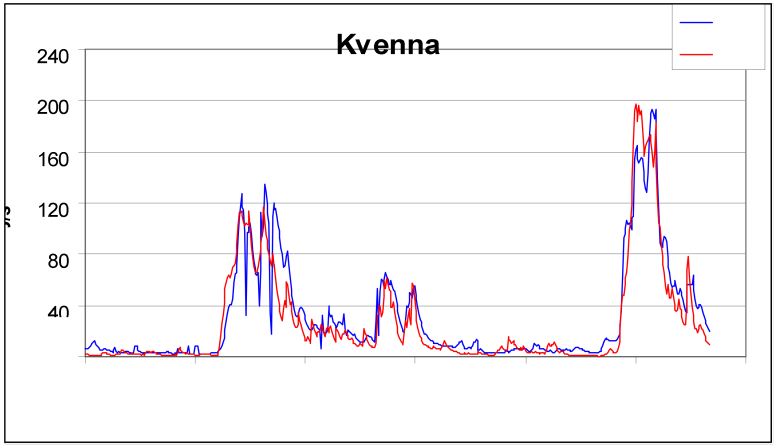


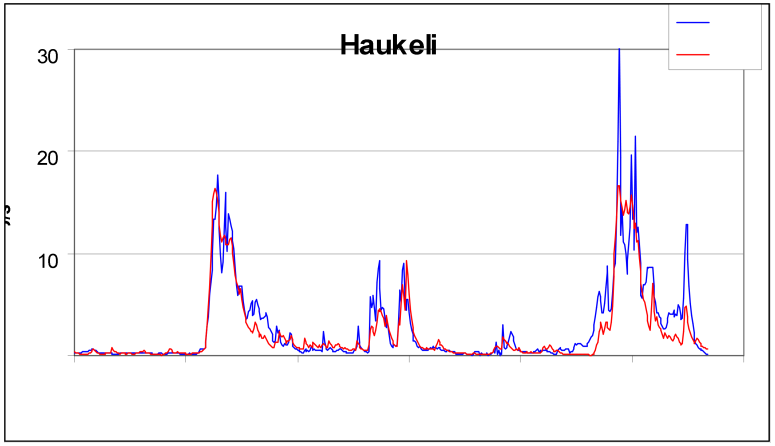
- Strong input gradients in mountainous basins
- Nonlinear processes
- Models need to be
  - More physical
  - Less calibrated
  - …but simpler

- Fewer states*
- Fewer parameters*
- Regional calibration
- Spatial parameter maps only where data allow

Regional simulation and calibration

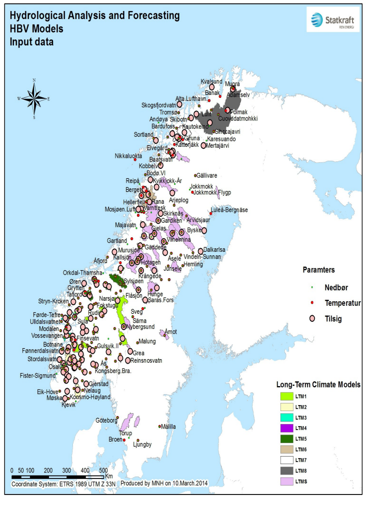




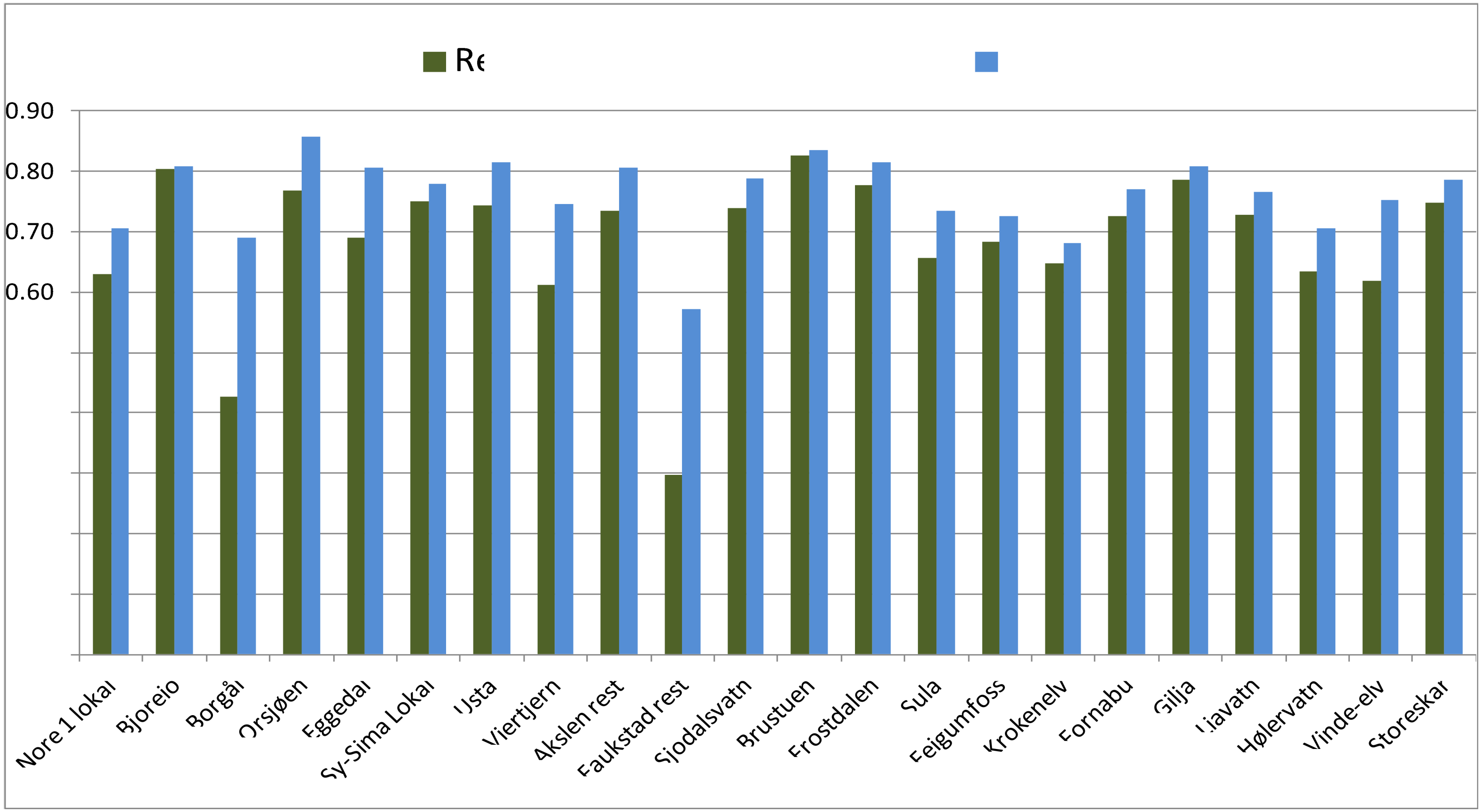


Why regional calibration?

- In a distributed model, the parameters are applied to a different spatial unit than they can be inferred from.
- Operative management: Simulate arbitrary areas / catchments
  - Compared to area scaling of discharge, differences in meteorology, elevation and land use are honoured
  - In a regional model, the performance in gauged catchments is an estimator of the perfomance in the ungauged catchments
- Calibration: Robust parameter estimates
  - By fitting several series simultaneously, the effect of errors and peculiarities in single catchments or series is reduced.
- Development: Discovery of errors and biases in model or data
  - Adaptation to poor observation series is avoided
  - Bad assumptions or data are exposed as errors
- **But:** Regional calibration always gives weaker performance in single catchments than specific calibration



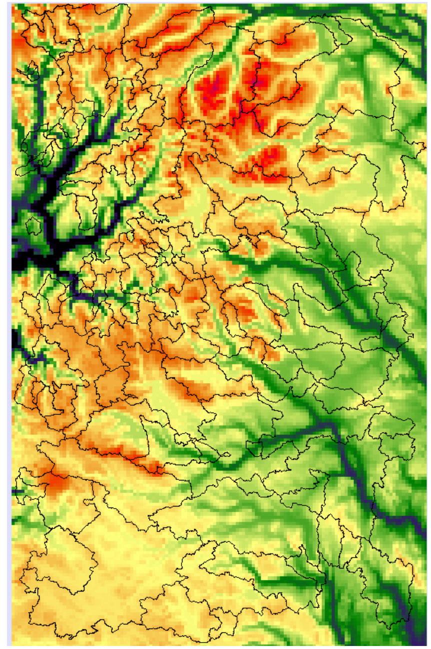
Regional and local R2

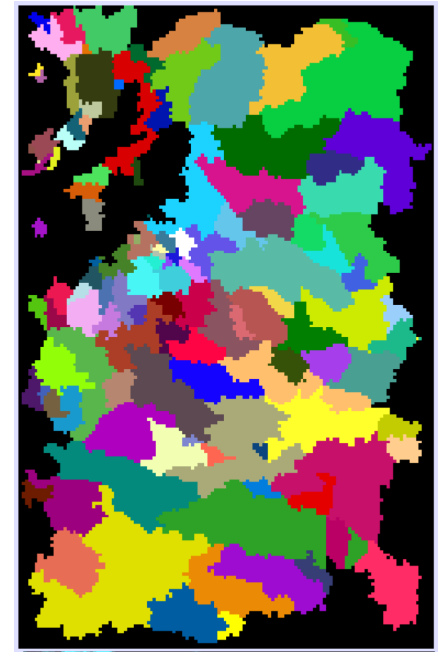


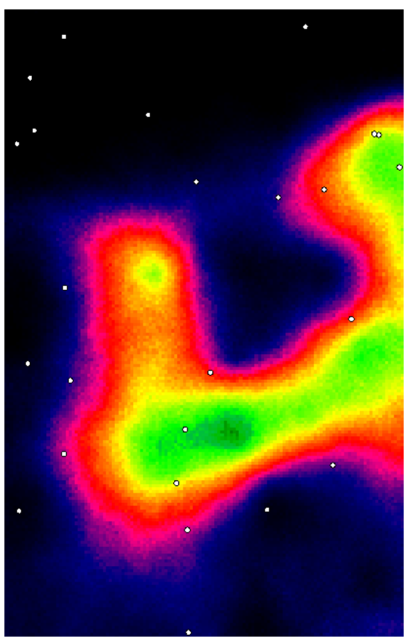
Average best R2	Regional	Local
Gridded HBV	0.679	0.741
2-par Kirchner	0.684	0.752

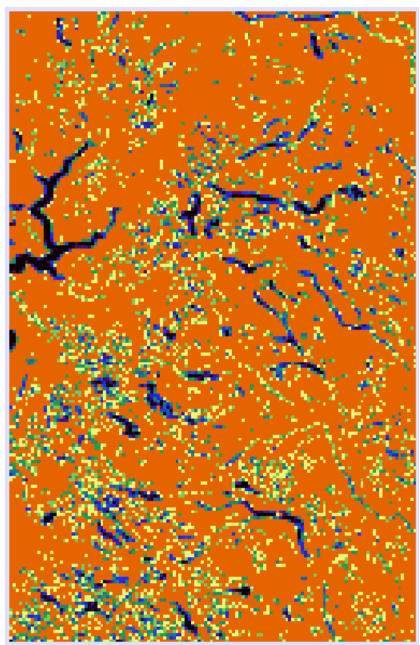
GIS based model setup:

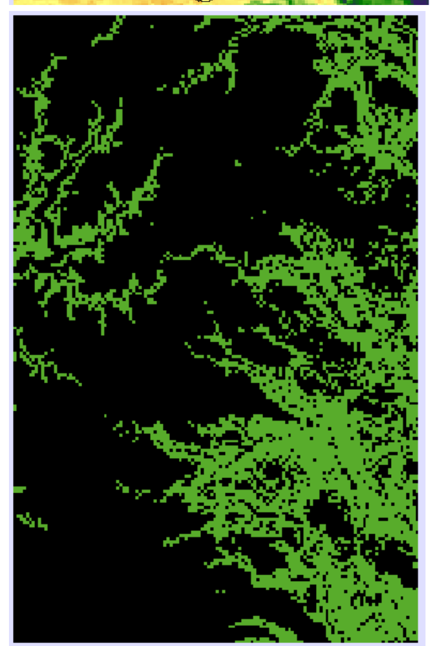
- Elevation map (DTM)
- Subcatchment delination
- Meteorological station map
- Lake percentage map
- Forest cover map
- Glacier cover map

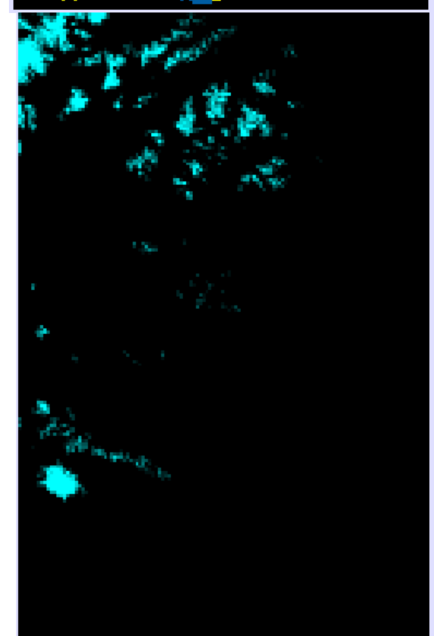






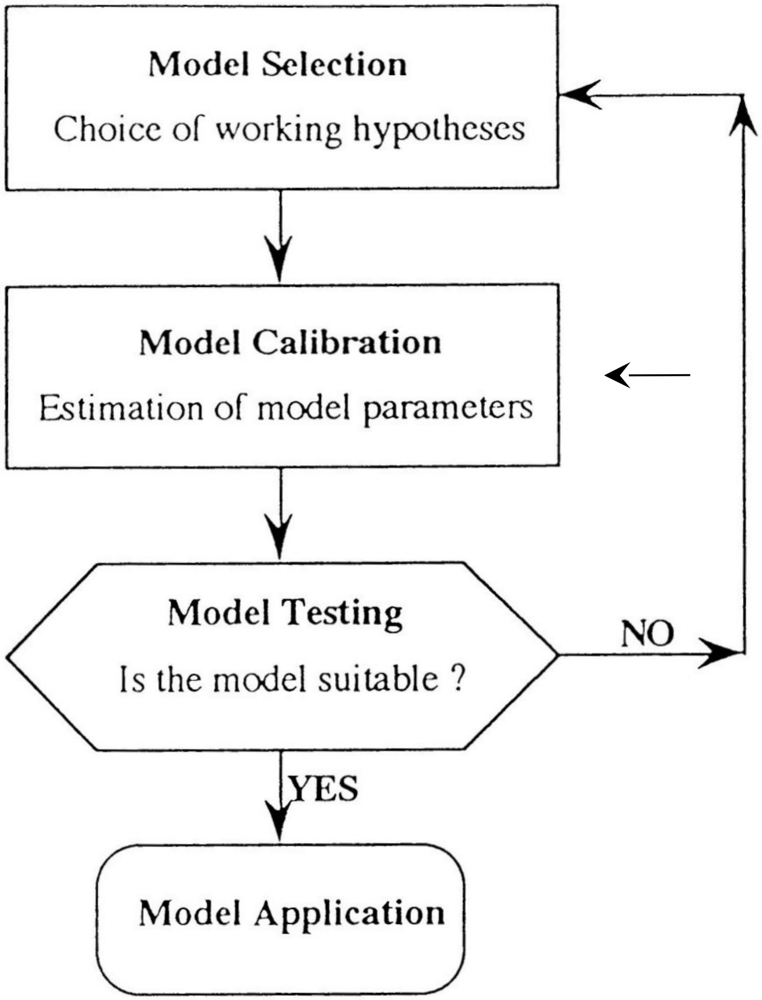






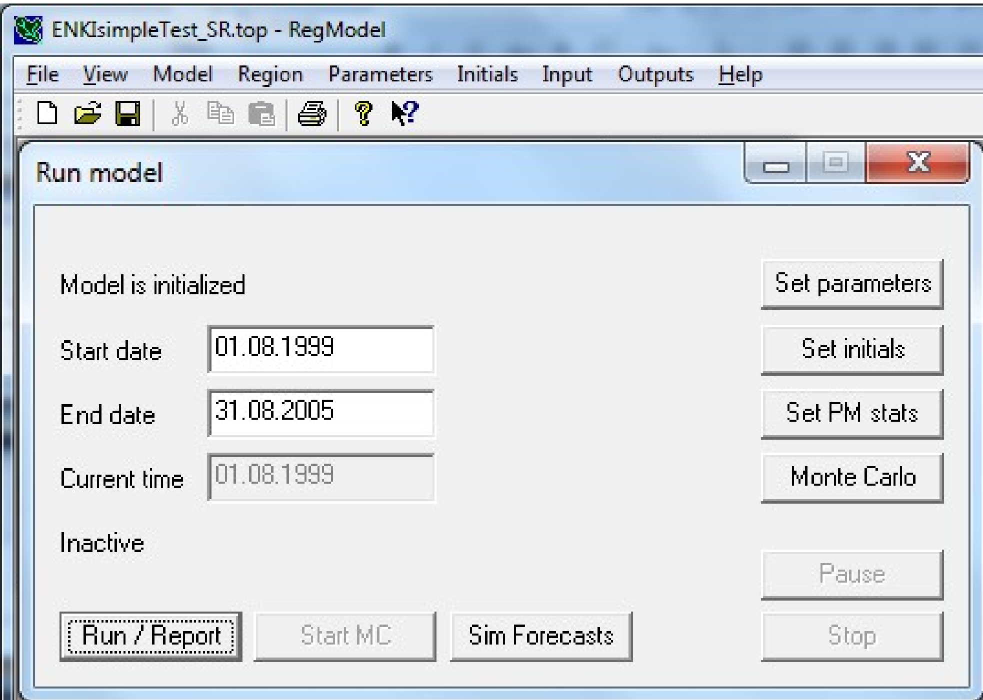
Procedure for model evaluation

- Selection:
  - Operational needs
  - Dominant processes
  - Available data
- Validation
  - Required performance
  - Achievable performance
  - Physical correctness?
- *«All models are wrong. Some, however, are useful» (Box, 1979)*
- *«A model should not only work well, but work for the right reasons» (Klemes, 1986)*

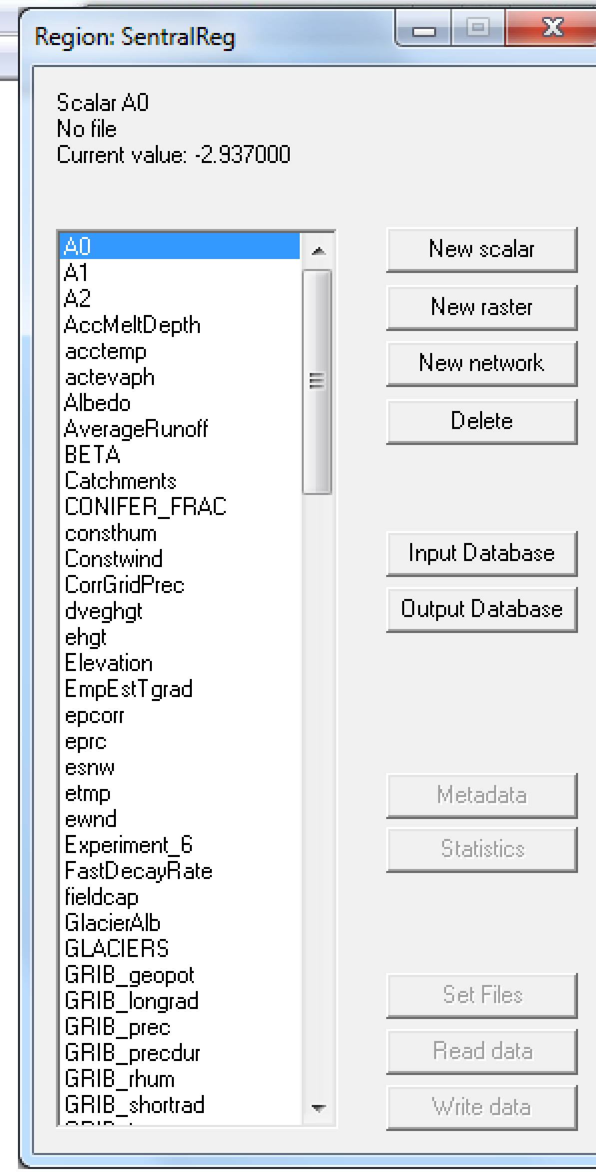


ENKI's three modes of operation

- **Model use or evaluation**: Interactive simulation, parameter estimation, import/export of GIS or TS data, construction of evaluation criteria etc.
  - No need to know the routines or internal variables in the model
- **Model building**: Link process methods to a complete model, manipulate spatial distribution
  - No need to code or compile
- **Routine development:** Implement new process routines
  - No need to handle user interface, data I/O, administration of model runs, calibration routines etc.



Model dialog



Region dialog

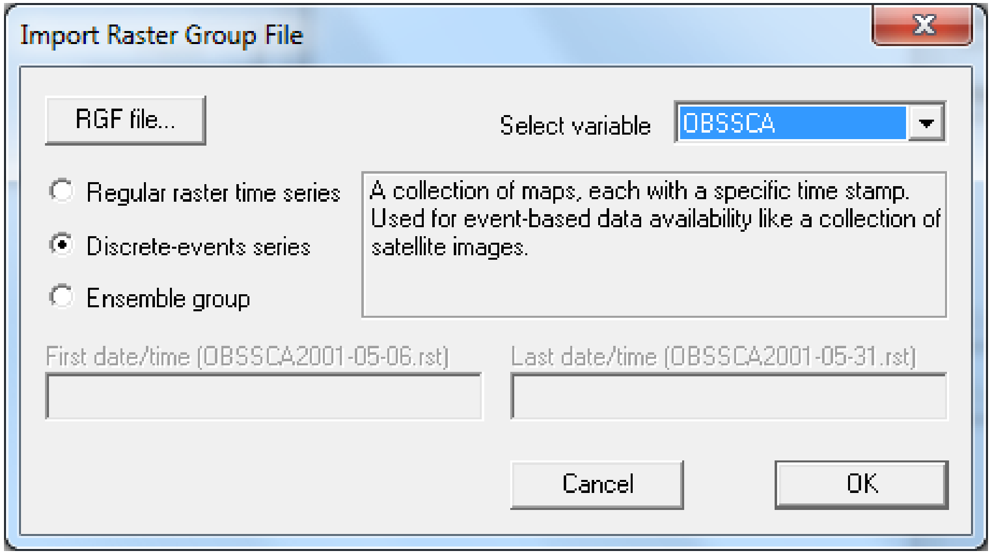
The ENKI framework

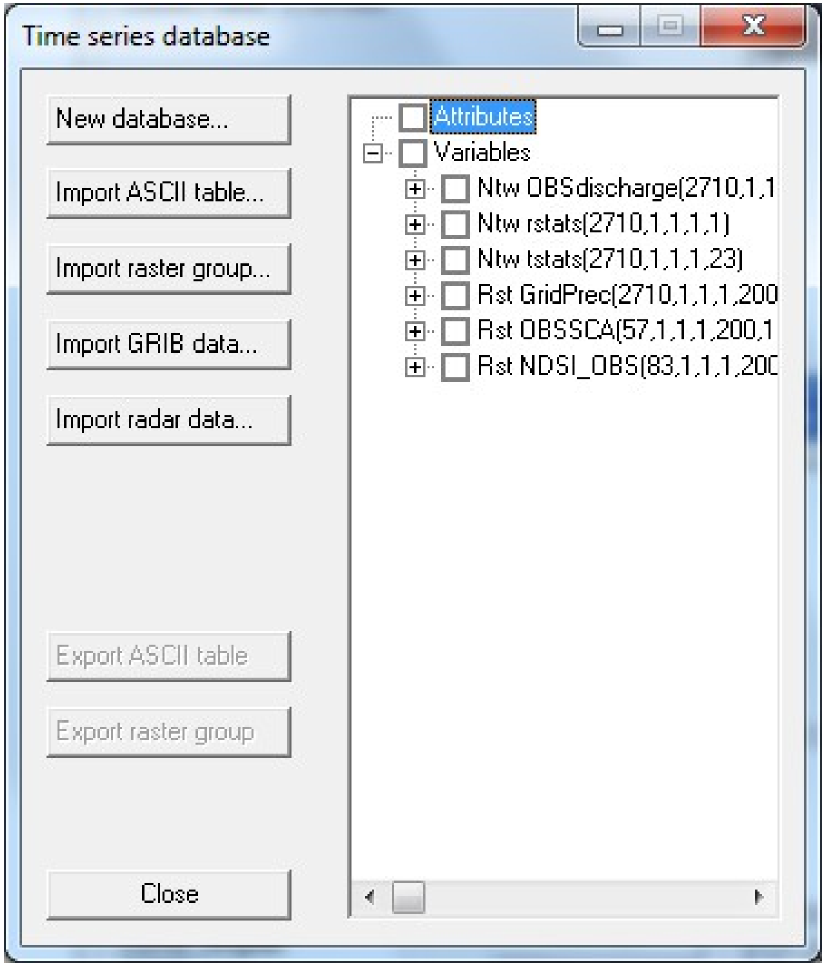
- Main objects are the **model** and the **region**
- A **region** is a set of static and dynamic GIS data
- A **model** is an ordered set of subroutines
- The subroutine variables are linked to the region's GIS data.

Ready NUM

Time series import

- Time series database uses NetCDF
- Discrete time series from ASCII files
- Raster time series from map groups
- GRIB and radar file import/reproj.

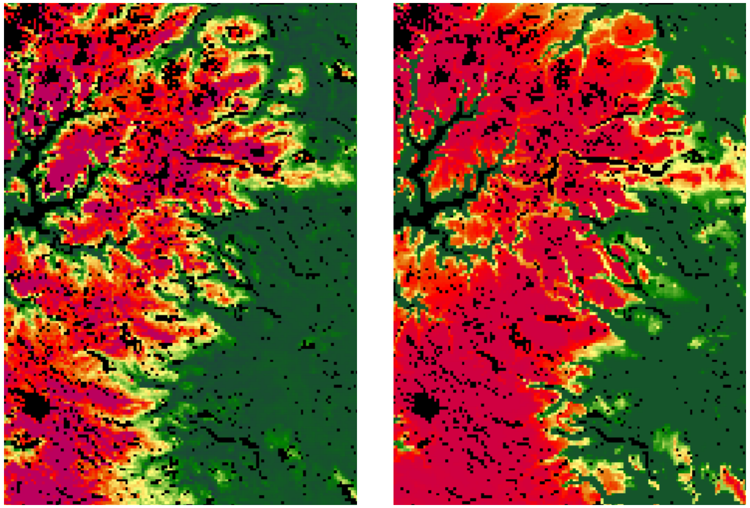




Assessing performance

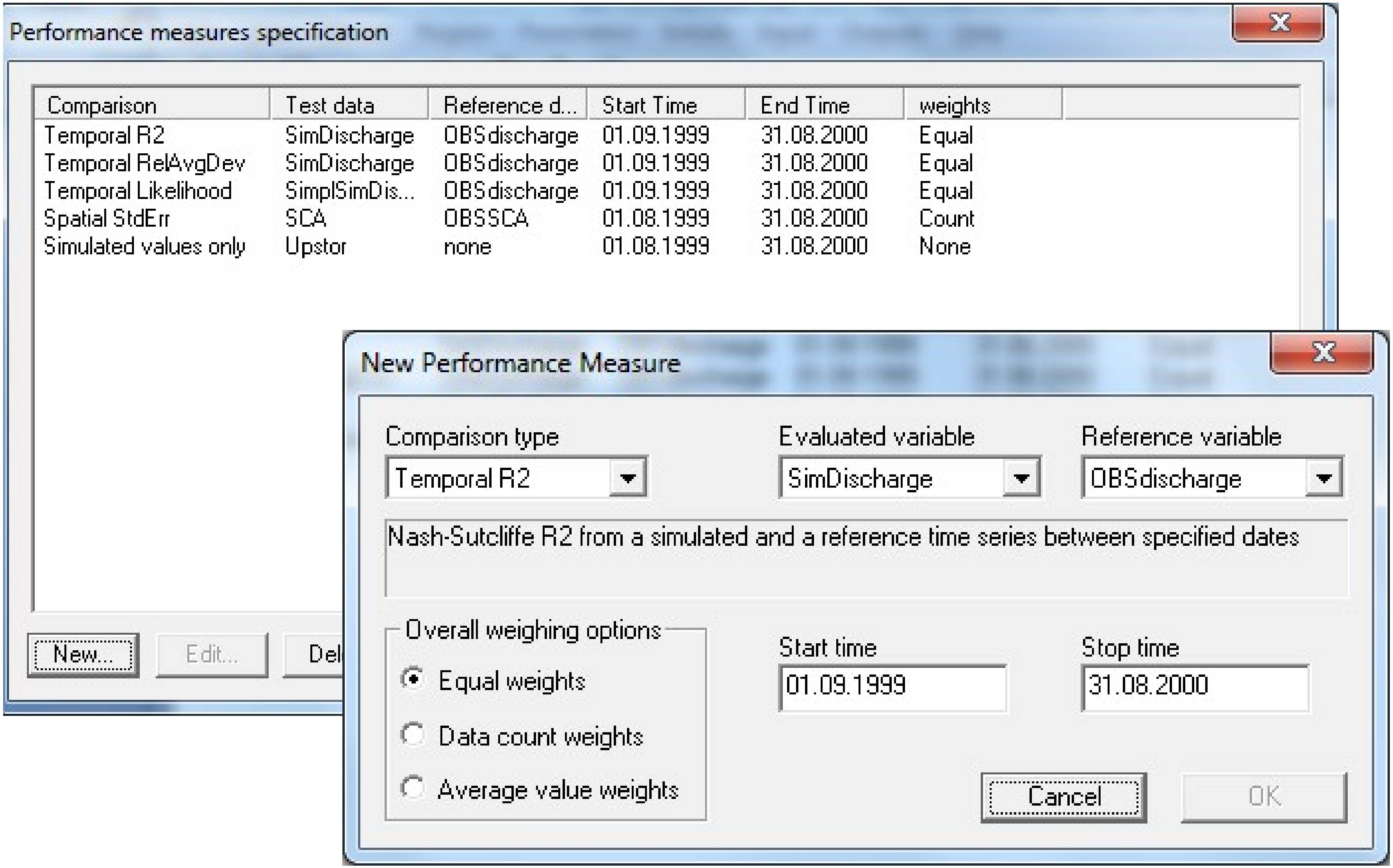
- Any simulated variable is available for evaluation
- Evaluation may be temporal or spatial
- A large number of objective functions are available:
  - Additive: Information strength independent of nobs.
  - Multiplicative (likelihood): Strength increases with nobs.

Temporal evaluation

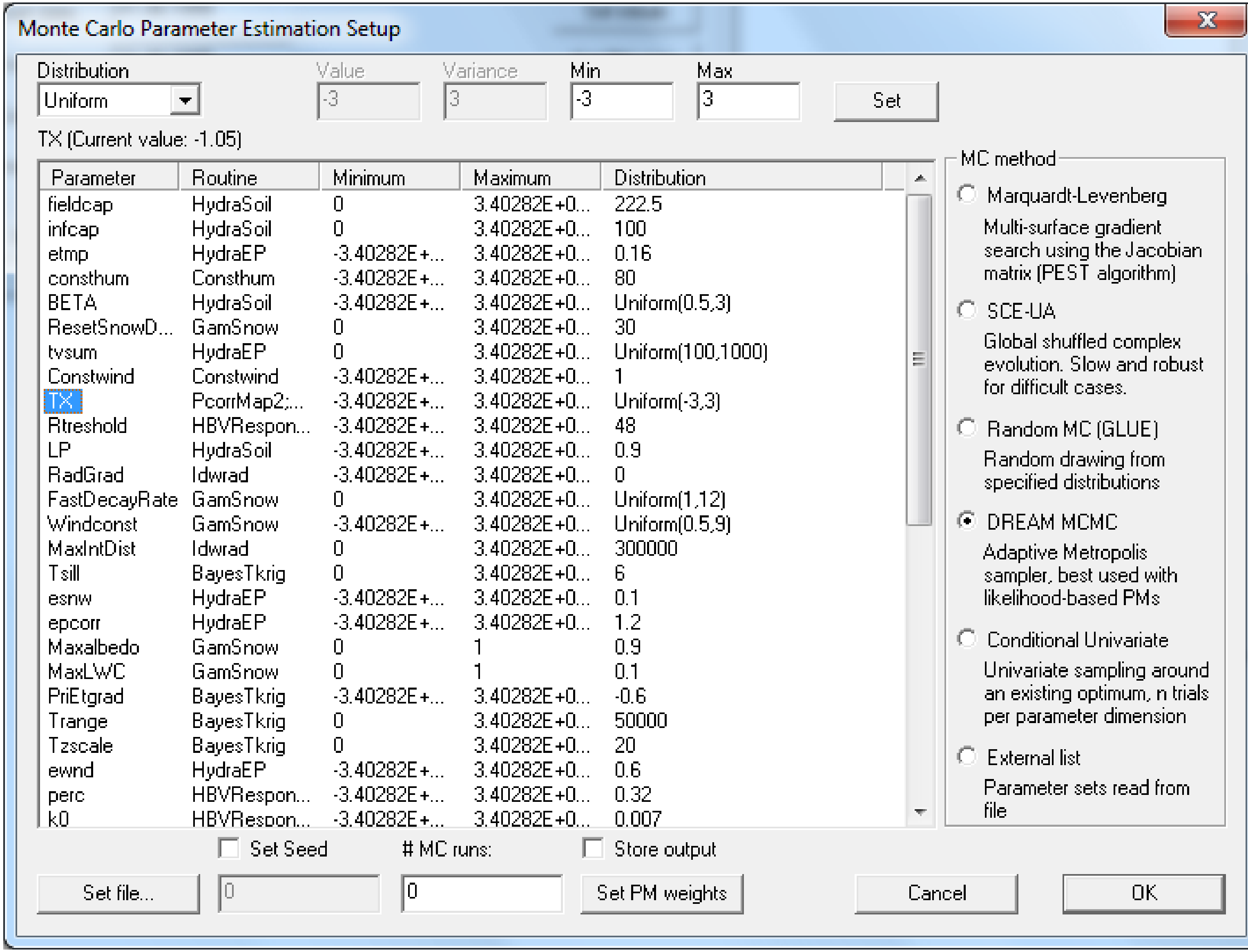


Spatial evaluation

Performance Measure specification



Parameter estimation



A typical model setup

- The model framework does not know the function of each routine
- Each time step, the framework calls the routines in specified order
- Each routine maintains the spatial repetition loop
- The routines operate on spatial variables owned by the region
- The region copies data from/to two time series databases before and after each time step

Interpolation | Interpolation | Interpolation

Snow routine

Soil water / evaporation

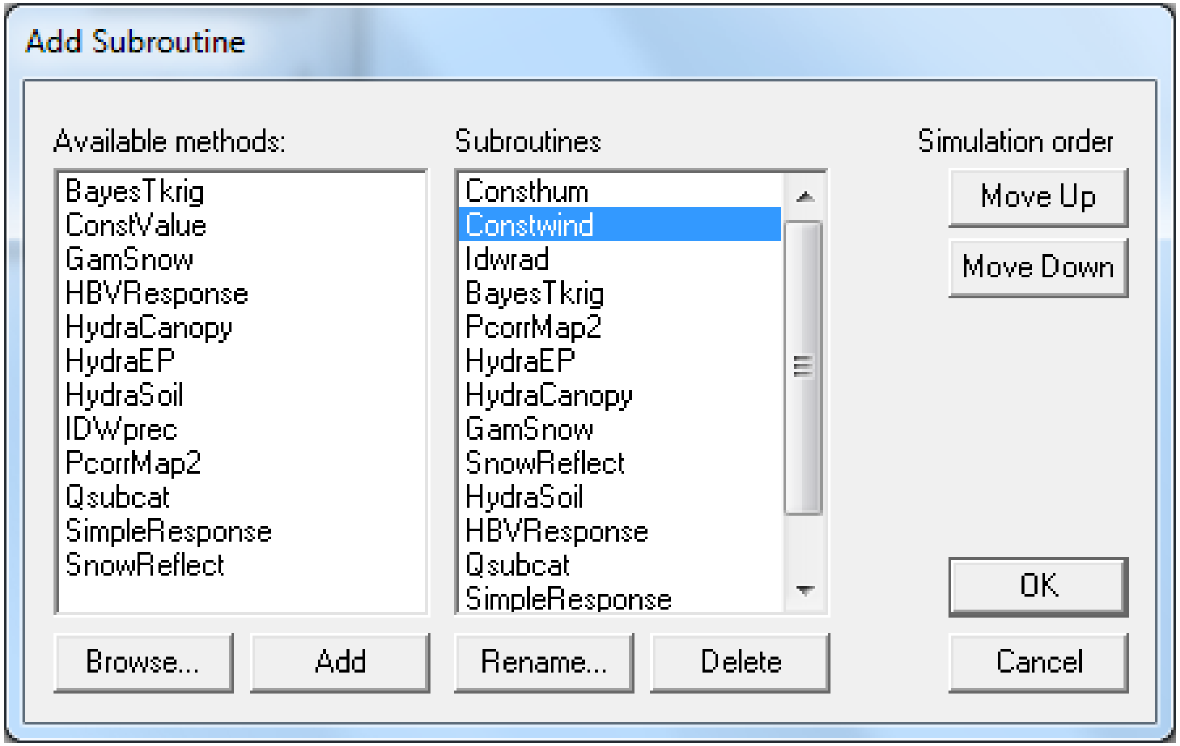
Response

Catchment aggregation

Channel routing

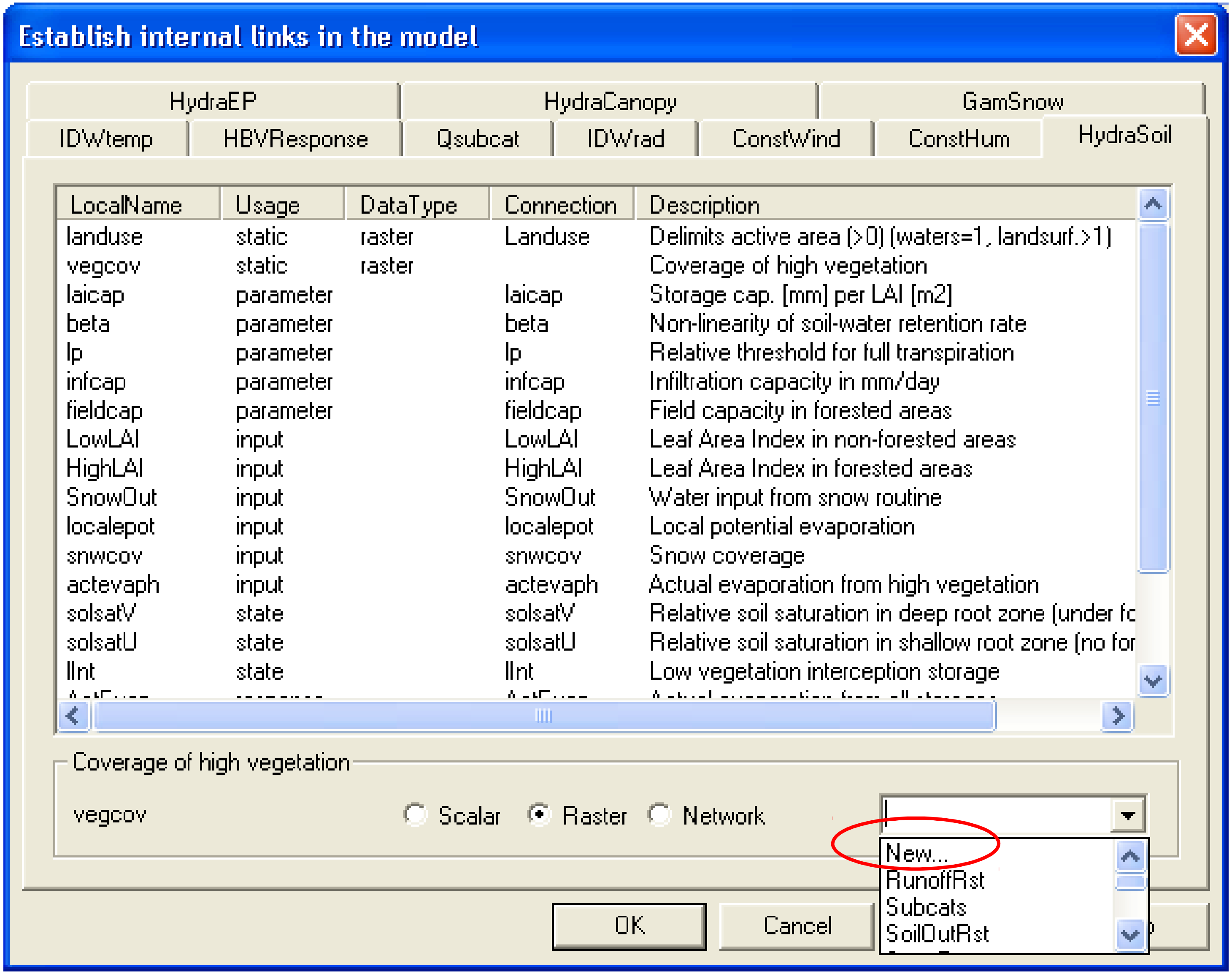
Results / Evaluation

Model building 1: Routine composition and order



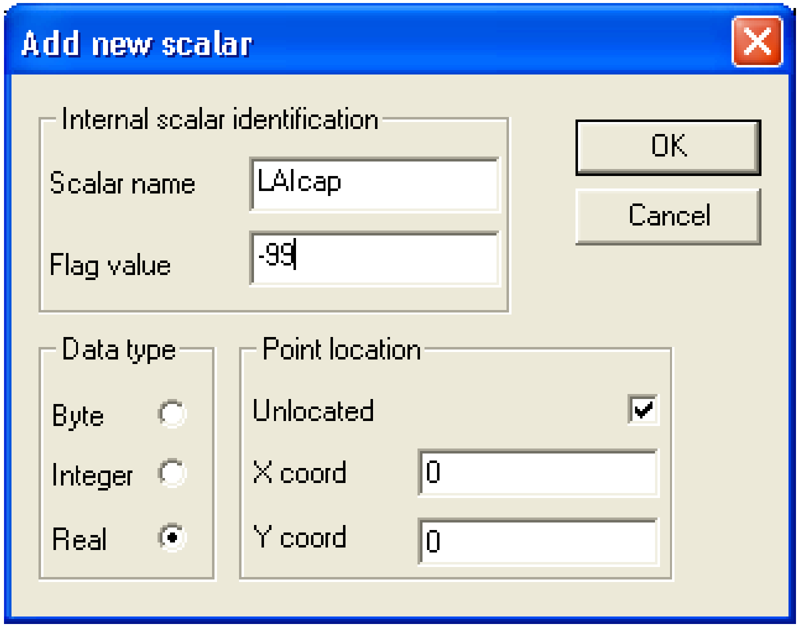
- Loaded DLL methods in left window, with browse capability
- Selected routines in right window, where simulation order is set
- Generic methods may be used for more than one routine

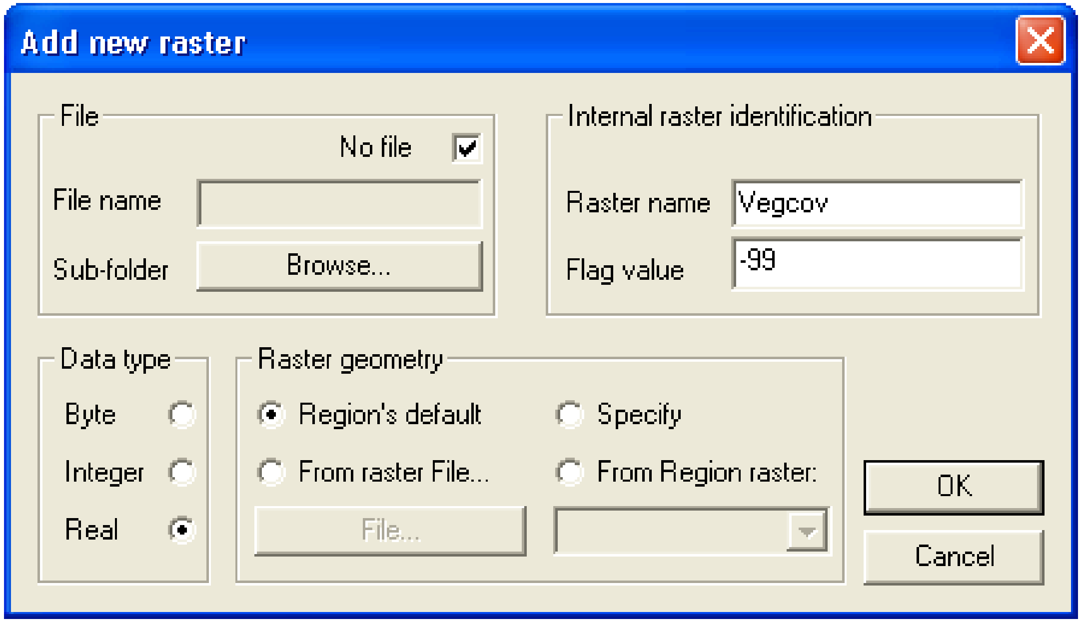
Model building 2: Routine variable interface



Adding new variables

- Raster, point network, or scalar
- All are defined as GIS data
- Scalars have no external file
- The region ”owns” the GIS variables





Main code modules in ENKI

RegModel.exe

Graphical user interface
Based on MFC
No visualisation, R&D oriented

Statkraft Connections

WEB based service
Links to EnkiAPI + SmG database
Daily operation oriented

EnkiAPI

Model construction
GIS and time series database
Different run functions

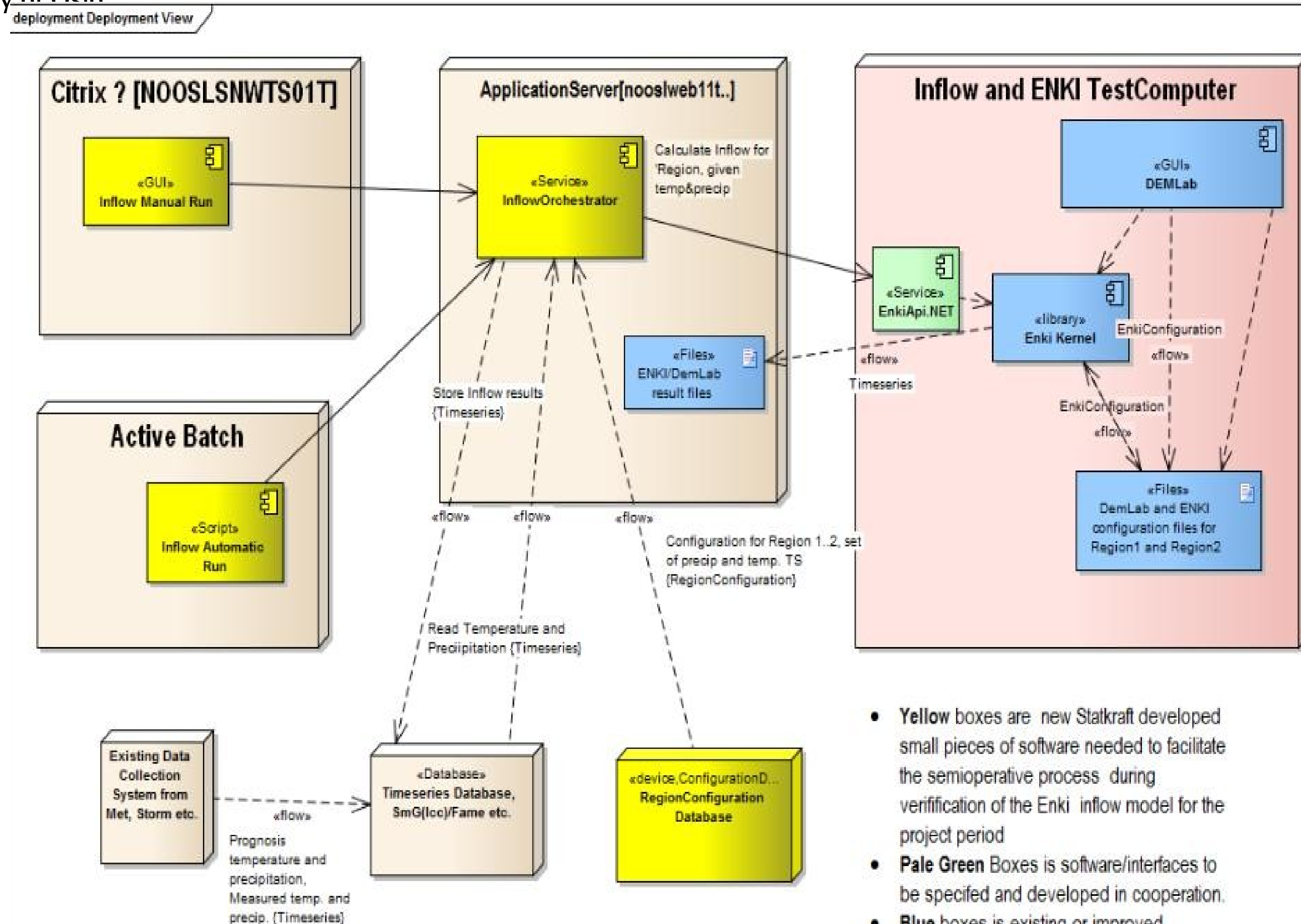
DHM

GIS data types
Method prototypes
GDAL integration

Methods

Method Base Class | **IDWtemp** | **HBVSoil** | **GamSnow** | **Etc**

Kobling mot Statkraft-system



- **Yellow** boxes are new Statkraft developed small pieces of software needed to facilitate the semioperative process during verification of the Enki inflow model for the project period
- **Pale Green** Boxes is software/interfaces to be specifed and developed in cooperation.
- **Blue** boxes is existing or improved versions of the Enki/DemLab software from Sintef.

Variable types i ENKI routines

- **Raster:** Rectangular grid, usually representing the simulation domain
- **Network:** Irregular point set, may extend outside the domain
- **Scalar:** Spatially constant quantity, located or not.

- **Static:** Time-invariant quantity not subject to calibration
  - Elevation model, lake map, forest map, gauge staion map etc.
- **Parameter:** Time-invariant quantity, available for calibration
  - Can be spatially distributed (raster, network), **or** calibrated (scalar)
- **Input:** Dynamic variable which is read, but not written
  - Must either be in input database, or also be a response/state in earlier routine
- **Response:** Dynamic variable which is written, but not read.
  - Output variabel, available for storage and evaluation
- **State:** Dynamic variable which is both read and written.
  - Need initialisation values

Available Model Methods in ENKI

- Numerous hydrologic routines have been implemented and are available for model development
- Method classes are available as part of the open source distribution
- Active development of method classes
- Documentation is poor! We are working to improve this.

Interpolation of input

Snow routines

Soil water / evaporation

Response functions

Catchment aggregation

Results / Evaluation

Automatic Calibration

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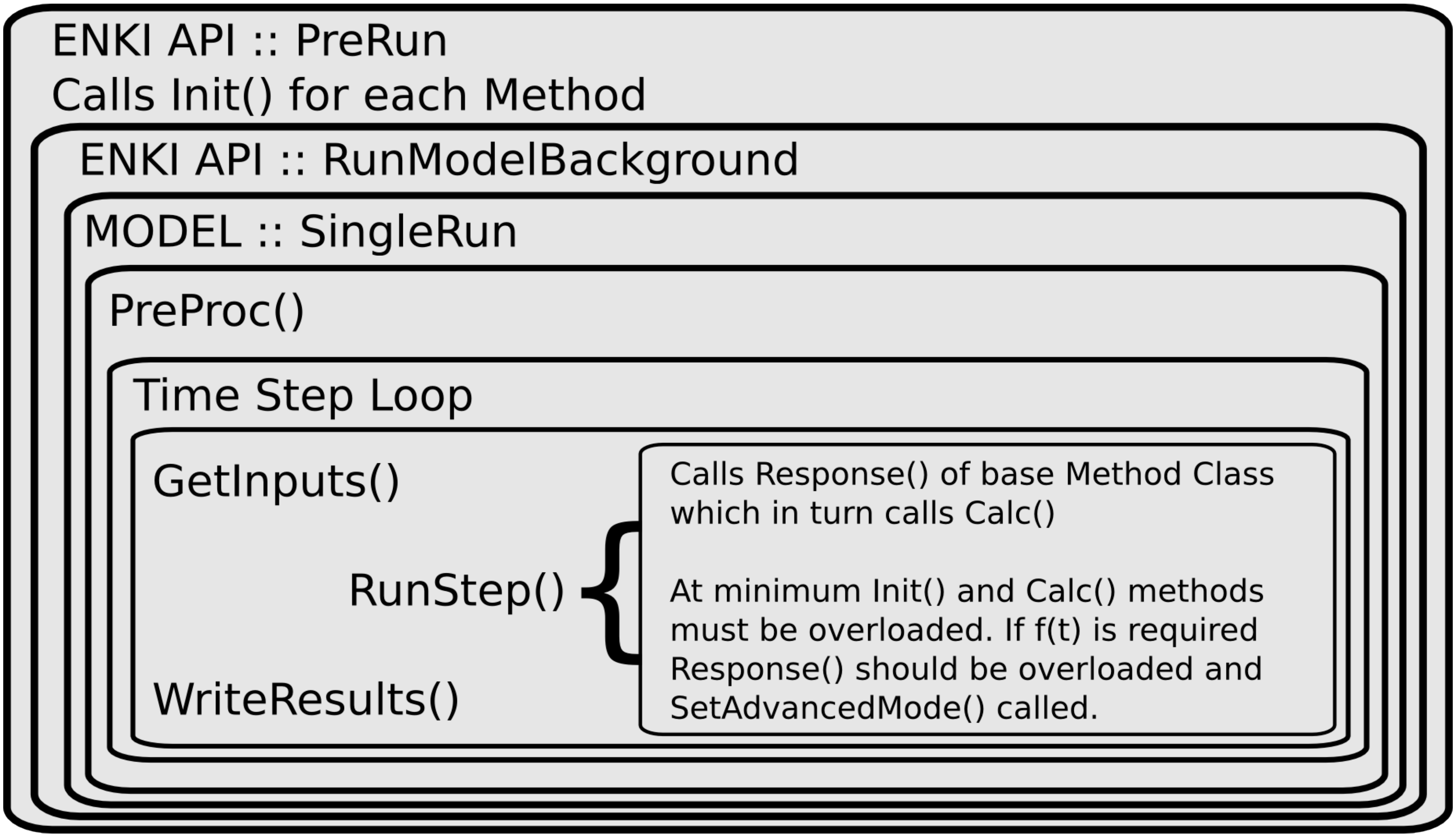
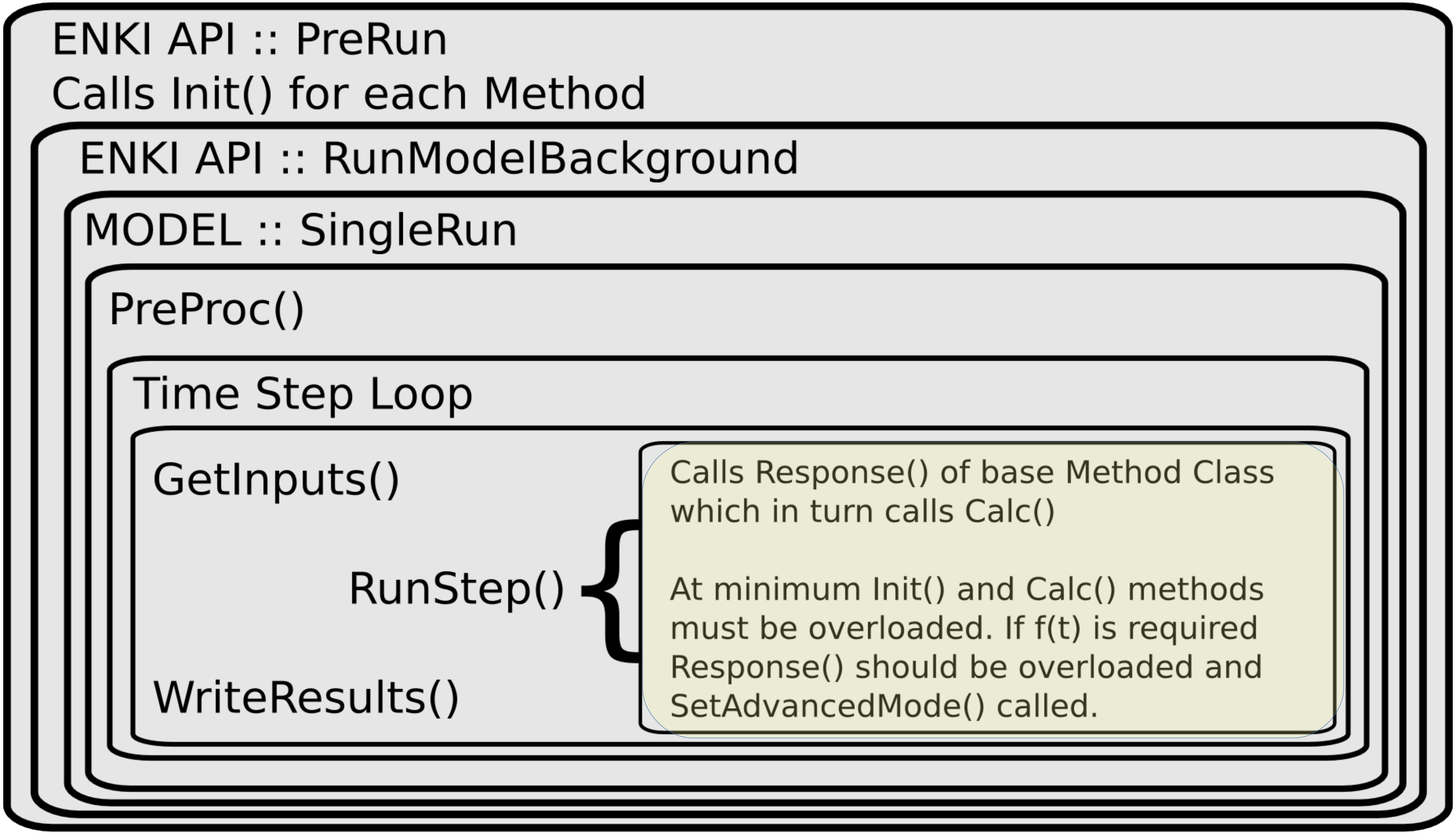
Coding of new routines



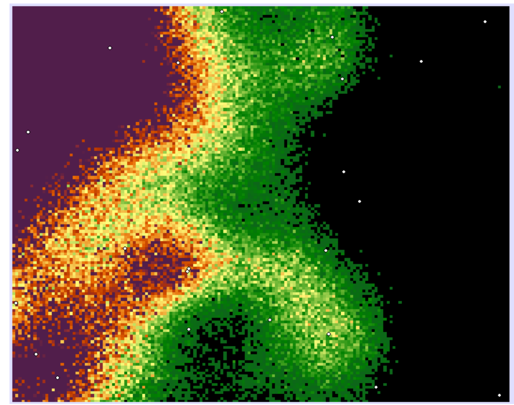
Coding of new routines

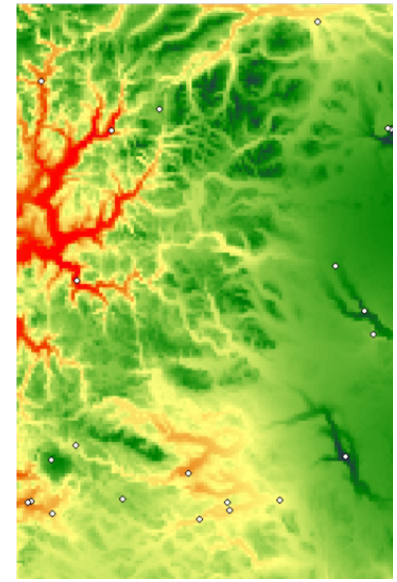


Coding of new routines

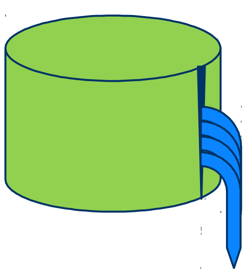
```
#include "lineartank.h”          // LinearTank.cpp implementation

LinearTank::LinearTank()        // Constructor
{
    storconst = newmethvar("storconst",true,"methvar","parameter",”Time constant, days",0);
    inflow = newmethvar("inflow",true,"methvar","input","Inflow to linear tank");
    storage = newmethvar("storage",true,"methvar","state","Response tank storage in mm",0);
    outflow = newmethvar("outflow",true,"methvar","response","Outflow from linear tank");
}

bool LinearTank::Calc()         // Response function
{
    storage->value += inflow->value;
    outflow->value = storage->value * (1 - exp(-steplength.m_span / storconst->value));
    storage->value -= outflow->value;
    return true;
}

CMethod* CreateMethodObject()     // Object factory
{
    CMethod *p = new LinearTank;
    return p;
}
```

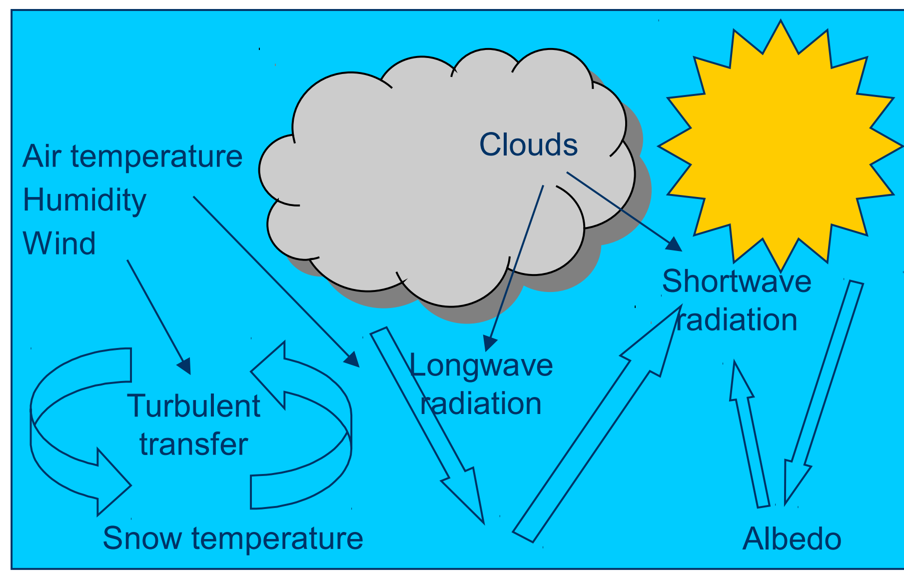
Model composition





- Bayesian temperature kriging
- GRF precipitation simulation
- Kriging of radiation, humidity, wind
- Energy-sum snow melt
- Priestley-Taylor potential evap
- Power-law response (Kirchner, 2009)





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Method Base Class
HBVSoil

Python Algorithms

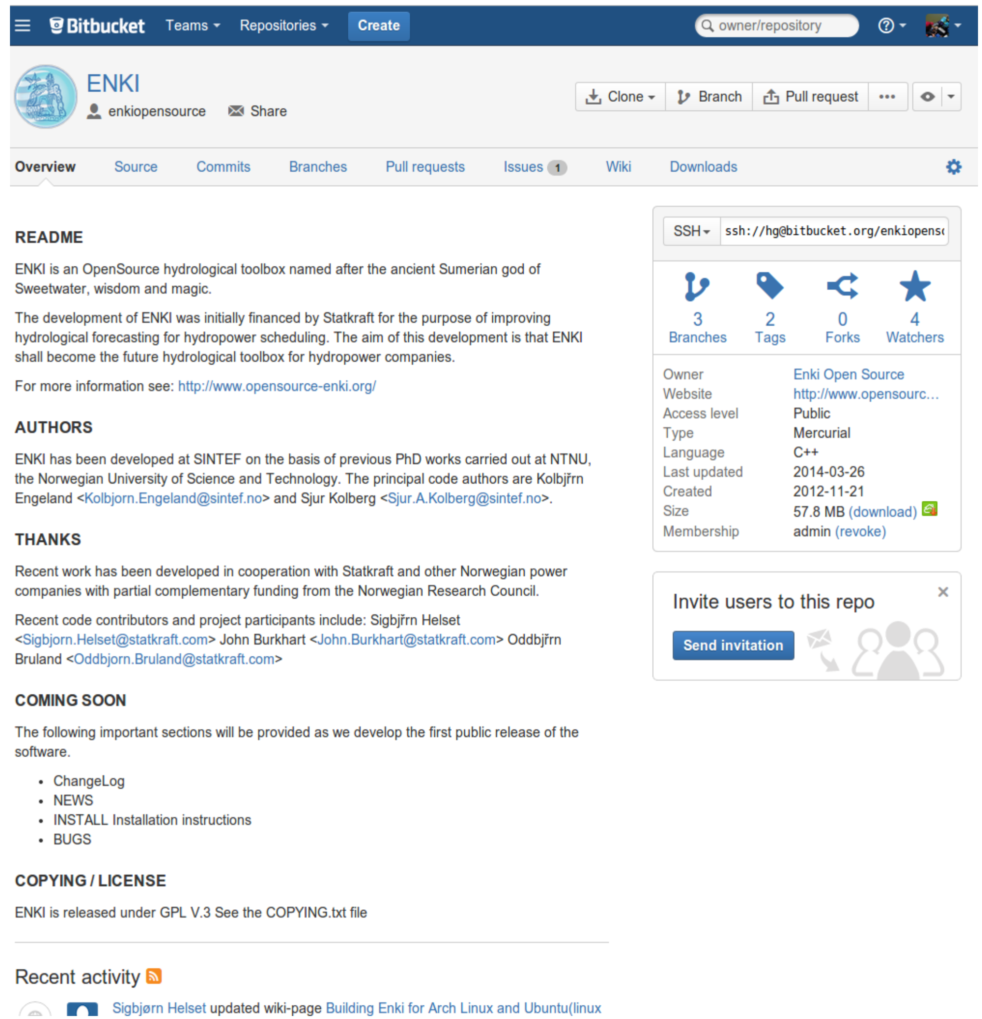
IDWtemp
GamSnow
Method Base Class
HBVSoil

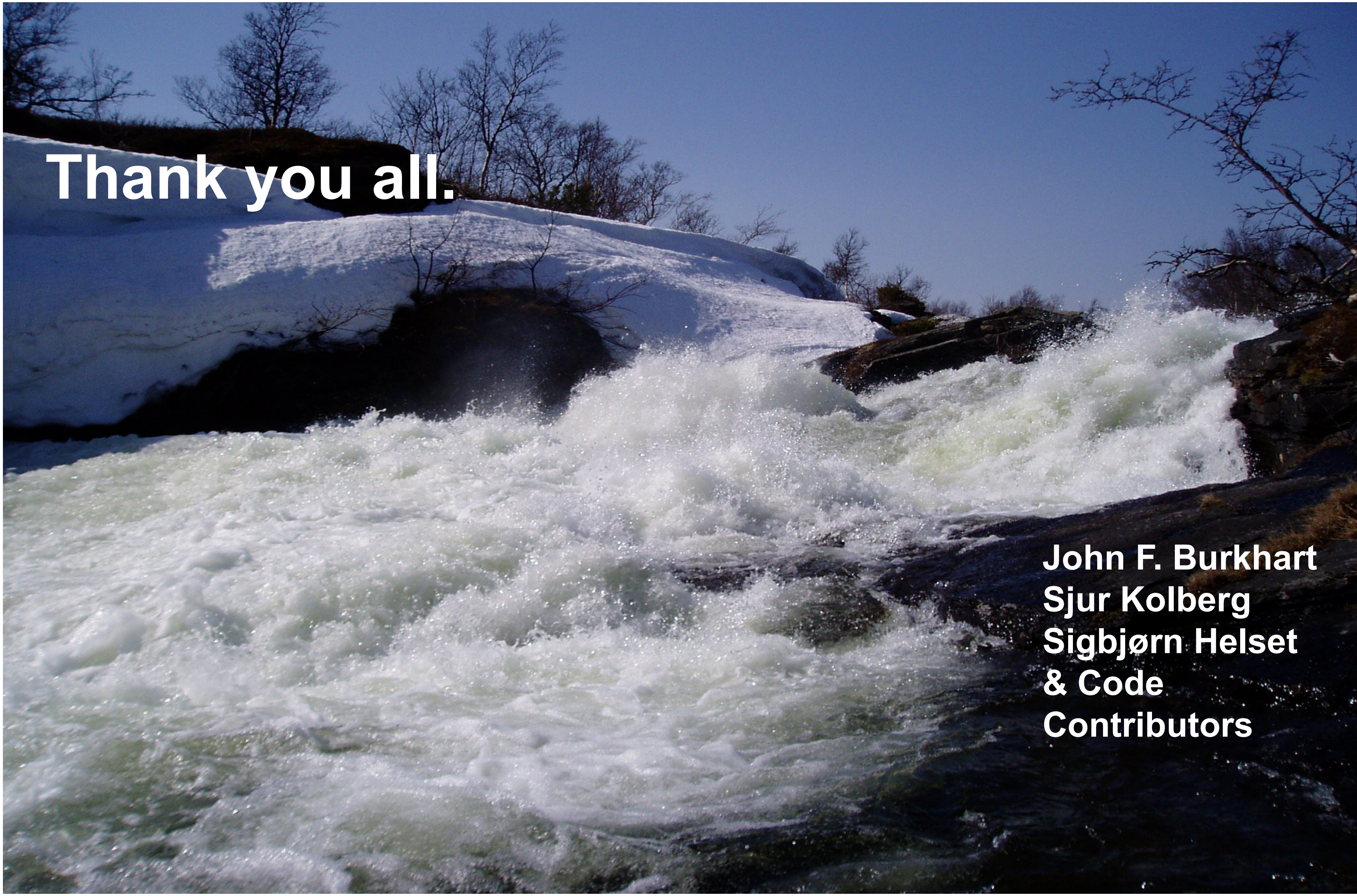
Summary

- ENKI an excellent tool for testing different model compositions and spatial setup alternatives
- Distributed modelling requires re-thinking of many subroutines, in particular regarding input data
- Regional calibration and restriction of calibration freedom show modest reduction of performance
- Improved parameter identifiability enables regionalisation
- ENKI recently released as OS under the LGPL license
- Currently in operationalisation phase both at Statkraft and among other companies

The Hydrologic Modeling Framework: ENKI

- Search: “ENKI Hydrology”
- Bitbucket is source for linux branch




Thank you all.
John F. Burkhart
Sjur Kolberg
Sigbjørn Helset
& Code
Contributors