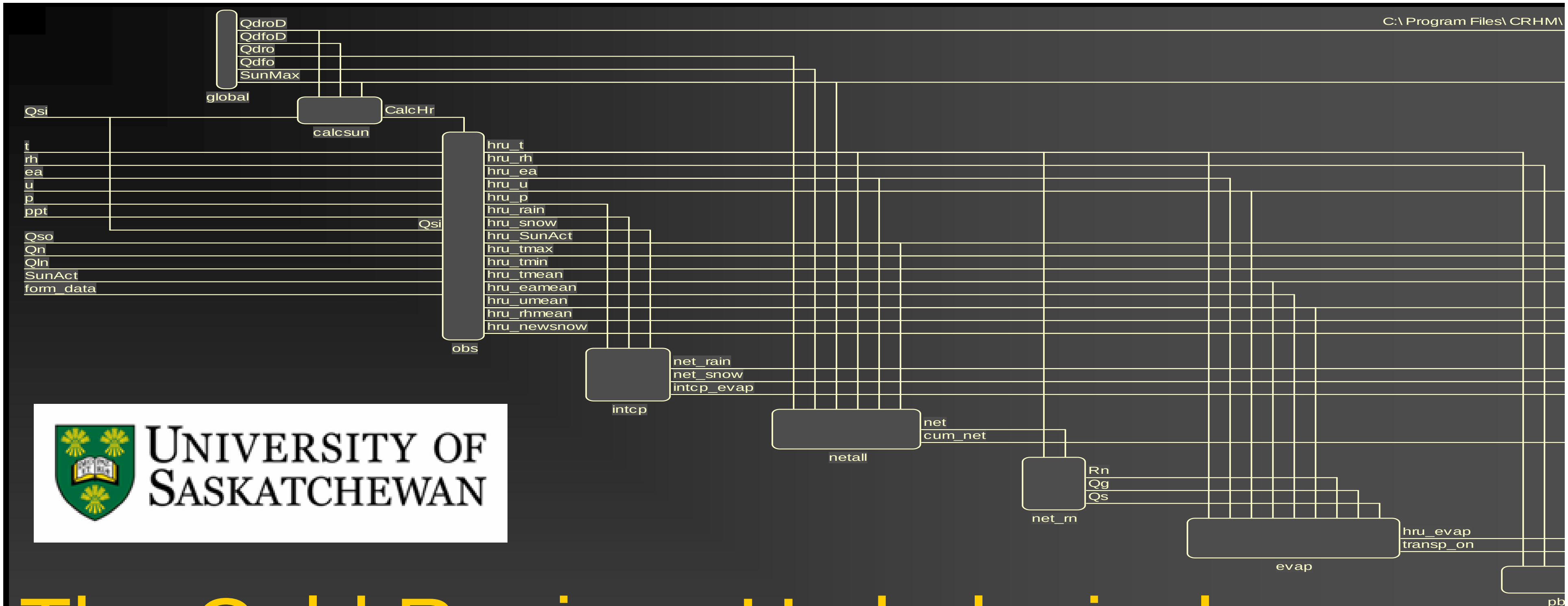


UNIVERSITY OF SASKATCHEWAN

The Cold Regions Hydrological Model: A Simulation Platform for Physically Based Hydrology

CENTRE FOR HYDROLOGY

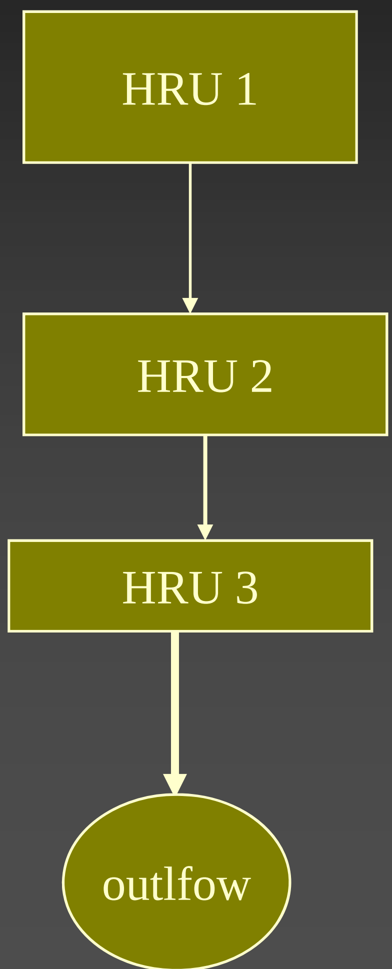
Objective

To develop a *hydrological cycle simulation system* that:

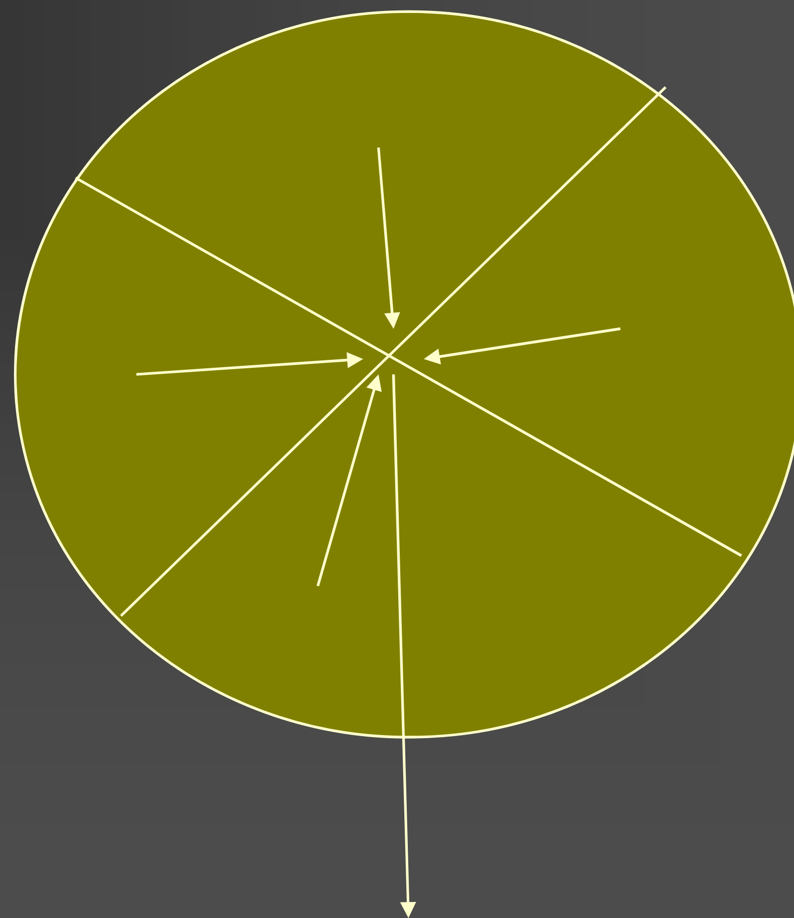
- **is distributed such that the water balance for selected surface areas can be computed;**
- **is sensitive to the impacts of land use and climate change;**
- **does not require the presence of a stream in each land unit;**
- **is flexible: can be compiled in various forms for specific needs;**
- **is suitable for testing individual process algorithms.**
- DOES NOT REQUIRE CALIBRATION!

Hydrological Response Units

Sequential HRU –
landscape connectivity



Grouped HRU – must drain to stream



Building Physically-based, Distributed Hydrological Models

- A HRU has 3 groups of attributes
  - biophysical structure - soils, vegetation, slope, elevation, area
  - hydrological state – snow water equivalent, snow internal energy, intercepted snow load, soil moisture, water table
  - hydrological flux - snow transport, sublimation, evaporation, melt discharge, infiltration, drainage, runoff

Building Physically-based, Distributed Hydrological Models

Cold Regions Hydrological Model

- uses a library of physically-based hydrological and energy balance process modules;
- handles the following aspects of the modelling process:
  - data pre-processing,
  - module and model building,
  - results analysis
- is easy to use: employs a Windows environment with pull-down menus.

Cold Regions Hydrological Model

DATA COMPONENT

Preparation of spatial and meteorological data.

- Spatial data (e.g. basin area, elevation, cover type) is analyzed using a Geographic Information System (GIS) interface that assists the user in basin delineation, characterization and parameterization of Hydrological Response Units (HRU).
- Time-series meteorological data include air temperature, humidity, wind speed, precipitation and radiation.
- Adjustments for elevation (lapse rate), snowfall versus rainfall, interpolation between input observations (stations)
- Unit conversions to consistent SI units

Cold Regions Hydrological Model

MODEL COMPONENT

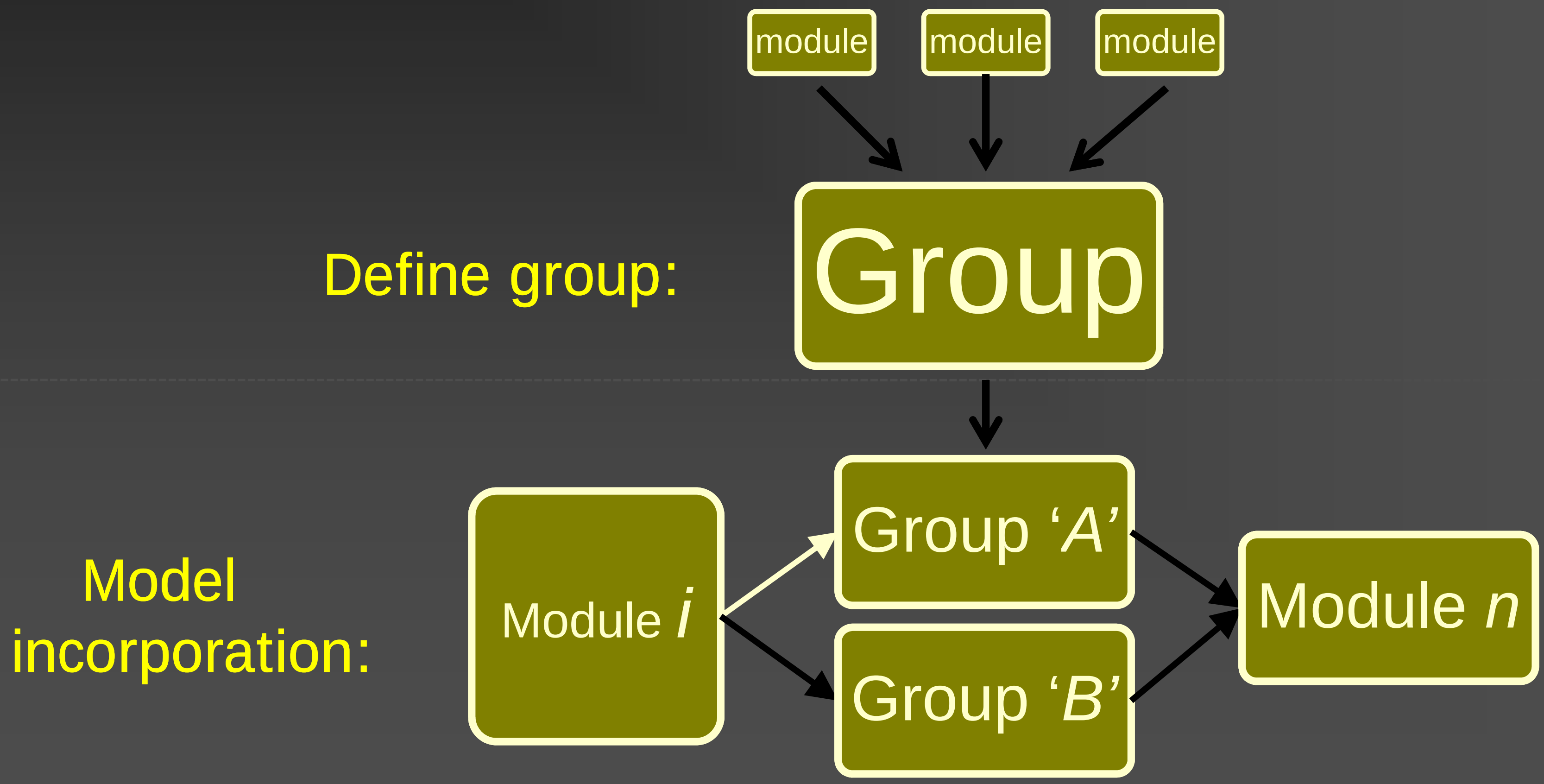
- Utilizes Windows-based series of pull-down menus linked to the system features.
- Modules, or process algorithms, are selected from the library and grouped together by the CRHM processor.
- Modules have a set order of execution with a common set of variables and parameters.
- Modules are created in C++ programming language.
- Macro modules can be created from within the model using a simple macro language.

Groups and Structures to Adapt to Real Basin Hydrology

- **Group. A collection of modules executed in sequence for all HRUs.**
  - collection of modules which can be used in place of specifying the individual modules.
  - if groups are defined with same modules, then can execute modules in parallel using different parameters or driving observations.
  - If groups are defined as different 'models', it is possible to execute the models in parallel using identical parameters and driving observations to check different responses.
- **Structure. A parallel collection of modules or Group assigned to an HRU and run in sequence.**
  - Comparison of algorithms
  - Customization of model to HRU characteristics - diverse sets modules to be representative of the HRU and basin.
  - Dynamic structural change *due to excess water or lack of it.*

Groups

- A collection of modules executed in sequence for all HRUs.



Groups

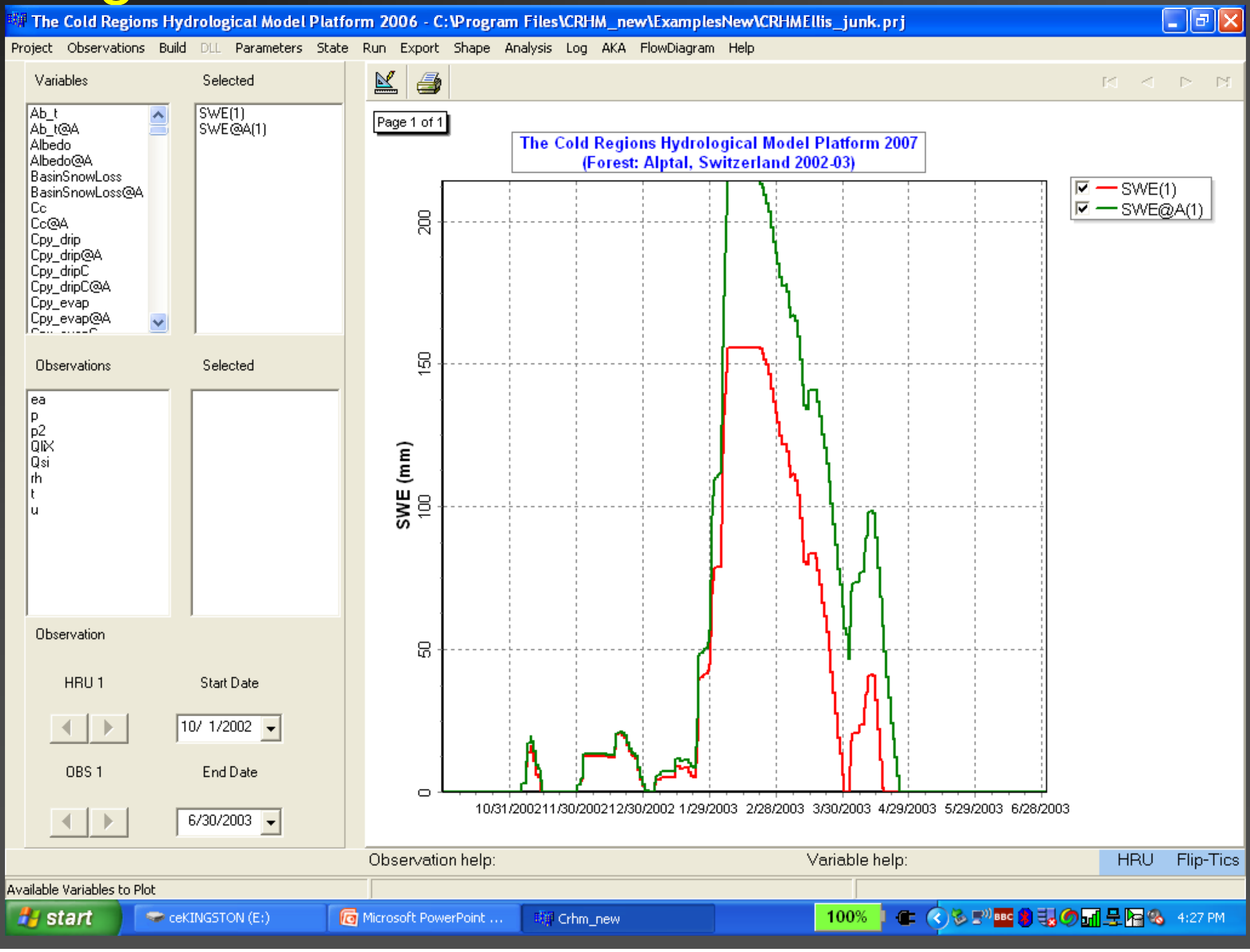
Group application:

1. If groups are defined with the same modules, it is possible to execute the models in parallel using different parameters or driving observations.

2. If groups are defined as different modules, it is possible to execute the models in parallel using identical parameters and driving observations to check different responses.

Groups

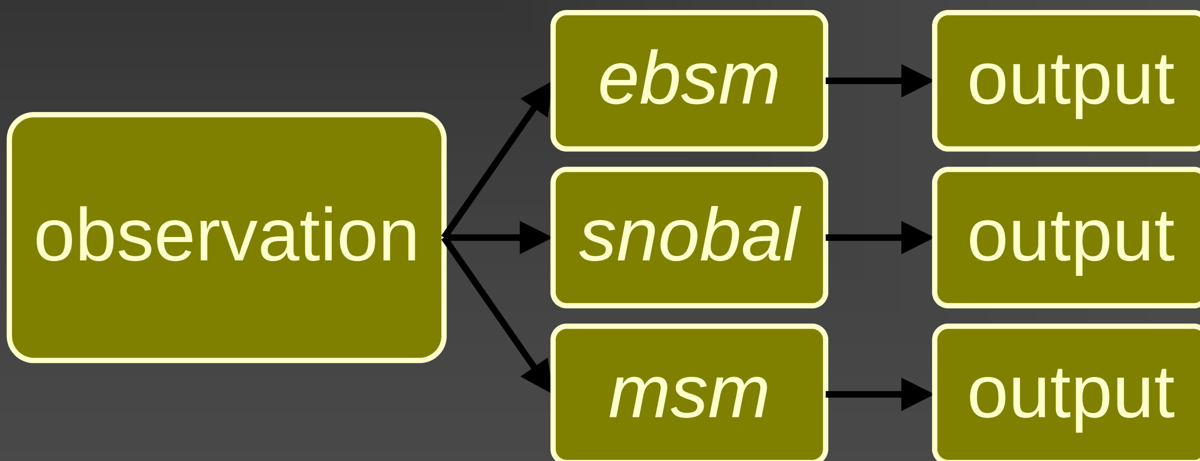
- E.g. estimate sub-canopy SWE for forests of differing leaf-area-index



Structures

- Running <u>similar</u> modules in *parallel*

e.g. snowmelt



Structures

Structure application:

1. Algorithm comparison. Intercomparison of algorithms with similar driving data and parameters
2. Mixed Land Use in Basin. Permits differing model structure for differing HRU (e.g. forest versus farmland
3. Dynamical Structural Change. Permits change in model structure in response to changing hydrological state (e.g. change grassland to a slough when leaving a drought). The decision about which module to use would be made by a preceding module based upon the availability of moisture.

Cold Regions Hydrological Model

ANALYSIS COMPONENT

- Used to display, analyze and export results (Excel, ASCII).
- Statistical and graphical tools are used to analyze model performance, allowing for decisions to be made on the best modelling approach.
- Sensitivity-analysis tools are provided to optimize selected model parameters and evaluate the effects of model parameters on simulation results.
- Mapping tools use ArcGIS files to map ouputs for geographical visualization.

CRHM Module Development

DATA ASSIMILATION

- Data from multiple sites
- Interpolation to the HRUs

SPATIAL PARAMETERS

- Basin and HRU parameters are set. (area, latitude, elevation, ground slope, aspect)

PROCESSES

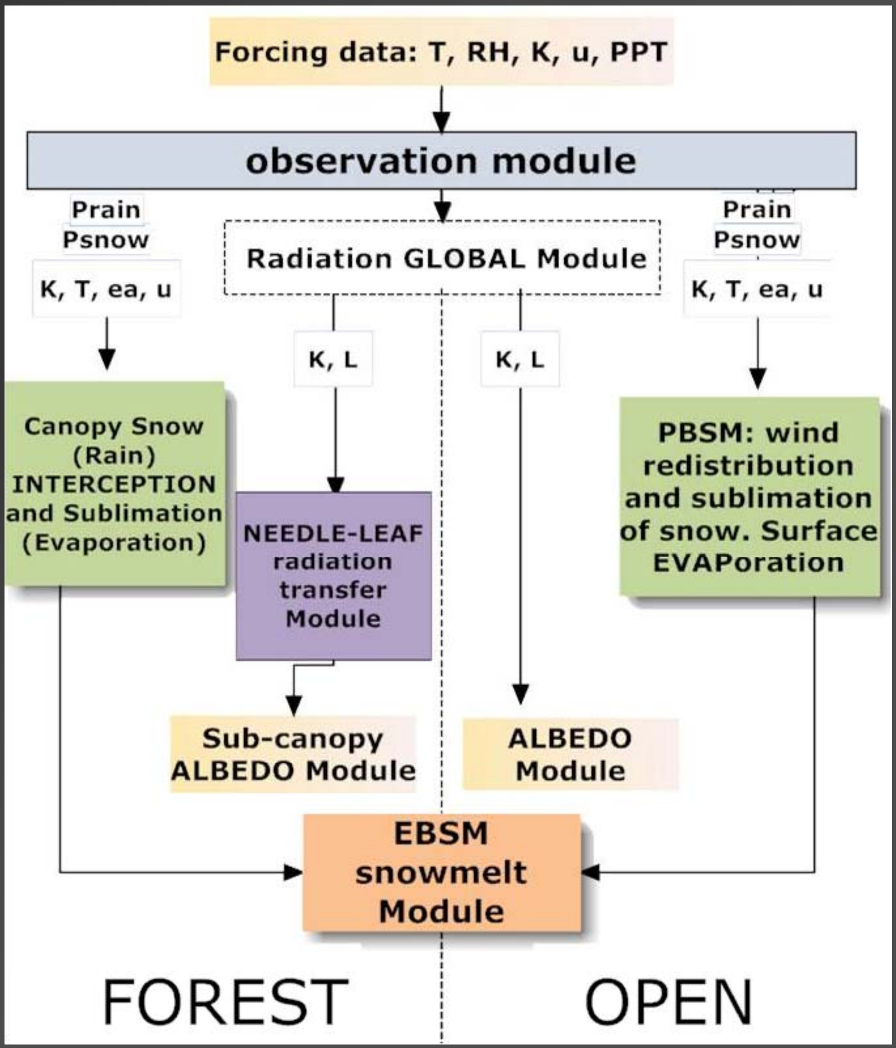
- Infiltration into soils (frozen and unfrozen)
- Snowmelt (prairie & forest)
- Radiation – level, slopes
- Evapotranspiration
- Snow transport
- Interception (snow & rain)
- Sublimation (dynamic & static)
- Soil moisture balance
- Sub-surface runoff
- Routing (hillslope & channel)
- Advection

2007 Modules

- *Snobal*- layered physically based snow energy balance model (Marks et al. 1998) – unique linkage to PBSM
- *Trees*- new forest energy and mass balance module.
  - Short and longwave radiation transfer
  - Snow interception, sublimation, unloading
  - Rainfall interception, drip, evaporation
  - Sub-canopy turbulent transfer parameterisation
- *Wamsley Wind*- wind speed correction for topography
- *Evap* - greater variety of evaporation models. Penman-Monteith, Bulk Transfer

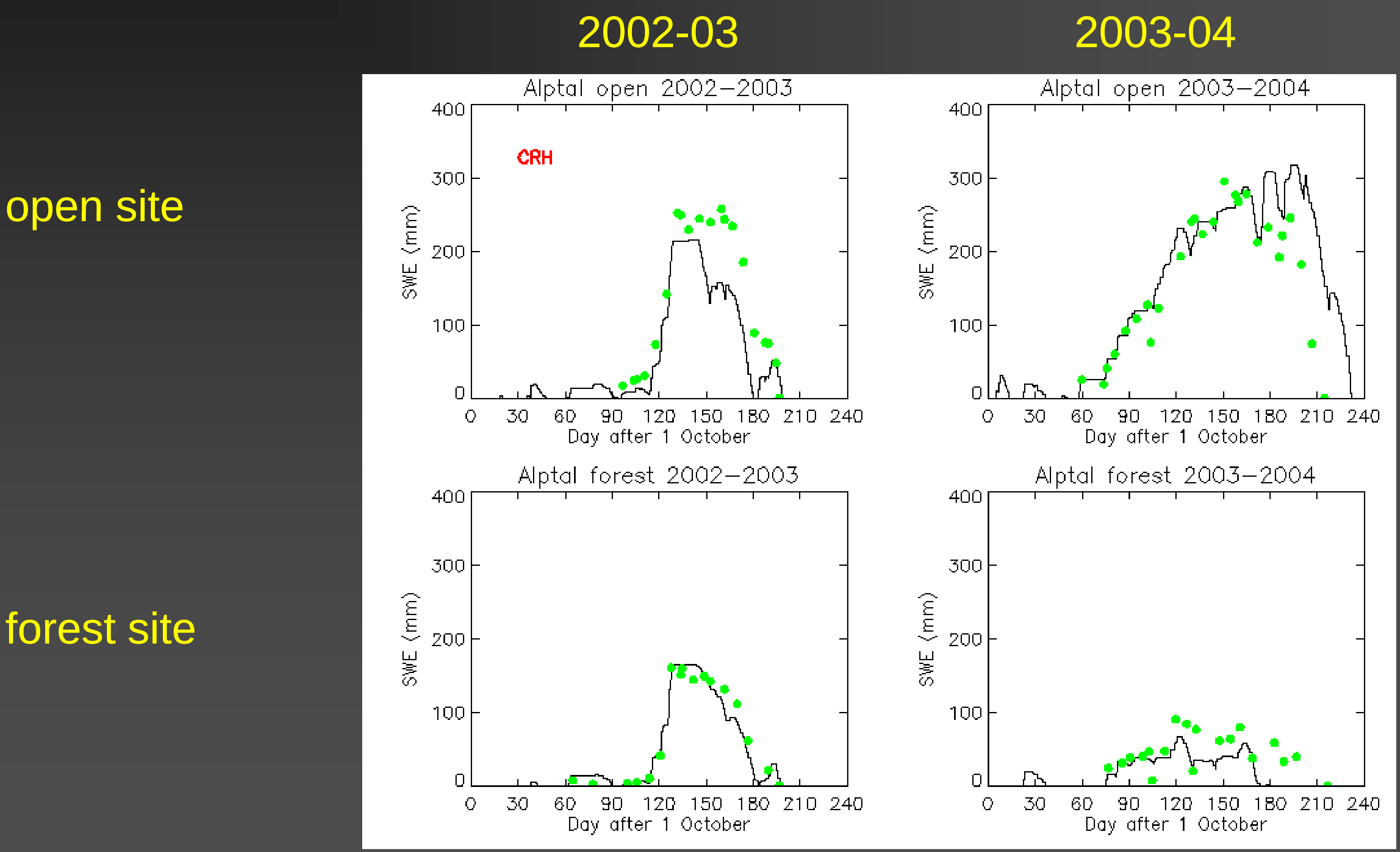
Trees

Basic model schematic

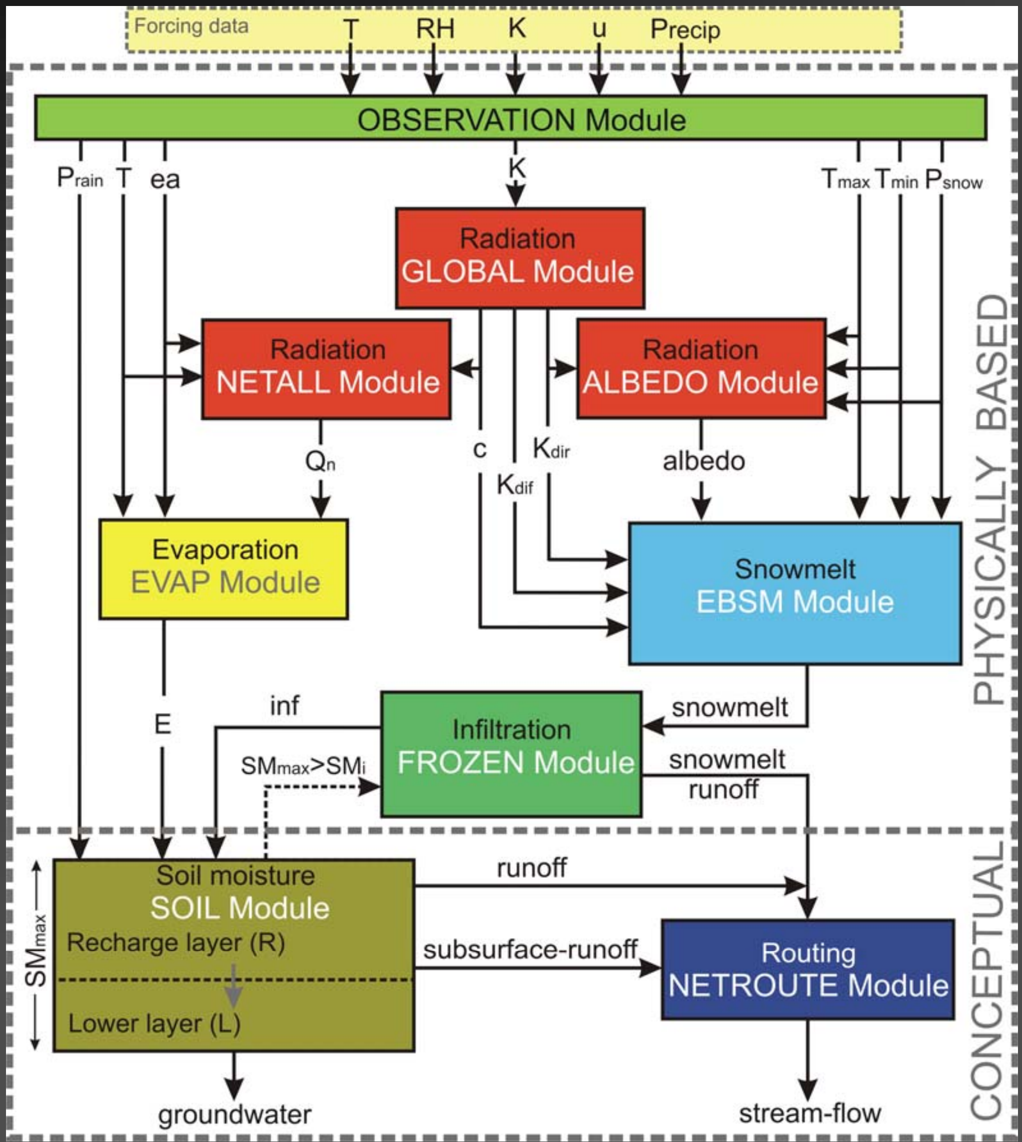


Effect of forest cover on snow accumulation and melt

SnowMIP2 runs: Alptal, Switzerland:



CRHM Test - Yukon



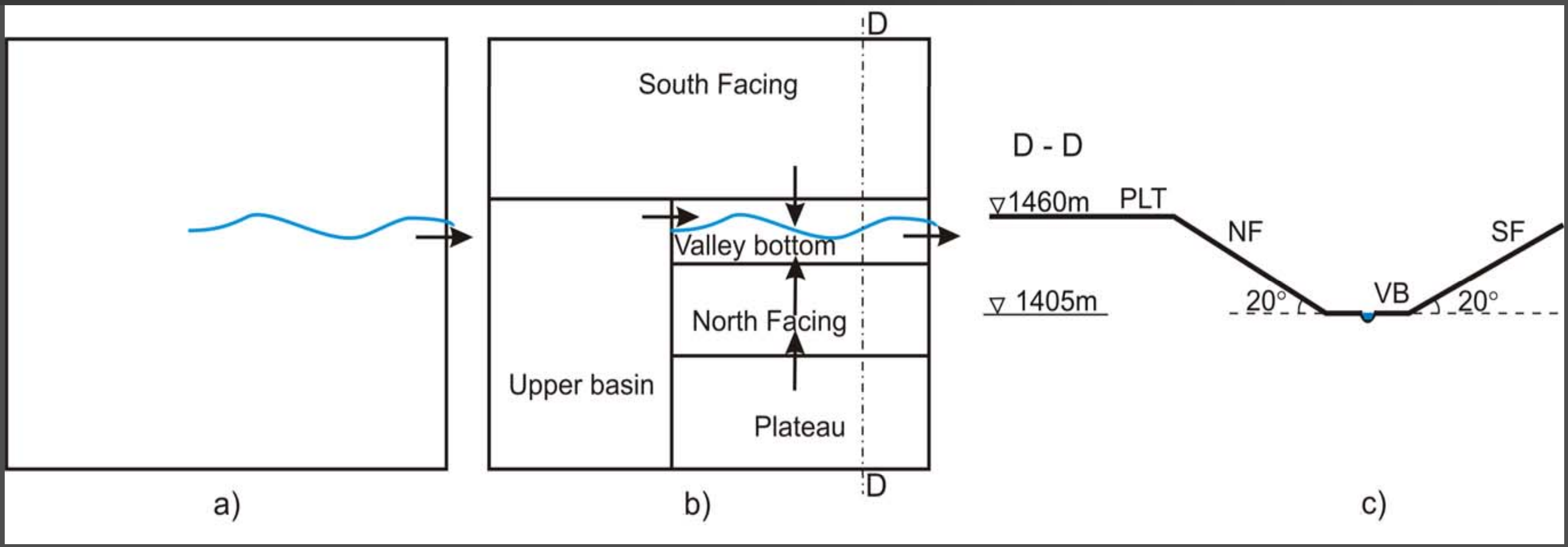
Modular structure
HRU based

$$INF = 5 \cdot (1-\theta p) \cdot SWE^{0.584}$$

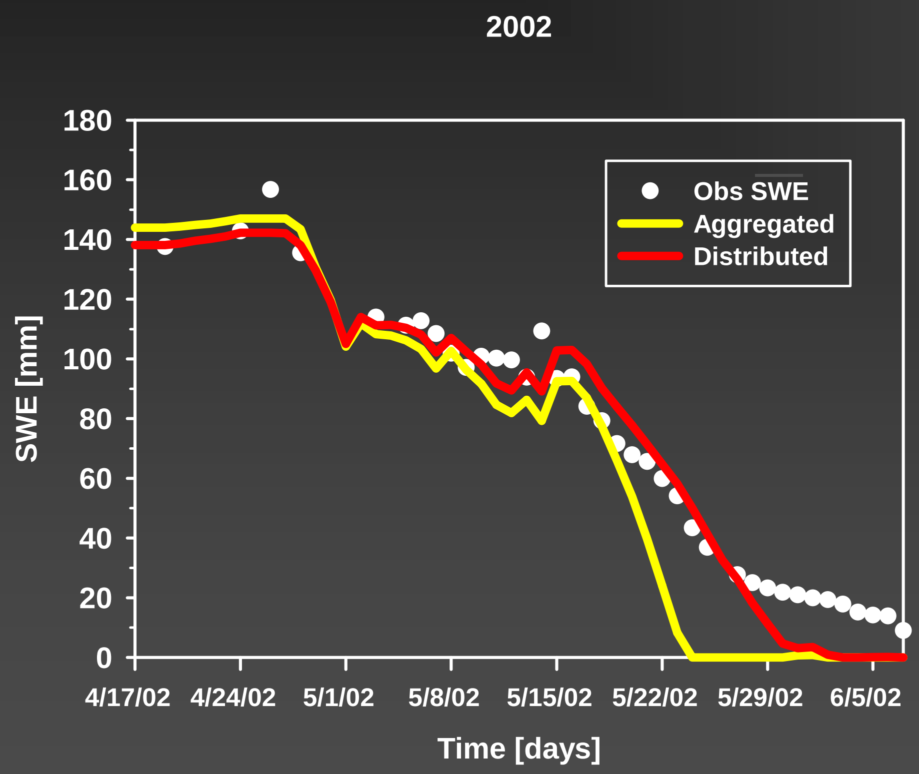
$$INF = C \cdot S_0^{2.92} \cdot (1-S_I)^{1.64} \cdot \left(\frac{273.15-T_I}{273.15}\right)^{-0.45} \cdot t_0^{0.44}$$

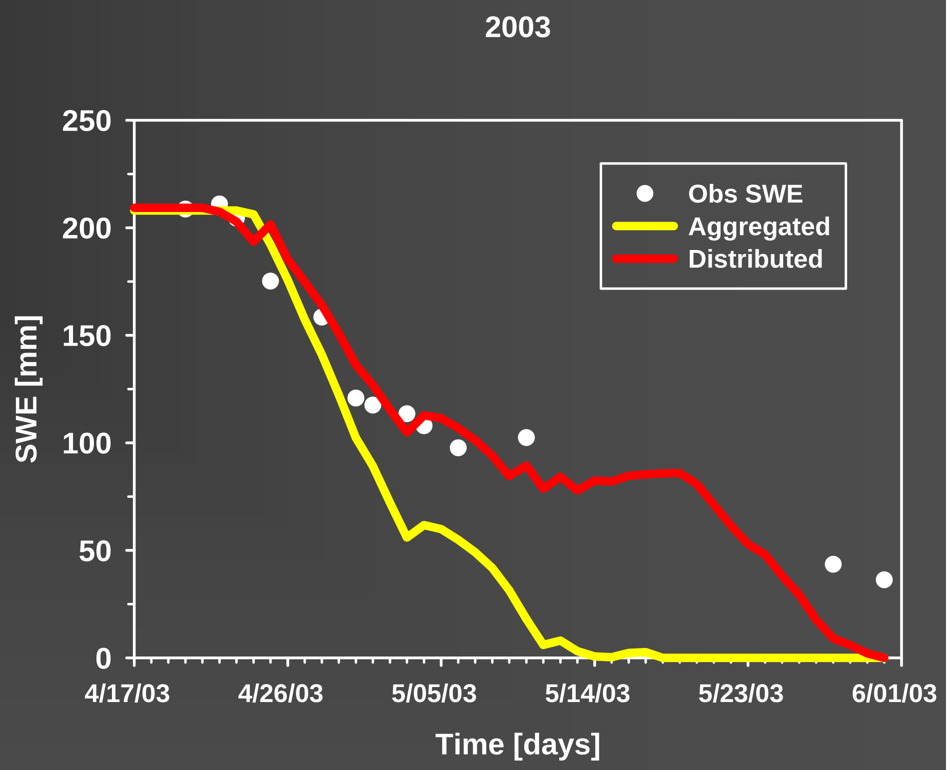
Modelling Approach

Aggregated vs. Distributed

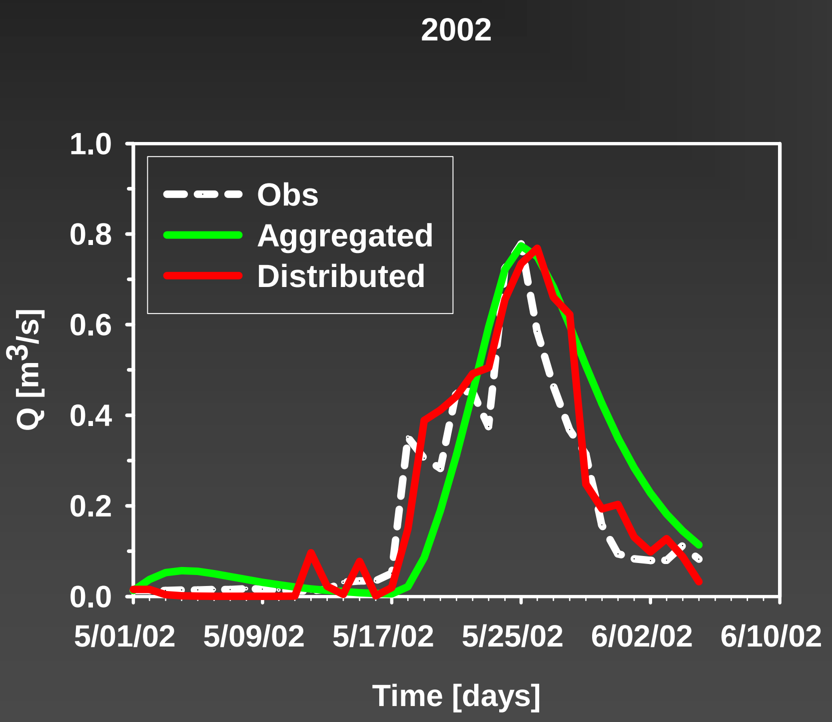


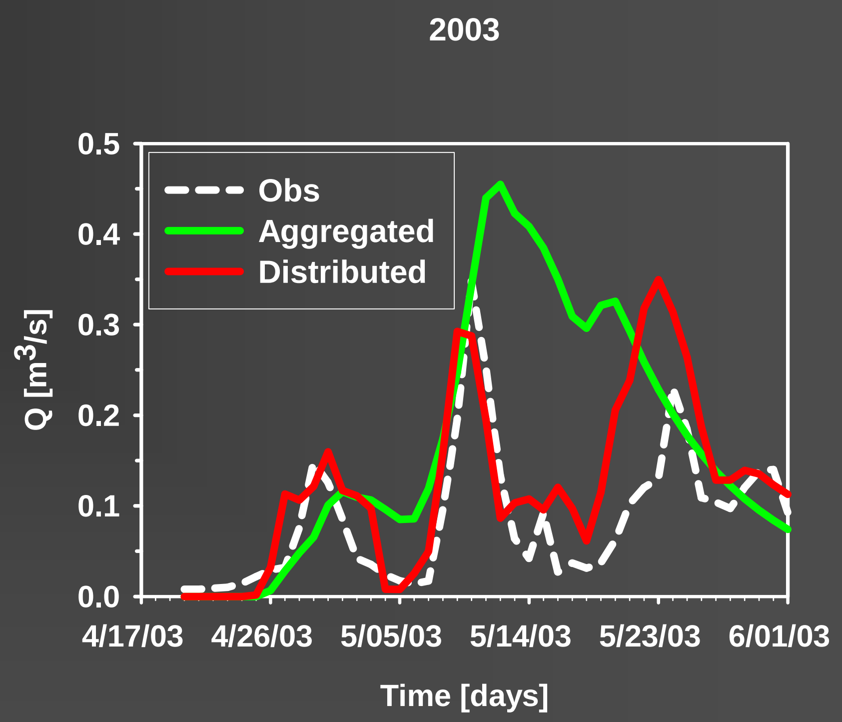
Basin Areal SWE NF, SF, and VB





Basin discharge





Conclusions

- Process algorithms can form the basis for physically-based hydrological model structure and parameter selection
- Flexible model structure and physically based components can lead to appropriate and robust hydrological simulation
- Errors in simulation identify gaps in understanding of processes, structure or parameters
- A process based modular model is able to simulate key components of the cold regions hydrological cycle from an understanding of principles, and without calibration of parameters except for routing
- Modular models are relatively simple to update as our science advances.