HOW TO COMBINE INDUCTIVE AND DEDUCTIVE APPROACHES TO PREDICTION IN UNGAUGED BASINS

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Philosophies of Modelling

Inductive Approach – Top Down

• Analyses processes based on data (e.g. dominant responses) at larger scales (e.g. basin) and then, if needed, make inferences about processes at smaller scales.

Deductive Approach – Bottom-Up

• Analyses processes at smaller scales using physical laws, and then extrapolates the process at larger scales using aggregation techniques.

PHILOSOPHIES OF MODELLING

Inductive Approach – Top Down

- Model structure is defined at the level of interest and it is inferred from data.
- Representation of basin processes $\rightarrow$ finding the simplest descriptions of the dominant responses of the system that are supported by both the available data and physical understanding.
- Used to describe the hydrological response at long temporal scale and large spatial scale (e.g. annual time and basin scale) and progressively narrowing down to processes at smaller scales.
- Reduce data requirements and limit model complexity
- Simple 'parsimonious' models $\rightarrow$ Lumped & Conceptual
- Difficulties in capturing all important processes
- Too "parsimonious" to properly describe heterogeneity

Philosophies of Modelling

Deductive Approach – Bottom Up

- Model structure is preconceived
- Based on deterministic mathematical equations founded on scientific laws
- Assumes that conceptualisations of individual processes are equivalent for the overall model domain.

- More realistic → physically based structure
- More complex models → able to describe different processes at different scales in time and space.
- Problems with parameter identifiability and with the different sources of uncertainties
- Too complex to support engineering and management decisions.

Hydrological Models

- Plethora of models
  - **Lumped or Distributed**
  - **Deterministic or Stochastic**

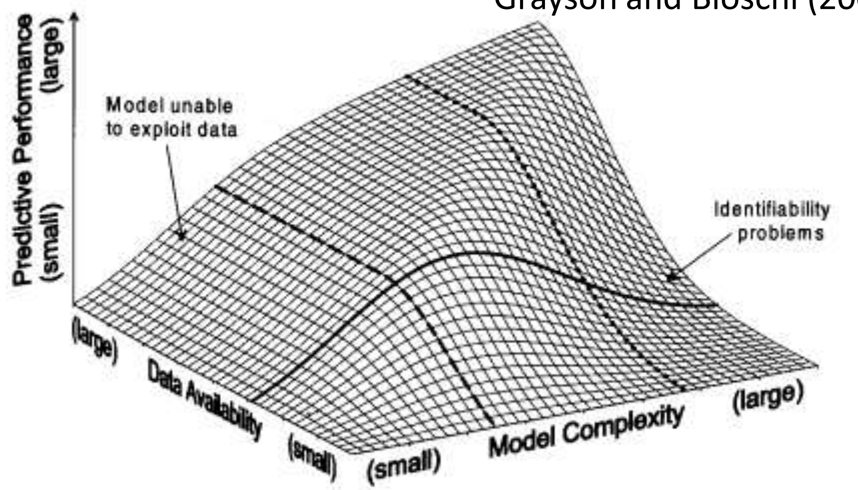
}

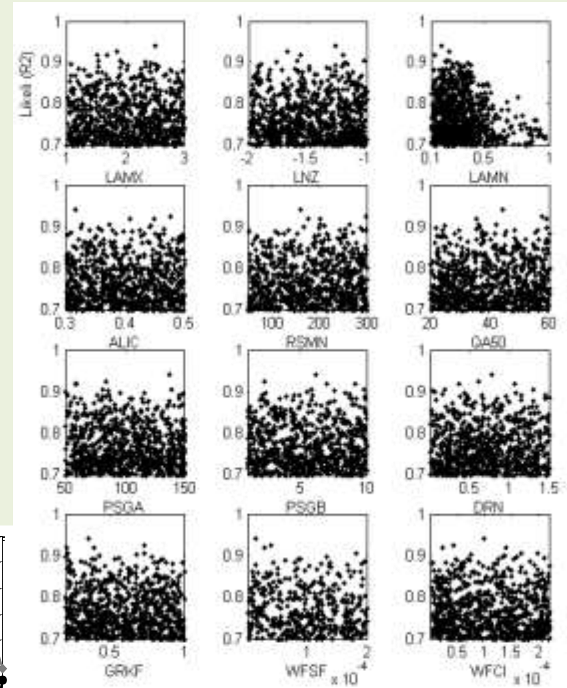
- **Conceptual**
- **Empirical**
- **Statistical**
- **Physically Based**

- Nonlinearity
  - Some Processes → still inadequately parameterised
  - Some Parameters → still conceptual
- Scaling
  - Lack of a scale consistent process descriptions
- Uniqueness – Equifinality
- Identifiability problems. Different parameter sets→ similar performance
- Uncertainty
  - Predictions constrained by data, model structure, and parameters

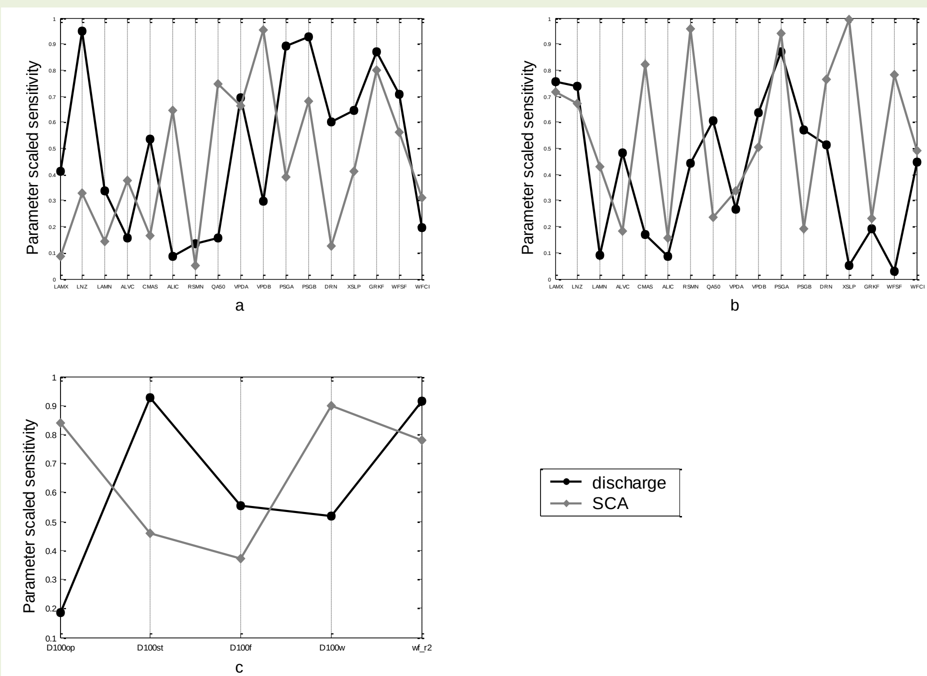
MODEL COMPLEXITY – DATA - MODEL PERFORMANCE

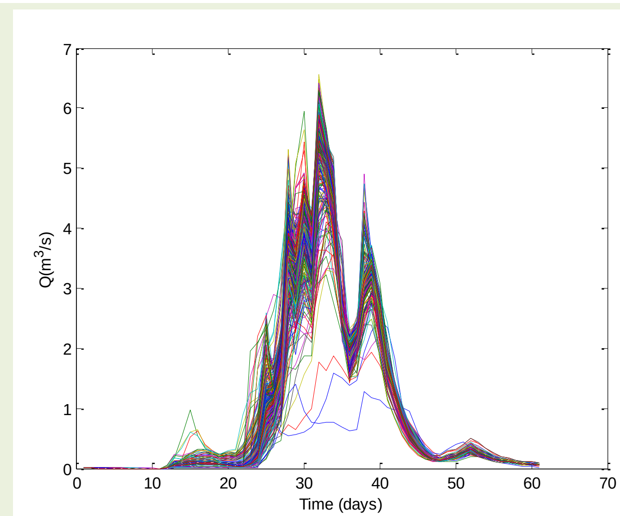
Grayson and Blöschl (2001)





Sensitivity analysis
WATCLASS parameters
Trail Valley Creek





Scaling Issues

- **Hydrological process at a range of scales**

  - Small length scales area associated with short times
  - Large length scales area associated with long times

Not always happens

Infiltration excess → Point scale phenomena

Saturation excess → Lateral flow → Area associated with the process

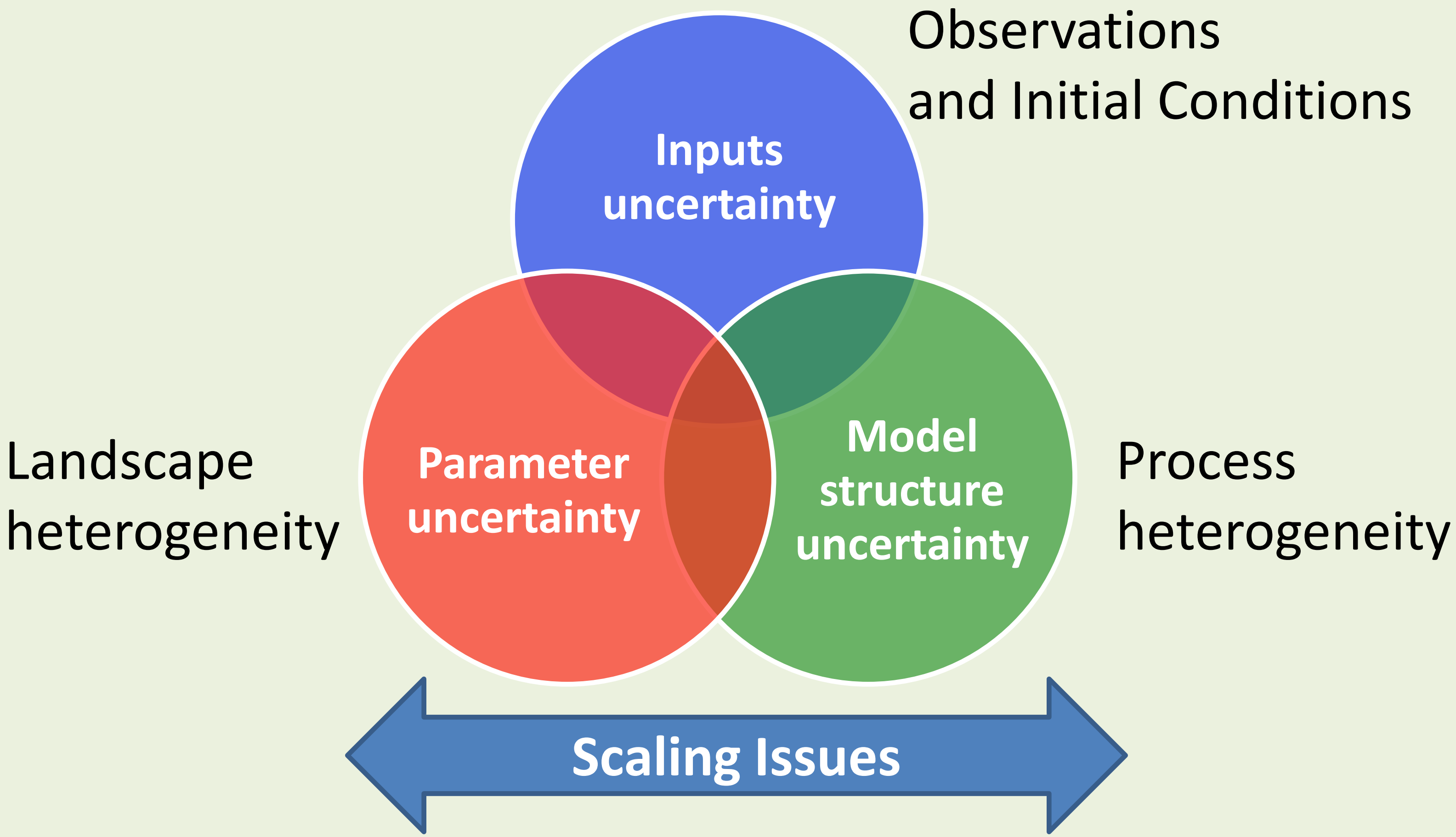
- **Mismatch between scales:**
  - Observation scales
  - Process scales
  - Modelling scales

↕ **Scaling (up-down)**
Transference of information

- **Scaling is limited by spatial heterogeneity and variability in hydrological process environments**

Definition → **Effective parameters**

Predictive Uncertainty



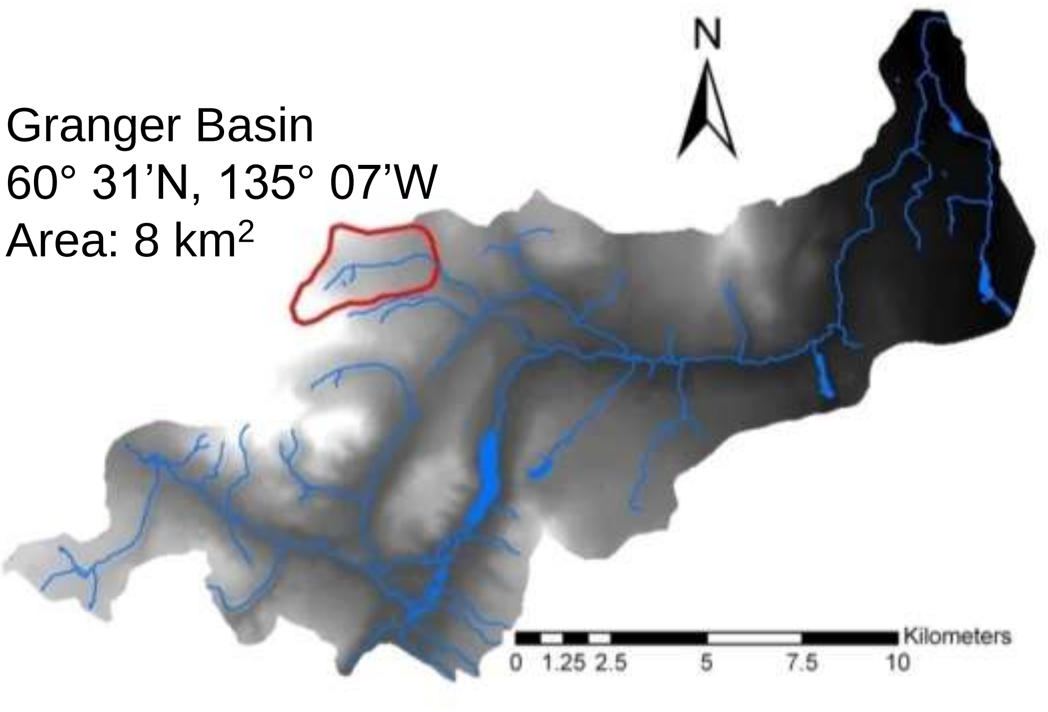
•This situation becomes even more important in cold regions areas due the ungauged nature of arctic and subarctic environments.

• New strategies that combine detailed process understanding with an overall knowledge of the system are needed.

STUDY AREA

Wolf Creek Research Basin
60° 31'N, 135° 07'W
Area: 195 km^2

Granger Basin
60° 31'N, 135° 07'W
Area: 8 km^2



Issues in Subarctic Environments

Snow :
- Reflects solar radiation
- Insulates the ground
- Stores water and nutrients
- Has high temporal and spatial variability

Topography
- Exerts a control in snowpack and soil energy balances due to the spatially varying incoming solar radiation and temperature.
- Control snow redistribution processes

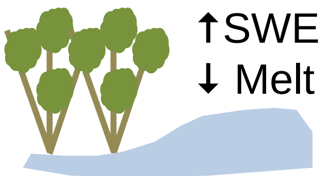
Vegetation :
- Traps falling and wind-blown snow
- Masks underlying snow

Permafrost
- Affects snowmelt runoff generation
- Soil energy and mass balance

Scaling Issues in Subarctic Environments

Small scale

Negative association Melt-SWE



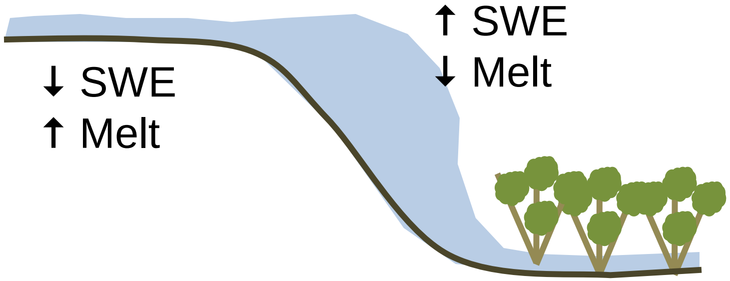
↑SWE
↓ Melt

↓ SWE
↑ Melt

Underestimation of melt duration 14%

Medium (Landscape) scale

Negative association Melt-SWE



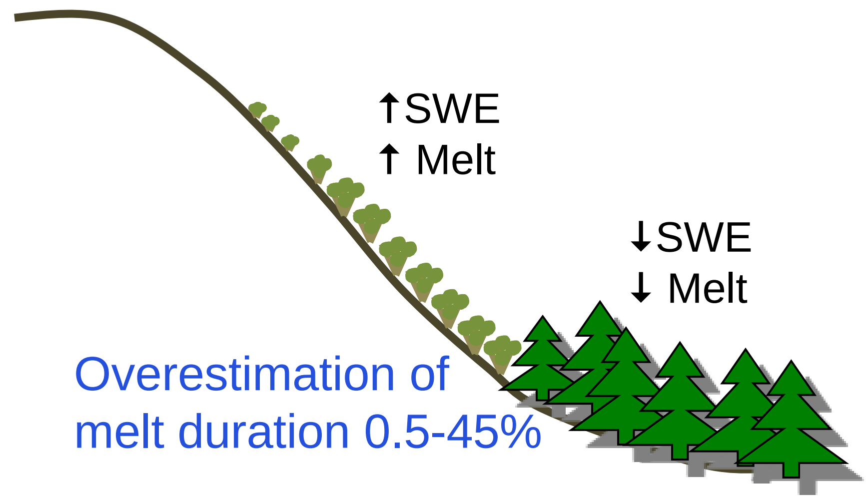
↓ SWE
↑ Melt

↑ SWE
↓ Melt

Underestimation of melt duration 4%

Large (basin) scale

Positive association M-SWE



↓SWE
↓ Melt

↑SWE
↑ Melt

↓SWE
↓ Melt

Overestimation of melt duration 0.5-45%

Pomeroy, Essery, and Toth (2004)
A. of Glaciol.,38,195-201.

Modelling Objectives

• Definition of an appropriate **modelling strategy** in complex subarctic environments.

1. Definition of an optimum representation of the **spatial heterogeneity** that would allow the scaling from point scale observations to catchment scale models in complex subarctic environments.
2. Effects of **spatially distributed solar forcing** and **initial snow conditions**.
3. Identification of **stable model parameterisations** using a landscape-based approach.

MODELLING METHODOLOGY

- **Distributed and Physically Based** → capture processes dynamics
- **Link mass and energy balances** → dominant structures in each of these different contexts are different

Combination of Top-Down and Bottom-Up Approaches

Modelling Methodology

Inductive Approach → basin segmentation

Deductive Approach ← process descriptions

Landscape based

Topography – vegetation

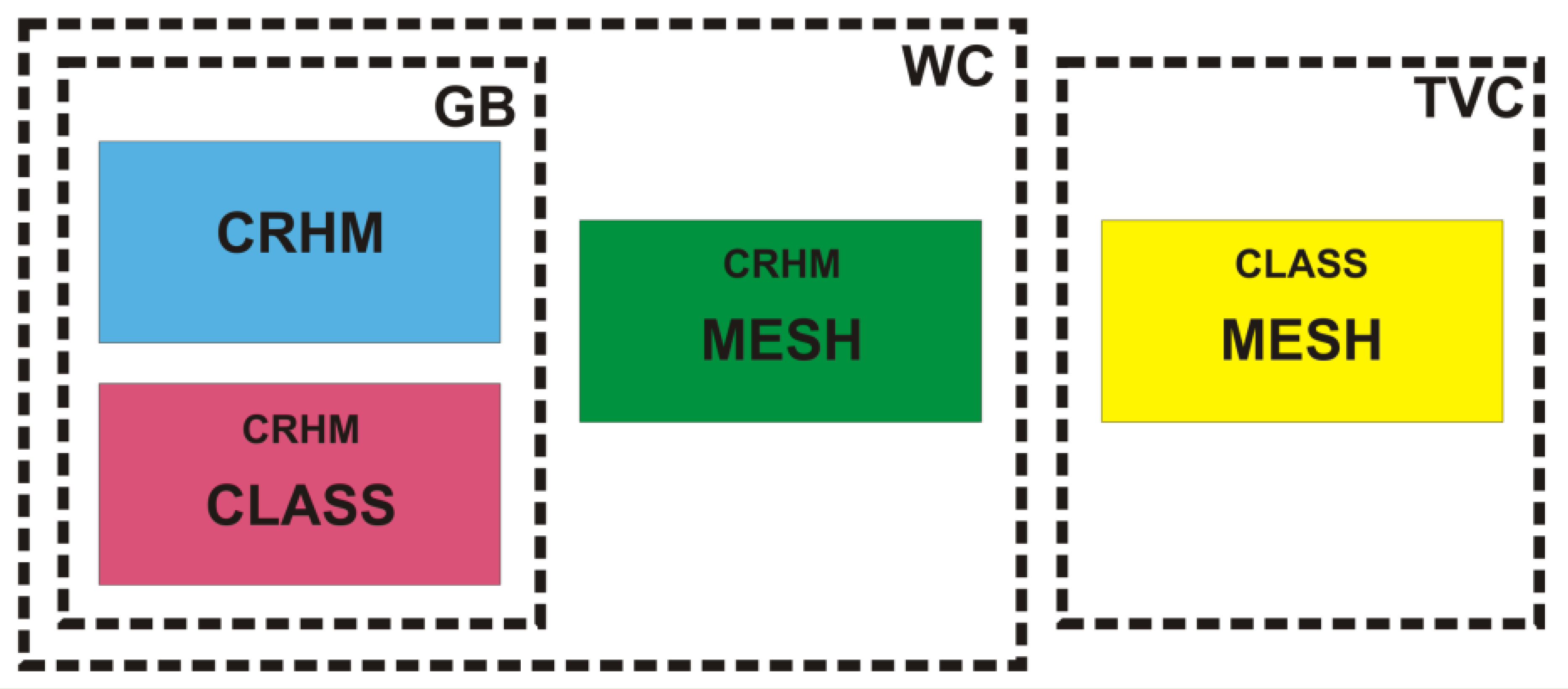
- Snow accumulation regimes
- Blowing snow transport
- Snowmelt energetics
- Snow interception
- Runoff generation/response

Detail process understanding
In cold regions research basins
(e.g. WC, TVC, prairies)

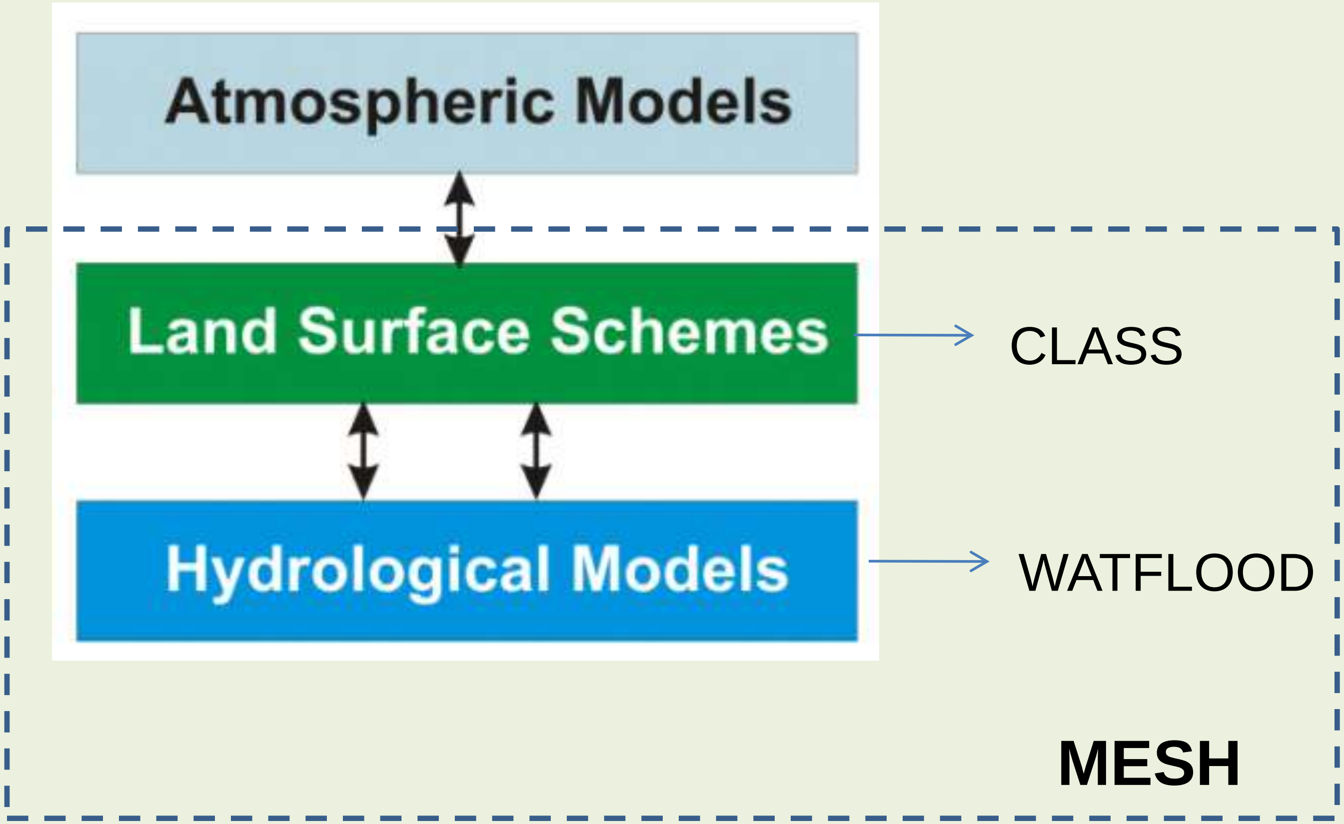
Modelling Methodology

Three models:

- Small-scale physically based Hydrological Model (CRHM)
- Land Surface Scheme (CLASS)
- Land Surface Hydrological Model (MESH)

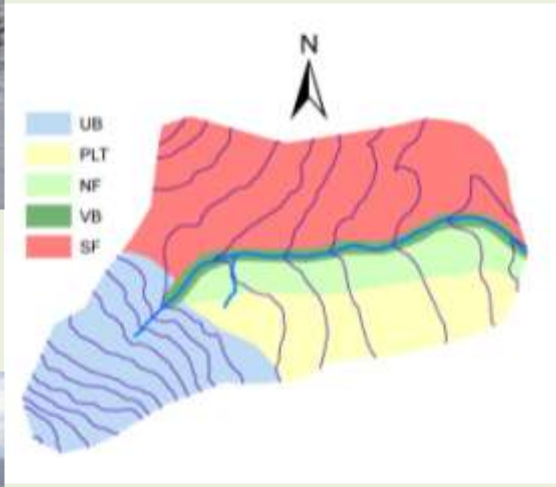


LAND SURFACE HYDROLOGICAL MODELS

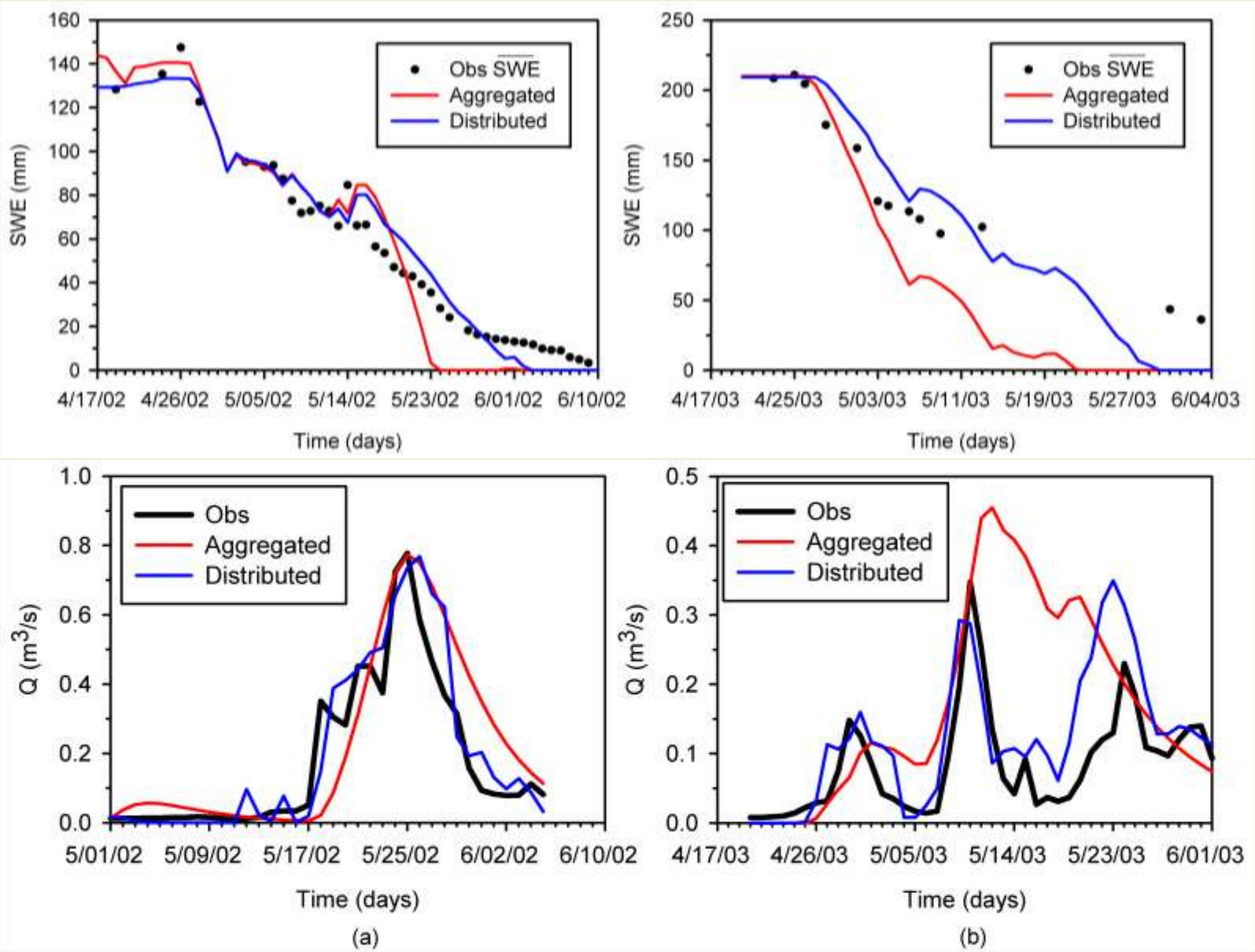


Landscape Heterogenety

Granger Basin

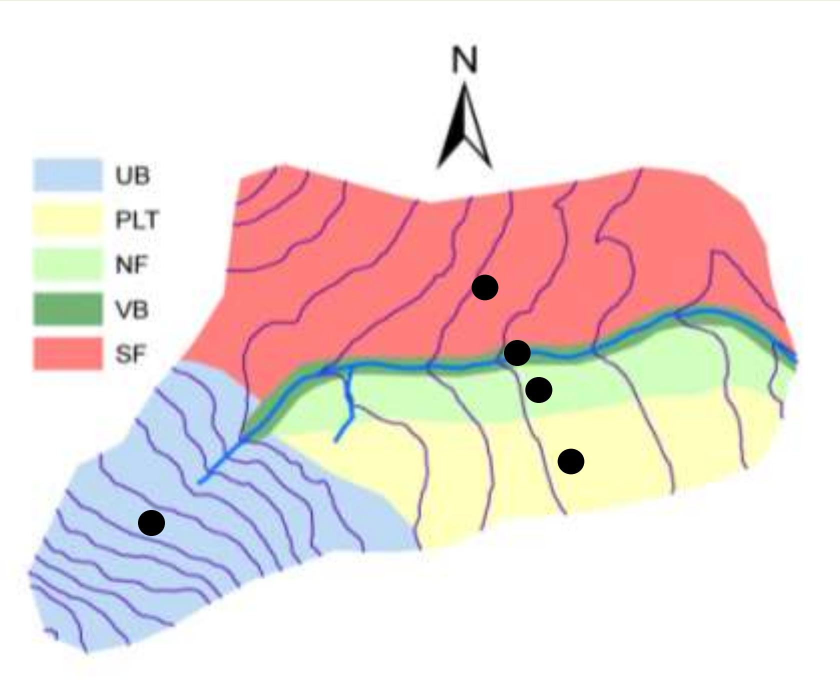


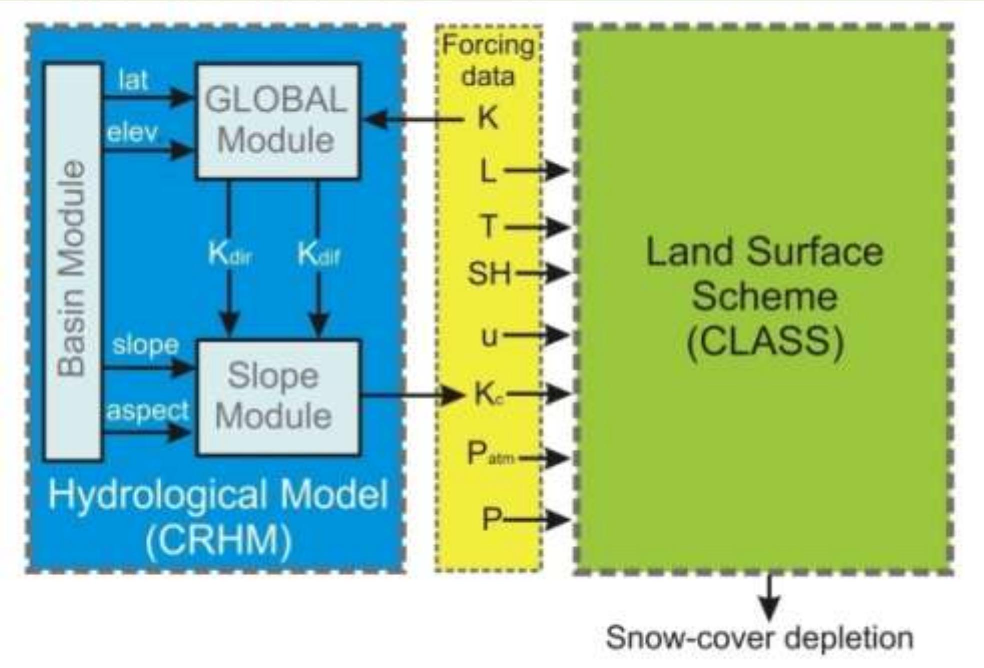
SNOWCOVER ABLATION AND SNOWMELT RUNOFF USING CRHM

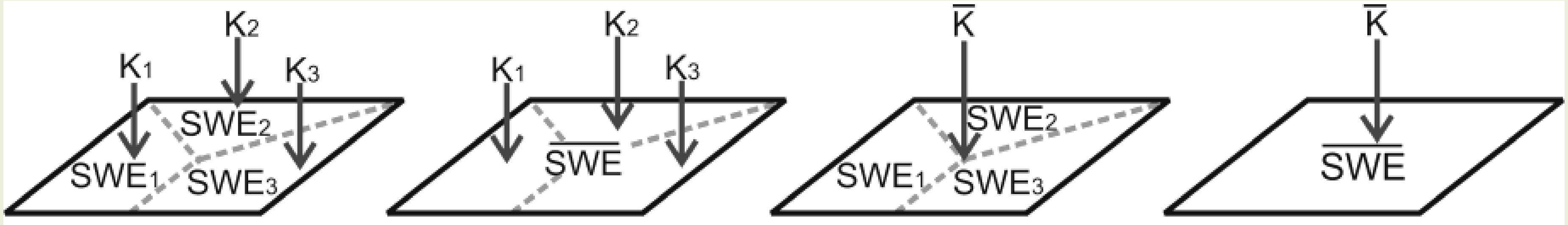


LAND SURFACE SIMULATIONS

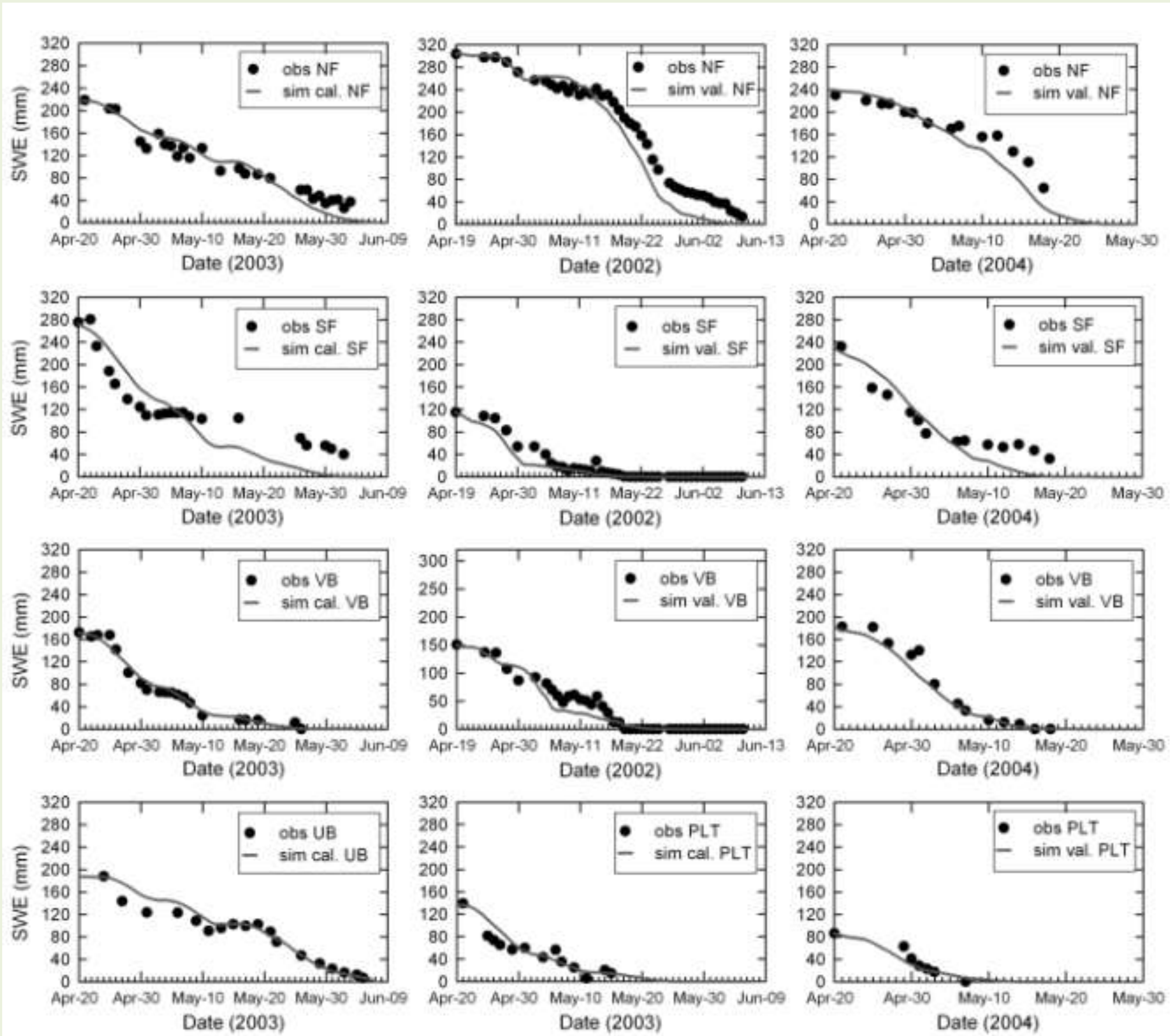
Snowcover ablation using 1D landscape based CLASS simulations



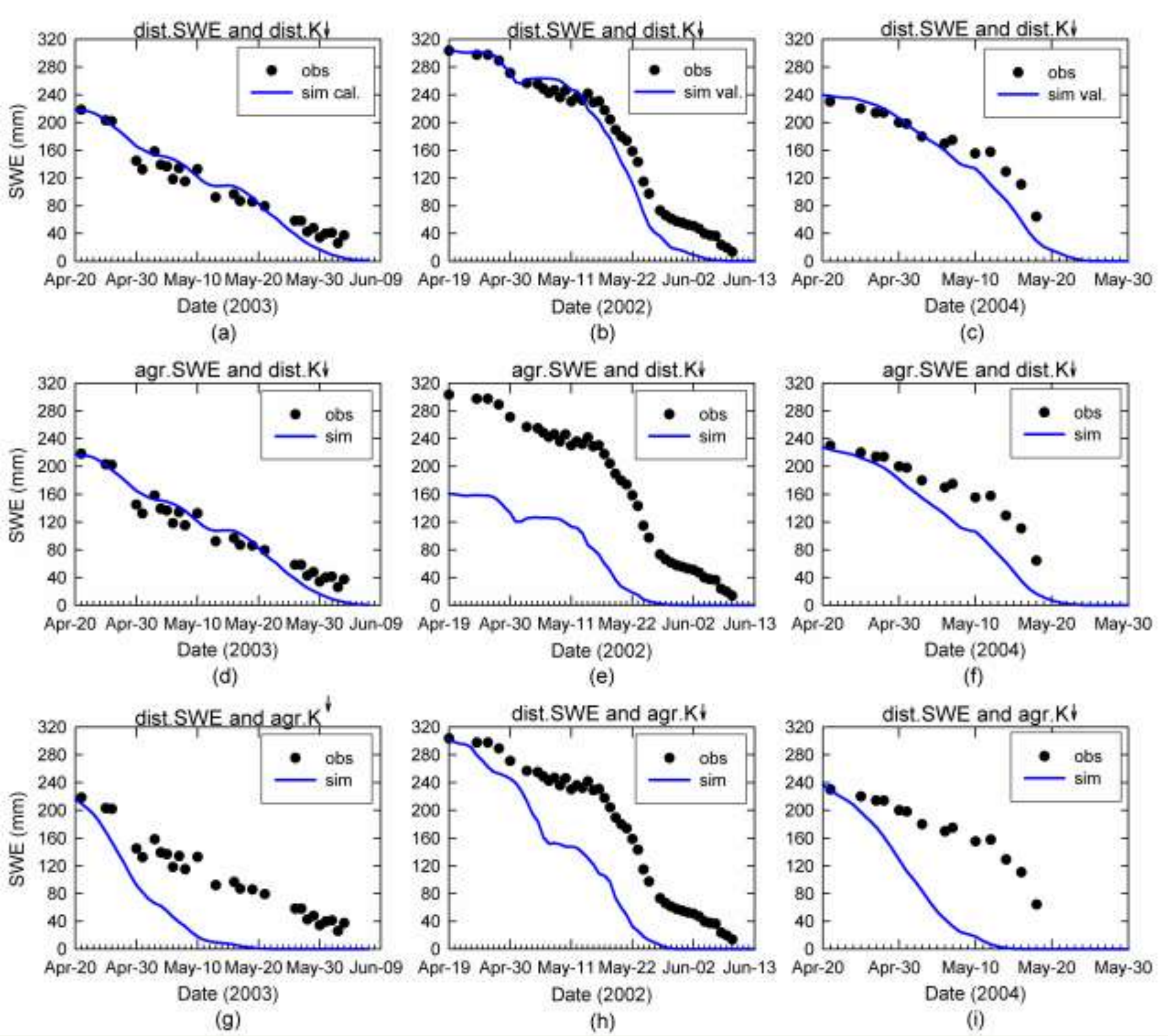




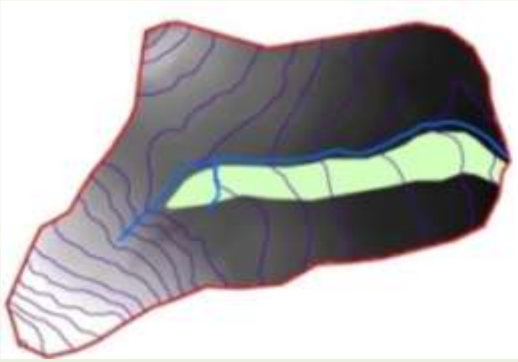
SNOW COVER ABLATION USING CLASS



INITIAL CONDITIONS AND SOLAR FORCINGS



North facing slope

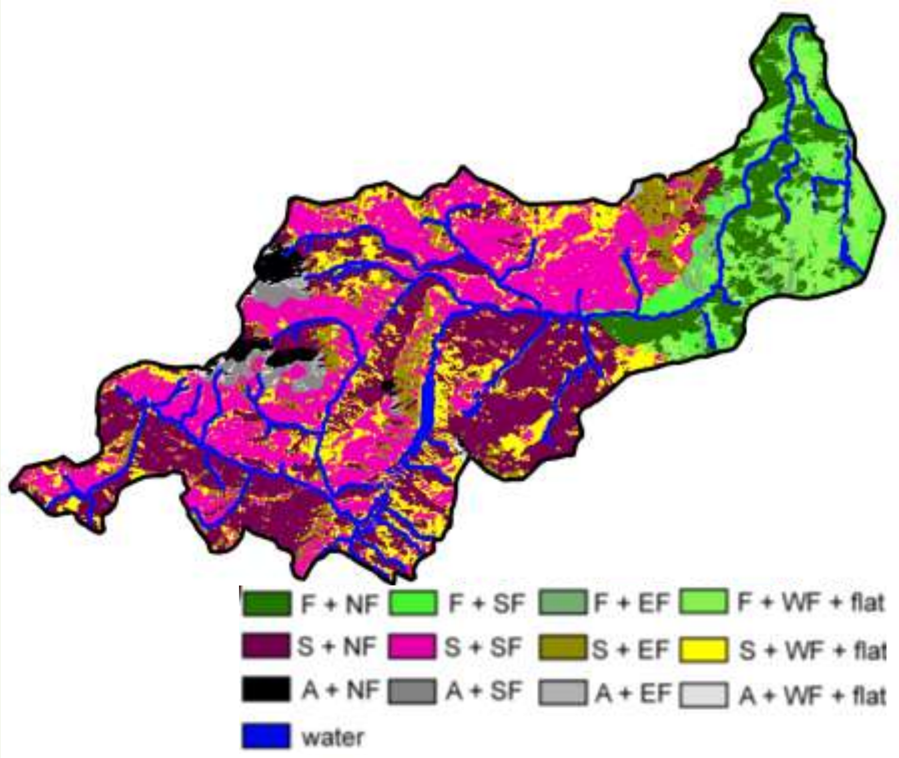


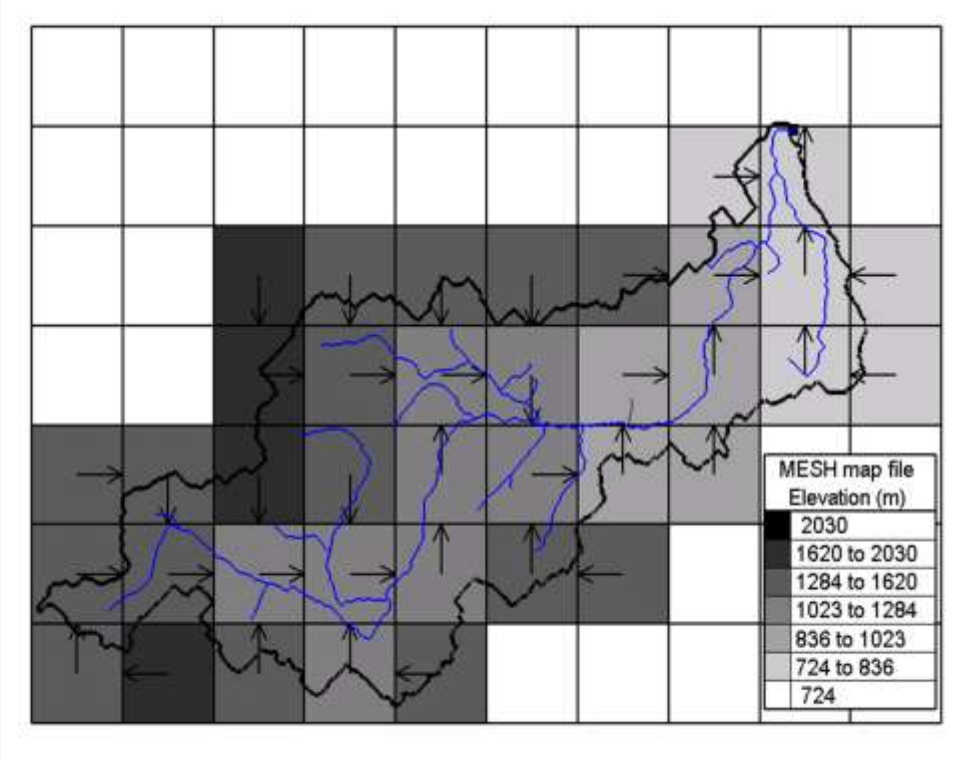
Hydrological Land Surface Simulations

Snowcover ablation and Snowmelt runoff using MESH

Spatial representation based on the GRU approach

- Definition of GRU based on:
    - Topography and vegetation cover

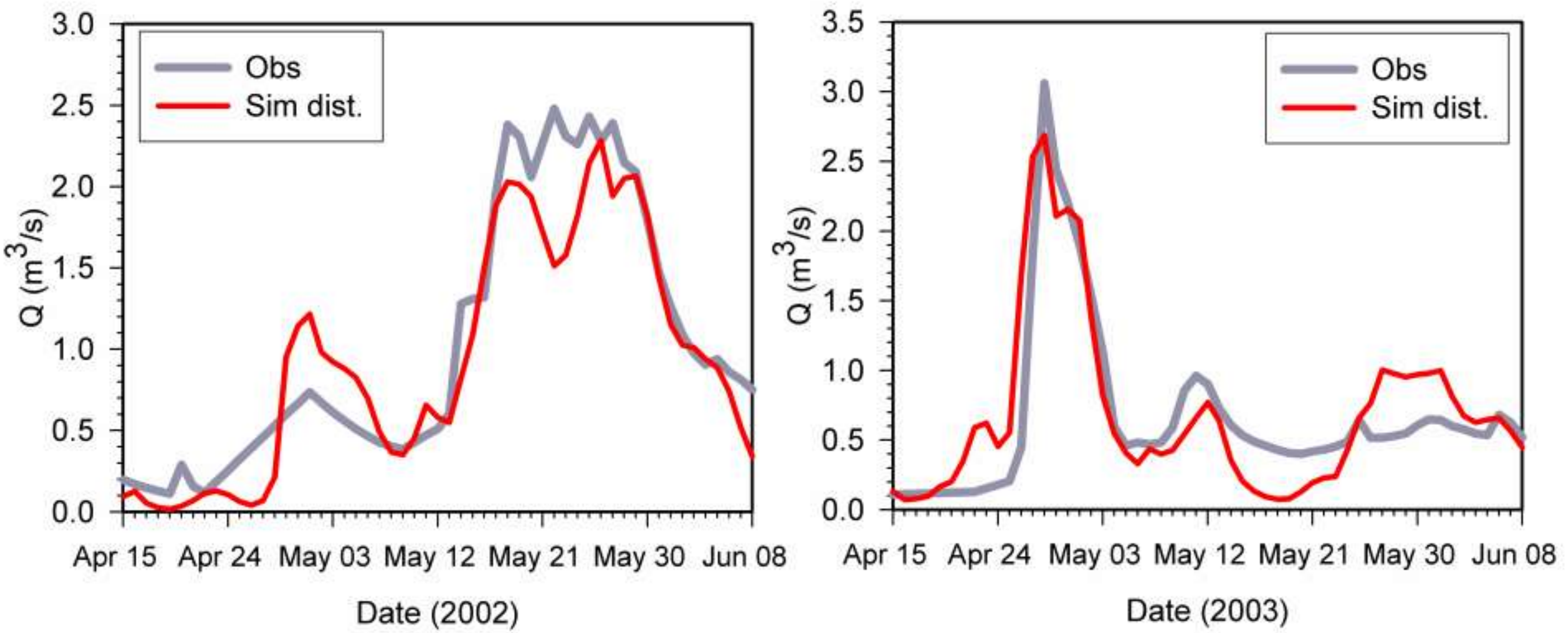




Grid size 3 km x 3 km

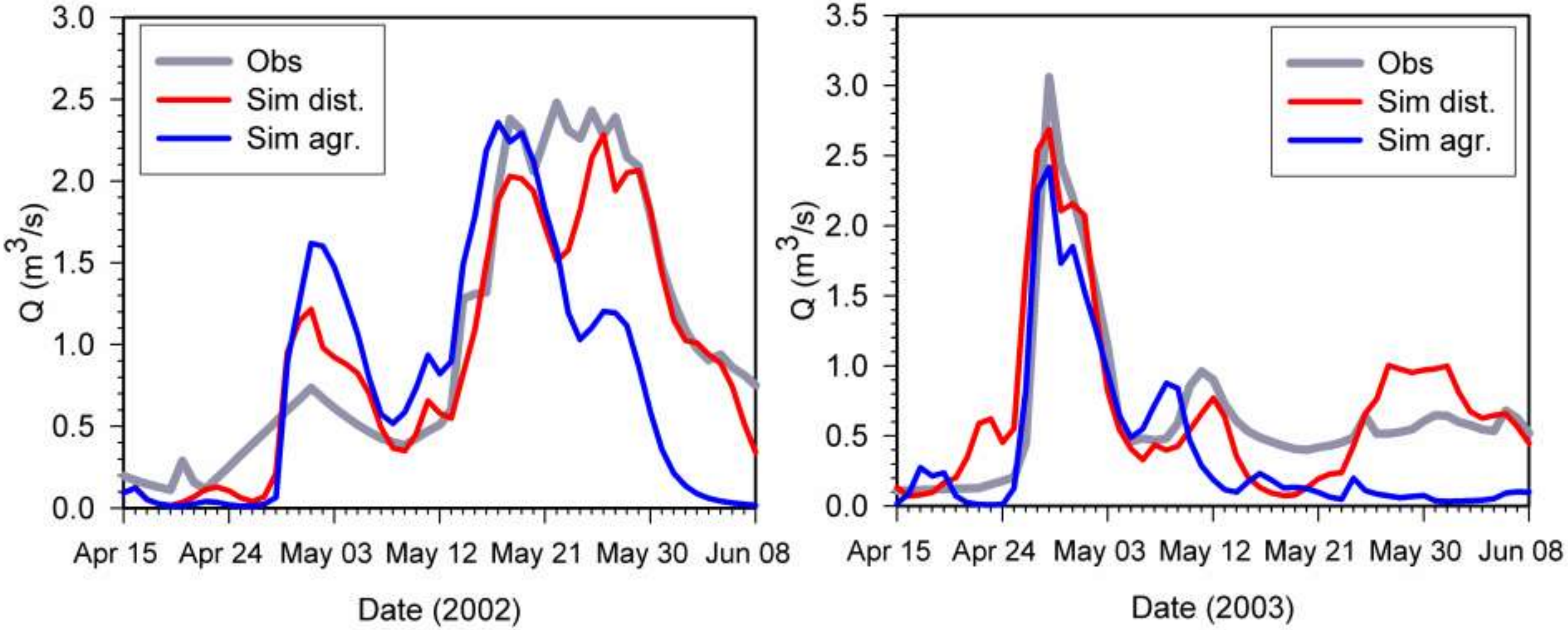
BASIN STREAMFLOW SIMULATIONS

Wolf Creek Reserach Basin



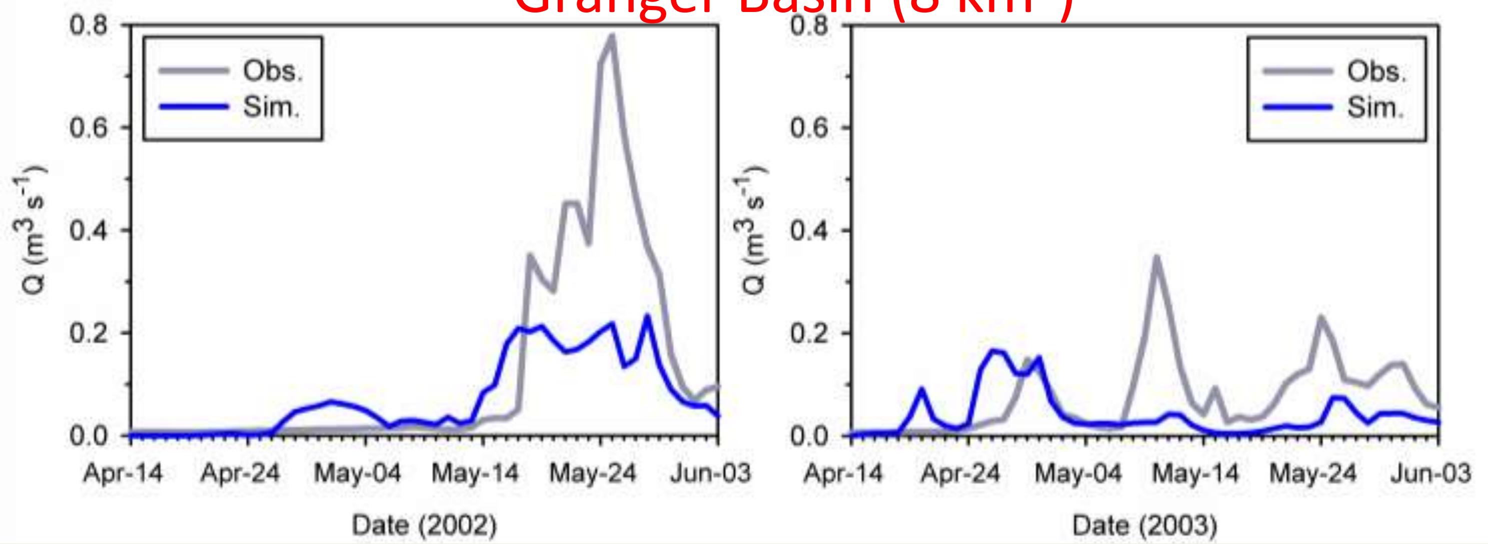
Basin Streamflow Simulations

Wolf Creek Reserach Basin

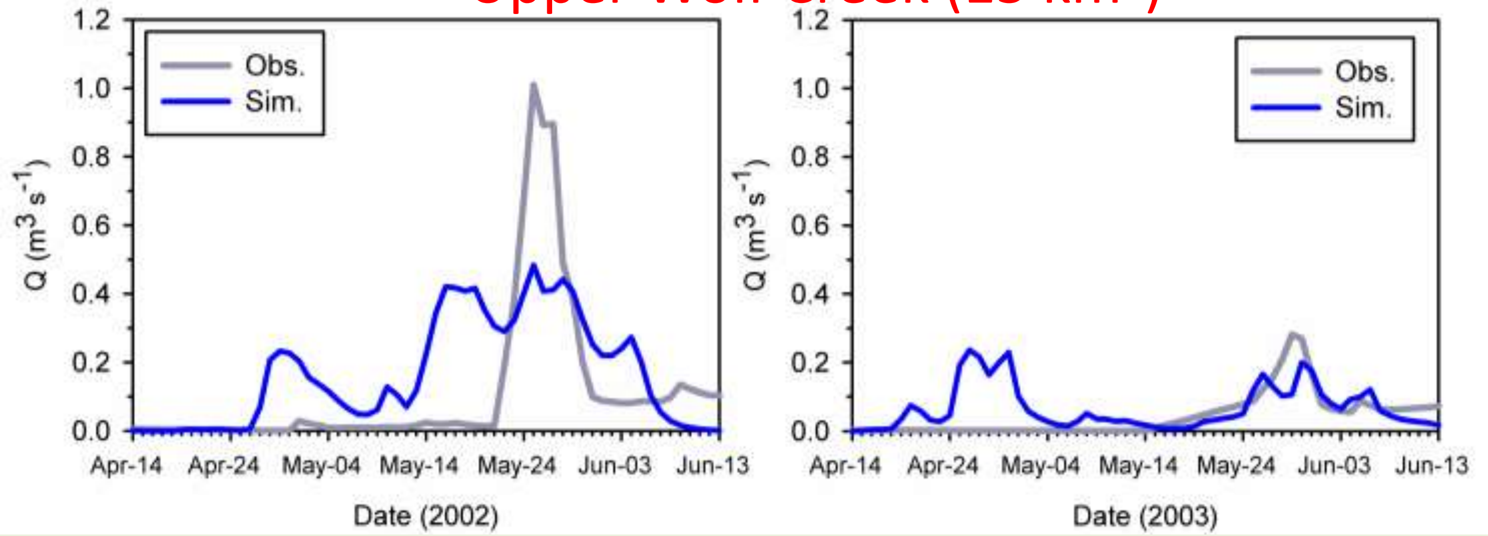


Distributed Validations of Streamflow Simulations

Granger Basin (8 km²)

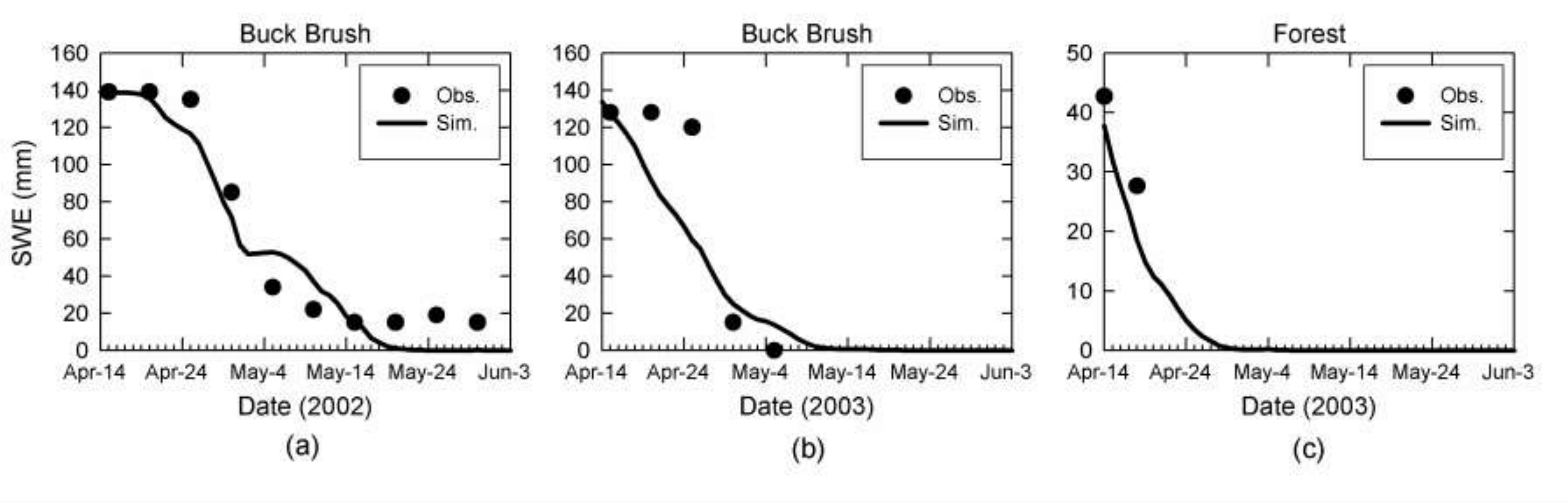


Upper Wolf Creek (15 km²)



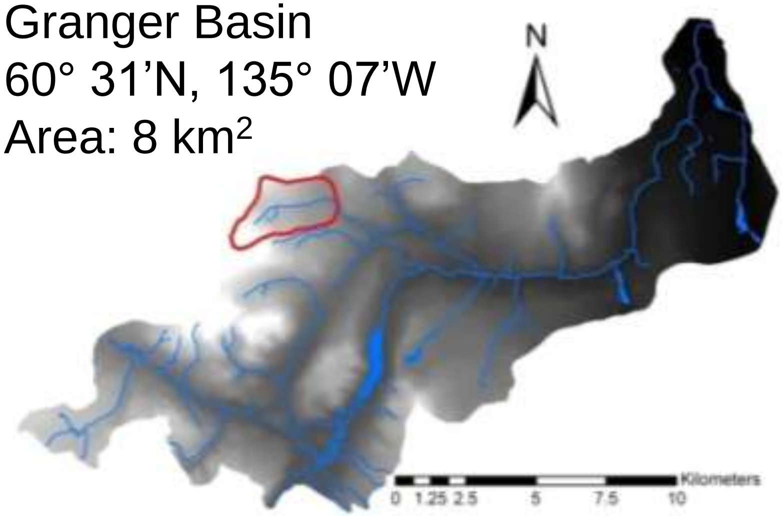
DISTRIBUTED VALIDATIONS OF SNOWCOVER ABLATION

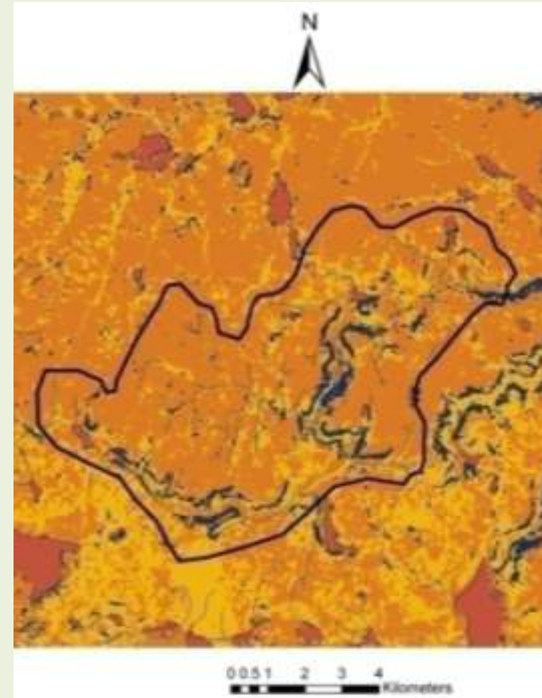
Wolf Creek Reserach Basin



PREDICTIVE UNCERTAINTY

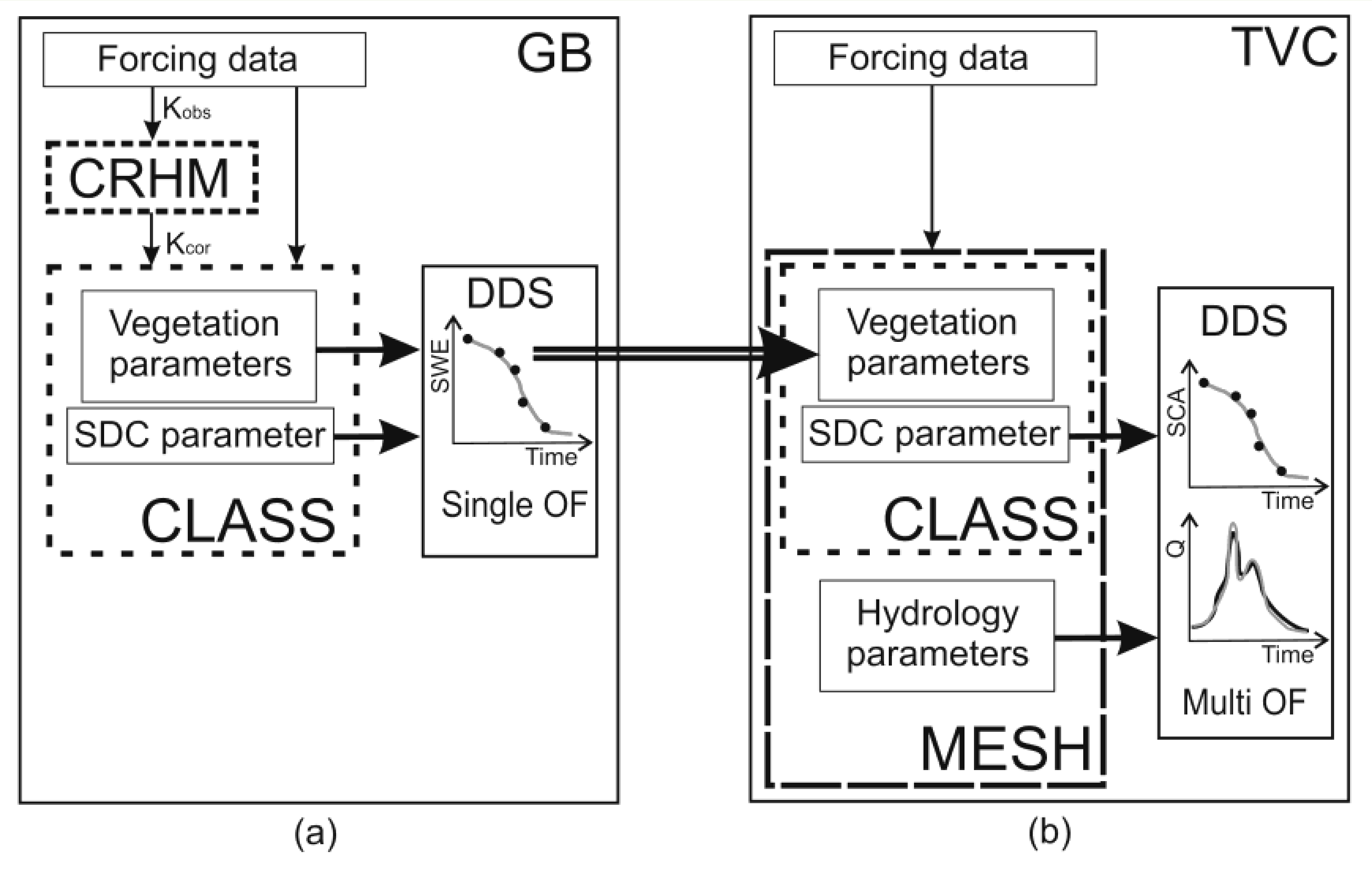
Granger Basin
60° 31’N, 135° 07’W
Area: 8 km^2



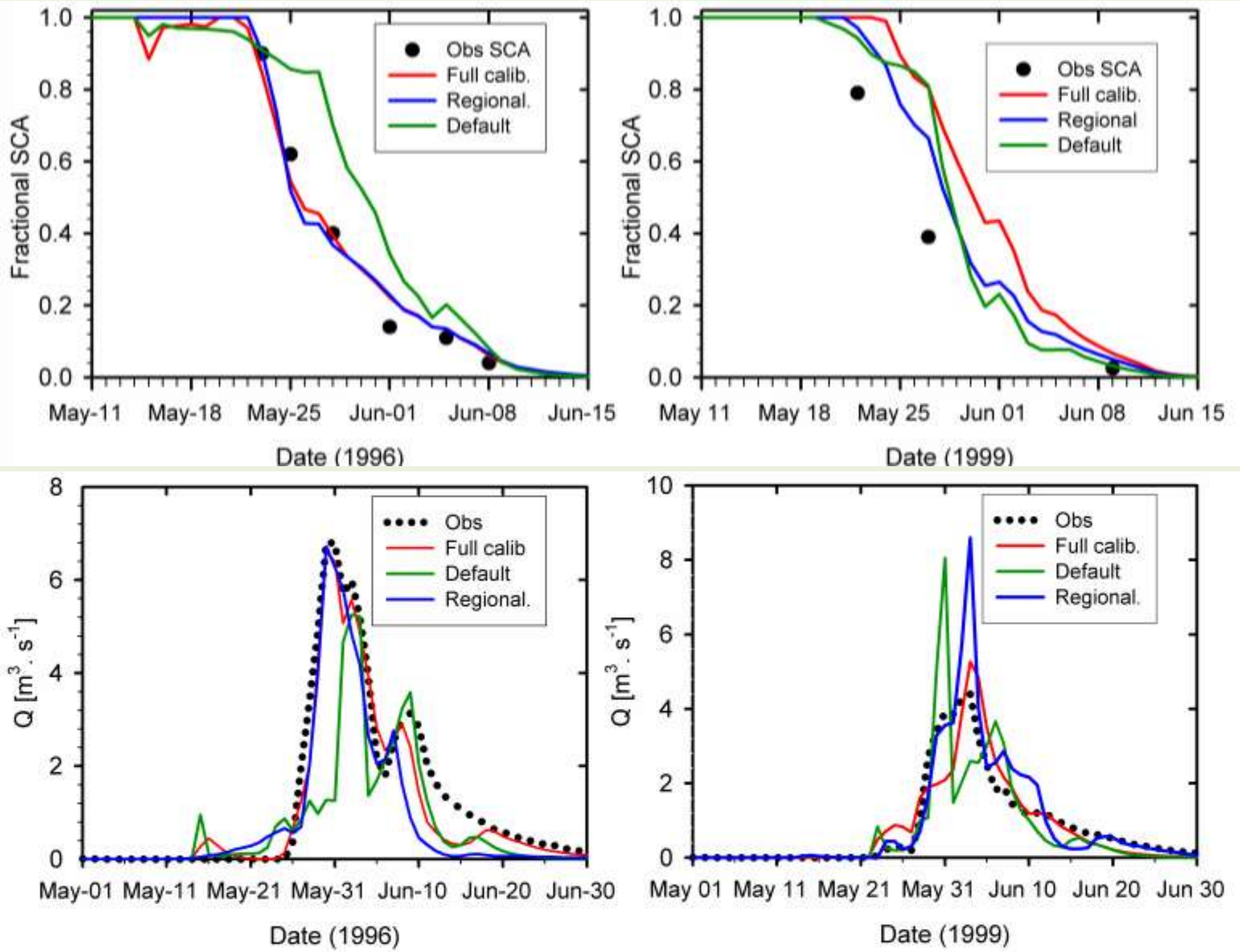


TVC Basin
68° 45’N, 133° 30’W
Area: 63 km^2

LANDSCAPE BASED APPROACH TO REGIONALISATION



LANDSCAPE BASED APPROACH TO REGIONALISATION



CONCLUSIONS

- The combination of deductive (BU) and inductive (TD) modelling approaches is an useful methodology for effectively representing and conceptualising landscape heterogeneity in sub-arctic environments.
- It is an modelling approach that learn from the capabilities of the BU in describing detail processes to somehow simplify landscape heterogeneity using an holistic TD approach.
- Landscape-based parameter can be transferred to similar landscapes in regional basins if physically based models are used, therefore reducing the predictive uncertainty of hydrological and LSS models in ungauged basins.
- Explicit landscape representations improve model predictions.
- Inadequate or unrepresentative initial snowcover conditions and forcing data caused unsatisfactory model predictions.

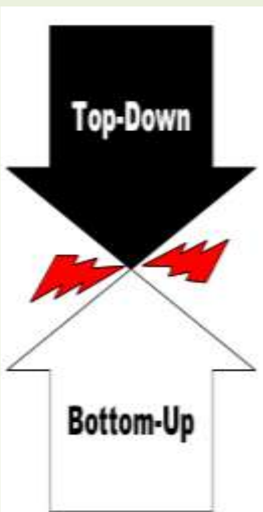
Contributions

- **Research implications**:
  - Development of a new modelling strategy for simulating snowcover ablation and snowmelt runoff in subarctic mountainous environments.
  - Verification that the representation of melt based on average energy flux, snow state, and flat-plane conceptualisation is not always appropriate.

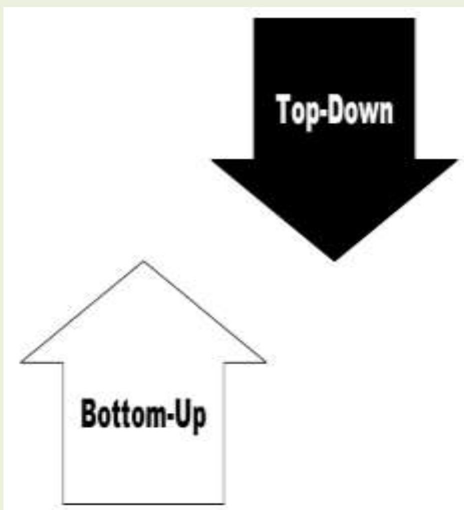
- **Practical Implications**:
  - The need for incorporation of blowing snow process to properly set the initial snow cover conditions.
  - The need for incorporation of differential forcing
  - Landscape basin segmentation / landcover based parameterisation necessary to reduce predictive uncertainty

MODELLING PHILOSOPHY

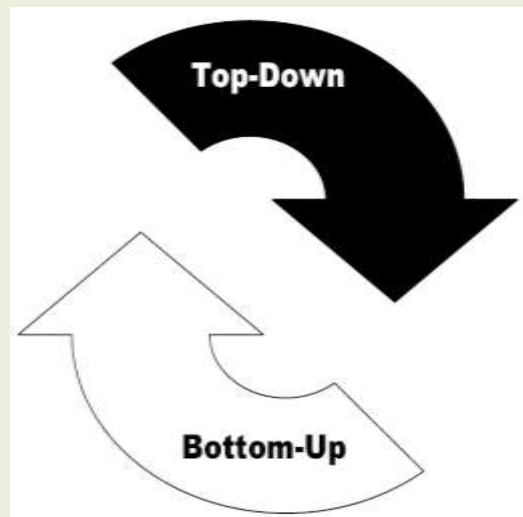
Two irreconcilable approaches



Two complementary approaches



Two approaches working together



Two approaches in fully harmony


Thank you