Toward an Improvement of the Hydrological Performance of the SWAT Model under Snow Cover and during Snowmelt

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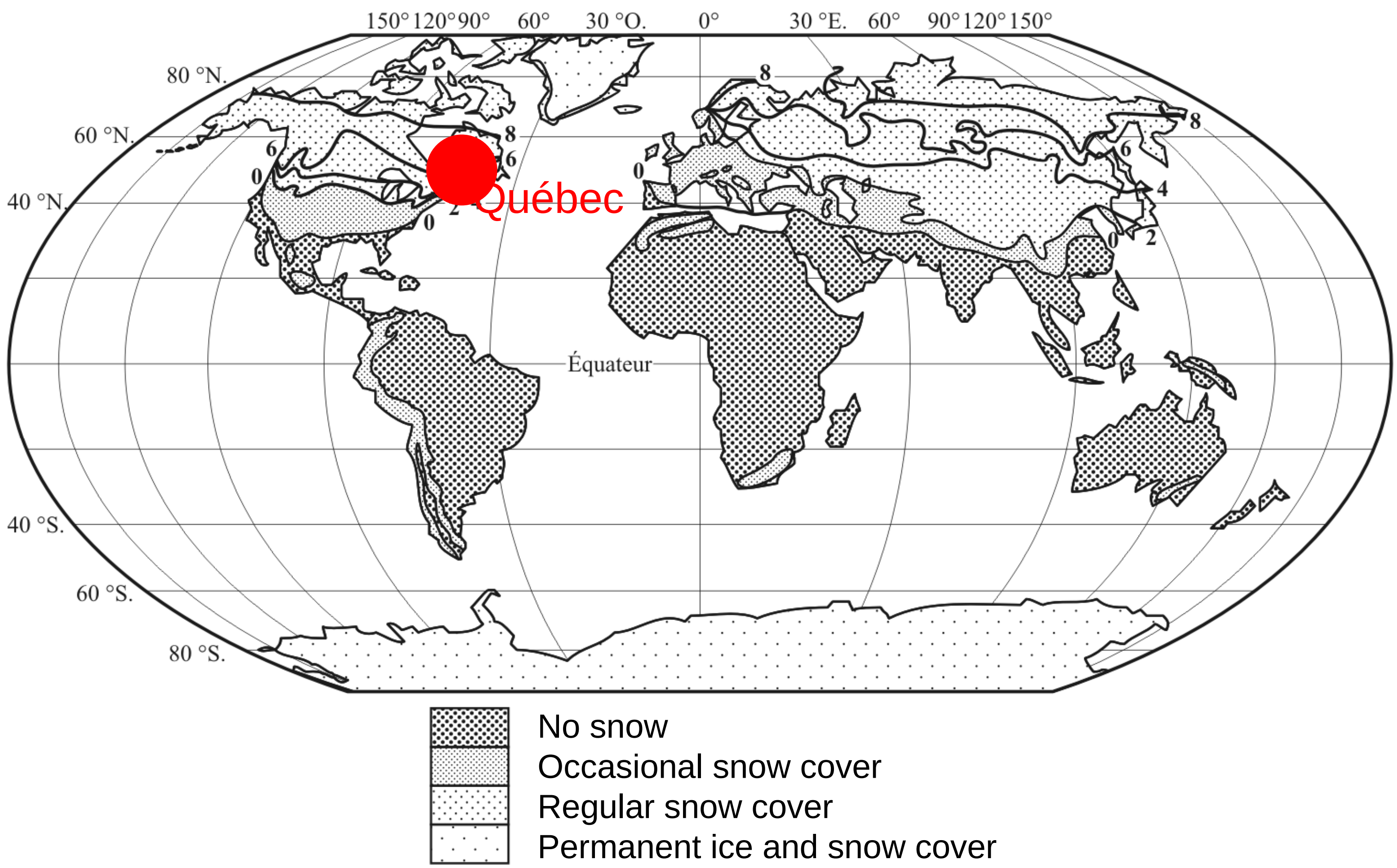
Winter season dynamics

- November to May (up to 7 months)
- Snow accumulation
  - Subfreezing air temperature
  - Low water level period
  - Minimum effluent dilution
- Snowmelt
  - Lasts 2 to 4 weeks
  - May combine with rainfalls
  - Generally leads to the most important flood of the year

Duration of the snow cover



Winter season dynamics

Q

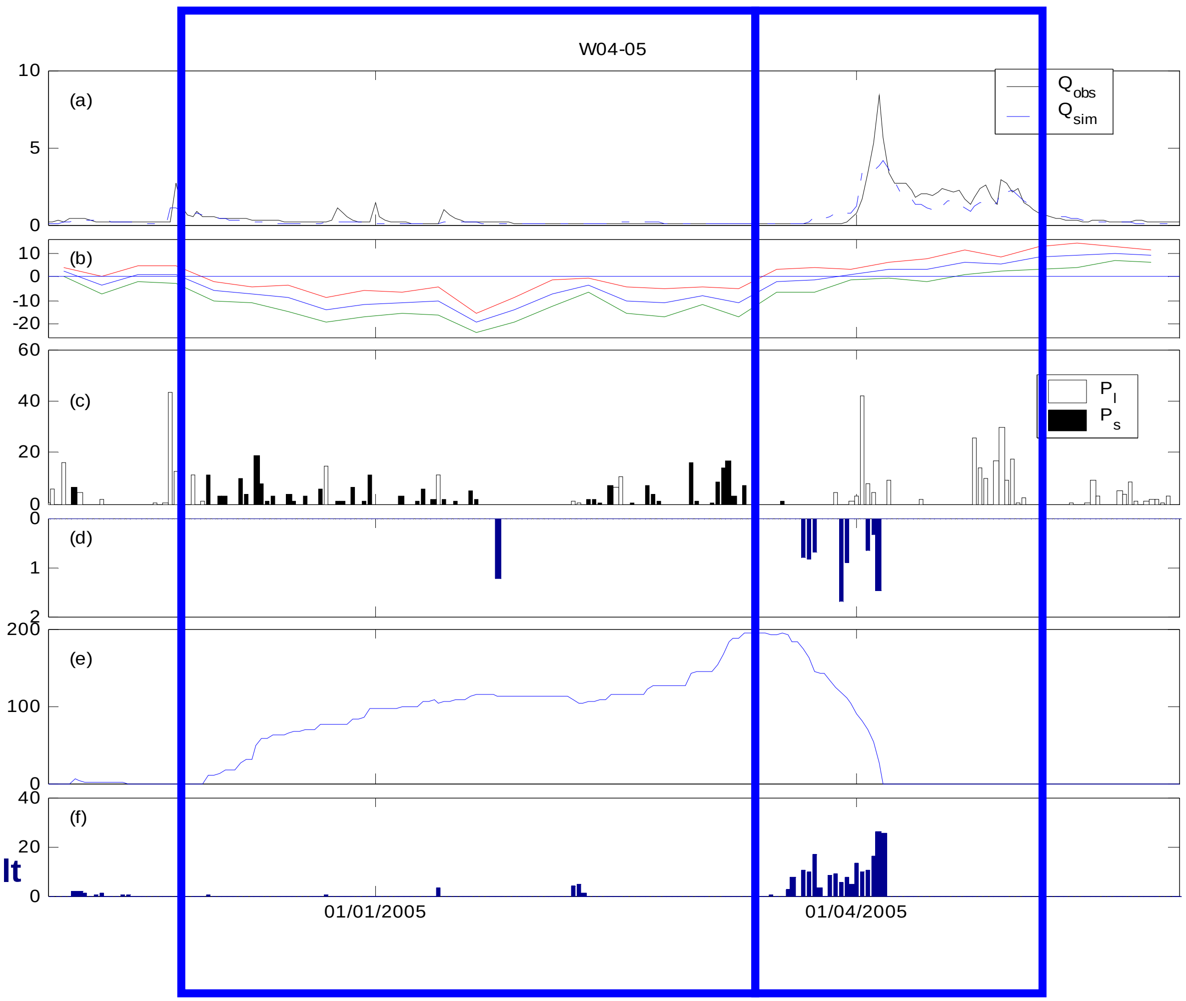
Temp

P_s

E_{sublim}

Snow

$Snow_{mlt}$



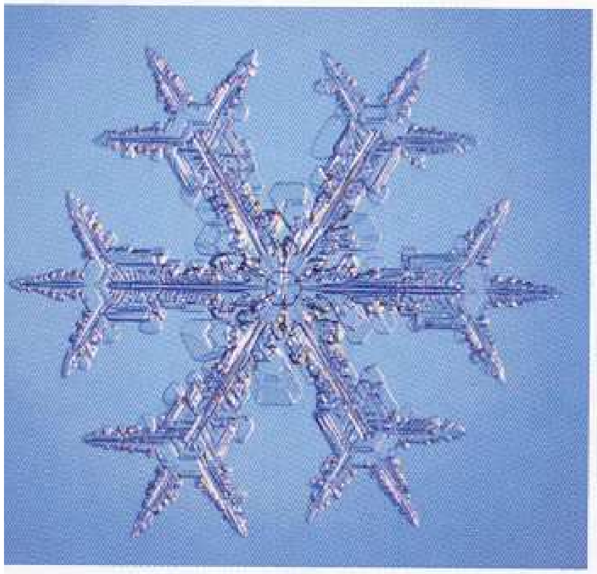
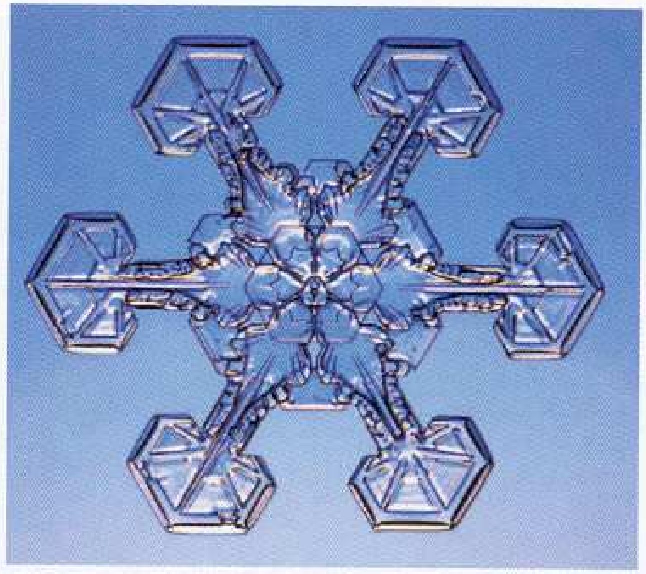
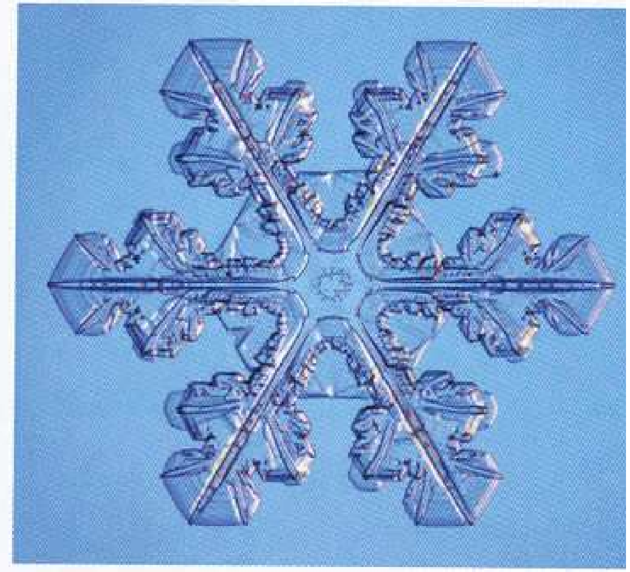
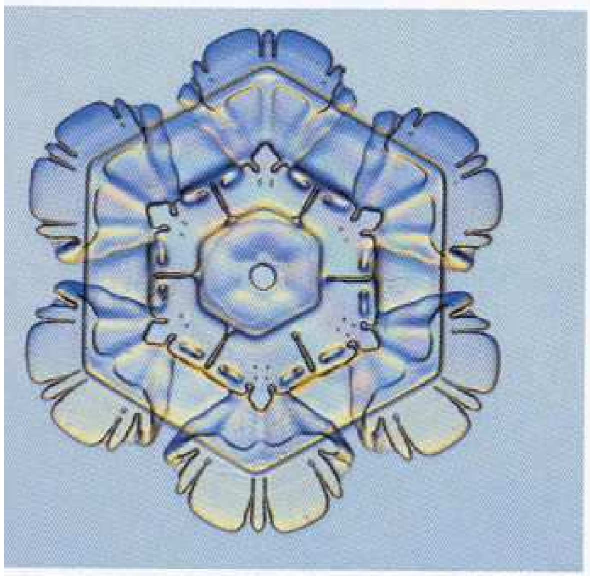
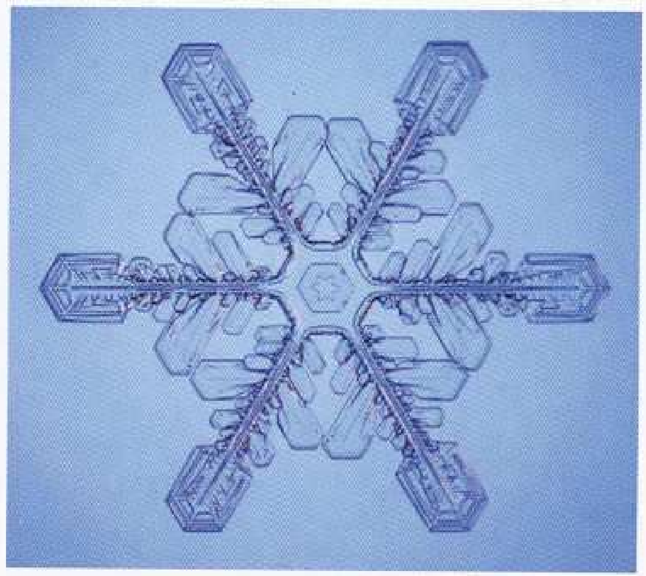
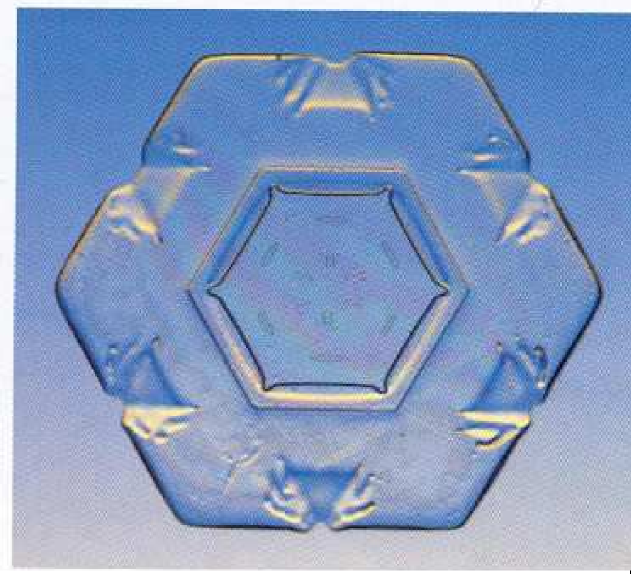
Low water level period

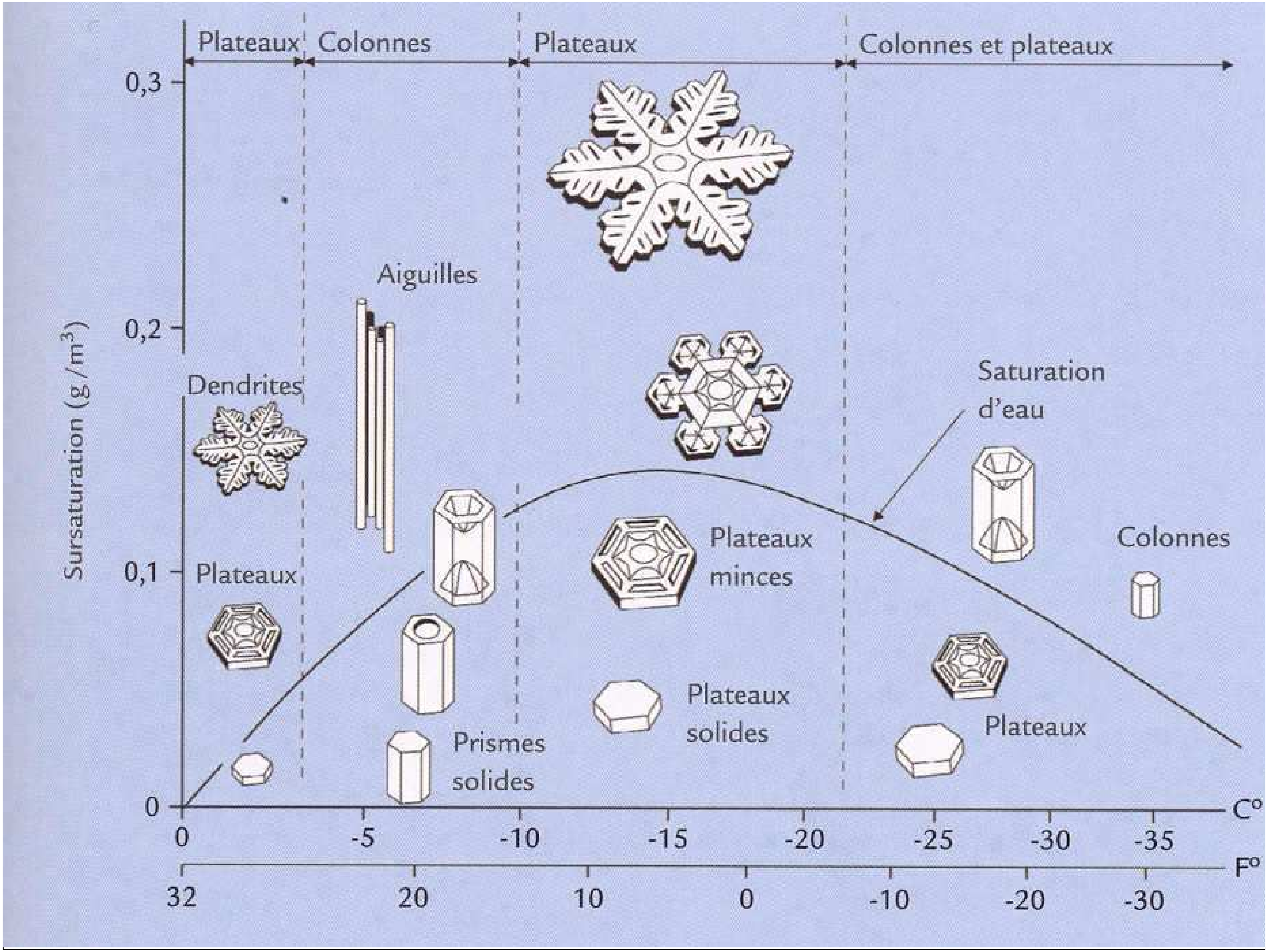
[+]

[-]

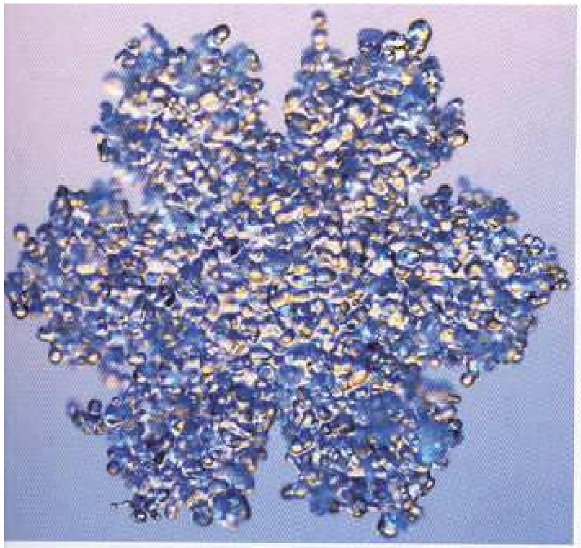
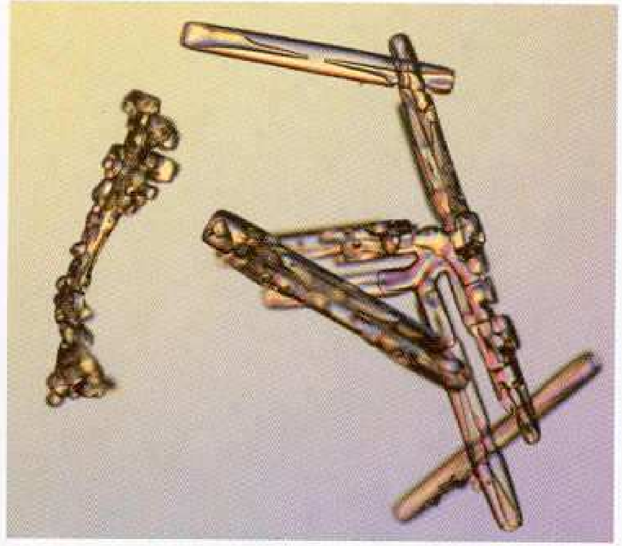
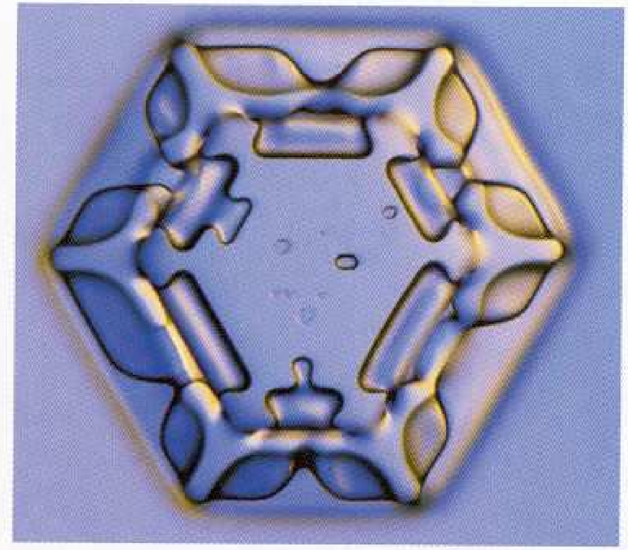
Spring flood related melt event

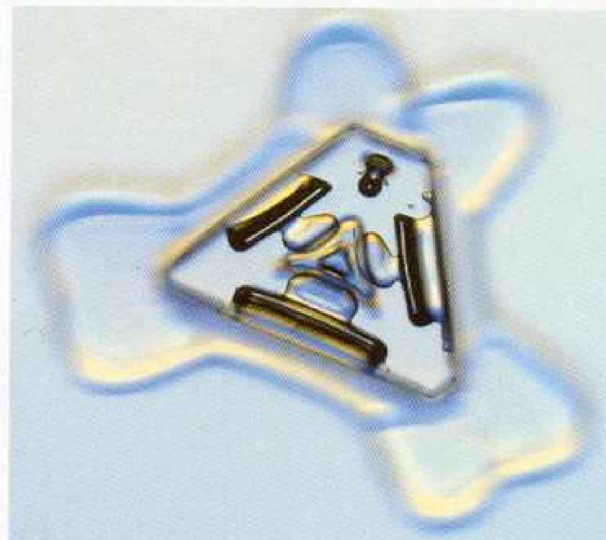
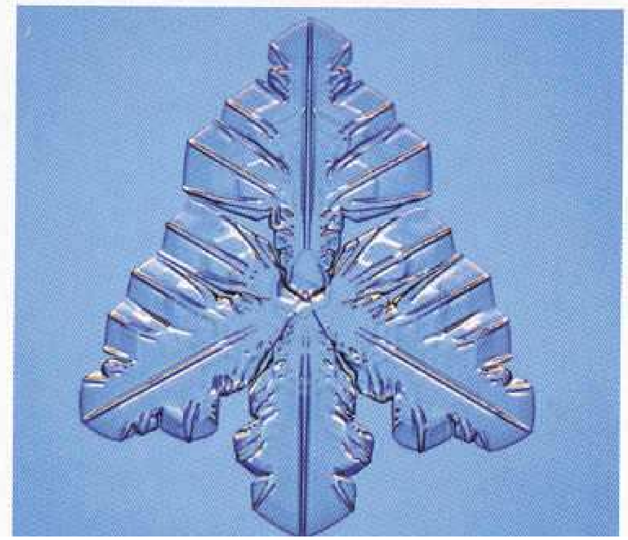
[-]



Plateaux
Colonnes
Plateaux
Colonnes et plateaux
0,3
0,2
0,1
0
Sursaturation (g / m³)
Aiguilles
Dendrites
Plateaux
Prismes
solides
Plateaux
minces
Plateaux
solides
Saturation
d'eau
Colonnes
Plateaux
C°
0
-5
-10
-15
-20
-25
-30
-35
F°
32
20
10
0
-10
-20
-30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Objectives

- Assess the required refinement level of the SWAT snow model

- Enhance water quantity and water quality simulations

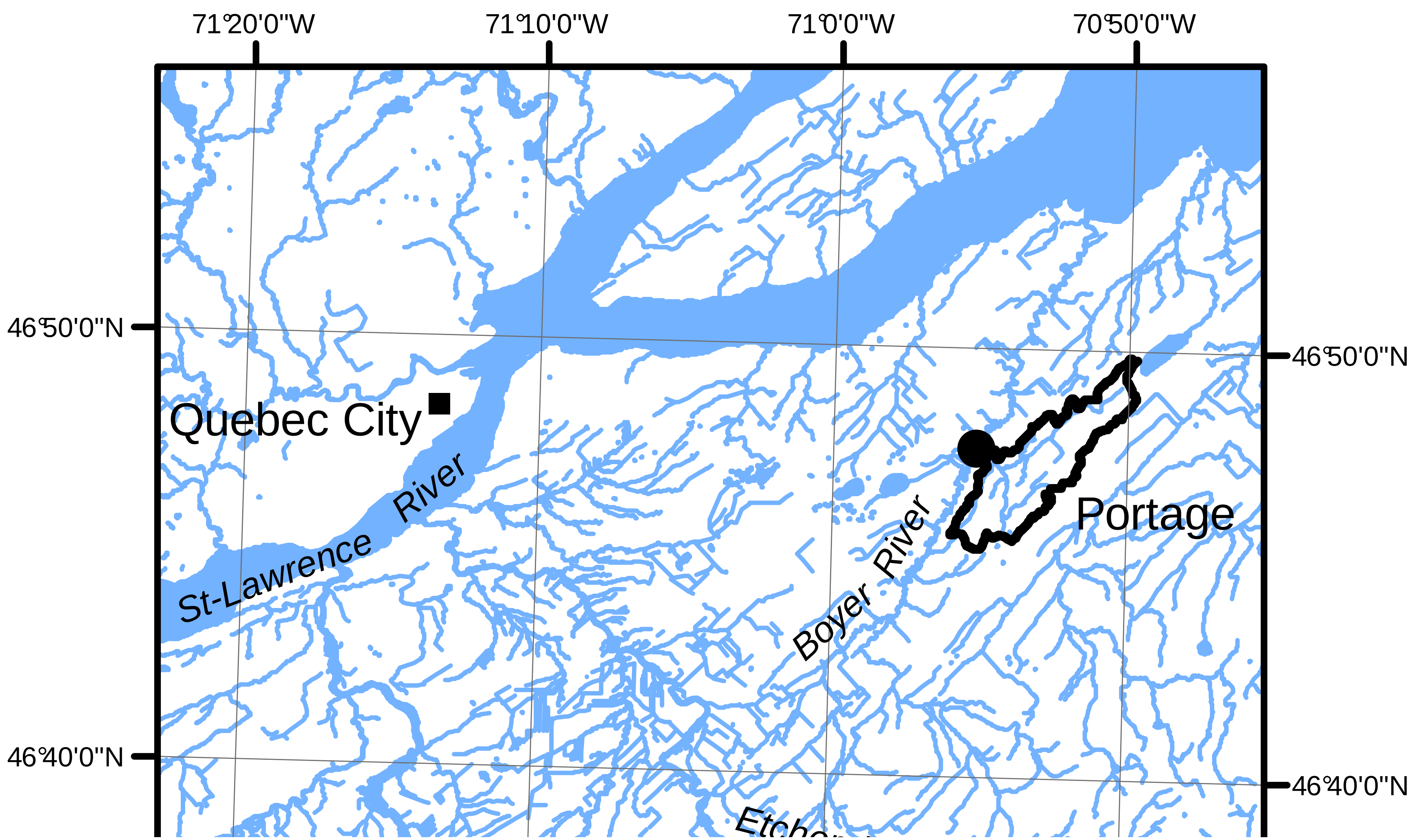
Scientific context

- The spring flood associated to the snowmelt largely contributes to the sediment and the annual nutrient loads
- Accurate modeling of the flow paths
  - Getting the right answers for the right reasons!

Experimental protocol

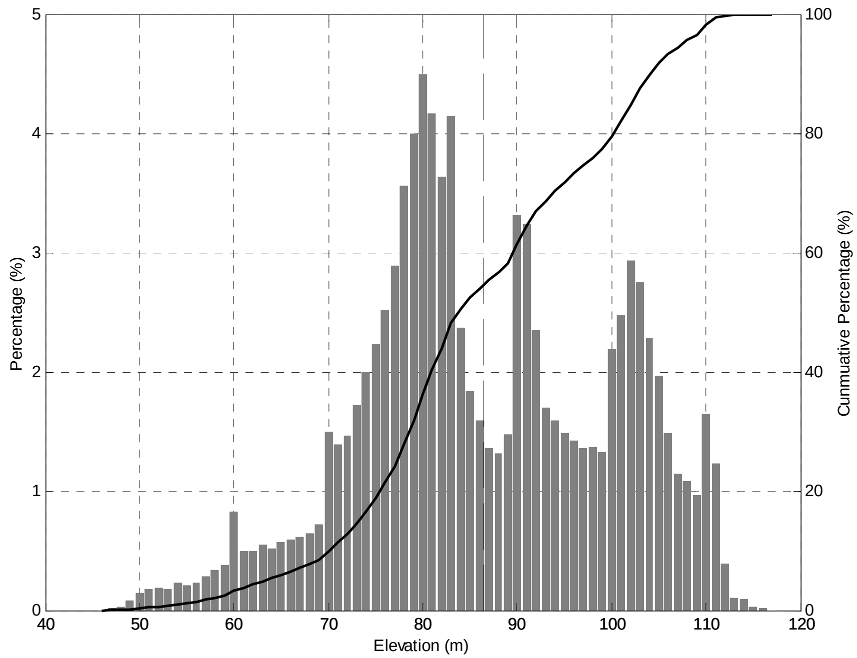
- Model
  - SWAT release 2005
- Sensitivity analysis
  - Latin Hypercube
    - One-at-the-time
- Automatic calibration
  - Shuffled Complex Evolution Algorithm – SCE-UA

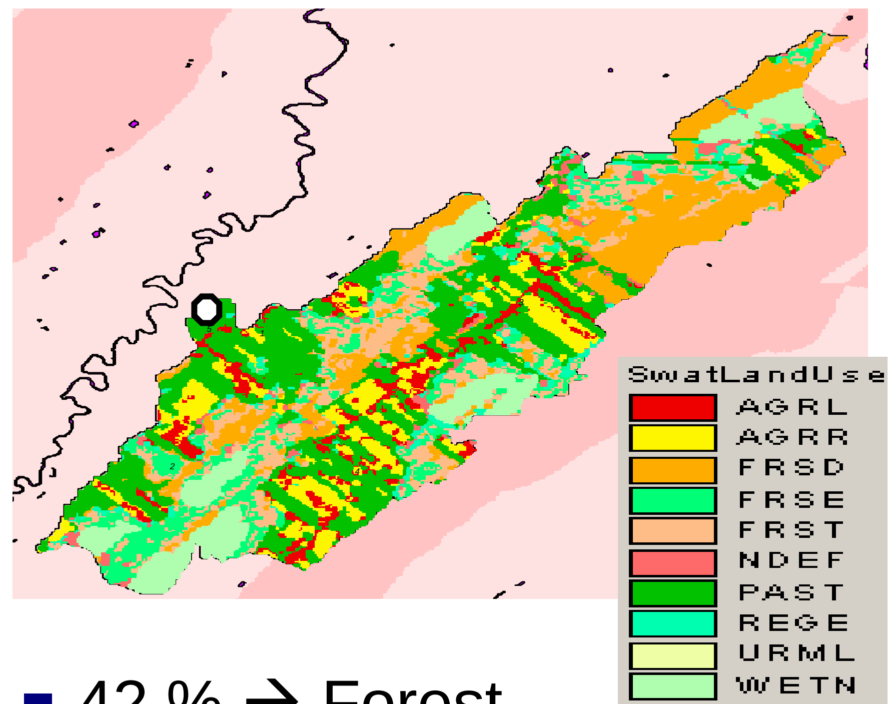
Ruisseau Portage



Ruisseau Portage

- 21,41 km^2
- 5 subbassins





- 42 % → Forest
- 16 % → Agriculture
- 27 % → Pasture

Winter hydrologic yield

- A → 1999 – 2002
- B → 2002 – 2005

$$r = \frac{\sum_{i=1}^{n} Q_i}{\sum_{i=1}^{n} P_i}$$

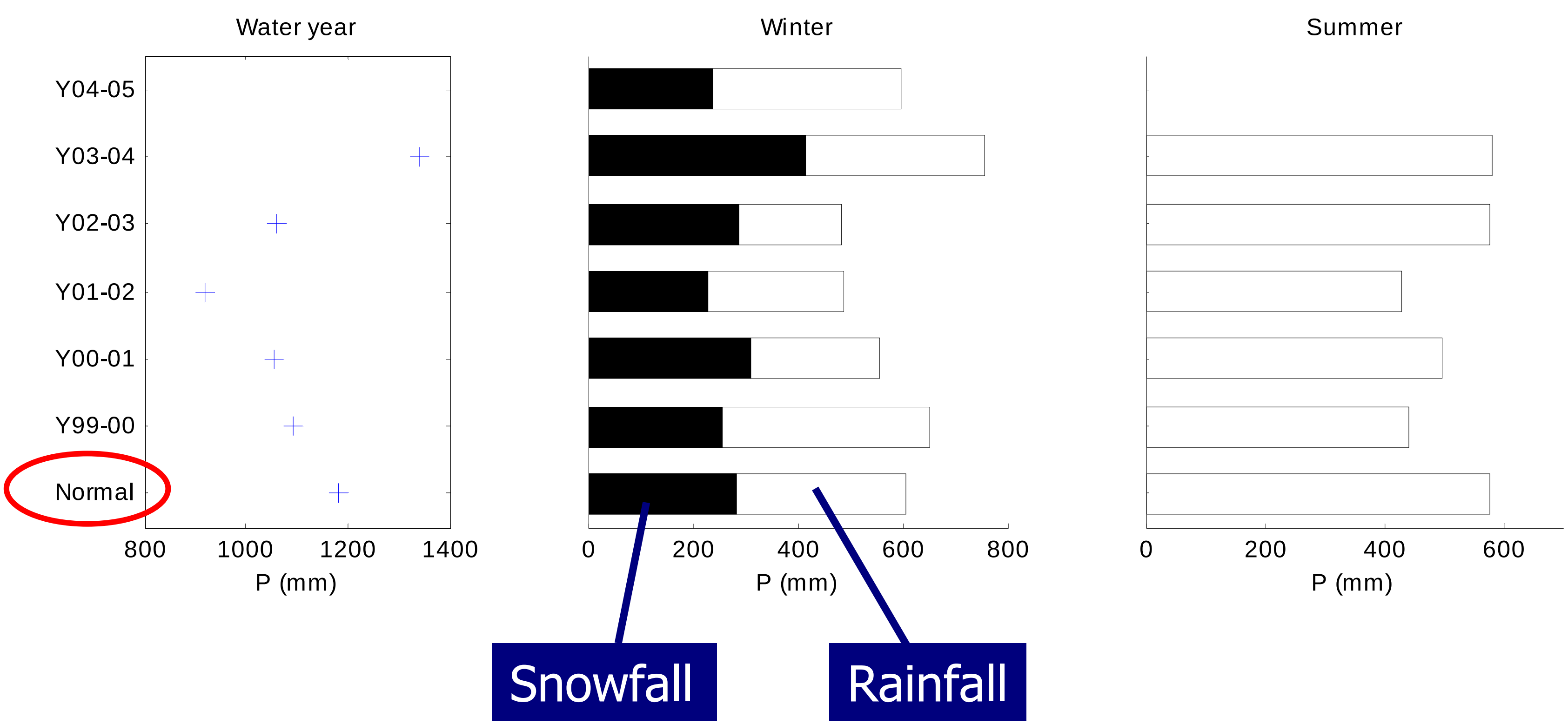
Winter	Obs	A→B	B→A
1999-00	0.8226	0.6759	0.6606
2000-01	0.8646	0.6696	0.6810
2001-02	N/A	0.5590	0.5879
2002-03	0.9215	0.6233	0.6339
2003-04	0.6806	0.7318	0.7573
2004-05	0.8320	0.6388	0.6477

Sources of uncertainty

- In the observations
  - Stream flows
    - The river ice cover leads to stream flow overestimation
      - Reduces the flow section
      - Amplifies the pressure within the water column
    - Are manually corrected by experienced staff
      - Reduced by a factor up to 20 or more !

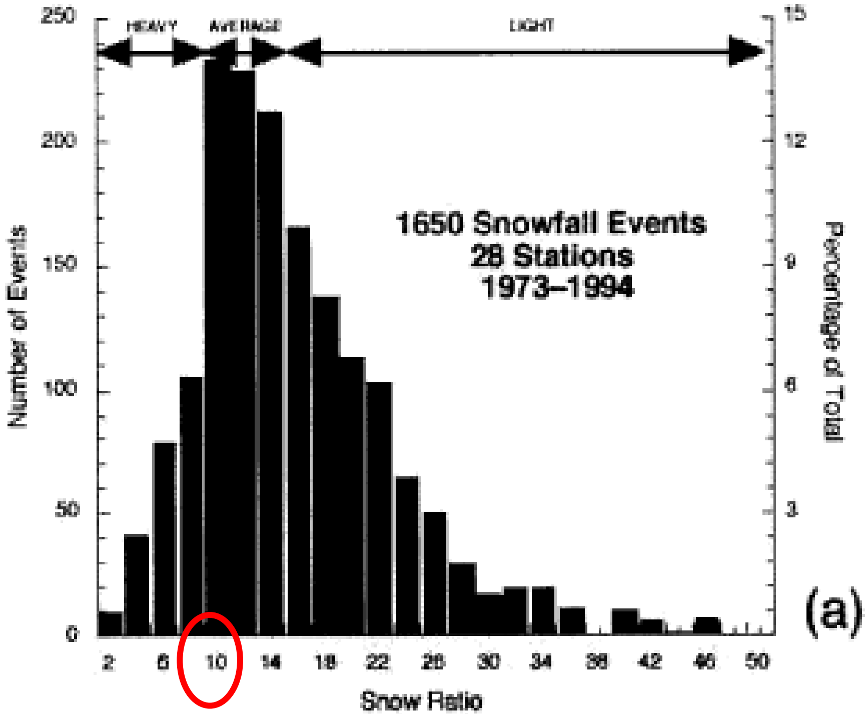
Sources of uncertainty

- Precipitation climatology



Sources of uncertainty

- In the forcing inputs
  - Precipitation
    - Snowfall is manually observed
      - But the snow ratio is assumed equal to 10
      - Snow ratio associated with average and light snow dominates the snow ratio distribution



Source: Roebber et al. (2003)

Sources of uncertainty

- In the snow model structure
  - Accumulation and aging of the snow cover
  - Simulation of the snow cover depletion
  - Simulation of the melt rate
  - Routing of the melt event

Sources of uncertainty

Q

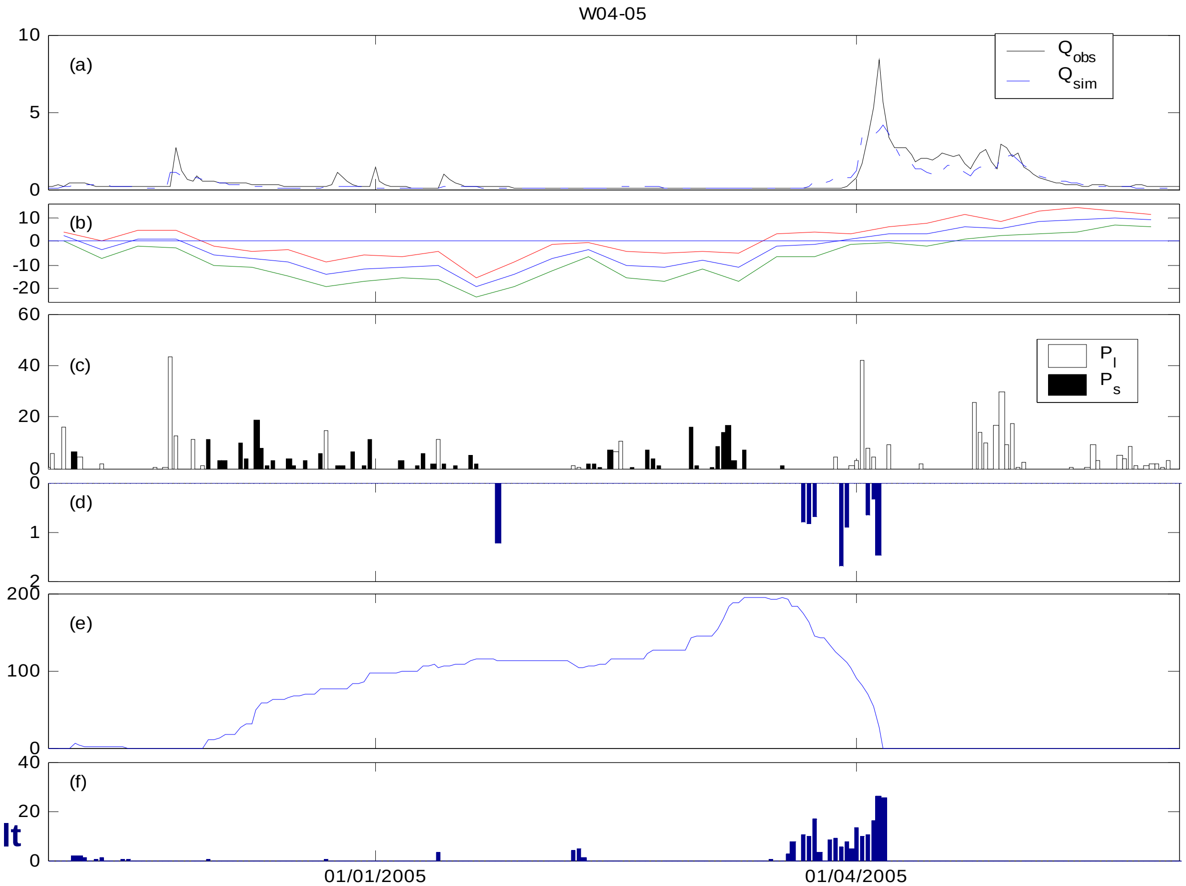
Temp

P_s [+]

E_{sublim} [-]

Snow

$Snow_{mlt}$ [-]



Recommendations

- Model snow interception processes and melt rates according to the HRU
  - Presence of a forest canopy strongly influences absorption and reflection of incoming solar radiation
  - Presence of a forest canopy affects wind and therefore heat exchange, leading to lower snow melt rates

Recommendations

- Refine soil temperature model in order to include heat exchange while water freezes/melts
  - Soil is frozen 2-3 weeks after major melt related flood event
  - Inclusion of a frozen soil temperature model will modify :
    - flow paths of water
    - soil water content after the snowmelt,
    - but not the yield of water that is routed down into the river
  - Model the three phases system air-water-solid in the soil reservoir

Recommendations

- Revise how free water is managed in the soil reservoir for subfreezing soil temperatures
  - The spatial distribution of frozen soil is highly variable: there is always water that will find its way to recharge the shallow aquifer
  - Allow free liquid water to percolate and/or to become subsurface flow under soil subfreezing temperatures
  - These changes will enhance low water level stream flow simulations in winter

Recommendations

- Perform shallow groundwater monitoring in order to model the transmissivity feedback mechanism (i.e. groundwater rise pushes subsurface “old” water out), and the favoured flow paths during the snowmelt period

- Question how the groundwater system is divided, more specifically the inclusion of a deep groundwater zone to which all recharges are considered as a loss

- Perform an albedo follow up (now: constant = 0.8 - fresh) using a prognostic scheme including forest canopy (= 0.3) specificities => better description of sublimation process