Challenges in modelling Prairie hydrology under future climates

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Prairie hydrology

- Historically, Prairie hydrology has been dominated by cold regions processes, but rainfall is increasing over time
- Cold-regions processes require coupling of energy and mass exchanges and phase change – this has been challenging to model
- However, *scaling* of cold-regions processes can be easier than rainfall-runoff processes
- Increasing rainfall also complicates the operation of cold-regions processes by increasing the types and complexity of phase change

Cold regions processes

- Prairie hydrology has been controlled by three sets of cold-region processes

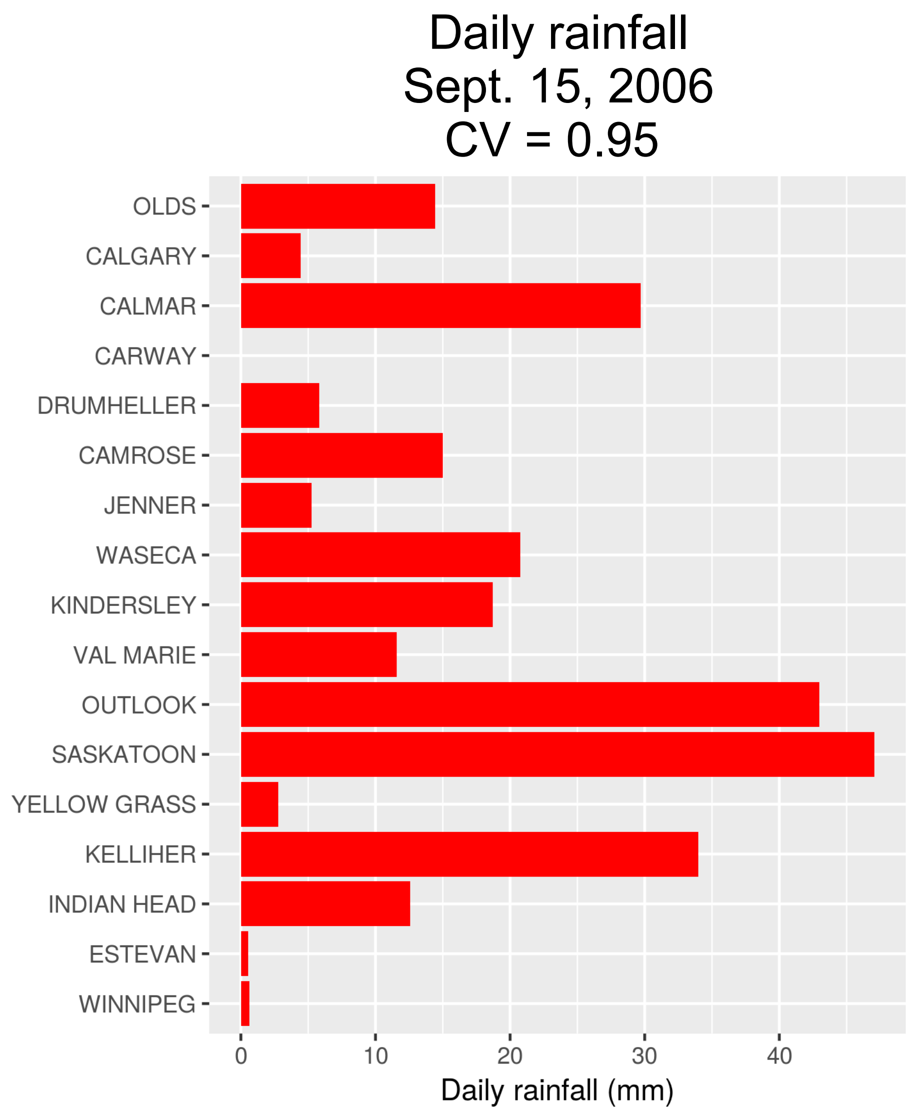
1. Snow accumulation
2. Snow melt
3. Infiltration to frozen soils

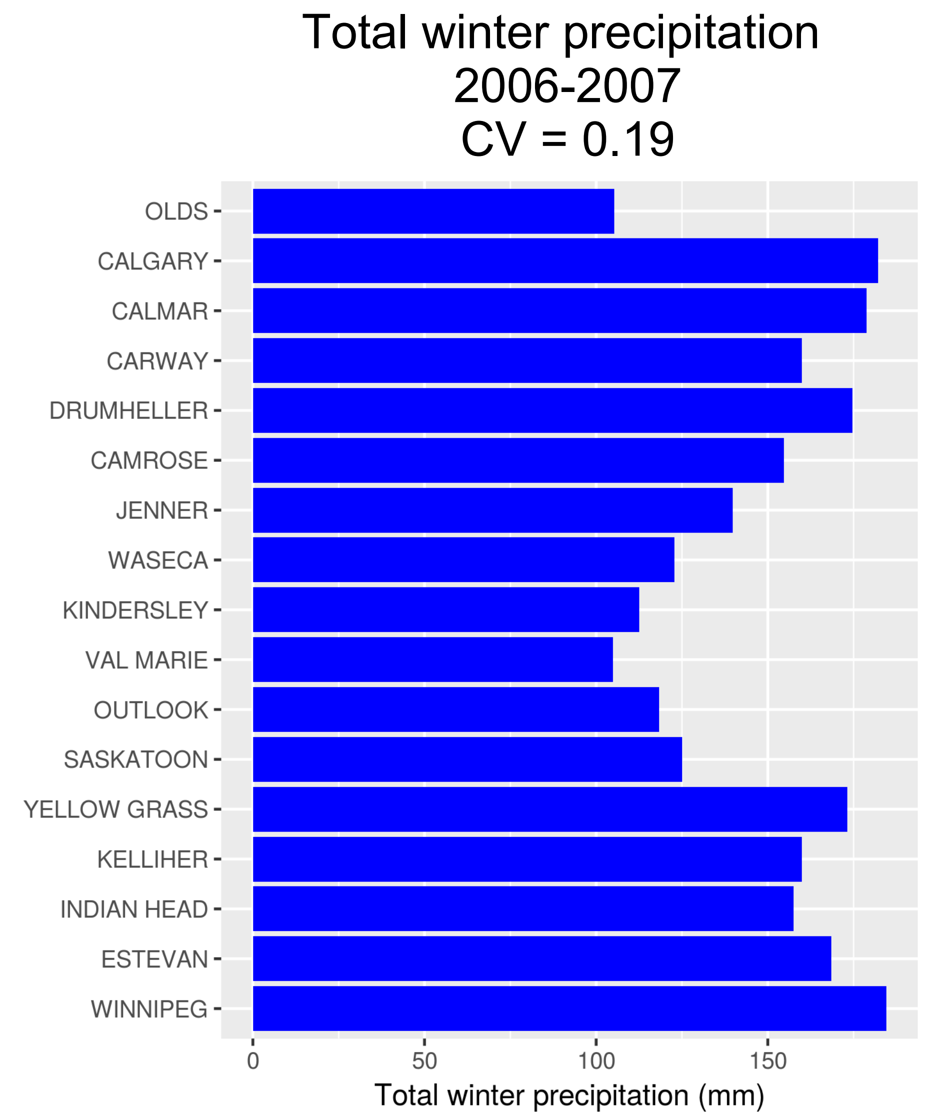
1. Snow accumulation

- Annual snowfall varies little over the Prairies
- SWE accumulation strongly affected by wind-transportation processes (erosion, deposition, sublimation)
  - Processes can be modelled physically (PBSM), using measurable surface parameters

Canadian Prairies

area = 469,000 km^2

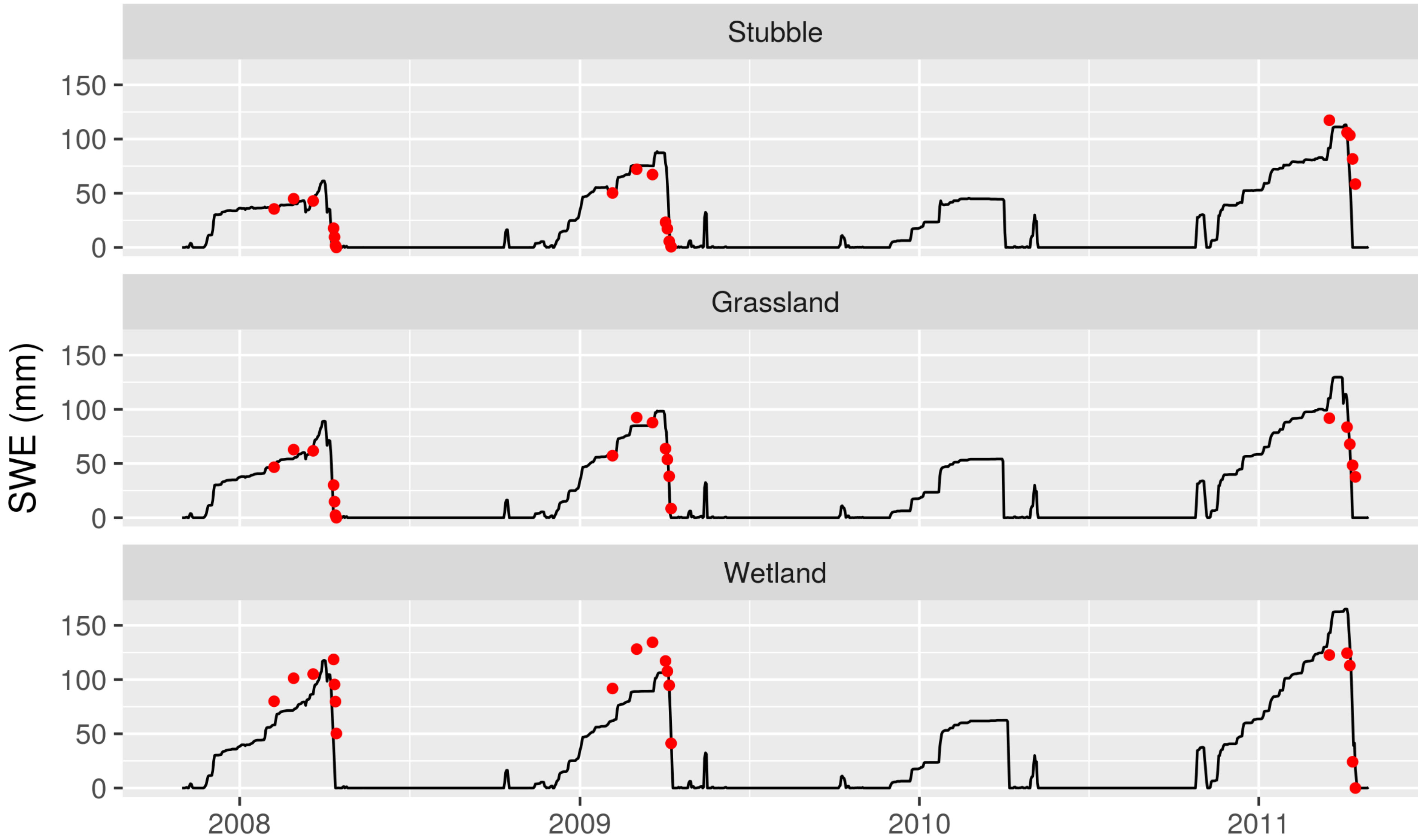




2. Snow melt

- Histoically, Prairie snowpacks have been continuous over the winter
- Melt has occurred in the spring
- Spring snowmelt is driven by solar radiation which can be simulated easily

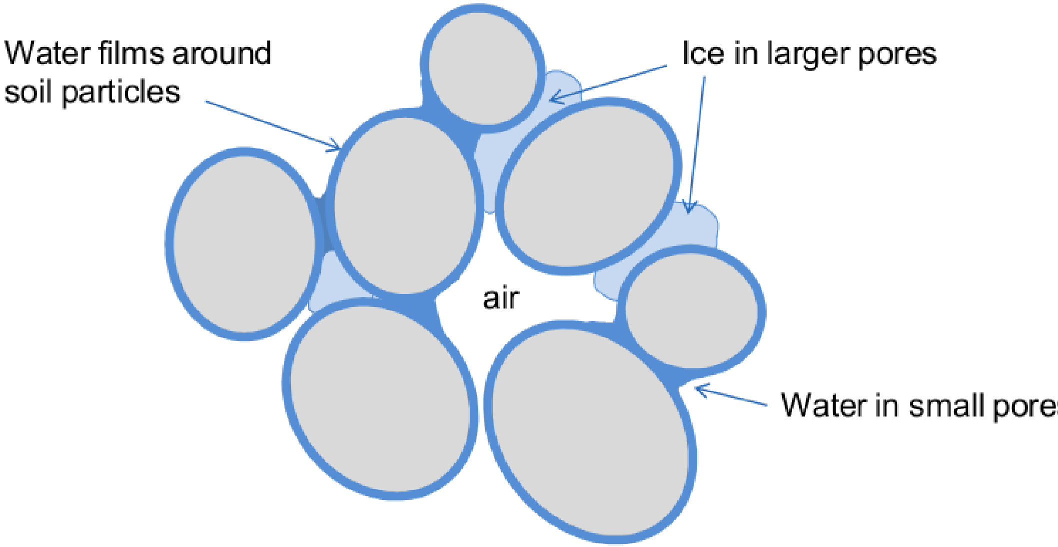
CRHM simulated SWE
Smith Creek, SK



3. Infiltration to frozen soils

- Much more complex than for unfrozen soils
- Coupled heat and mass transfer
- Ice reduces pore diameter
  - Increases matric potential
  - Reduces available porosity

- Hydraulic conductivity is very low
- Everything changes with melt/infiltration



Adapted from photos and drawings by Colbeck 1982 and 1985 and freezing concepts from Ireson et al 2013

Parametric infiltration model
(Zhao and Gray, 1997)

- Parametric solution to coupled heat and mass-transfer finite-element model

$$INF = C\, S_o^{2.92} \left(1 - S_i\right)^{1.64} \left(\frac{273.15 - T_i}{273.15}\right)^{-0.45} t_o^{0.44}$$

C = bulk coefficient,

S_o = surface saturation

S_i = initial soil saturation

T_i = initial soil temp (C)

t = infiltration opportunity time (h)

- Soil properties (saturated hydraulic conductivity) are not present!
- Means that spatial variability of soil properties is not very important.

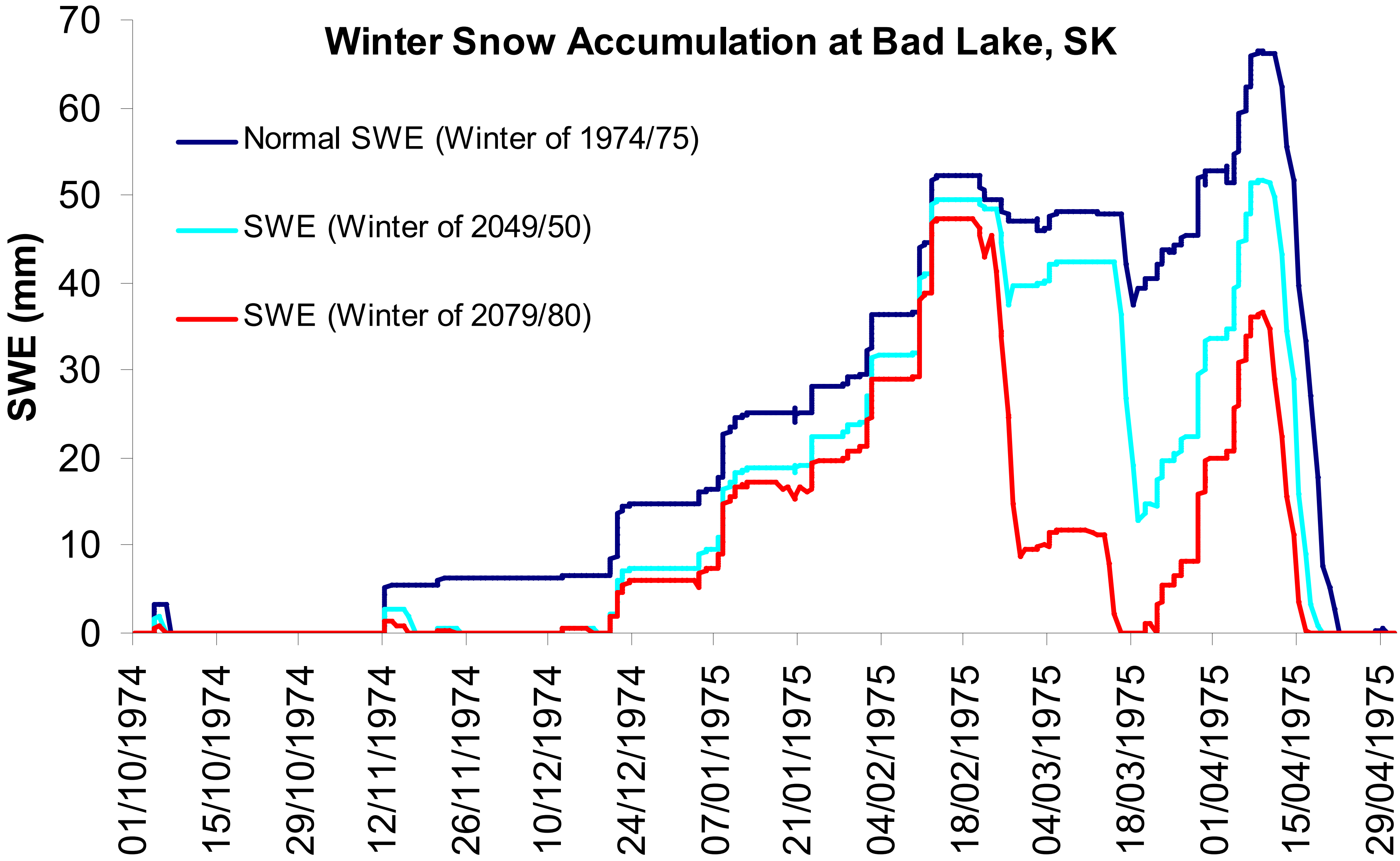
Climate change

- Many changes observed in the Prairie climate over the last century
  - Increases in air temperature,
  - Changes in precipitation phase,
  - Increases in size and duration of multiple-day rainfalls
- All of these make Prairie hydrology harder to simulate

Increasing air temperatures

- Suppress blowing snow
- Can also cause mid-winter melting
  - Harder to simulate than spring melt
    - turbulent fluxes (latent and sensible heat) more important, and harder to simulate, than radiation
  - Snowpack may be partially-ablated
    - Difficult to simulate distribution of SWE when new snow falls

CRHM simulation of Prairie Climate Change



Change in precipitation phase

- Have been significant changes in phase (snow to rain) in spring and fall precipitation
- Harder to model
  - Vertical advection of energy (rainfall and/or condensation)
  - Can cause formation of ice layer at bottom of snowpack: inhibits infiltration
  - Reduces the snowfall, which increases its spatial variability

Annual flow volumes Smith Creek, SK

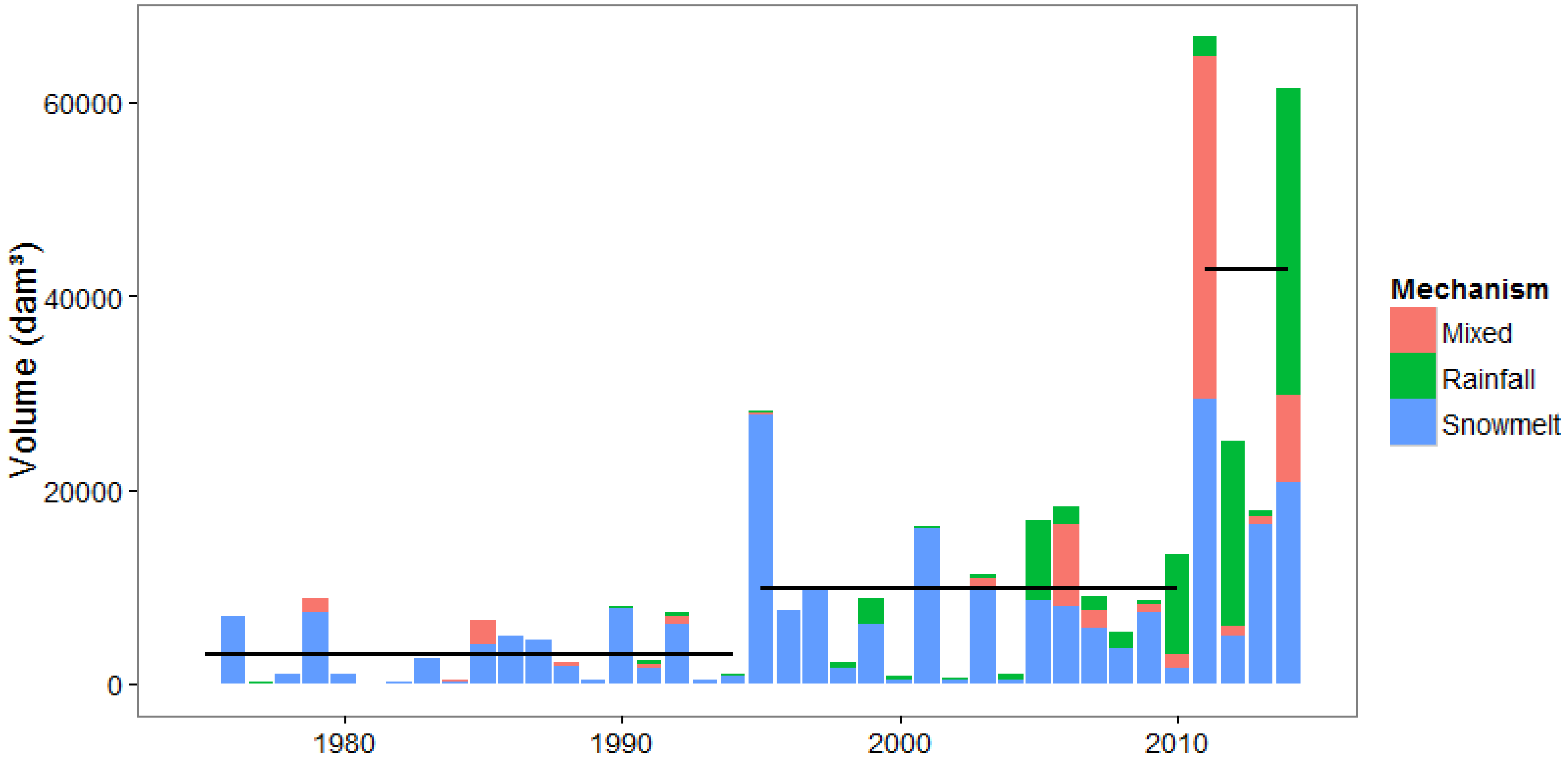
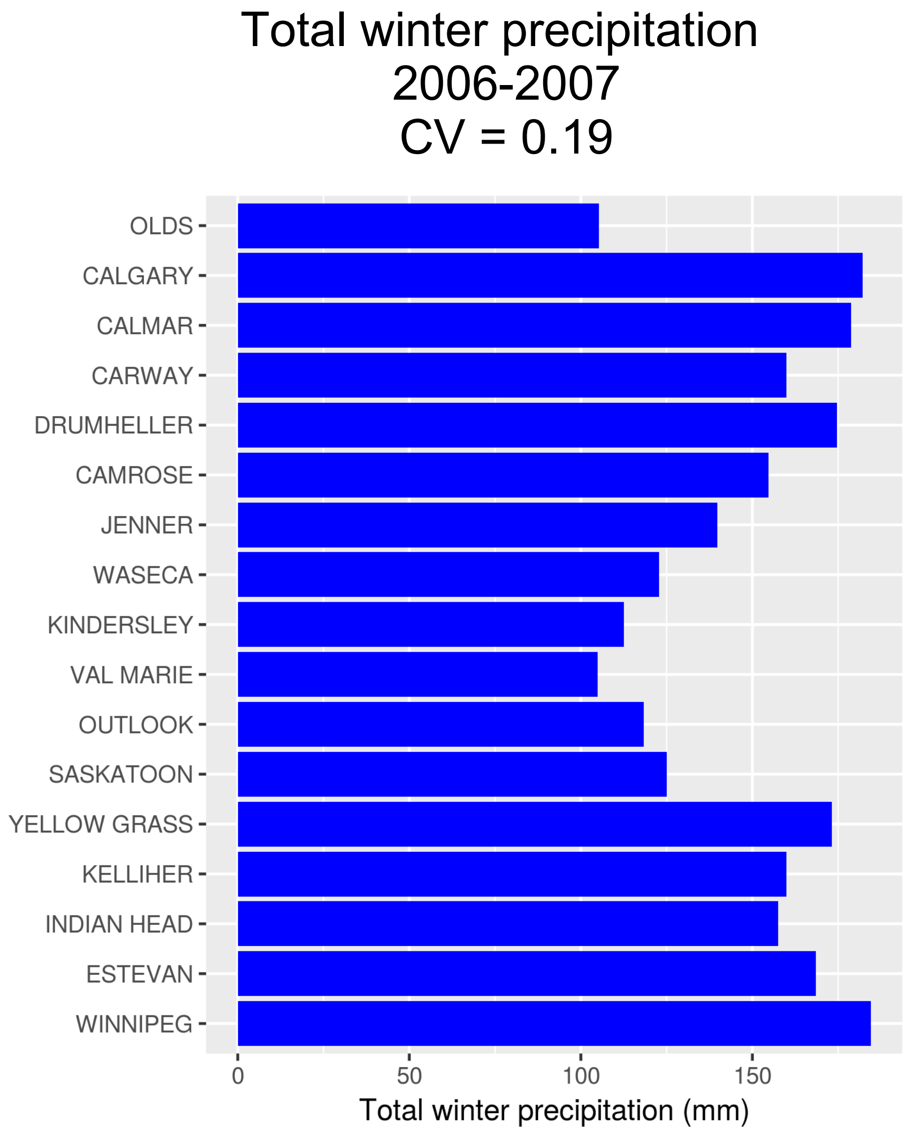
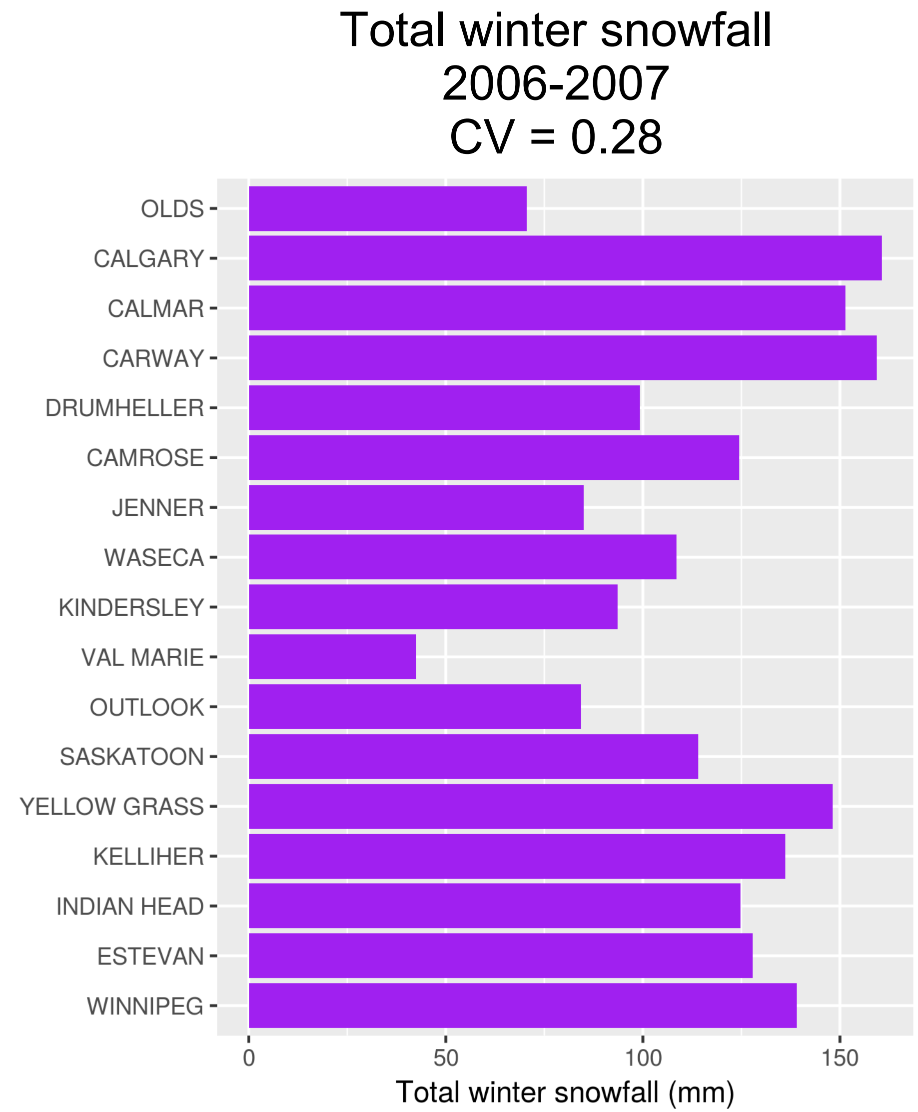


Figure by Stacey Dumanski

Total snowfall is more variable than total precip





Infiltration to frozen soils

- Will become more complex
- Simple infiltration models unlikely to work well in the future
  - More than one melt event
  - Soils may only be partially-frozen
  - Over-winter dessication of soils not covered by snow

Large-scale rainfalls

- Are now seeing large-scale summer rain events in Prairies
  - Consistent with trends in increasing magnitude and length of mutiple-day rain events
- Have been causing peak streamflow events
- Means that rainfall-runoff is now important
  - Greater spatial/temporal variability than snow processes
  - Soil parameters (and their scaling) will matter for infiltration

Summary

- We have developed physically-based representations of cold-regions processes which have worked well in the Prairies
- These process models have been based on the very cold climate
- As the Prairies warm, the processes will become more complex, and existing hydrological models will have to be modified