

# Soil Moisture Analysis and Seasonal Forecast of Drought

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# Objectives

- To produce and analyse a soil moisture climatology
  - Land surface schemes VIC, CLASS in stand-alone mode
  - Methodology verified over China
  - Application of VIC to Prairies
  - Coupling of CLASS to groundwater module (gCLASS)
- To examine seasonal forecast of drought
  - HFP2 model output (AGCM3/CLASS) from Canadian CLIVAR (1969-2003)
  - Soil moisture in seasonal forecasts

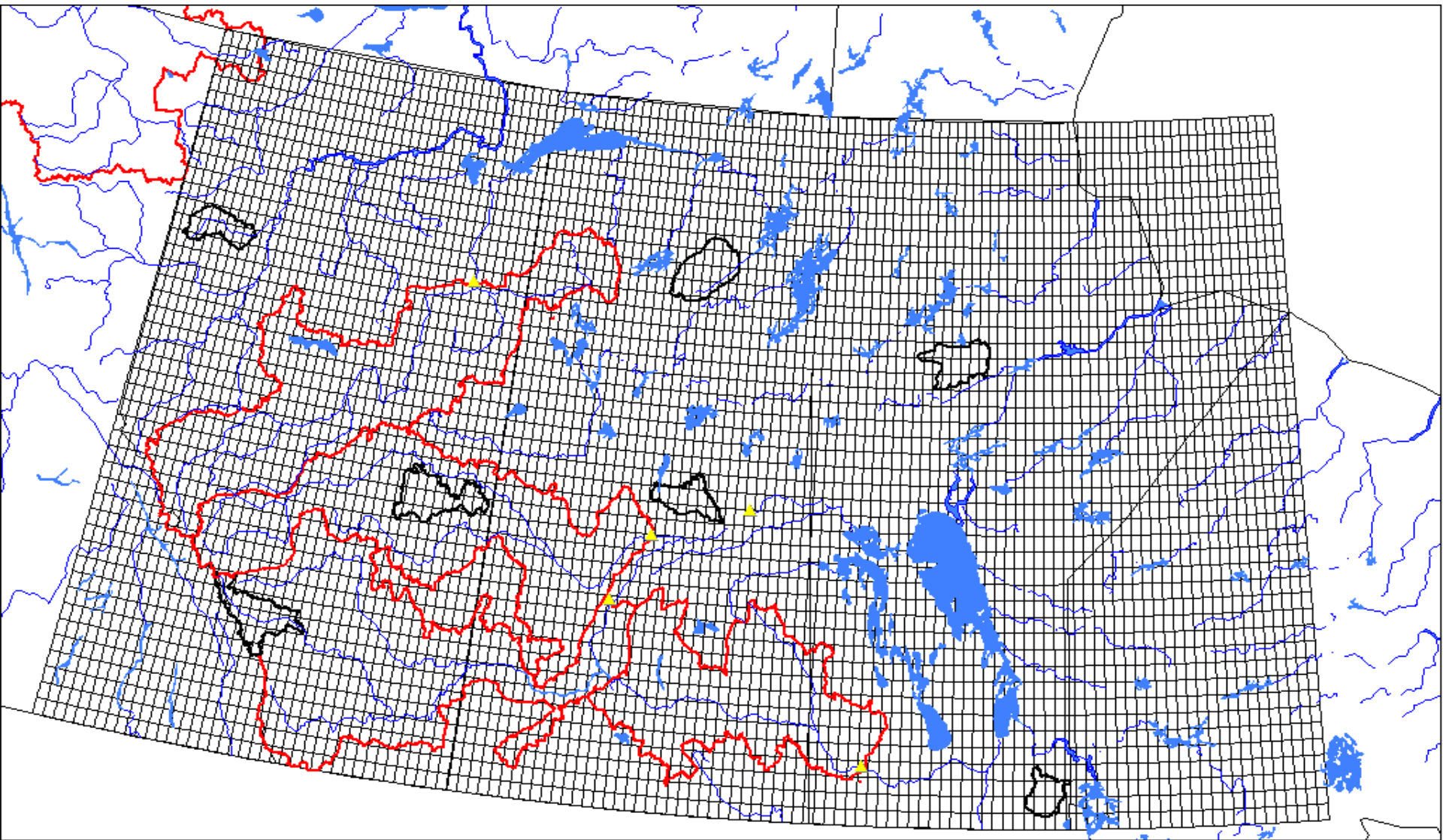
# VIC in stand-alone mode

Soil moisture simulation (1950-2005) for 3 layers in  
top 1m

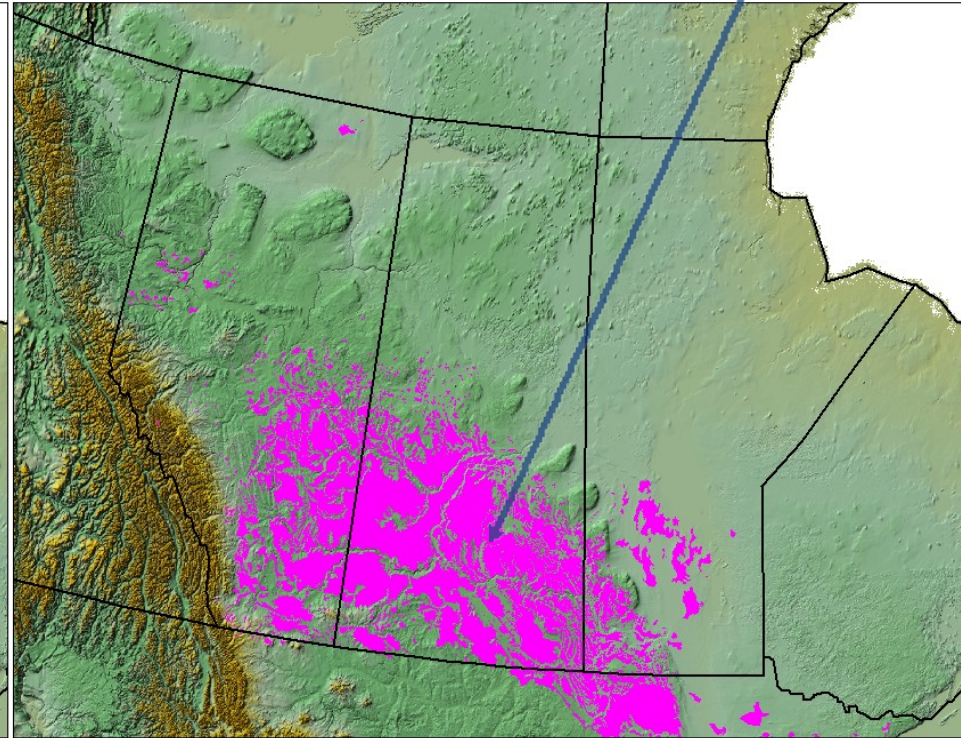
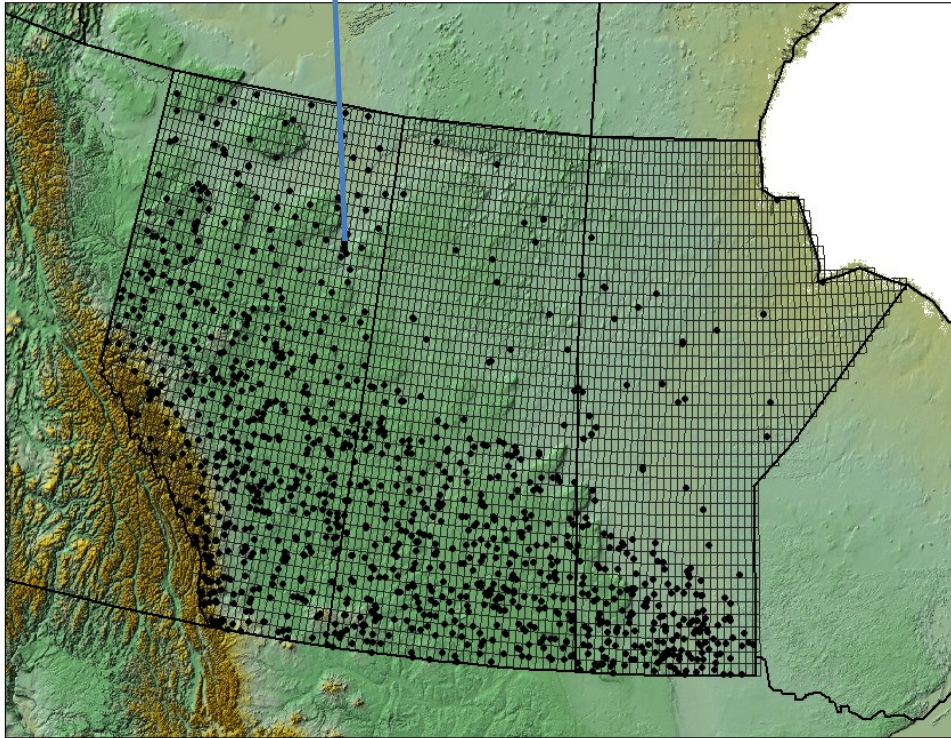
<http://www.meteo.mcgill.ca/~leiwon/vic/prairies/>

# VIC model over the Prairies

(area of 1,964,000 km<sup>2</sup>, grid resolution of 0.25° x 0.25°, total of 4393 points)



1,167 met stations (black dot)  
providing driving forces for VIC

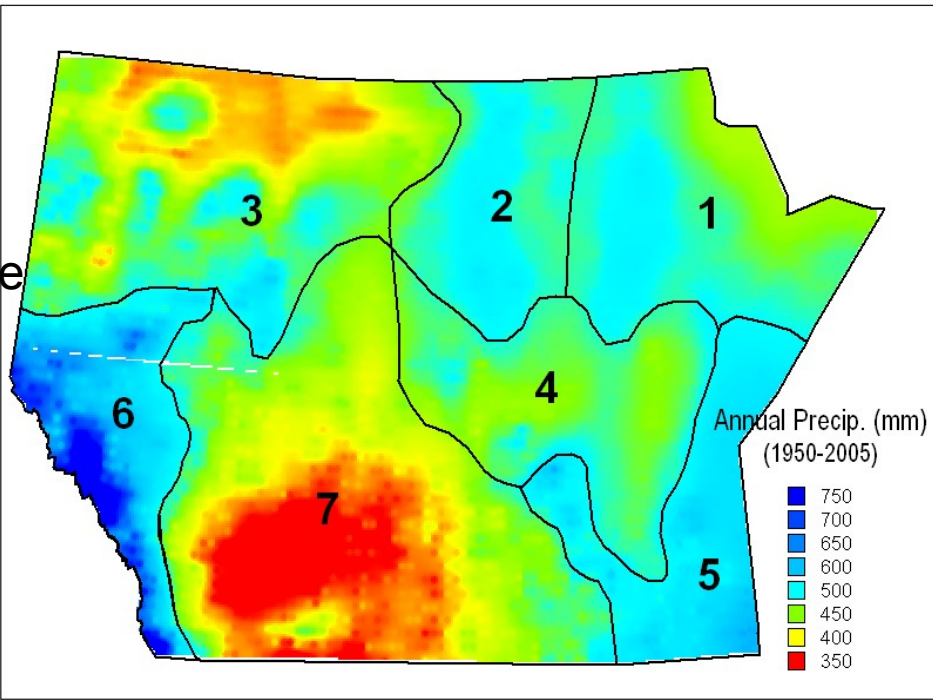
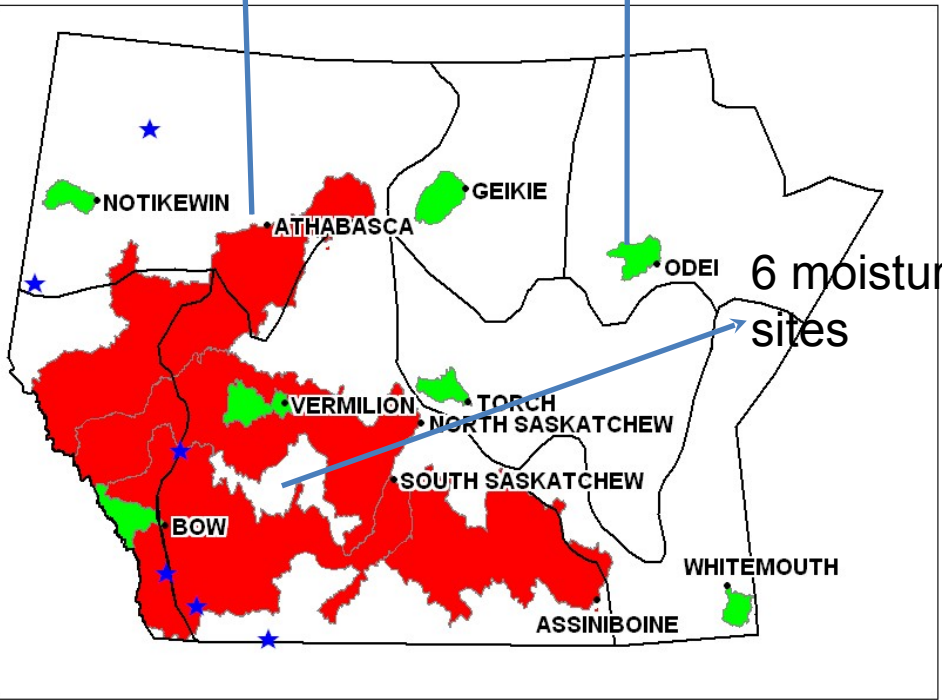


Non-contributing drainage  
areas present a challenge

Define 7 simulation regions based on annual precipitation (1950-2005)

4 additional validation catchments in red

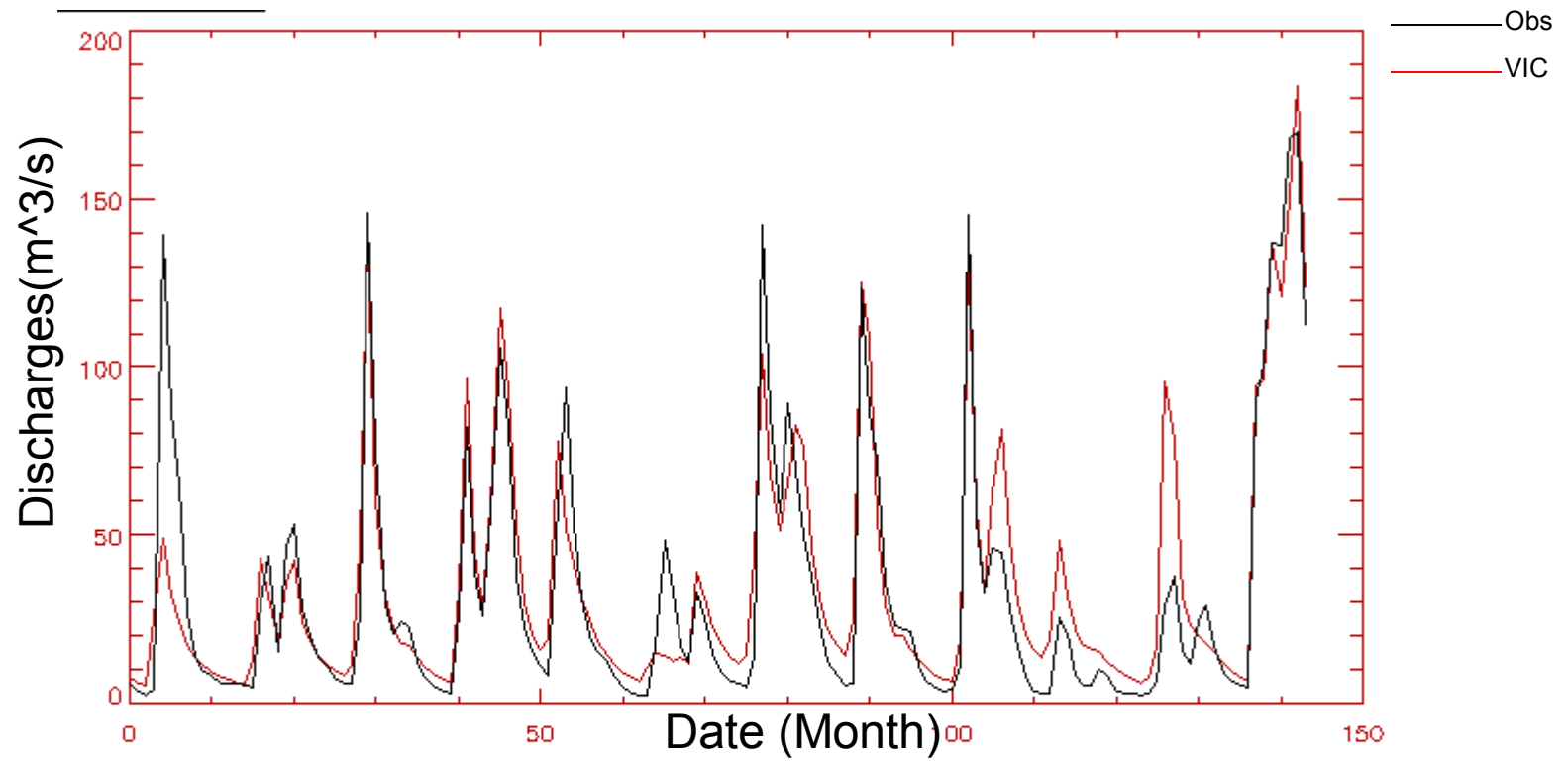
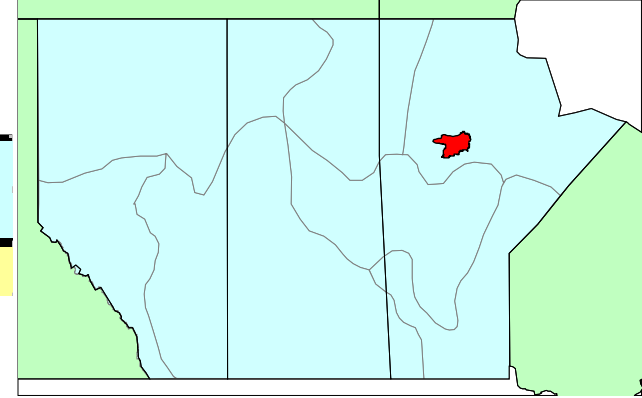
7 calibration catchments in green



- Calibrate using observed daily hydrographs at outlets of the 7 calibration catchments (1994-1999)
- Validate over 7 calibration catchments and additional 4 catchments (1975-2001), as well as comparison with soil moisture measurements at 6 Alberta sites.

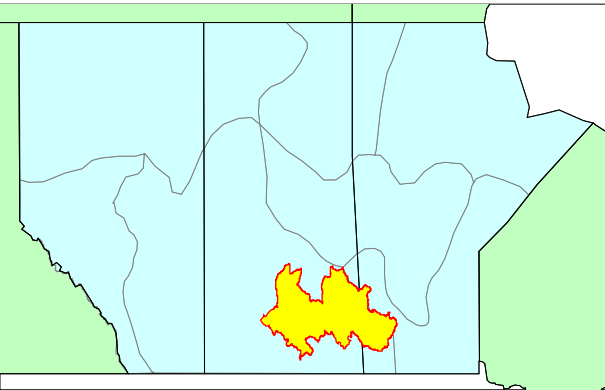
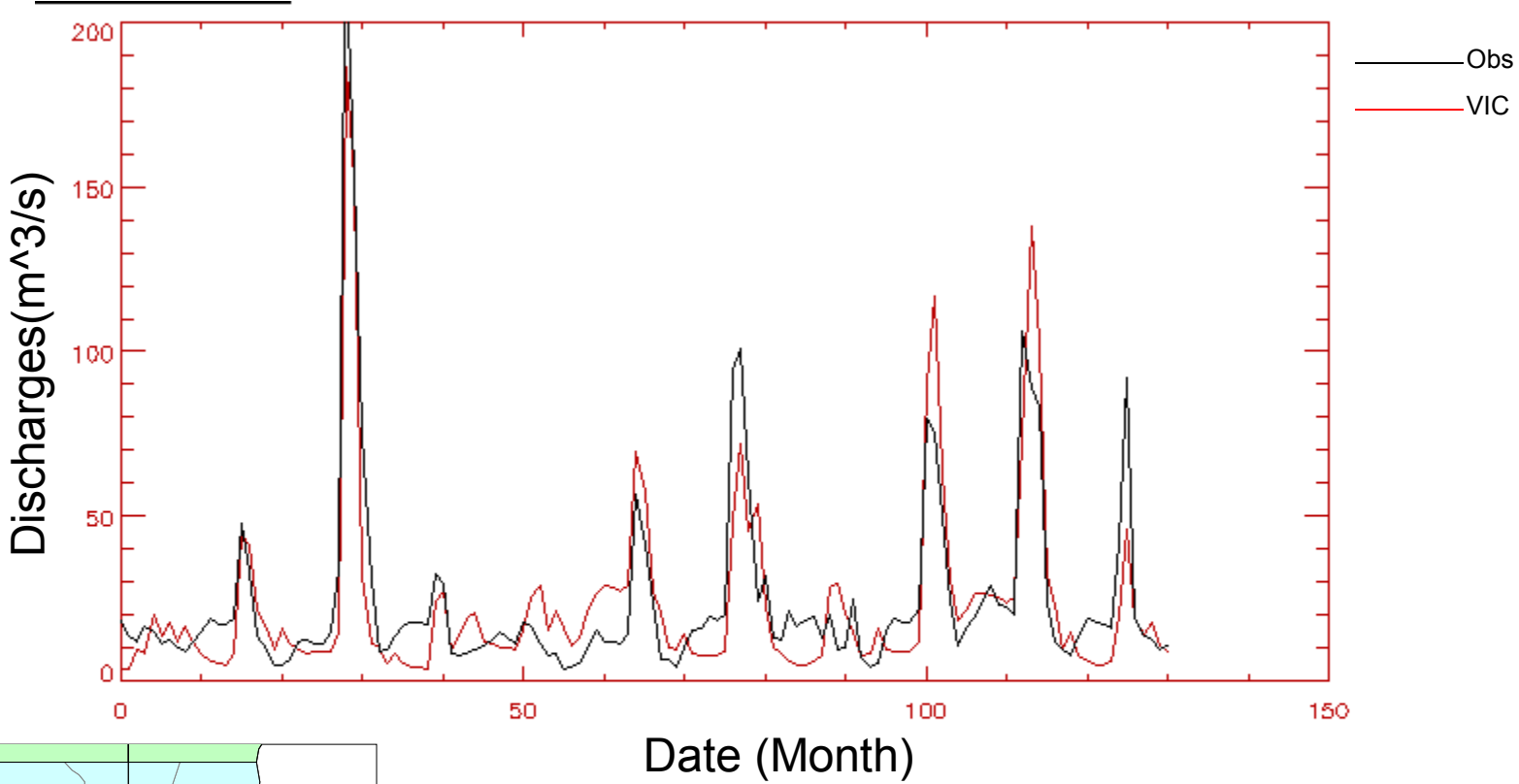
# An example of calibration result: Odei catchment

| River Name | Period    | Err. (%) | Nash (day) | Nash (Mon) |
|------------|-----------|----------|------------|------------|
| ODEI       | 1994-2005 | 7.3      | 0.73       | 0.82       |



# An example of validation result: Assiniboine catchment

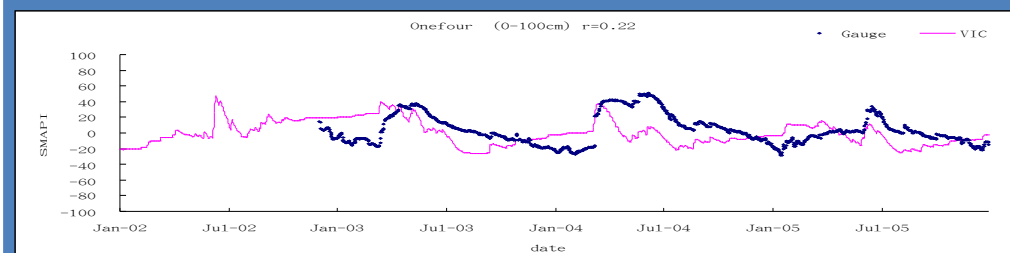
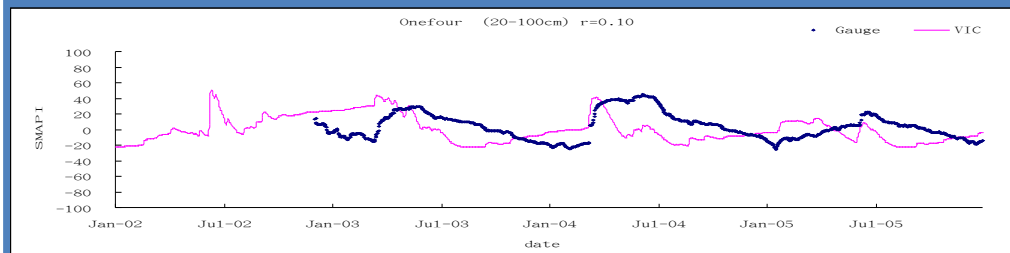
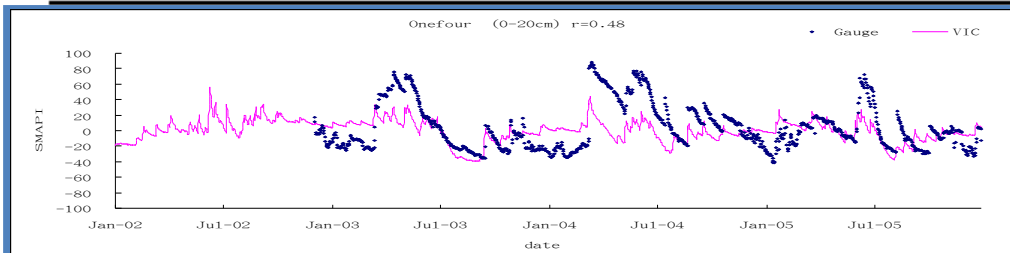
| River Name  | Period    | Err. (%) | Nash (day) | Nash (Mon) |
|-------------|-----------|----------|------------|------------|
| ASSINIBOINE | 1977-1987 | -5.4     | 0.62       | 0.77       |





# Comparison of simulated and observed soil moisture anomalies from 6 Alberta sites

| Site                 | Annual       | Site      |            | VIC grid  |            | Correlation coefficient ( $r$ ) |           |          |
|----------------------|--------------|-----------|------------|-----------|------------|---------------------------------|-----------|----------|
|                      | Precip. (mm) | Lat. (°N) | Long. (°W) | Lat. (°N) | Long. (°W) | 0-20 cm                         | 20-100 cm | 0-100 cm |
| <u>Fortremillion</u> | 364          | 58.38     | 116.04     | 58.38     | 116.13     | 0.17                            | -0.09     | 0.09     |
| Beaver Lodge         | 337          | 55.20     | 119.40     | 55.16     | 119.38     | 0.44                            | 0.56      | 0.59     |
| Lacombe              | 451          | 52.45     | 113.76     | 52.38     | 113.88     | 0.45                            | 0.61      | 0.58     |
| <u>Stavelly</u>      | 513          | 50.18     | 113.88     | 50.16     | 113.88     | 0.34                            | 0.58      | 0.56     |
| Lethbridge           | 359          | 49.63     | 112.80     | 49.63     | 112.88     | 0.67                            | 0.65      | 0.69     |
| <u>Onefour</u>       | 335          | 49.12     | 110.47     | 49.13     | 110.38     | 0.48                            | 0.10      | 0.22     |

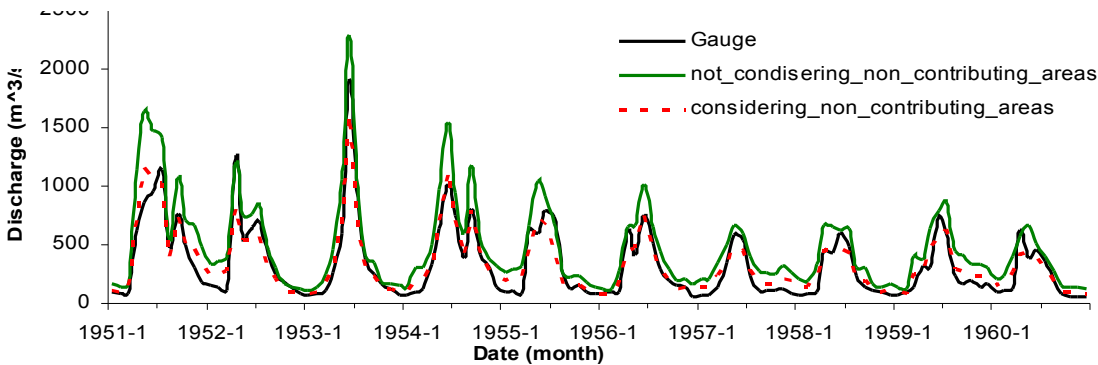


Note the simulated soil moisture represents an average of a  $0.25^\circ \times 0.25^\circ$  grid box. VIC is not specifically calibrated for any of these 6 sites.

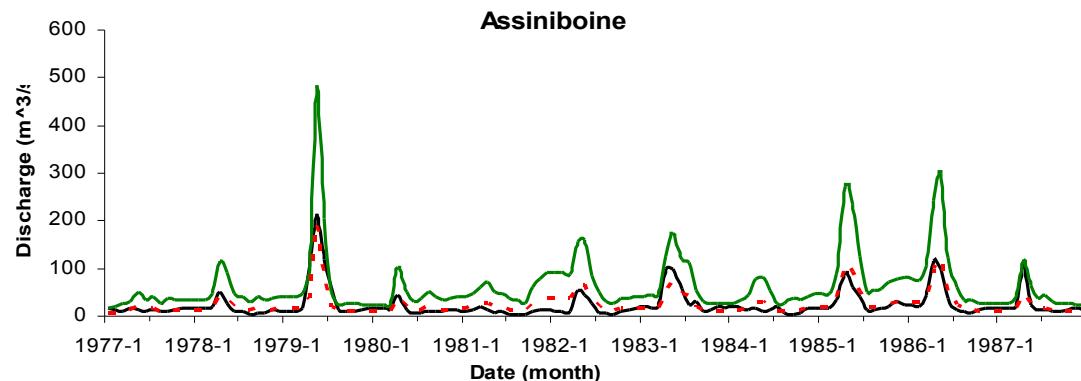
Results at the Onefour site

# Study of non-contributing drainage area effect on runoff generation

|    | Catchment   | Station             | Drainage Area (km <sup>2</sup> ) |           | Period | With non-contributing area |       | Without non-contributing area |       |
|----|-------------|---------------------|----------------------------------|-----------|--------|----------------------------|-------|-------------------------------|-------|
|    |             |                     | Total                            | Effective |        | $E_r$ (%)                  | $E_c$ | $E_r$ (%)                     | $E_c$ |
| 8  | Athabasca   | McMurray            | 133000                           | 131000    | 66-75  | 14.0                       | 0.81  | 14.3                          | 0.80  |
| 9  | North Sask. | <u>Princealbert</u> | 131000                           | 72300     | 91-00  | 0.9                        | 0.80  | 53.4                          | -0.45 |
| 10 | South Sask. | Saskatoon           | 141000                           | 88100     | 51-60  | 3.1                        | 0.91  | 47.5                          | 0.54  |
| 11 | Assiniboine | Brandon             | 93700                            | 36500     | 77-87  | 5.3                        | 0.77  | 163.2                         | -2.23 |

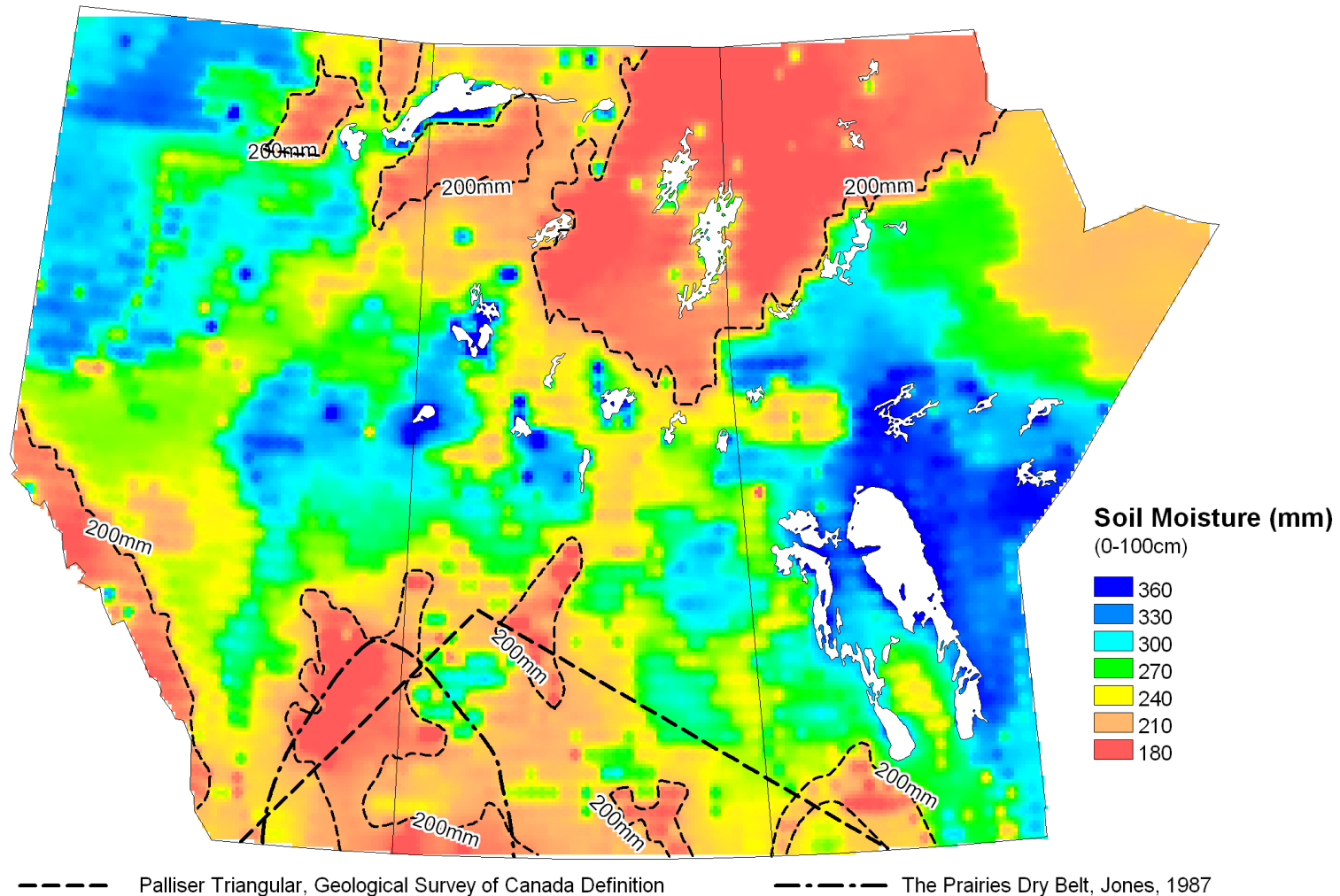


Incorporating **non-contributing drainage areas** into runoff calculations substantially improves model simulation of surface and sub-surface runoff in regions where the wetlands are dominant.



Results at the outlets of the South Saskatchewan and Assiniboine catchments

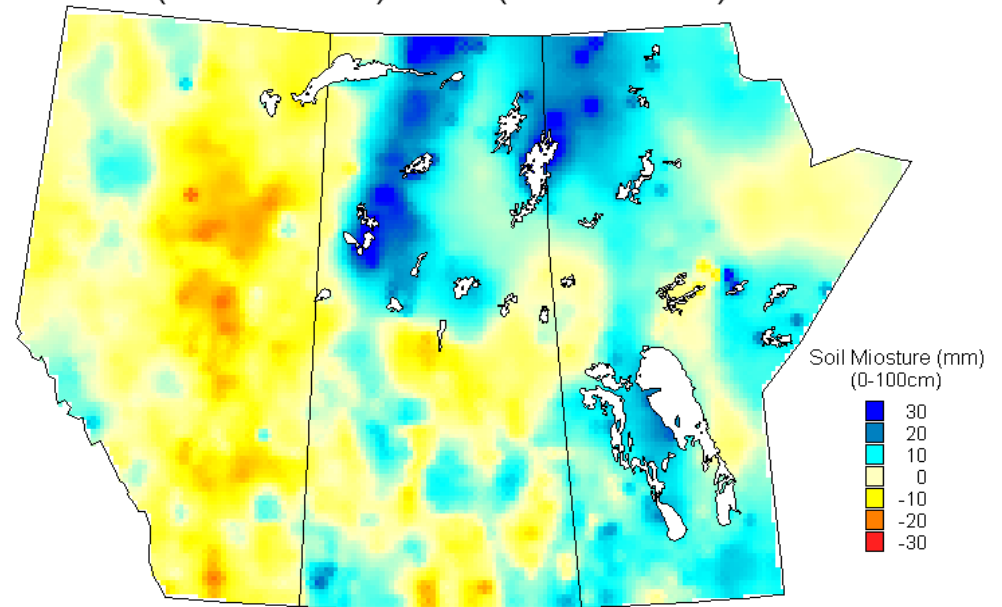
# 56-yr (1950-2005) VIC soil moisture (top 1-m) climatology (200 mm soil moisture contour highlighted as delineating dry areas)



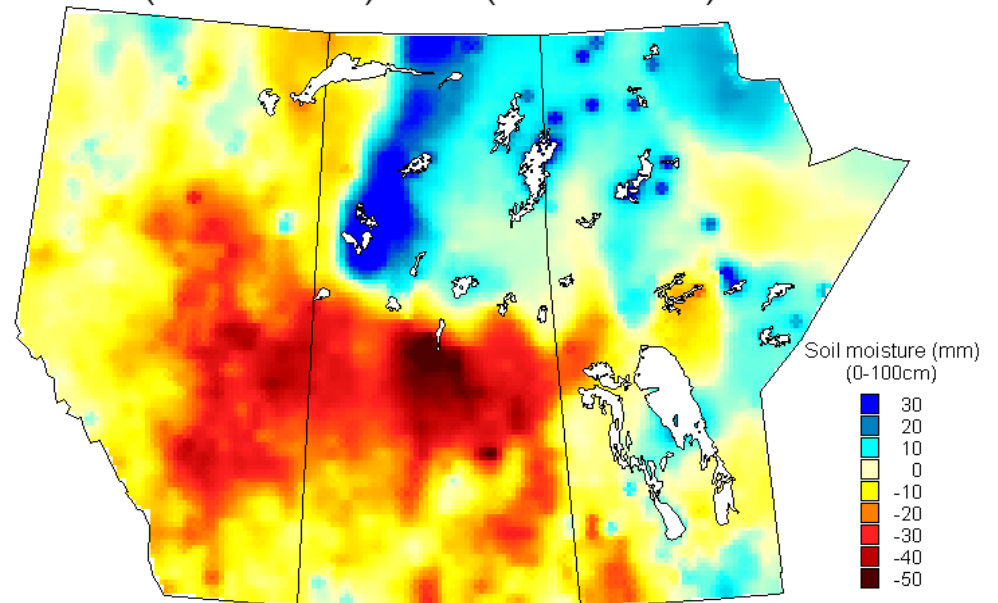
Identification of the Palliser Triangle and the Prairie Dry Belt

Soil moisture deficit of two periods with respect to the 56-year climatology:  
1999-2005 (top)  
2001-2002 (bottom)

SM(1999-2005) - SM(1950-2005)



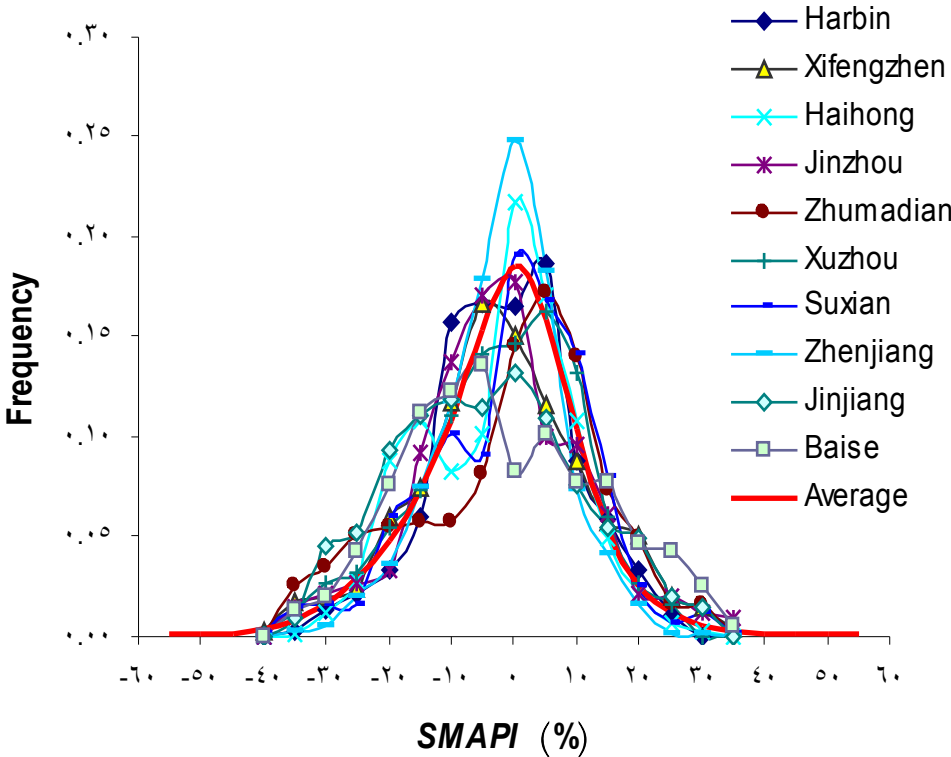
SM(2001-2002) - SM(1950-2005)



# Soil Moisture Anomaly Percentage Index (**SMAPI**)

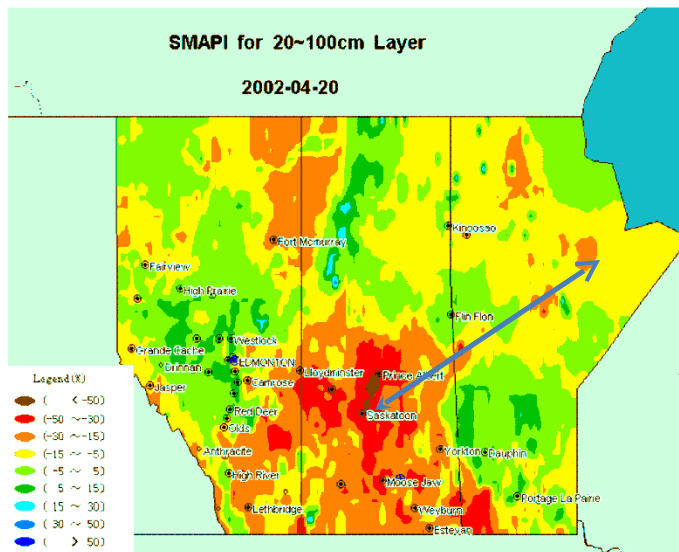
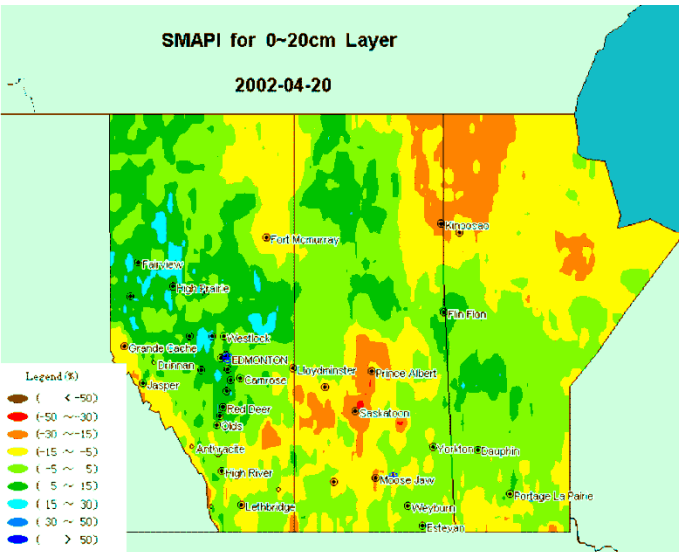
$$SMAPI = \frac{\theta - \bar{\theta}}{\bar{\theta}} \times 100\%$$

- Concept of relative soil wetness to measure drought severity
- Statistical analysis over China sites reveal a near-Gaussian distribution

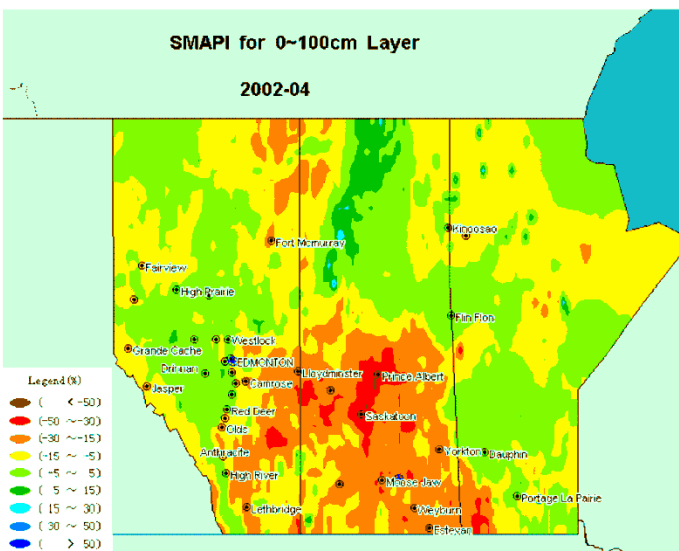
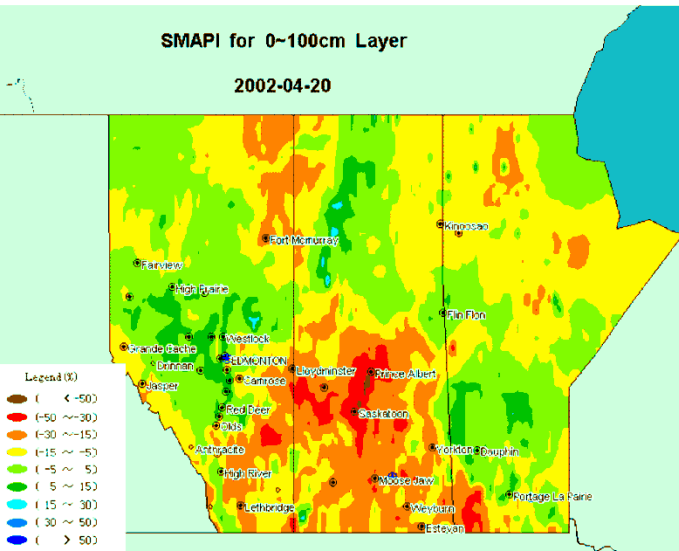


Drought classifications based on SMAPI

| Category         | SMAPI        | Average Frequency |
|------------------|--------------|-------------------|
| extreme drought  | ≤ -50%       | 0.005             |
| severe drought   | -50% to -30% | 0.020             |
| moderate drought | -30% to -15% | 0.100             |
| mild drought     | -15% to -5%  | 0.200             |
| near normal      | -5% to 5%    | 0.350             |
| slightly wet     | 5% to 15%    | 0.200             |
| moderately wet   | 15% to 30%   | 0.100             |
| very wet         | 30% to 50%   | 0.020             |
| extremely wet    | > 50%        | 0.005             |



Southern Saskatchewan,  
April 2002 (Taken from  
Stewart)

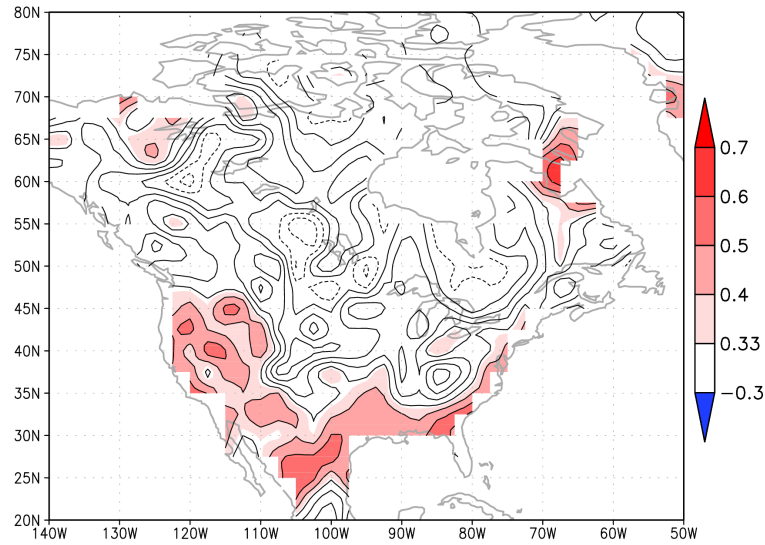


Daily SMAPI  
distribution of three  
soil layers for April 20,  
2002, together with the  
April 2002 average

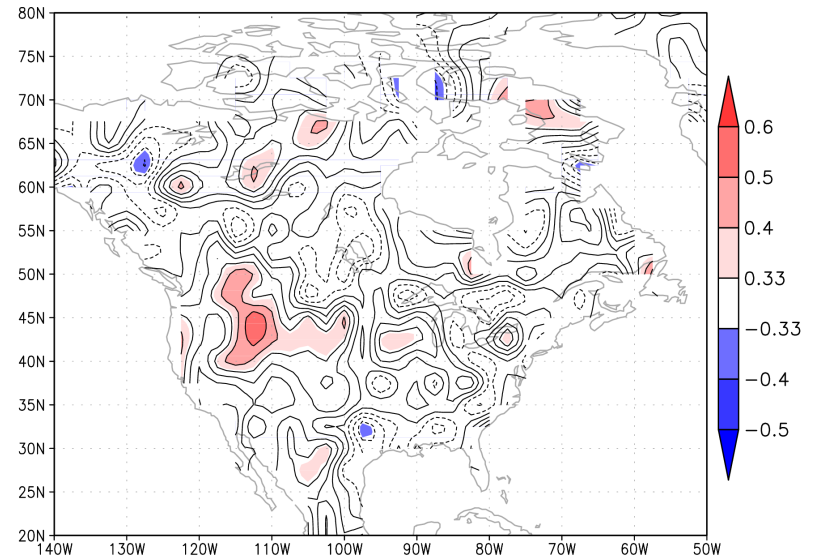
Daily SMAPI for three soil layers (0-20, 20-100, and 0-100 cm) at each of the 4,393 grid points for the Prairies from January 1, 2006 up to the present  
<http://www.meteo.mcgill.ca/~leiwen/vic/prairies/>

# HFP2 Seasonal Forecast (AGCM3/CLASS, 1969-2003)

Temporal correlation between the observed (CANGRID) and GCM3 seasonal forecast of precipitation for DJF (left) and JJA (right), over the period 1969-2003. Shaded areas have statistically significant correlation at 5% level.



GrADS: COLA/IGES



GrADS: COLA/IGES

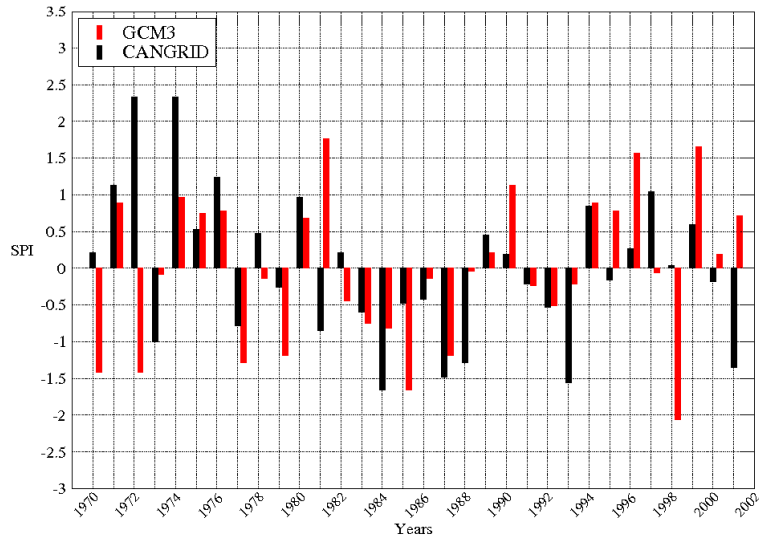


% area in North America with significant correlation for 500 hPa (Z500), surface air temperature (SAT) and precipitation

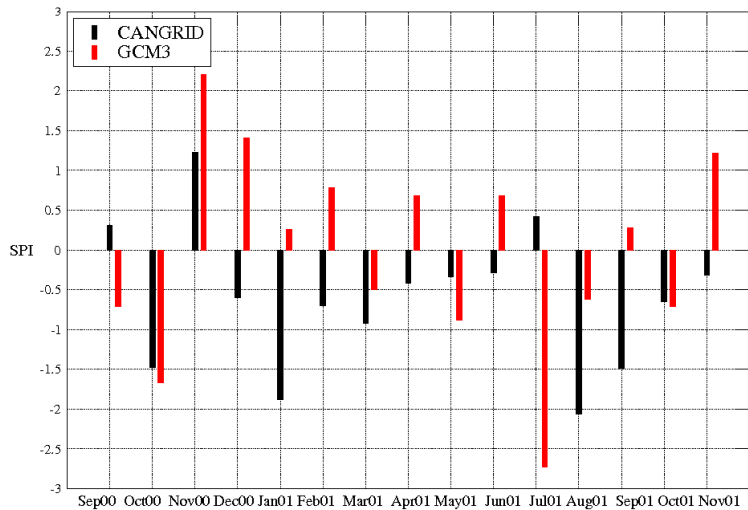
| Season | Z500 | SAT | Precip |
|--------|------|-----|--------|
| DJF    | 76   | 51  | 27     |
| JJA    | 66   | 48  | 12     |

Average correlation over North America

| Season | Z500 | SAT  | Precip |
|--------|------|------|--------|
| DJF    | 0.47 | 0.30 | 0.20   |
| JJA    | 0.40 | 0.29 | 0.09   |



The winter (DJF) Standard Precipitation Index (SPI) averaged over the Canadian Prairies for the period 1969-2001



Monthly SPI averaged over the Canadian Prairies for the period September 2000 to November 2001

# Networking

- VIC Soil moisture analysis: John Pomeroy
- Seasonal forecast evaluation: Jacques Derome, McGill University; CLIVAR
- CLASS and gCLASS simulation: Alan Woodbury
- Soil moisture and seasonal forecast: Aaron Berg, Guelph University
- VIC soil moisture data set is available to DRI
- Established linkages with Eric Wood (Princeton University) and Dennis Lettenmaier (University of Washington) on using VIC over Canada

# Further Work

- Use real time operational GEM daily forecasts to drive VIC over the Prairies for soil moisture simulation from January 1, 2006 up to the present
- Calculated daily SMAPI distribution is available with a 6-day lead time (<http://www.meteo.mcgill.ca/~leiwen/vic/prairies/>)
- Collaborate with Alan Woodbury's group to run CLASS and gCLASS (groundwater module) over a western Canada domain (51-km resolution) with  $100 \times 90$  grid points
- Examine soil moisture simulation in seasonal forecast experiments and possibility of enhanced skill due to better initial soil moisture conditions (with Aaron Berg)