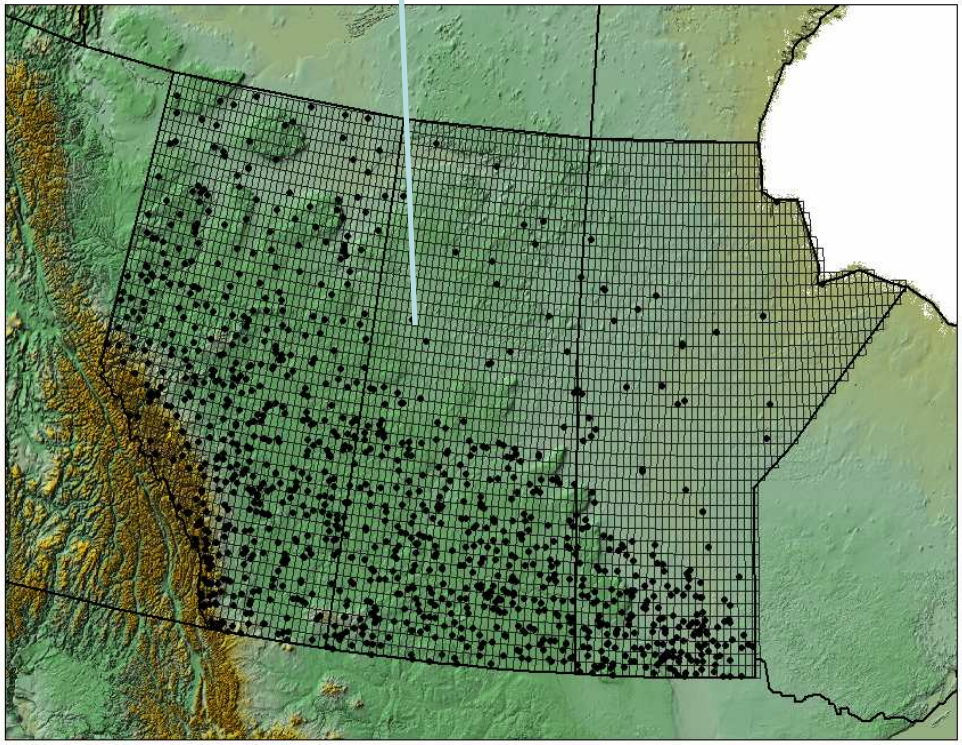
Analysis of real-time prairie drought monitoring and forecasting system

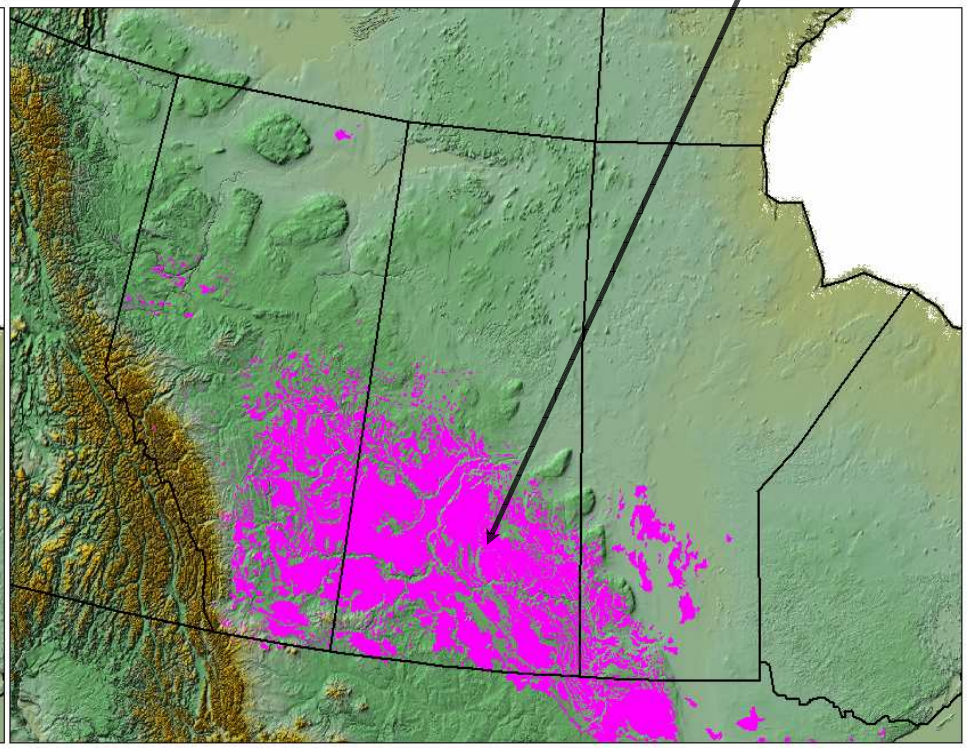
Lei Wen and Charles A. Lin

Back ground information

- A real-time drought monitoring and seasonal prediction system has been developed for the Canadian Prairies
- The system uses the Variable Infiltration Capacity (VIC) land surface macroscale hydrology model to simulate daily soil moistures for three soil layers (0-20 cm, 20-100 cm, and 0-100 cm) starting from 1 January, 1950, and continually running through present into the future with a lead time up to 35-day
- The system is driven by daily maximum and minimum air temperatures and precipitation from 1,167 meteorological stations for reconstructing and monitoring runs up to the present, and by the operational Canadian GEM model forecast + the operational 40-number super ensemble forecast + the operational CMC ensemble seasonal forecast for forecasting VIC runs
- The VIC soil moisture is used together with the 60-yr climatology (1950-2009) to calculate a soil moisture index SMAPI (Soil Moisture Anomaly Percentage Index) for measuring the severity of both agricultural and hydrological droughts
- The reconstructed VIC SMAPI can be used to explain historical drought events in the Prairies over the past 60 years; and compares favorably with three independent drought datasets
- The system is updated daily at present; and the result of SMAPI is publicly accessible online (http://www.meteo.mcgill.ca/~leiwen/vic/prairies/)

1,167 met stations (black dot); providing VIC with meteorological driving forces for monitoring runs



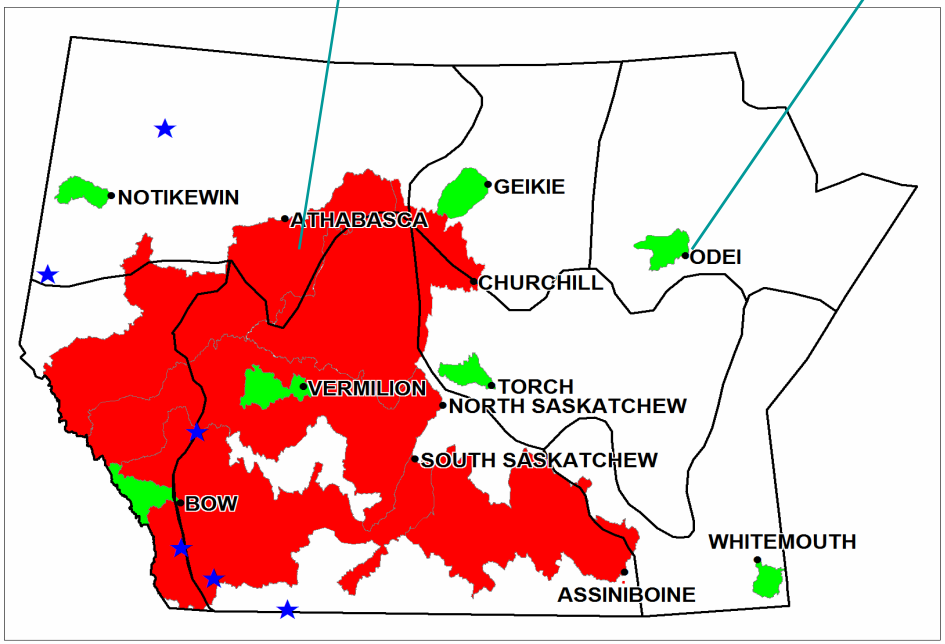


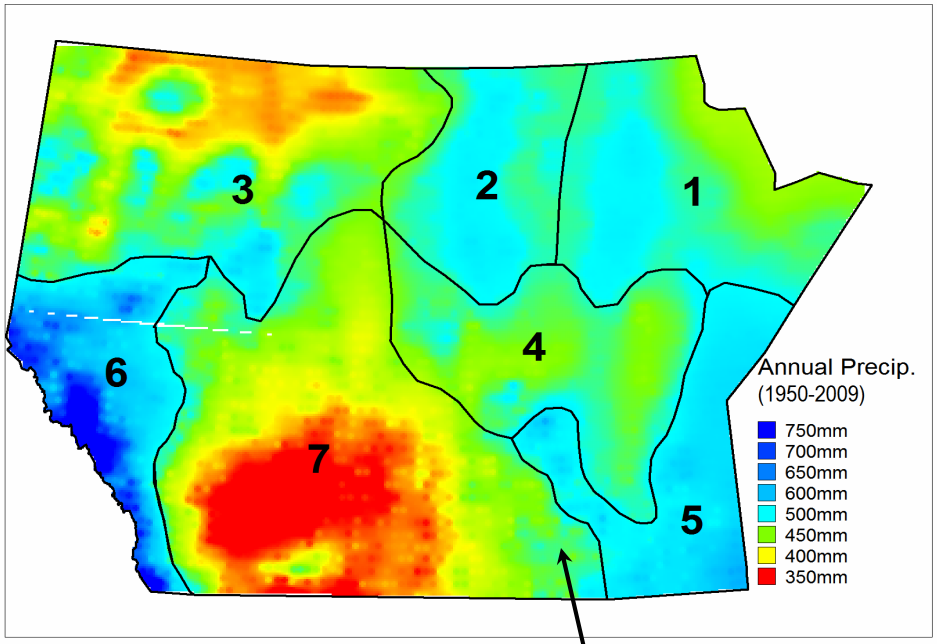
The VIC model is applied over a Prairies domain consisting of 4393 grid points with a resolution of 0.25 ° x 0.25 °

Flat terrain and non-contributing drainage areas; bring challenges to hydrological modeling

5 additional validation catchments in **red**

7 calibration catchments in **green**;





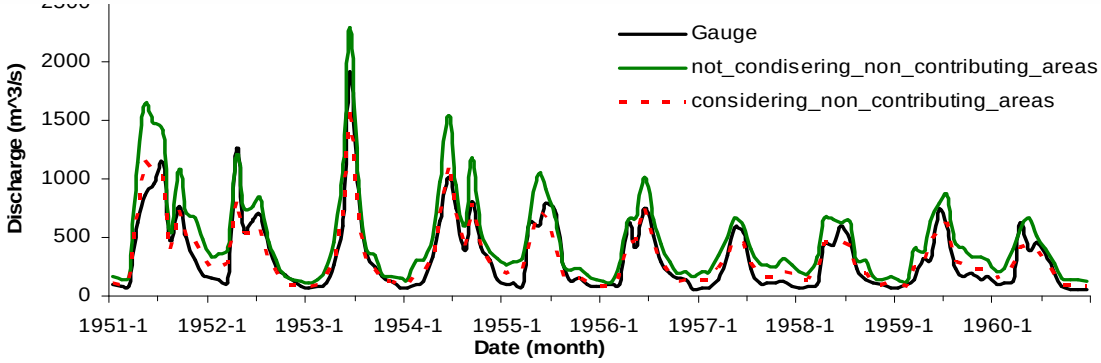
- We calibrate the six VIC user-calibrated hydrological parameters using observed daily hydrographs at the outlets of each of the 7 calibration catchments.
- The validation of the calibrated VIC over the Prairies involves the following three parts.

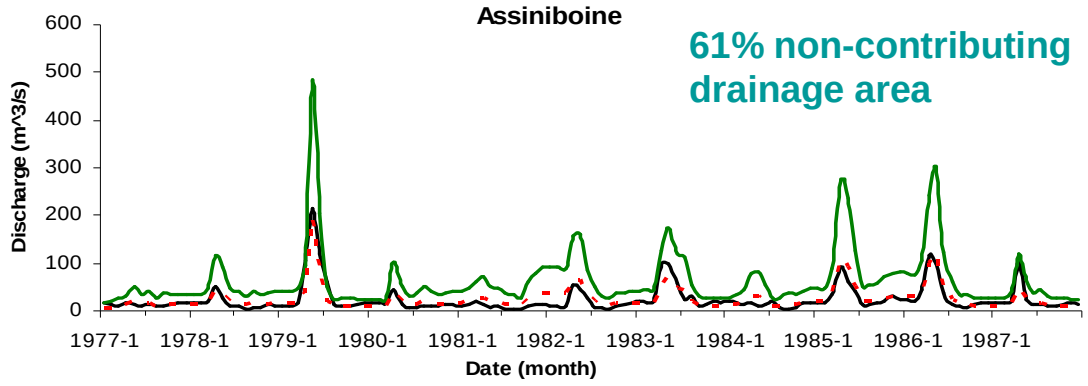
1. First, we validate VIC using observed daily hydrographs from the same 7 calibration catchments taken over different periods than for calibration.
2. Second, we further validate VIC using observed daily hydrographs from 5 additional catchments.
3. Third, we compare simulated soil moisture anomalies with *in situ* observations from 6 Alberta sites.

We define 7 VIC simulation regions over the Prairies; which are based on annual precipitation from 1950 to 2009

Study of non-contributing drainage area effect on runoff generation

	Catchment	Station	Drainage Area (km²)		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.	Princealbert	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





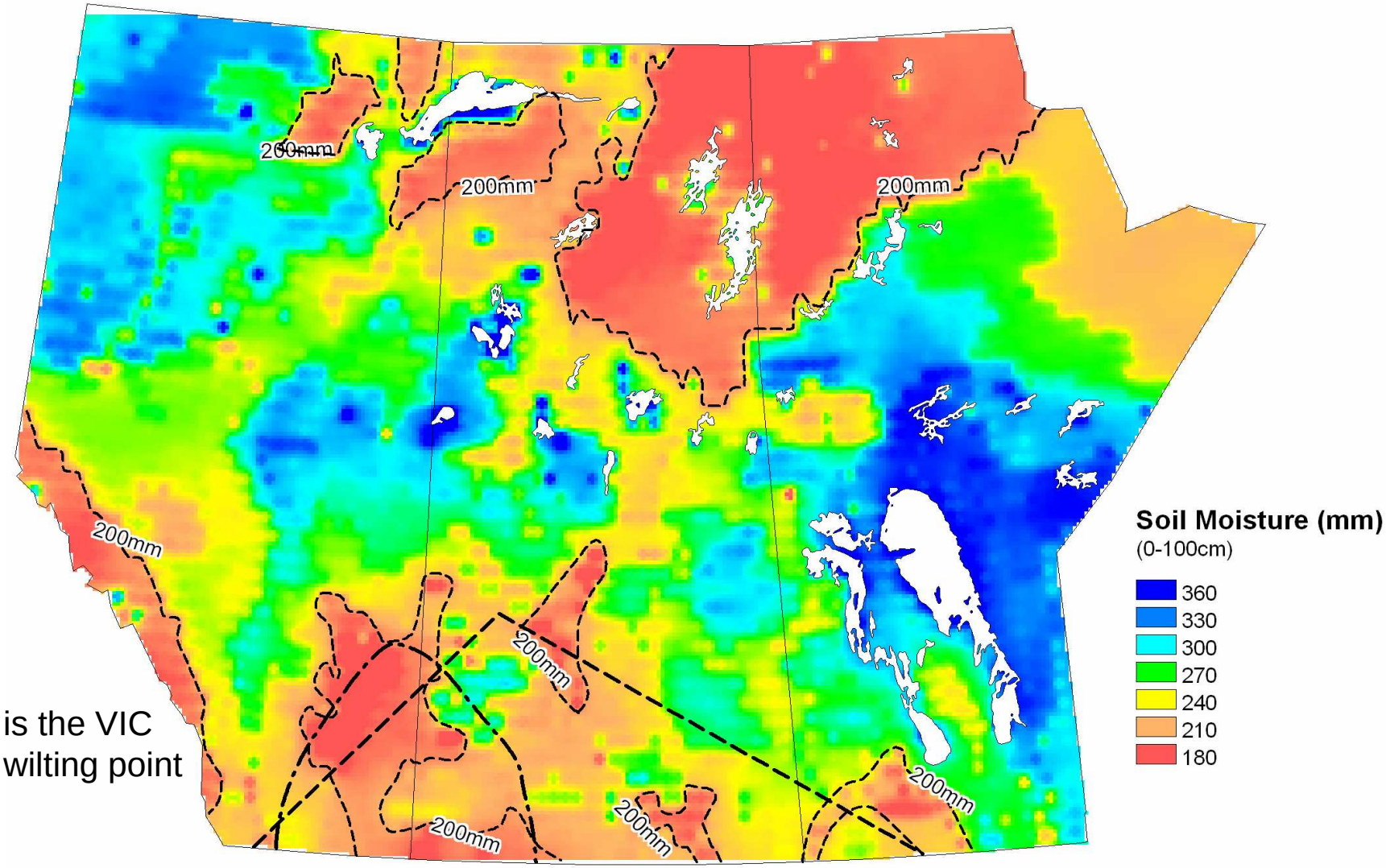
By incorporating **non-contributing drainage areas** into runoff calculations (red dashed-lines) could substantially improve the ability of hydrological models to simulate surface and sub-surface runoff in regions where the wetland is a dominant feature of land covers.

Comparison results at the outlets of the South Saskatchewan and Assiniboine catchments

3. Applications of VIC soil moistures

60-yr (1950-2009) average of soil moisture (top 1-m) over the Prairies

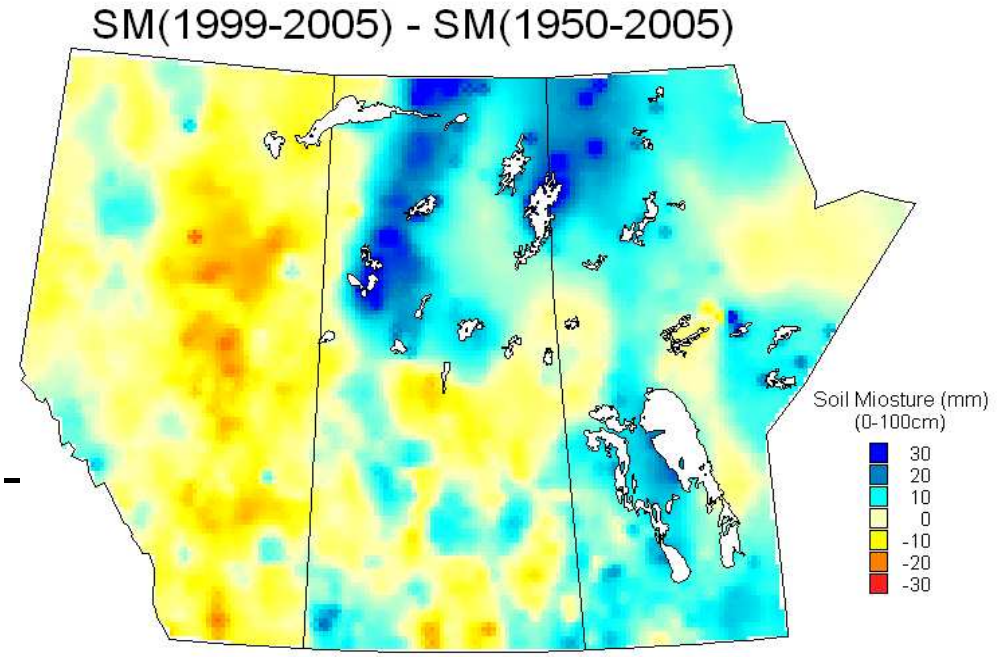
with the 200 mm soil moisture contour, showing modeled very dry areas

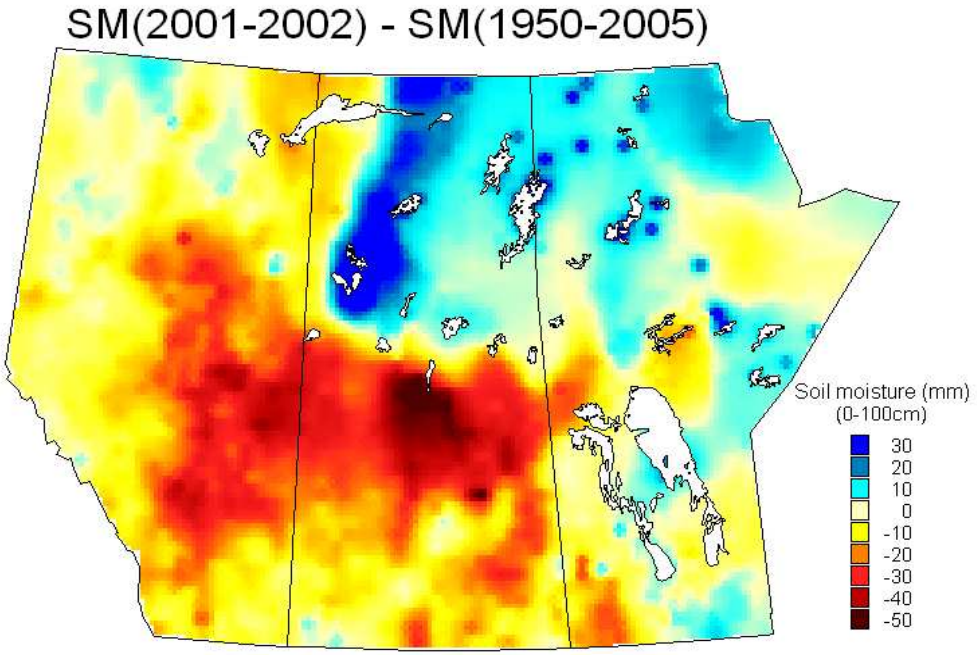


200 mm is the VIC average wilting point

Identifications of the Palliser Triangle region and the Prairie Dry Belt (Jones, 1978) in South Prairies.

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

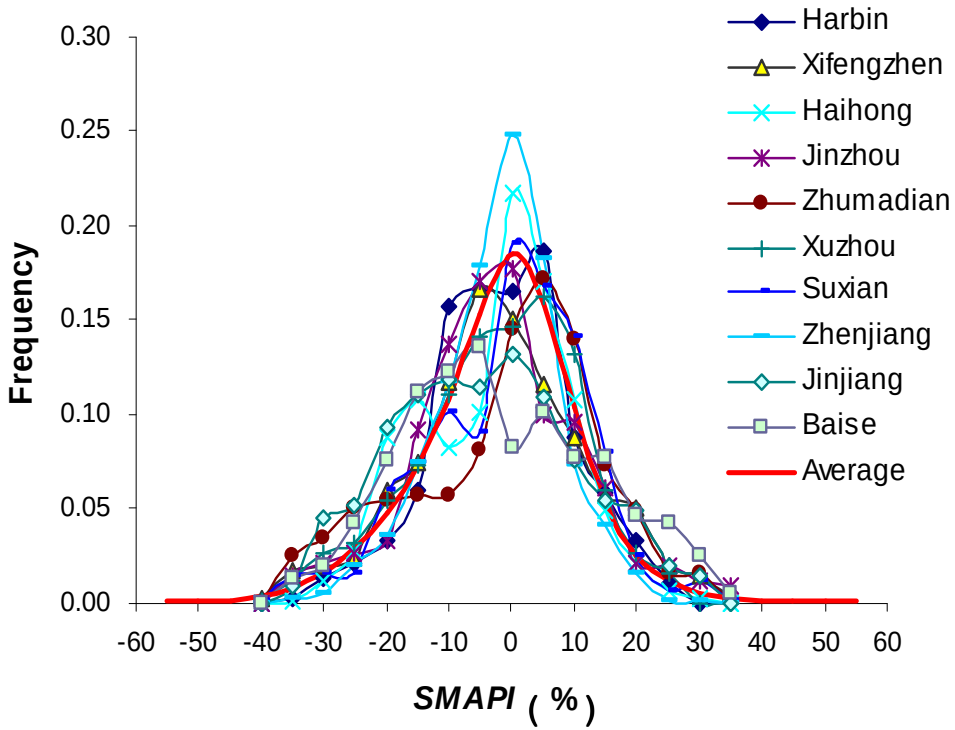




Soil Moisture Anomaly Percentage Index (SMAPI)

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

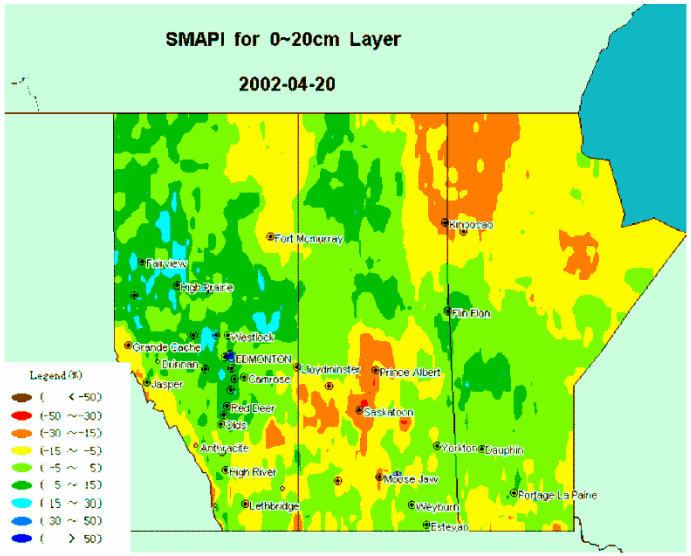
- The soil moisture climatology reflects local characteristics and mirrors the hydro-meteorological phenomena of a region
- The concept of relative soil wetness for use in measuring drought severity
- The study of Quiring and Papakryiakou (2003) indicates that the Z-index is best suited for predicting yield. The Z-index is a measure of the monthly soil moisture anomaly

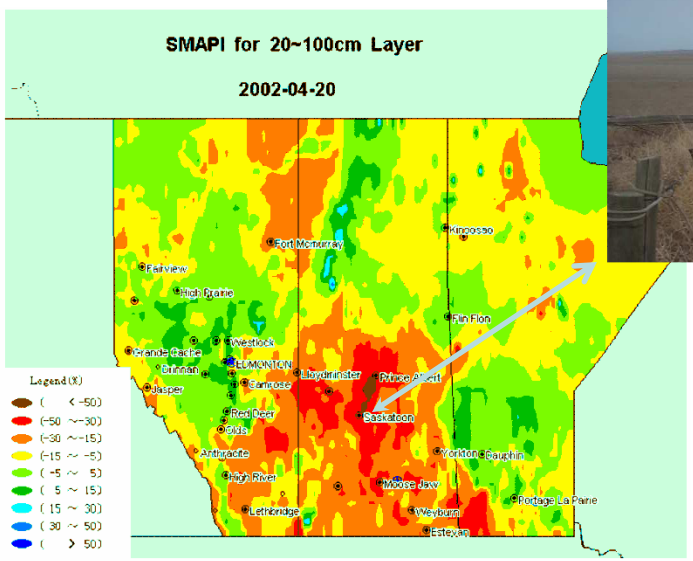


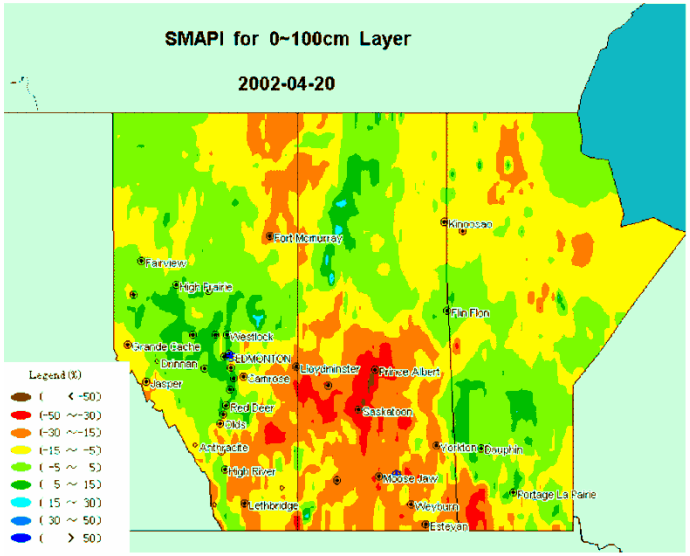
Drought classifications based on SMAPI

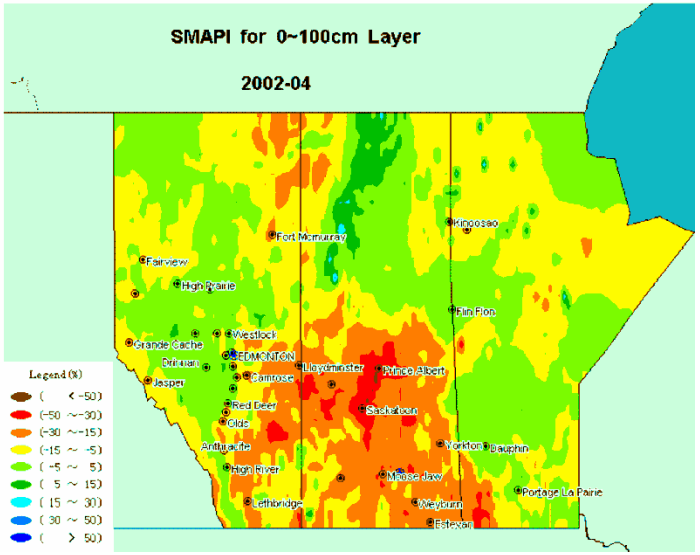
Category	SMAPI	Average Frequency
extreme drought	≤ -50%	0.005
severe drought	-50% to -30%	0.020
moderate drought	-30% to -15%	0.100
mild drought	-15% to -5%	0.200
near normal	-5% to 5%	0.350
slightly wet	5% to 15%	0.200
moderately wet	15% to 30%	0.100
very wet	30% to 50%	0.020
extremely wet	> 50%	0.005

Reconstructing prairie drought history



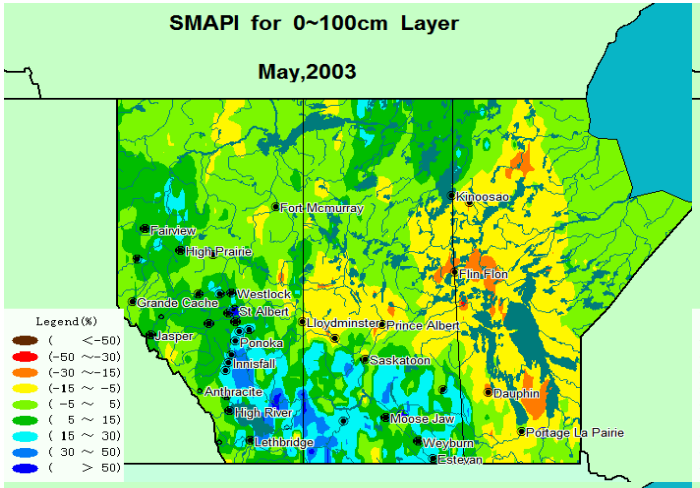


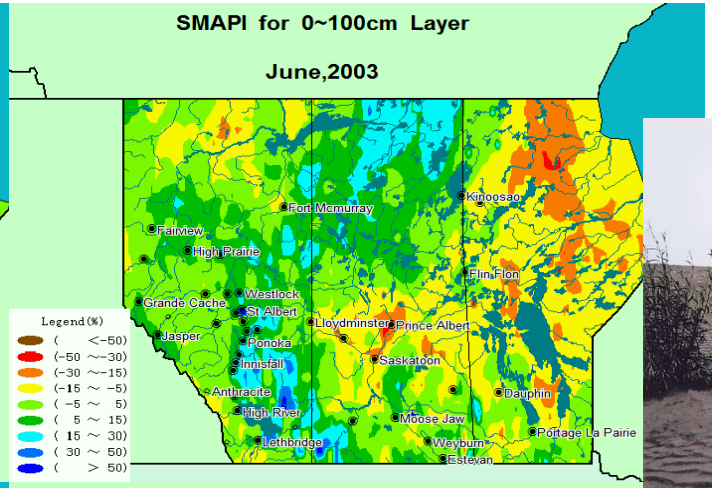


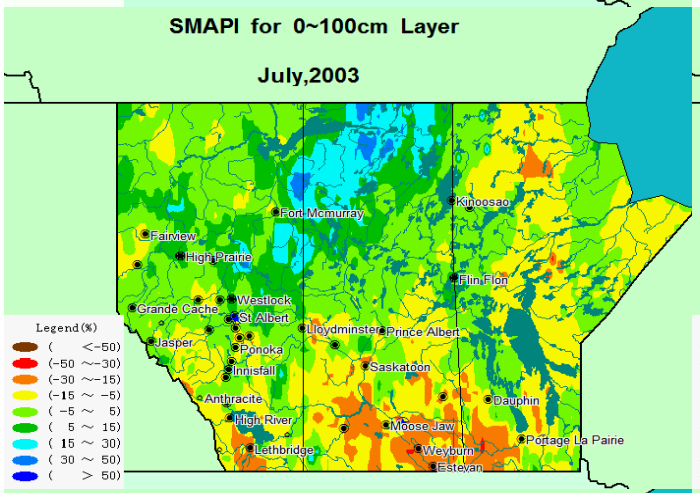


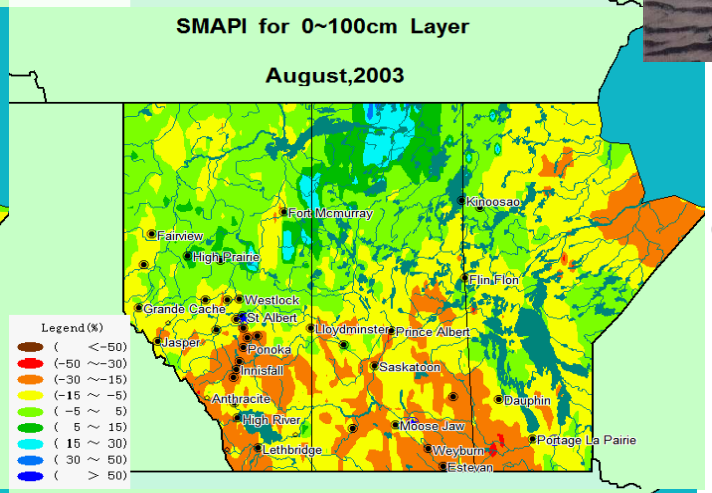
Southern Saskatchewan, April 2002; Taken from Stewart

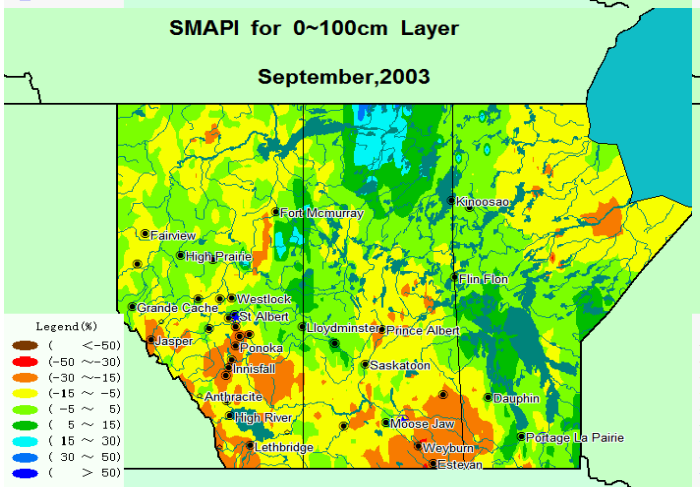
Example 2: daily SMAPI distributions of the three soil layers for April 20, 2002, together with the April-2002 average

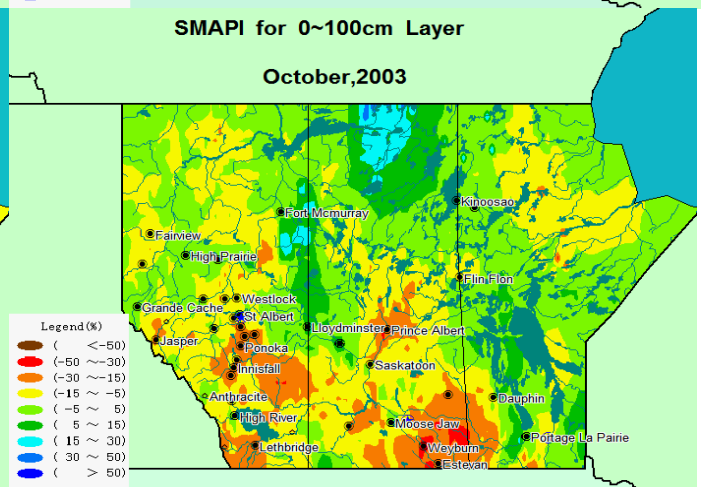












Wind erosion and dust storms caused considerable soil and much other damage in a large area south of Saskatoon, Saskatchewan, in the summer of 2003 (photo by E. Wheaton, SRC)

Example 3: monthly SMAPI distributions of May, June, July, August, September and October, 2003

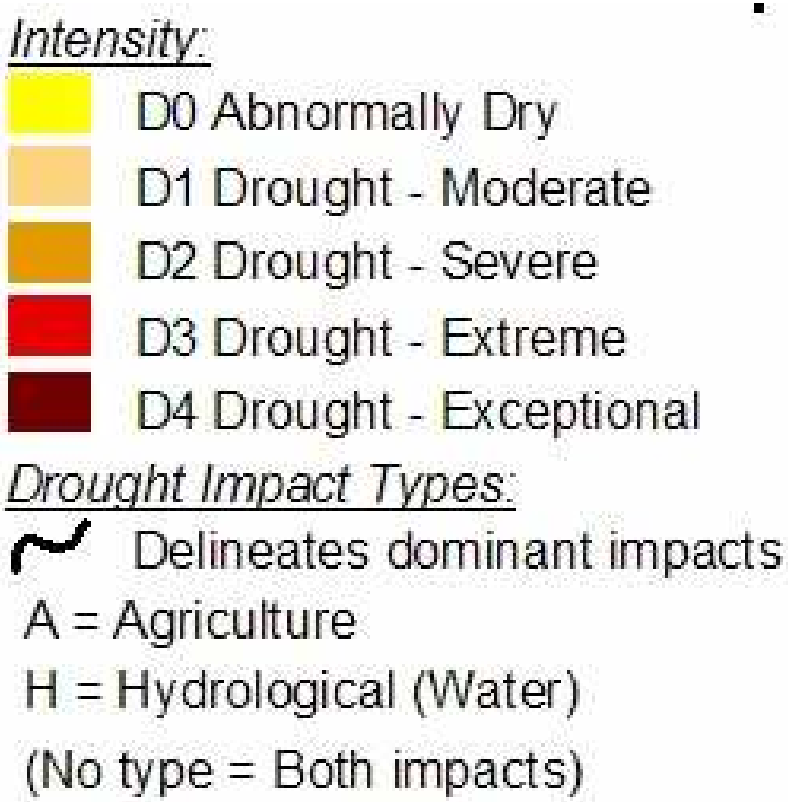
Clearly showing soil conditions changed from wet to dry

Analysis of real-time prairie drought monitoring and forecasting system

Comparing SMAPI with ‘soft’ data

Comparison of drought indexes of soil moisture from VIC simulation and **North American Drought Monitor** (‘observation’). The index of VIC model is the monthly averaged value; and NADM index represents the mean of the month. This is a qualitative comparison.

NADM



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
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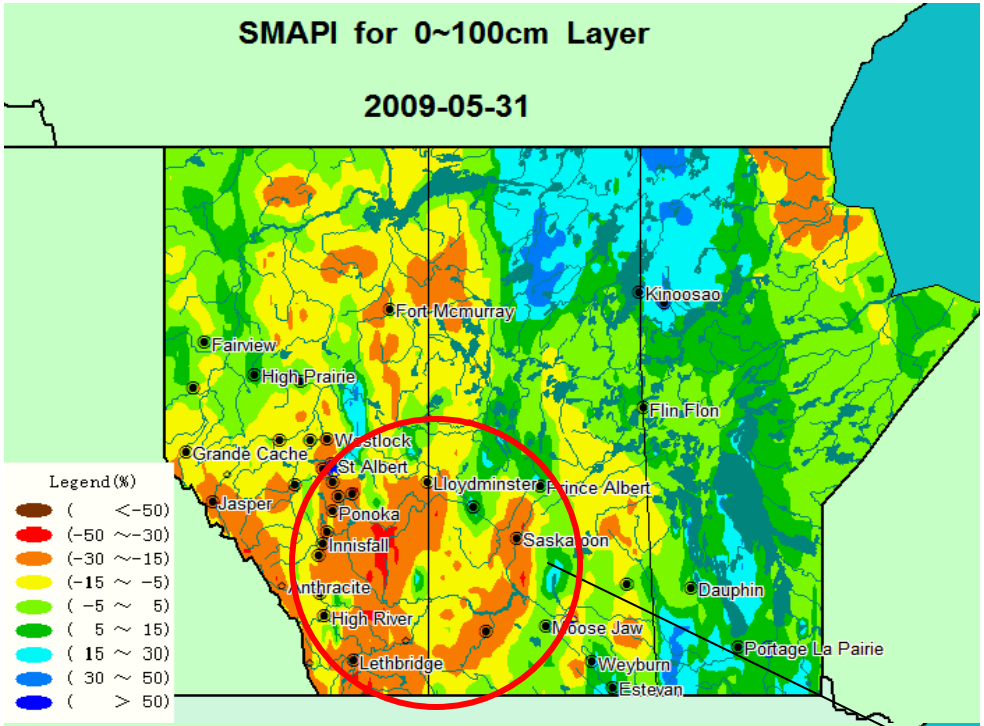
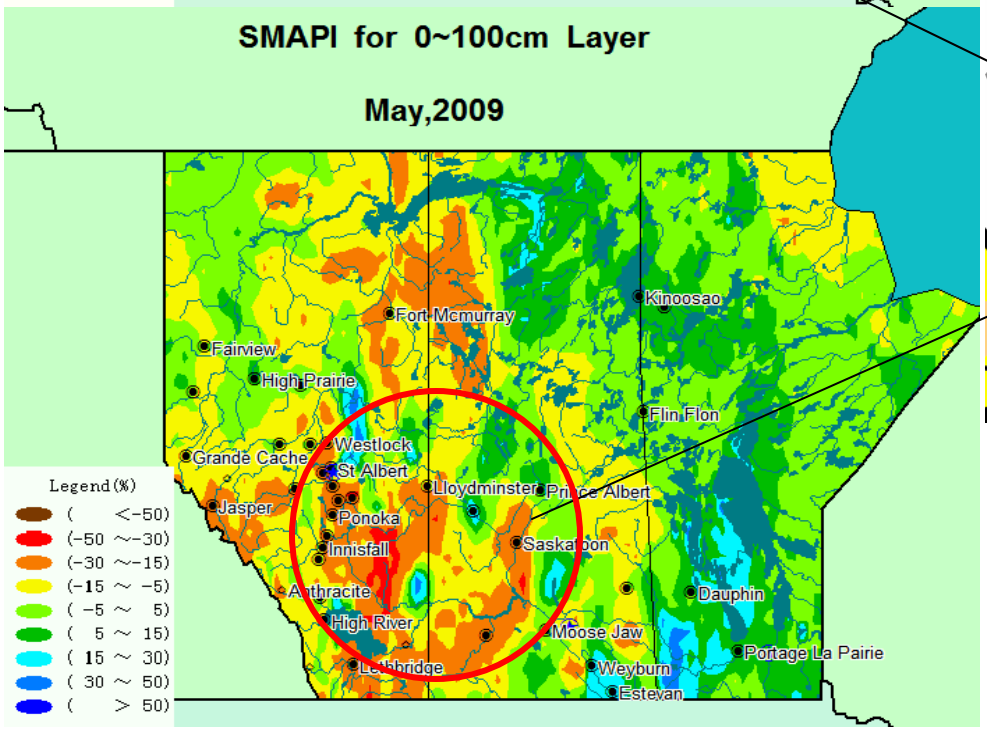
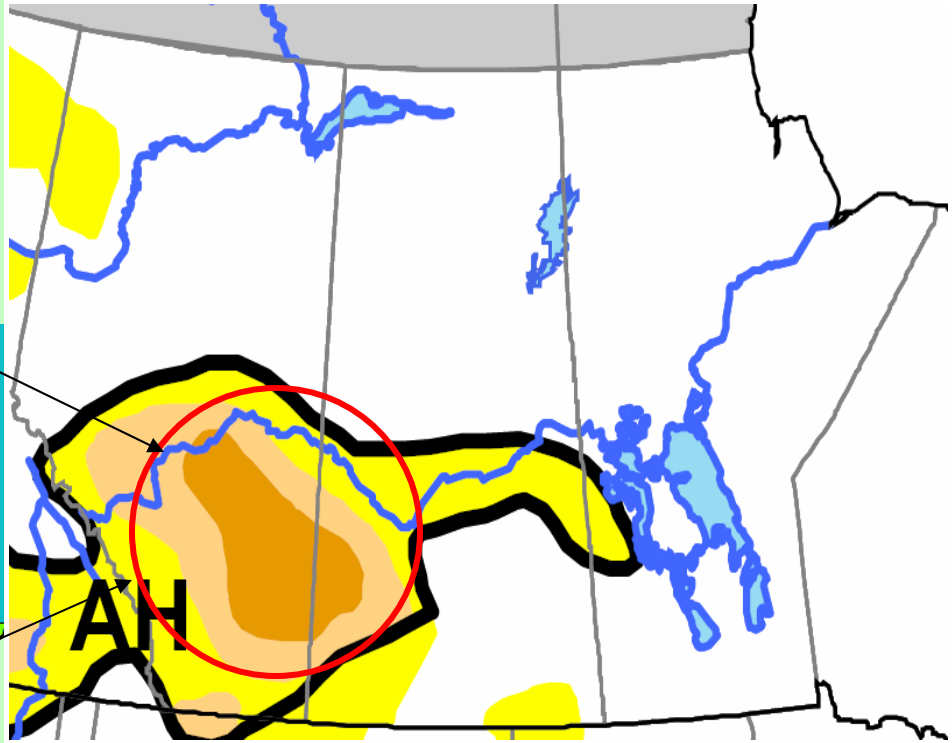
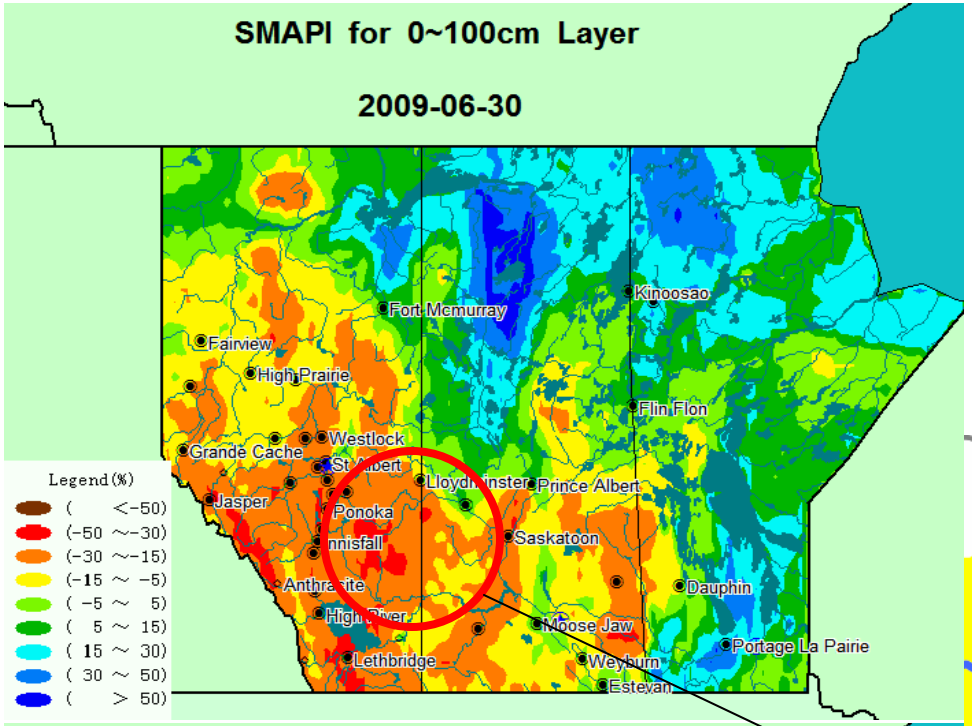
very wet	30% to 50%	0.020
extremely wet	> 50%	0.005

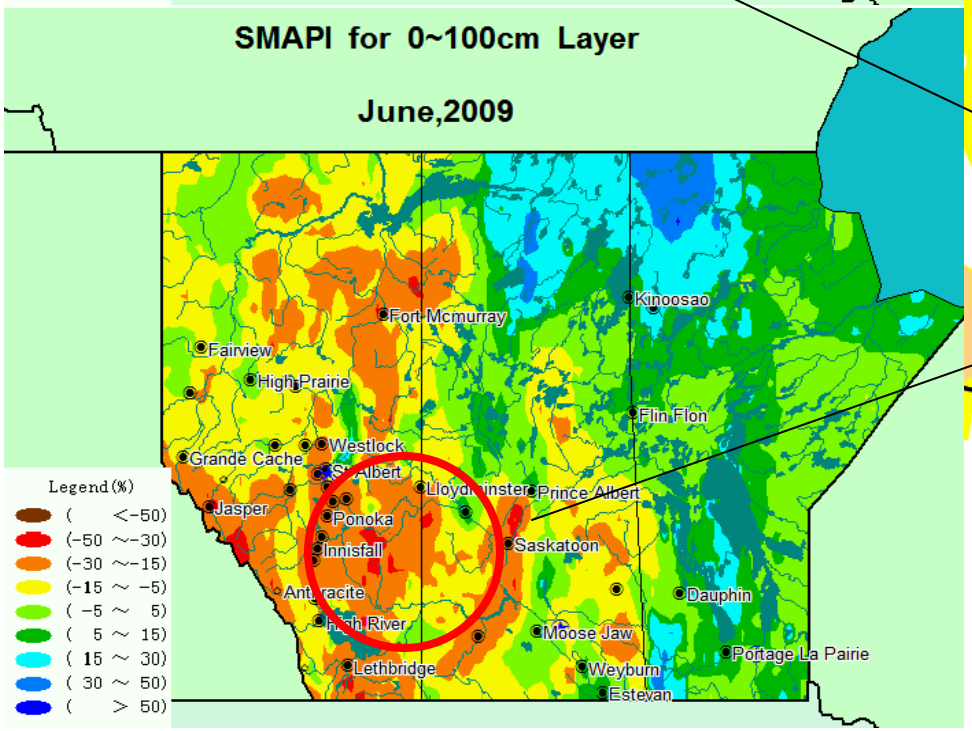




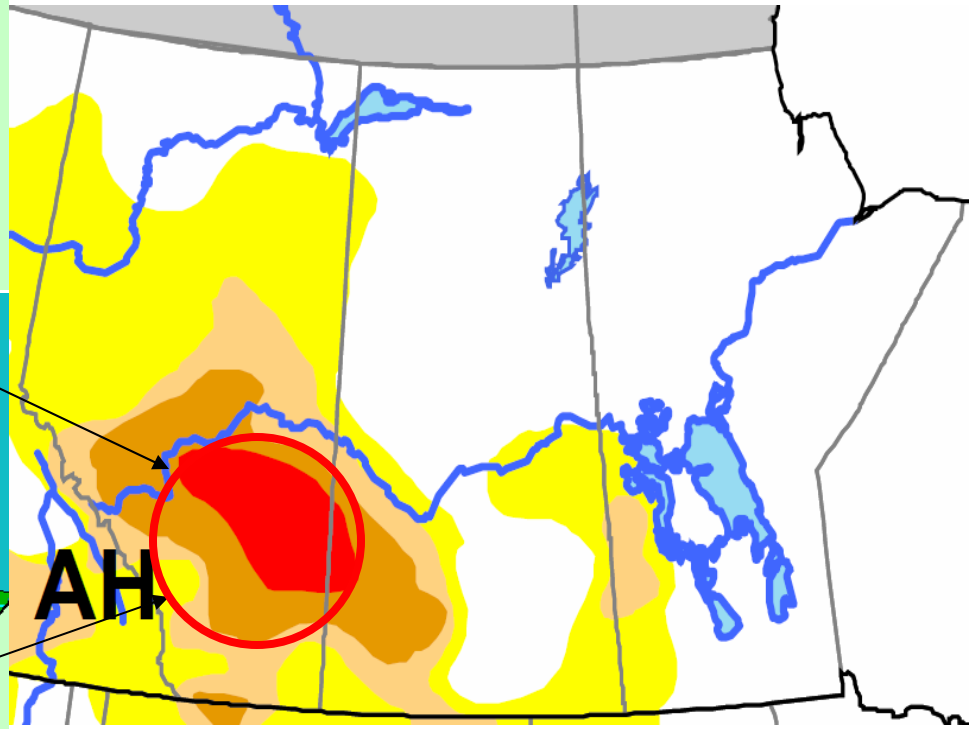


Our VIC forecast for May-2009 average

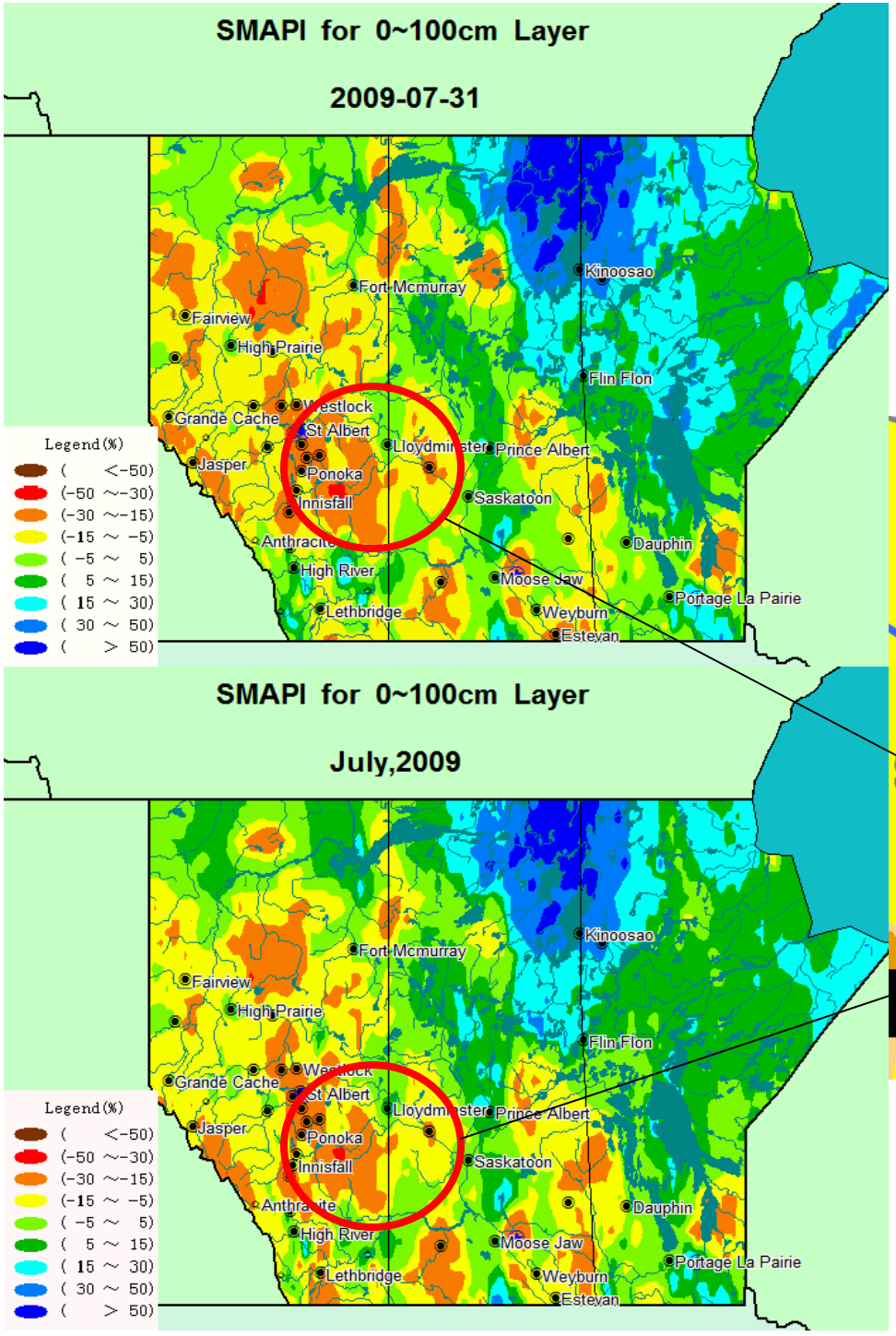




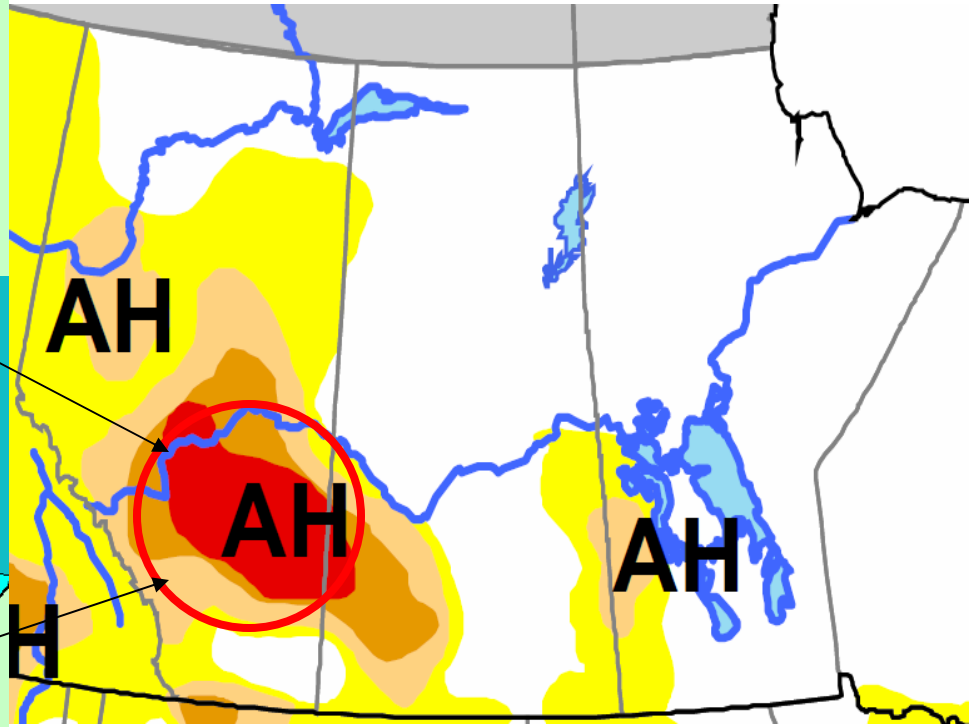
Our VIC forecast for June 30, 2009



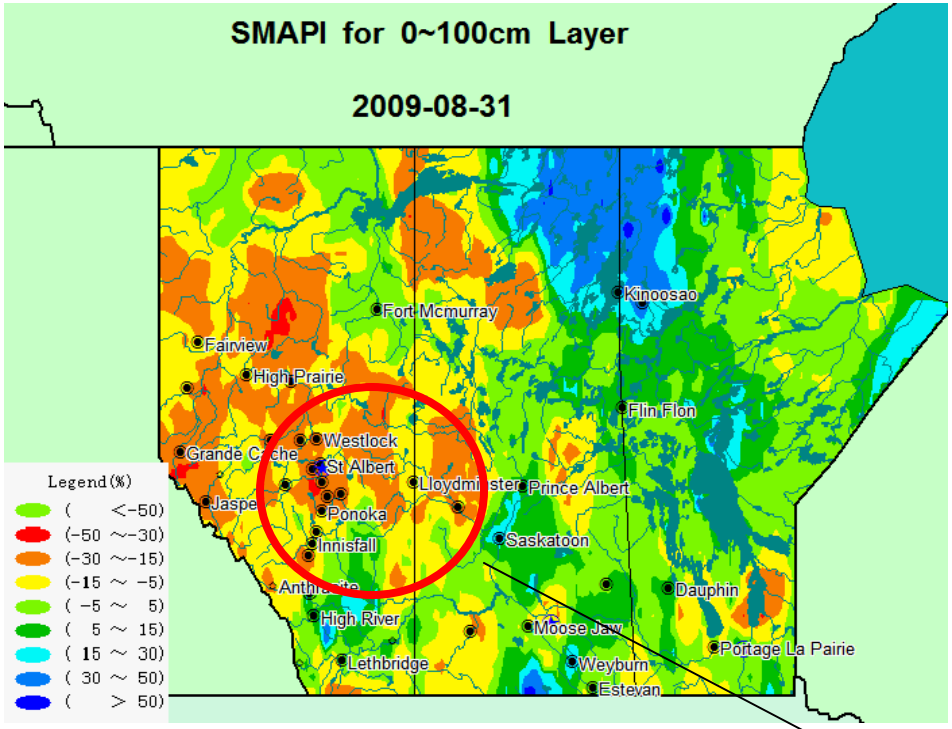
Our VIC forecast for June-2009 average

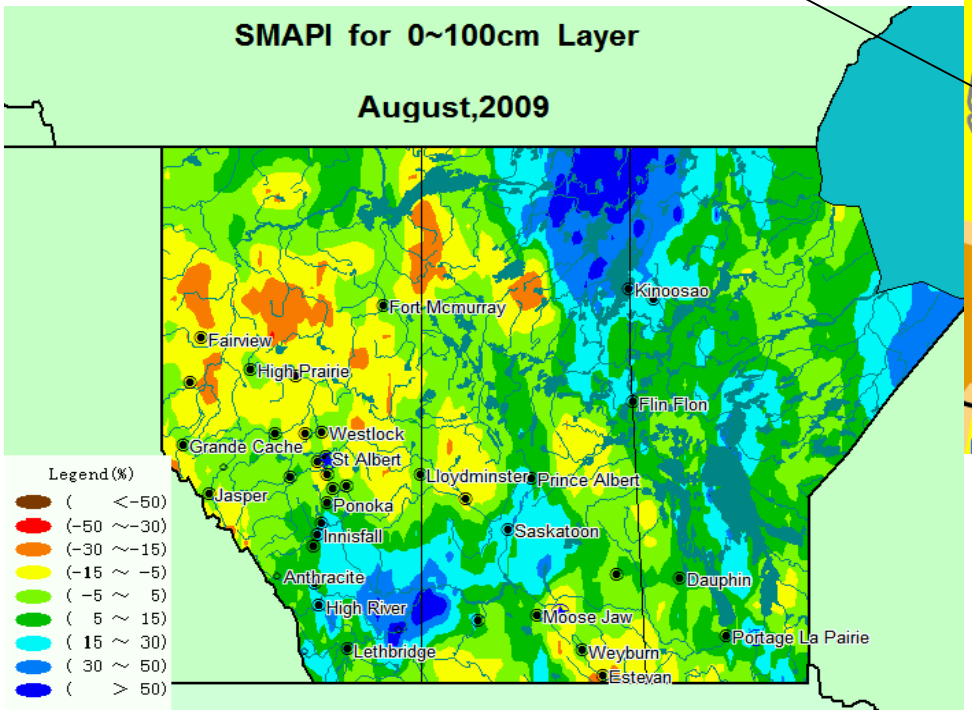


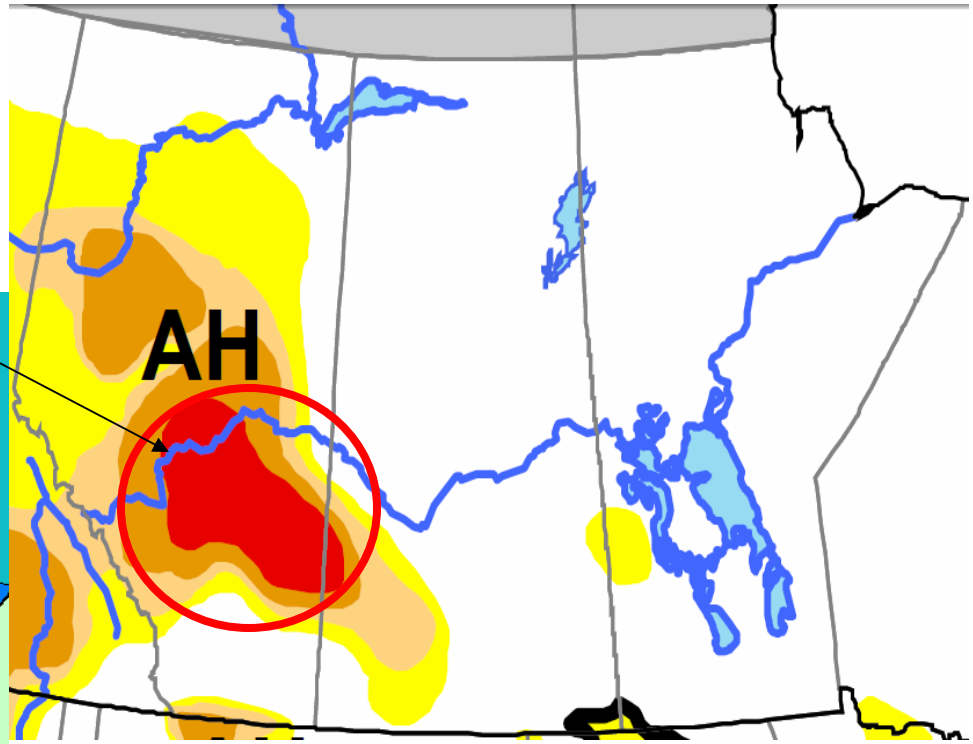
Our VIC forecast for July 31, 2009



Our VIC forecast for July-2009 average



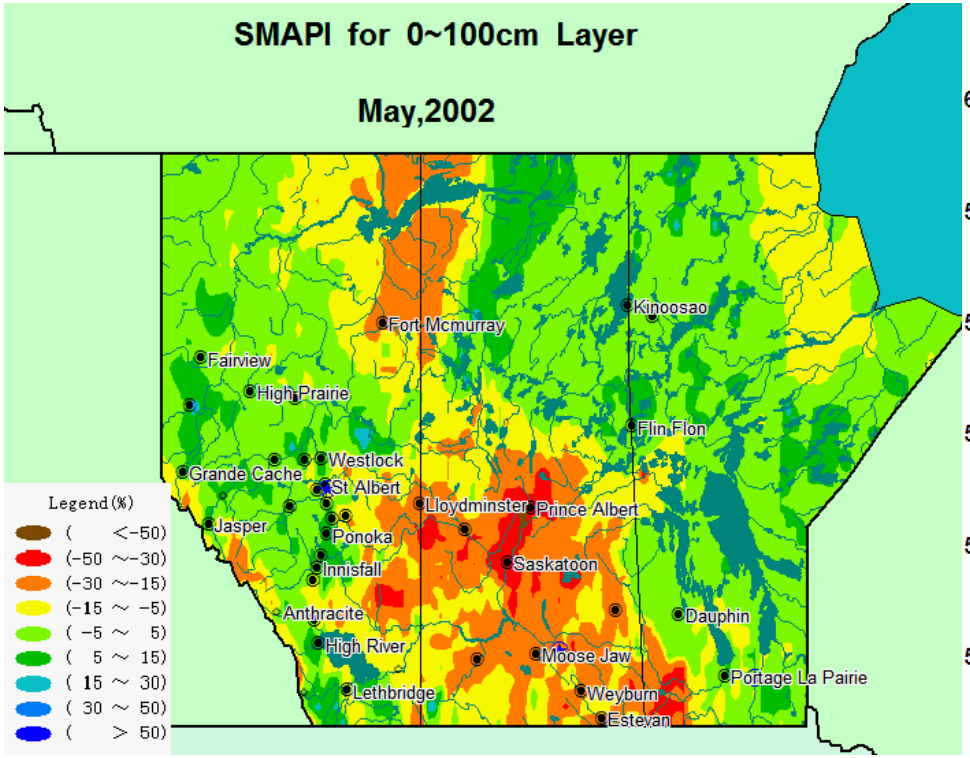


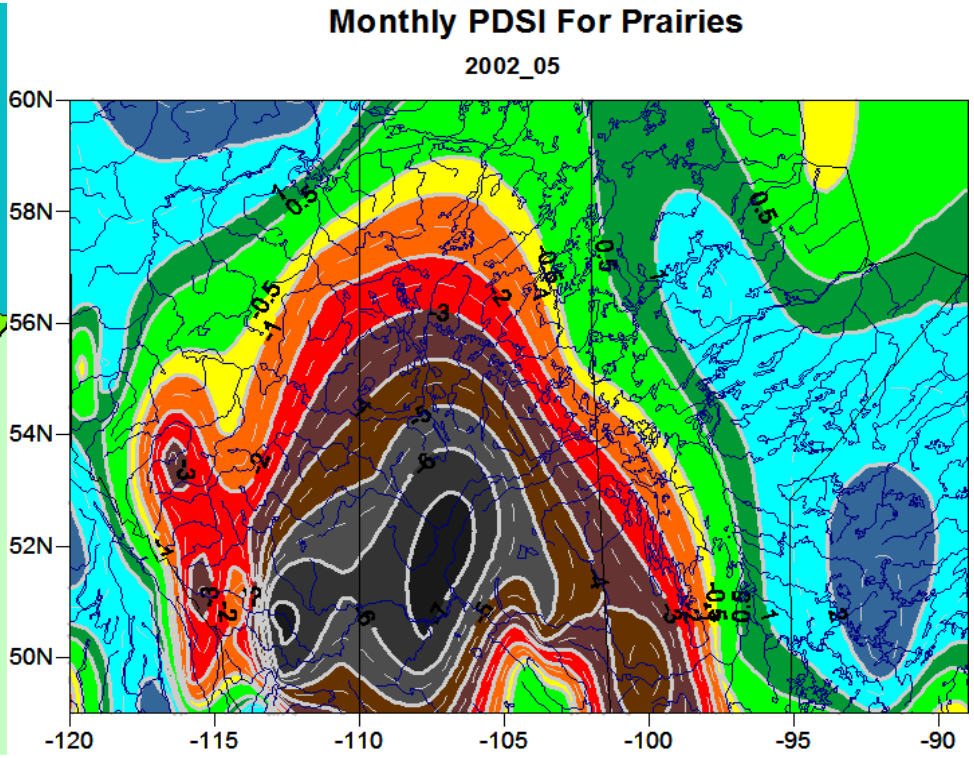


Our VIC forecast for August-2009 average

Comparison of monthly mean drought indexes of soil moisture from VIC simulation and Environment Canada PDSI for the period January 1951 to December 2007

http://www.meteo.mcgill.ca/~leiwen/vic/prairies/month-seasonal-annual/index_compare.html





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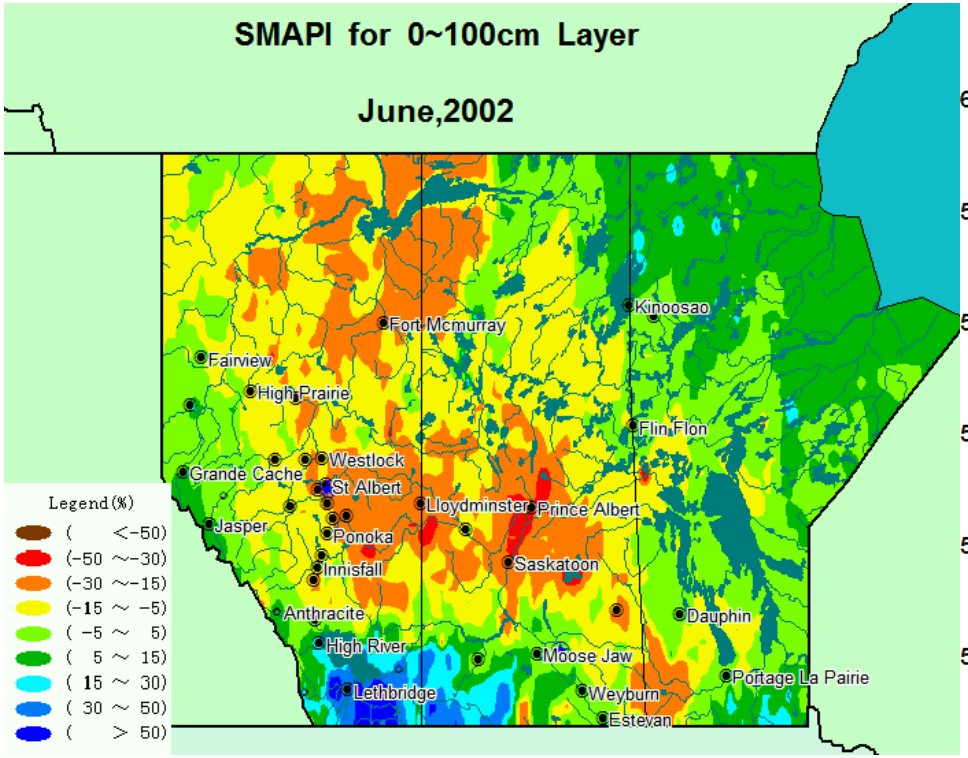

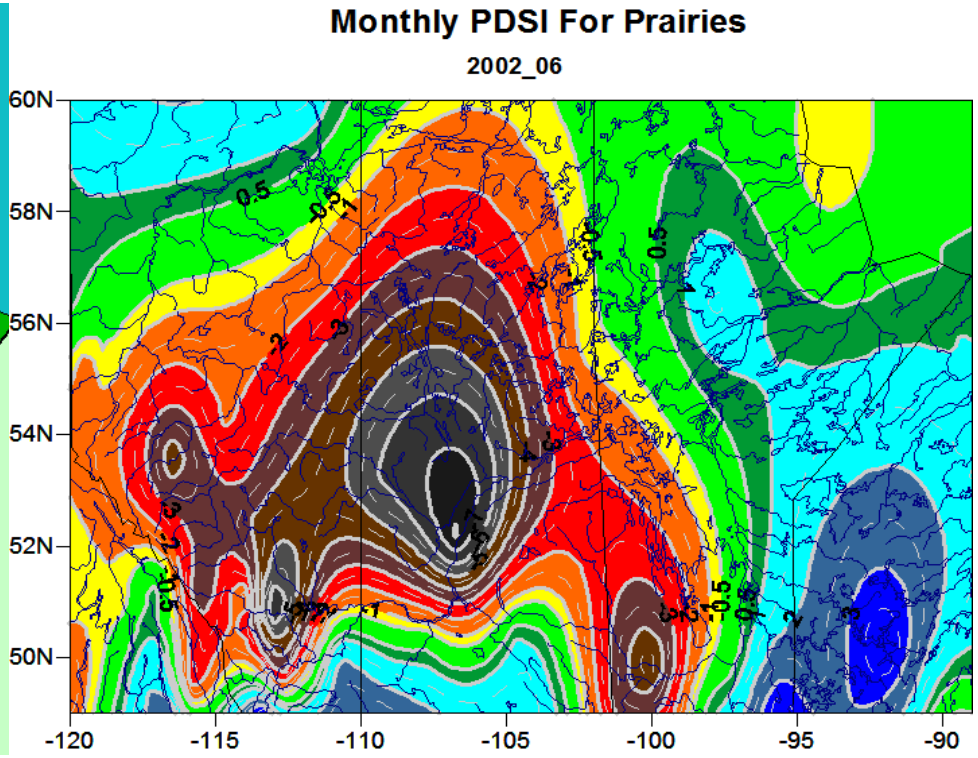

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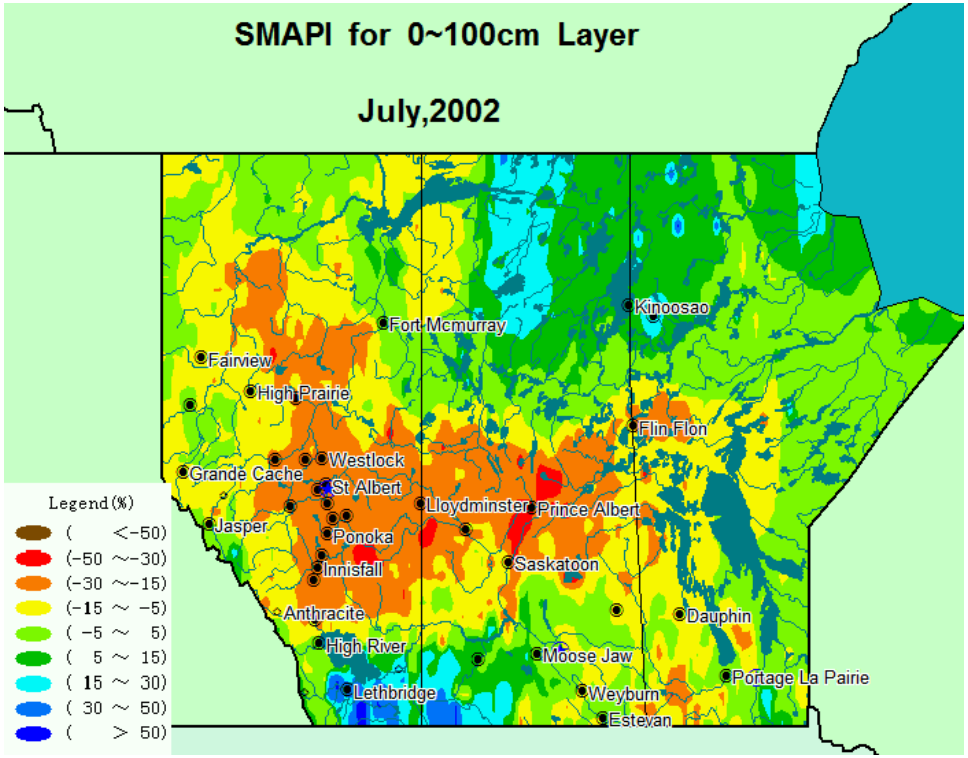

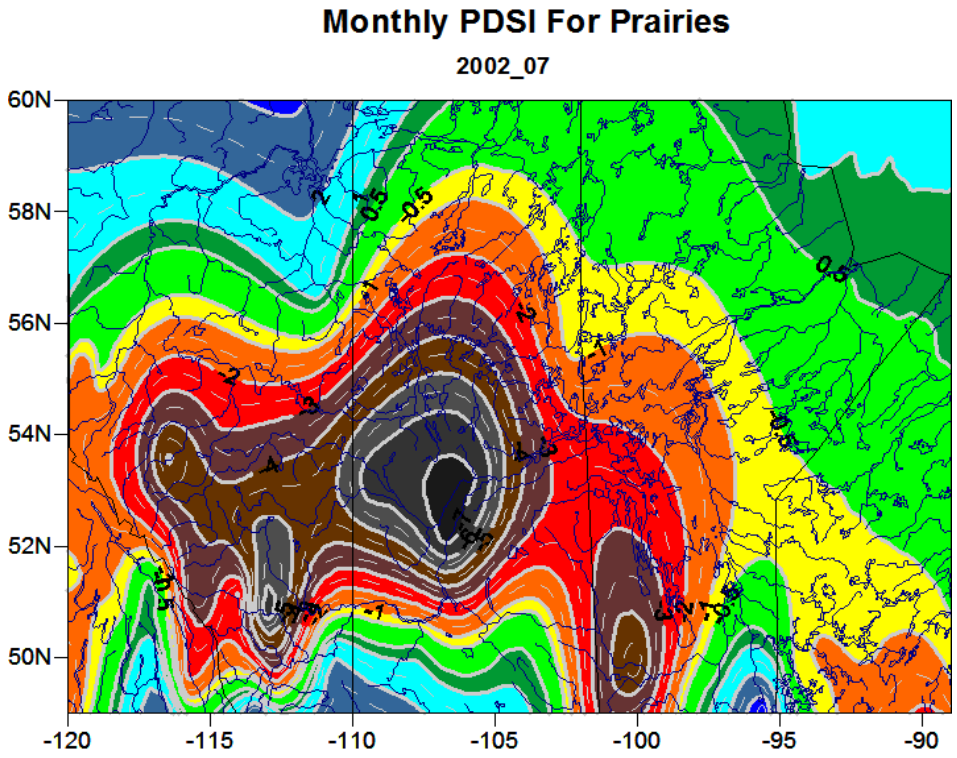

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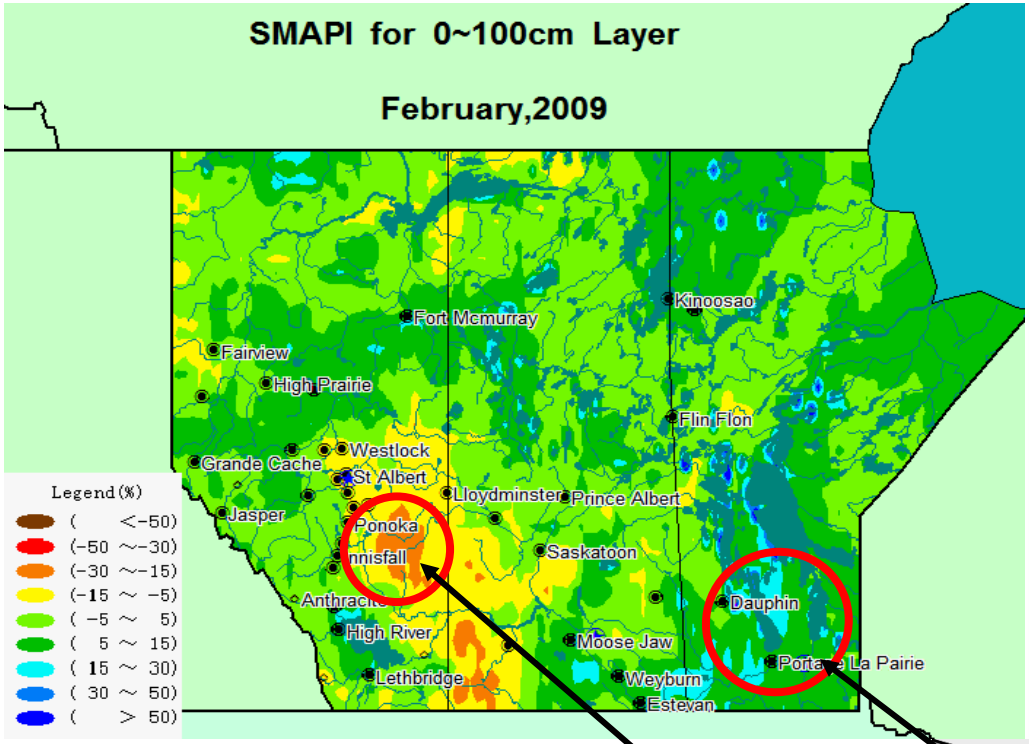
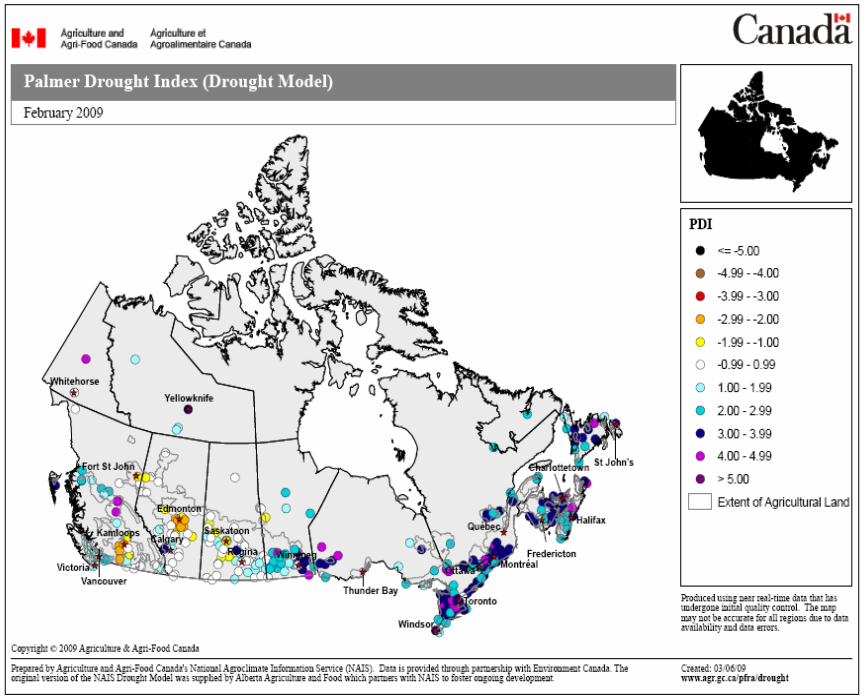
Real-time forecasting Winnipeg 2009 spring flood

Comparison of drought indexes of soil moisture from VIC simulation and Agricultural and Agri-Food Canada PDSI

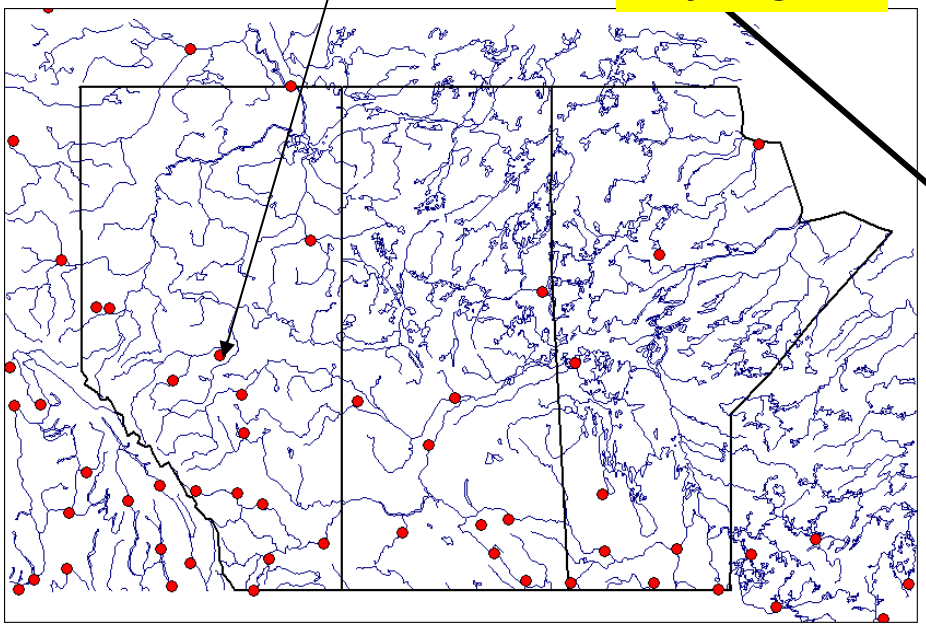
VIC driven forces: the operational Canadian GEM model forecast (0-6 days) + the operational 40-number super ensemble forecast (7-15 days) + the operational CMC ensemble seasonal forecast (16-35 days)

Our drought forecast is updated daily and corrected by station precipitation



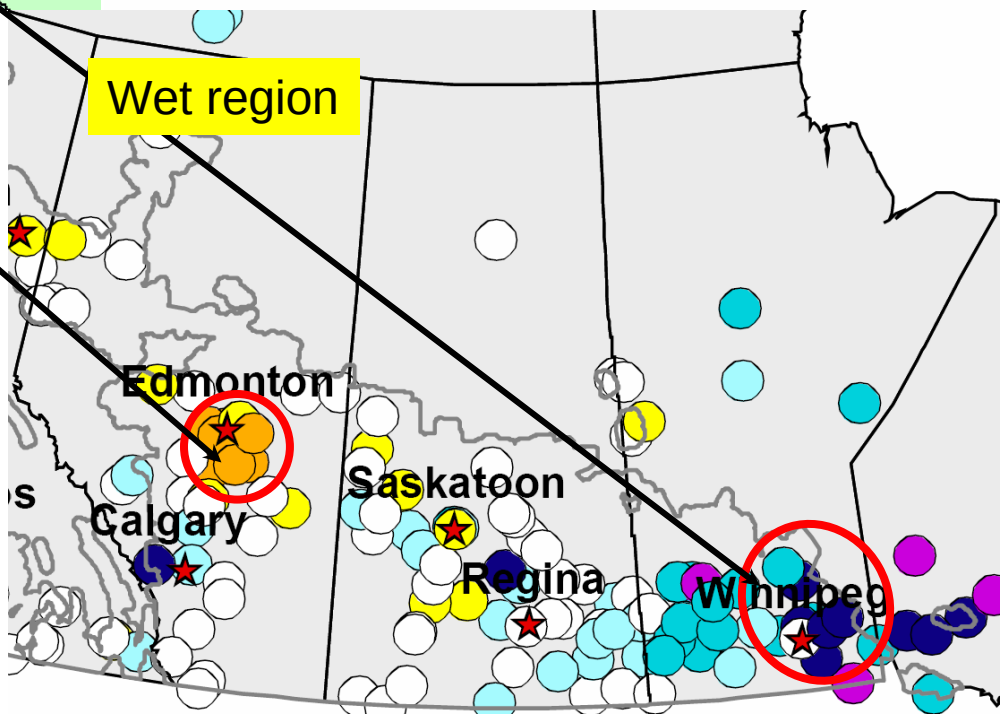


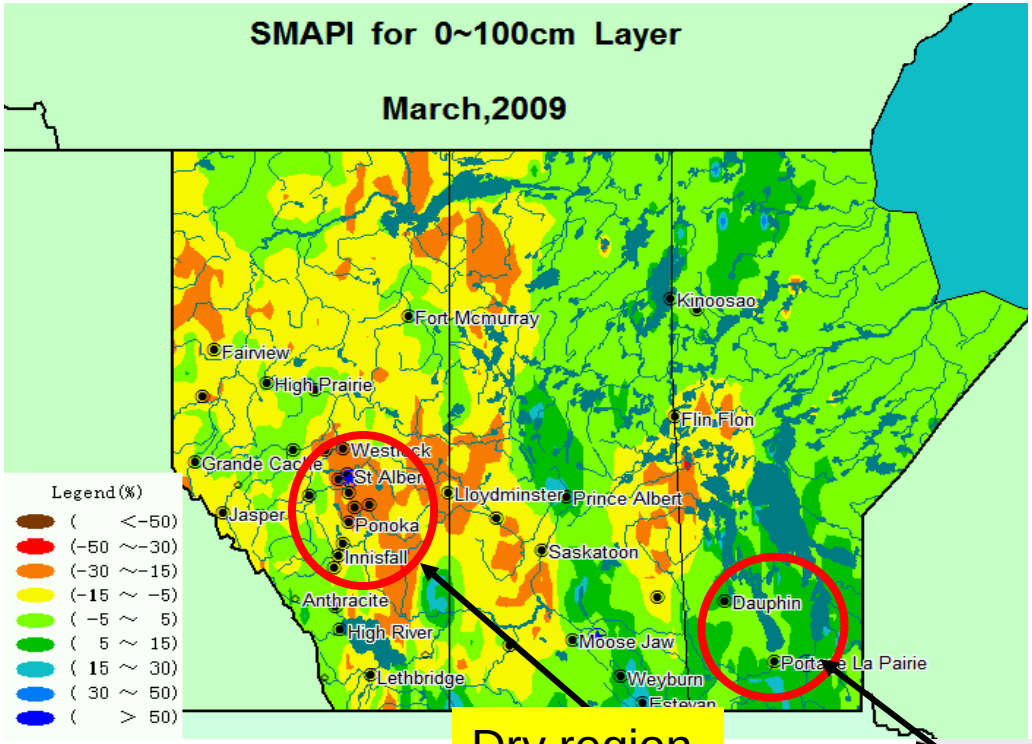
Locations of PDSI stations

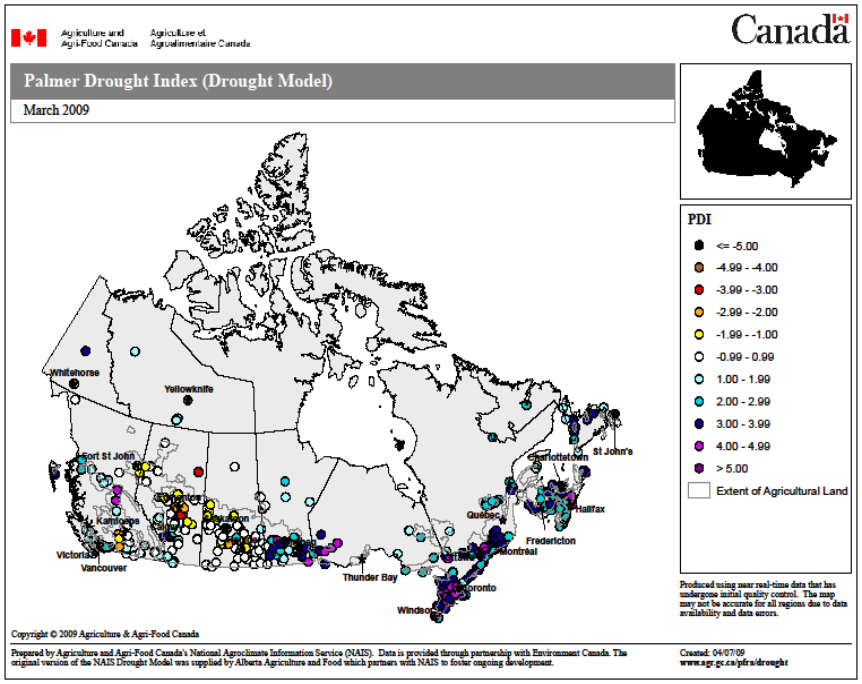


Dry region

Wet region







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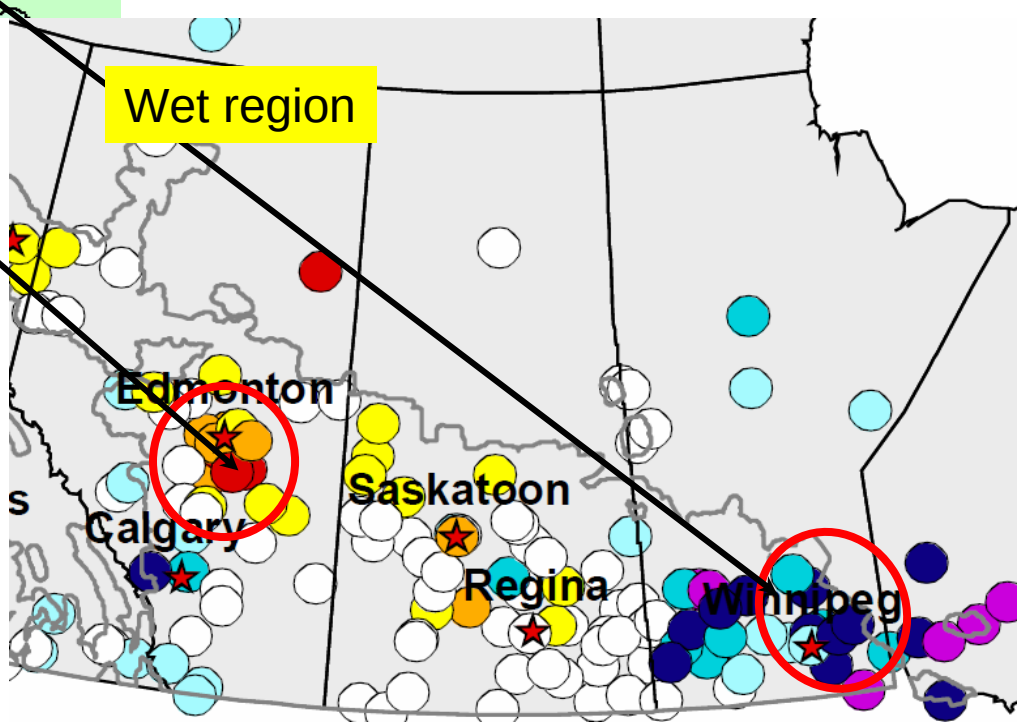
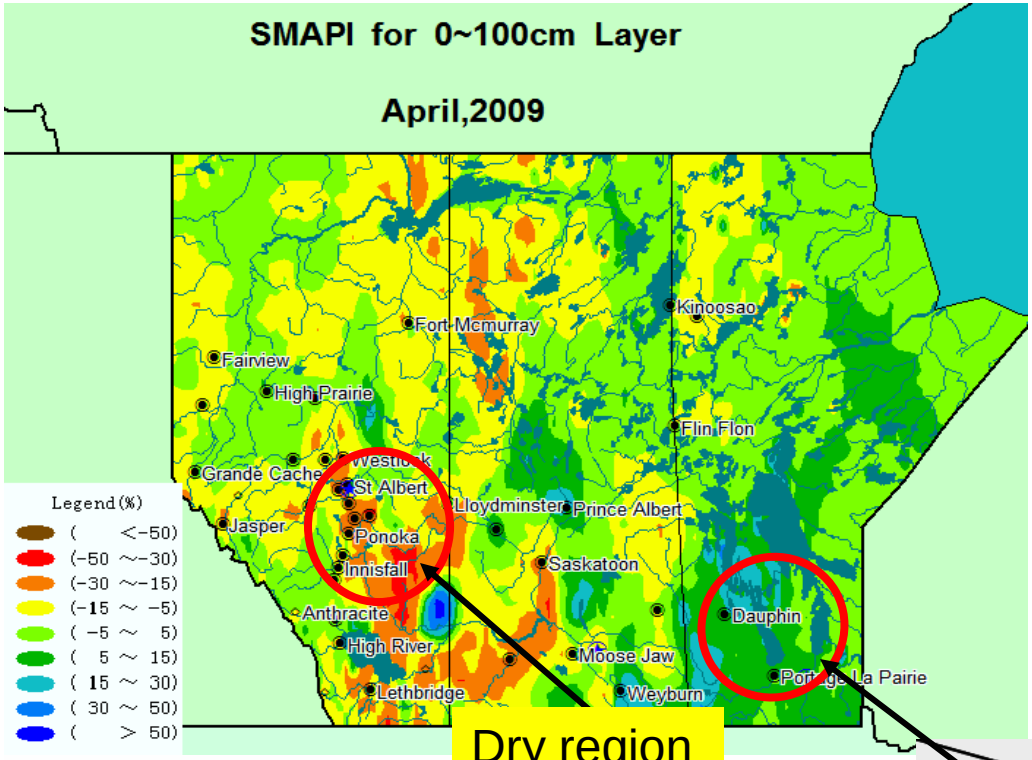
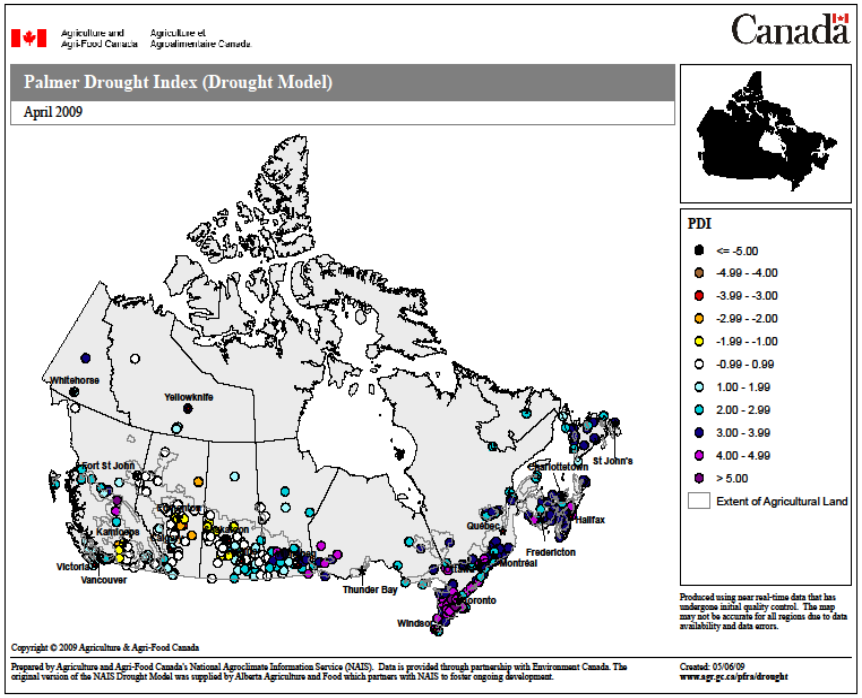
extremely wet	> 50%	0.005

Wet region



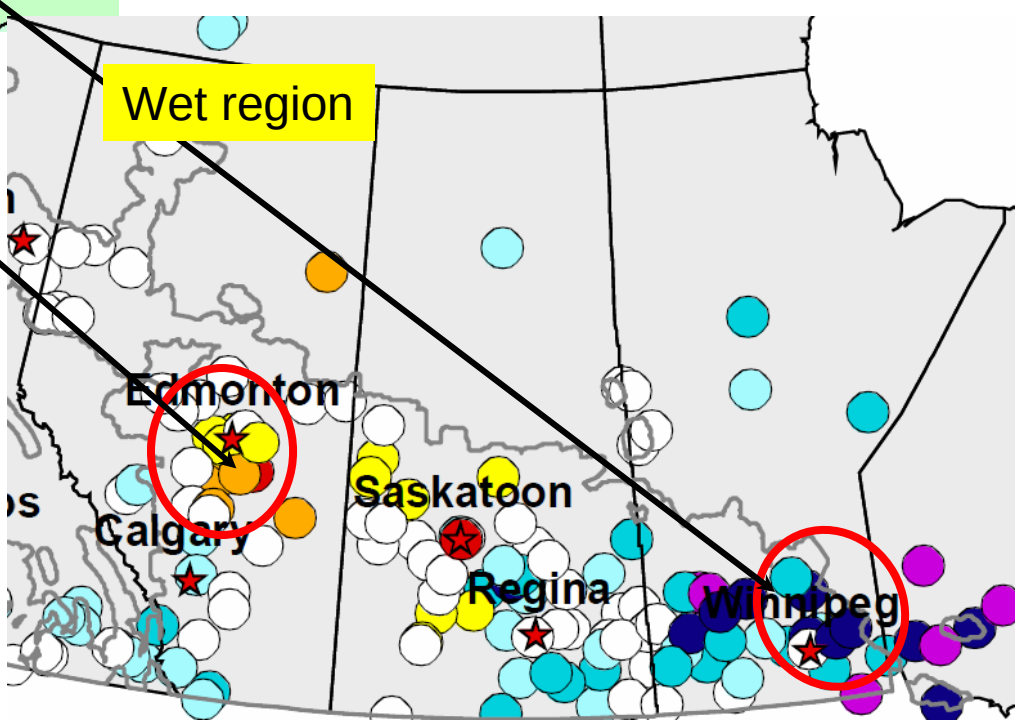


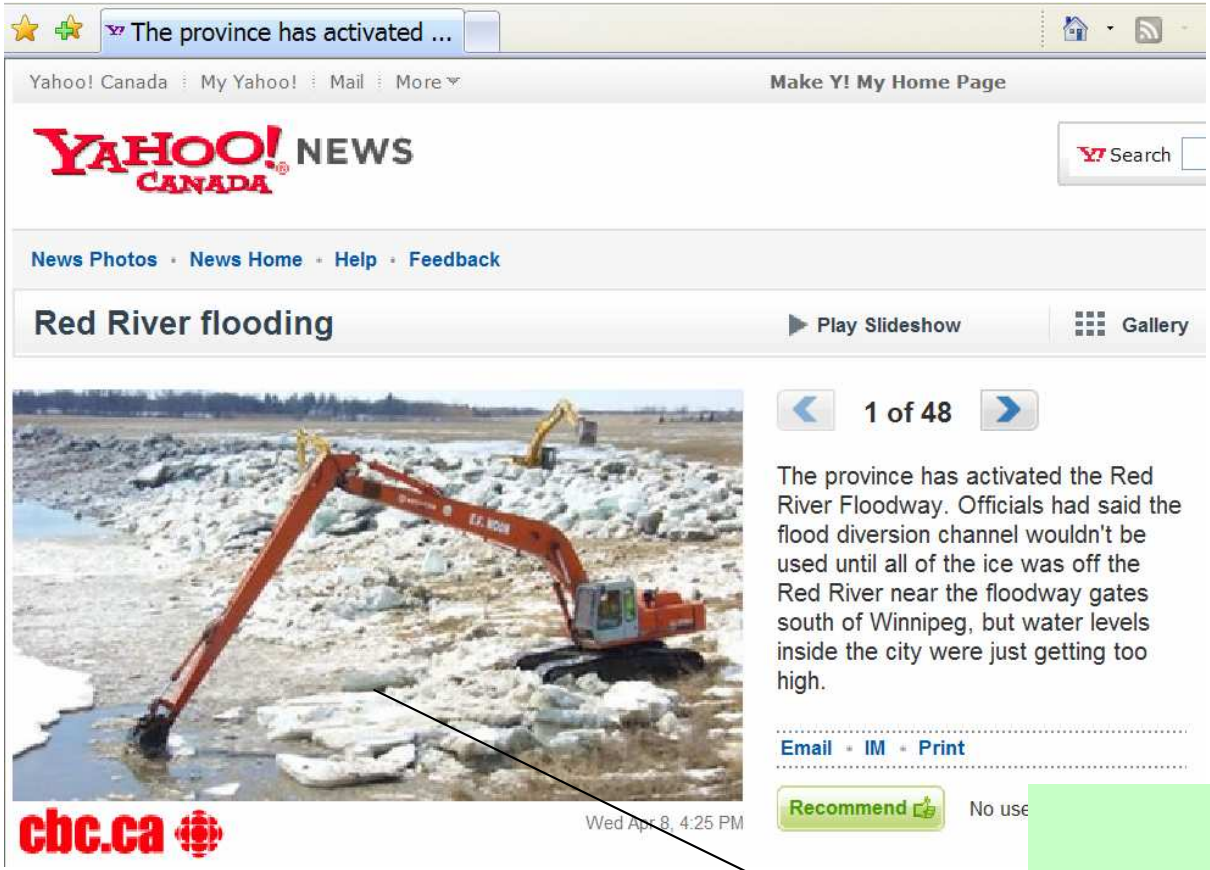


Dry region

Wet region

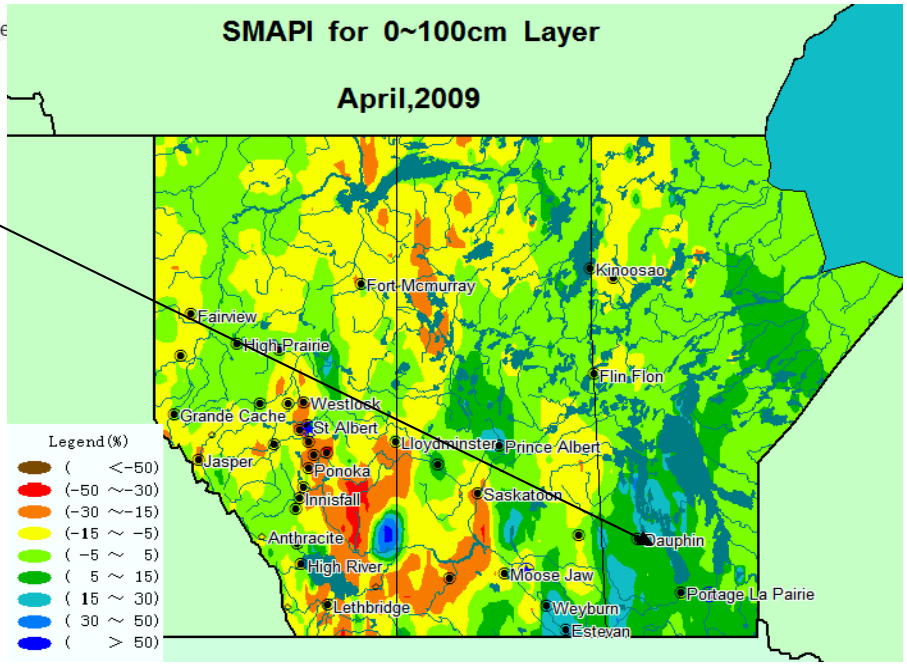
Category	SMAPI	Average Frequency
extreme drought	≤ -50%	0.005
severe drought	-50% to -30%	0.020
moderate drought	-30% to -15%	0.100
mild drought	-15% to -5%	0.200
near normal	-5% to 5%	0.350
slightly wet	5% to 15%	0.200
moderately wet	15% to 30%	0.100
very wet	30% to 50%	0.020
extremely wet	> 50%	0.005



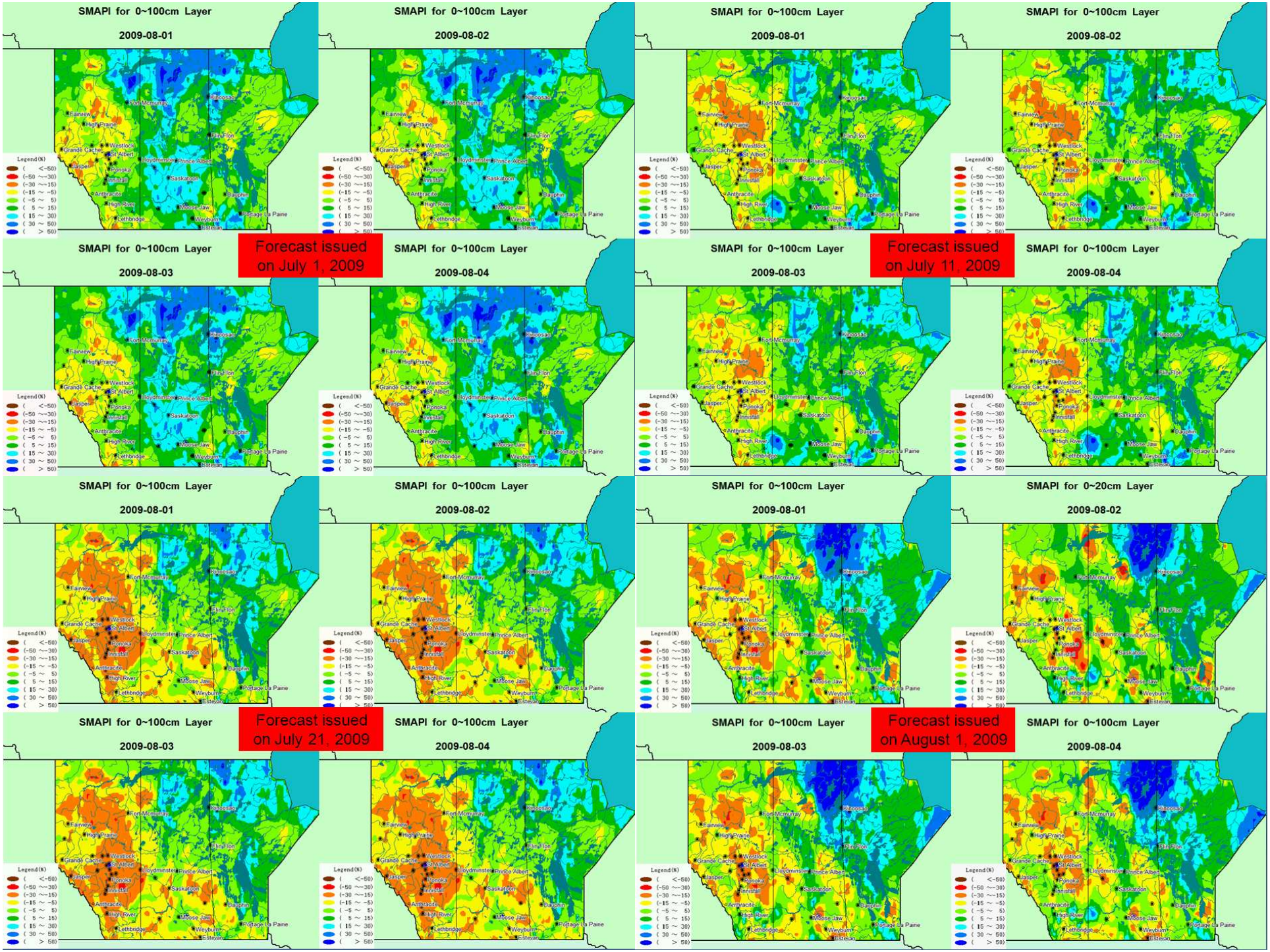


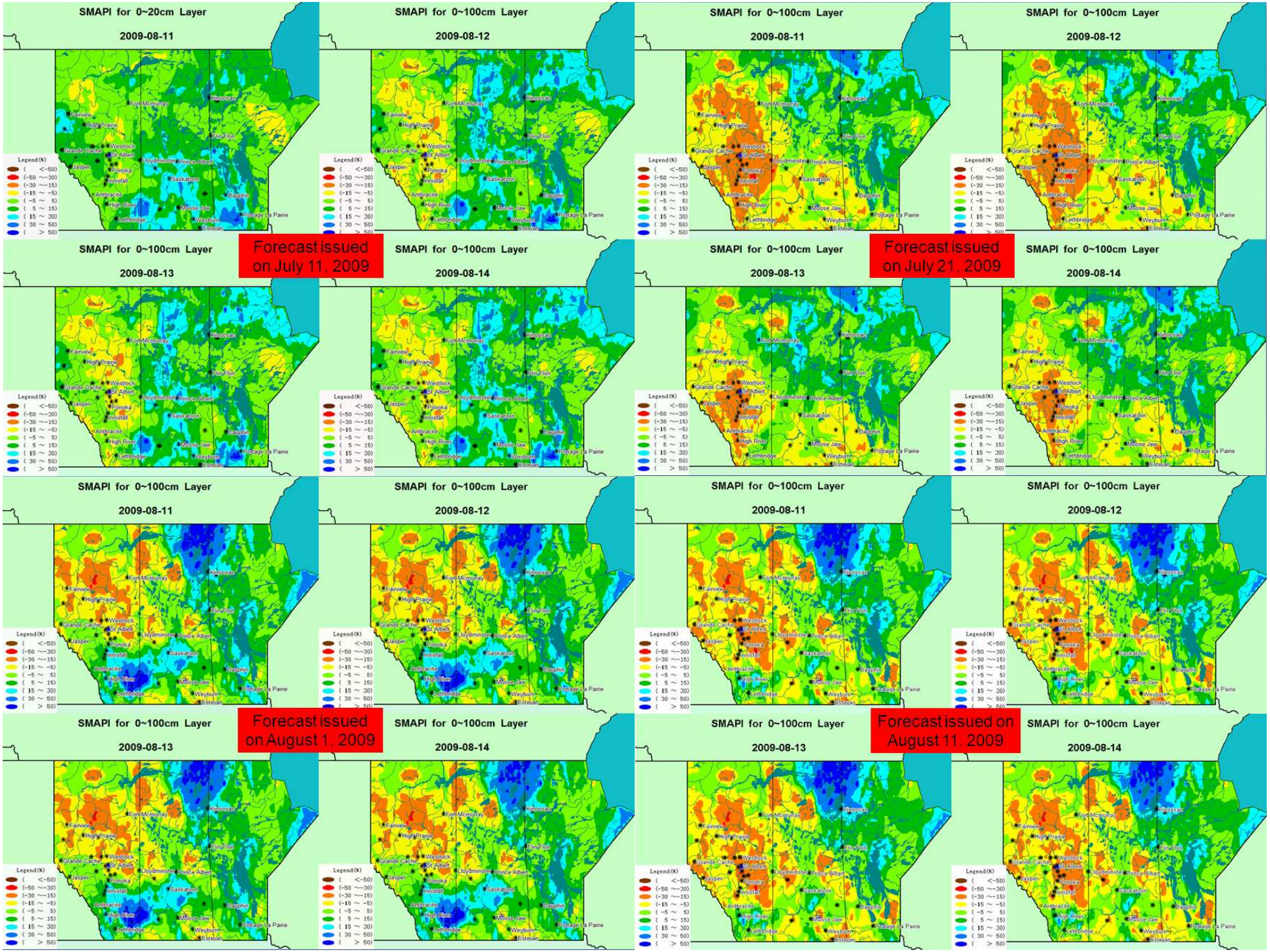
NOW!

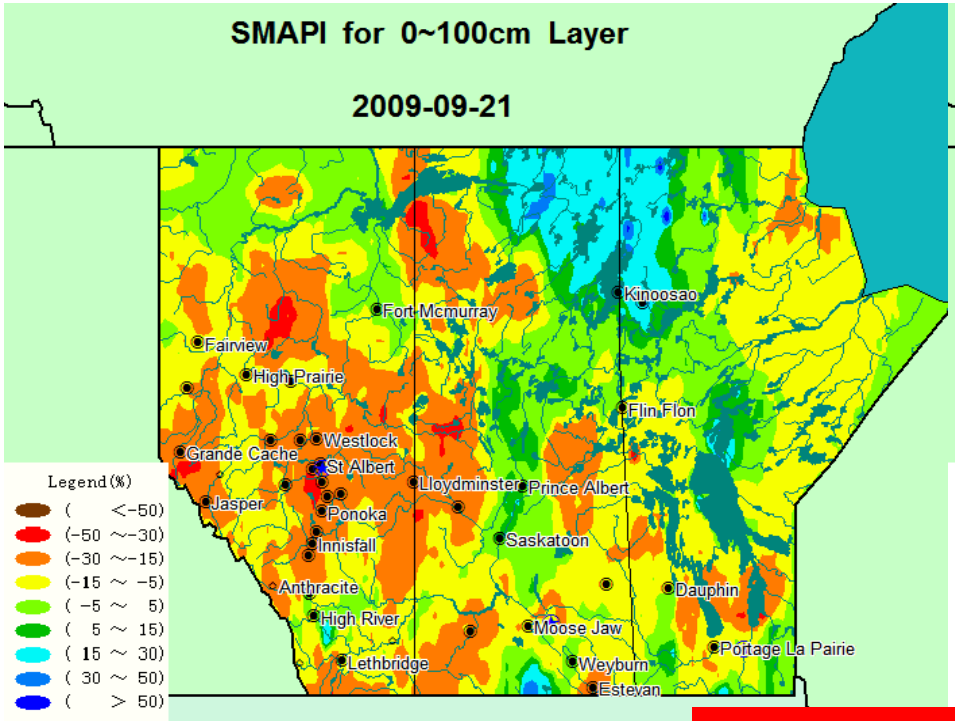
Monitoring and forecasting prairie flooding

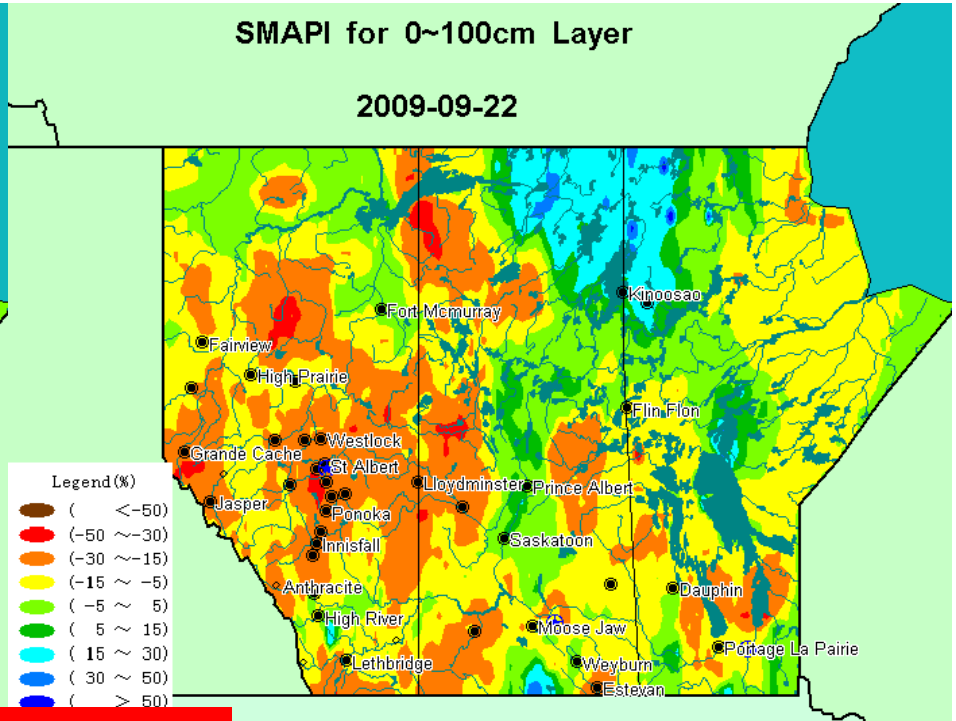


Real-time forecasting Prairie droughts with a lead time of 35 days

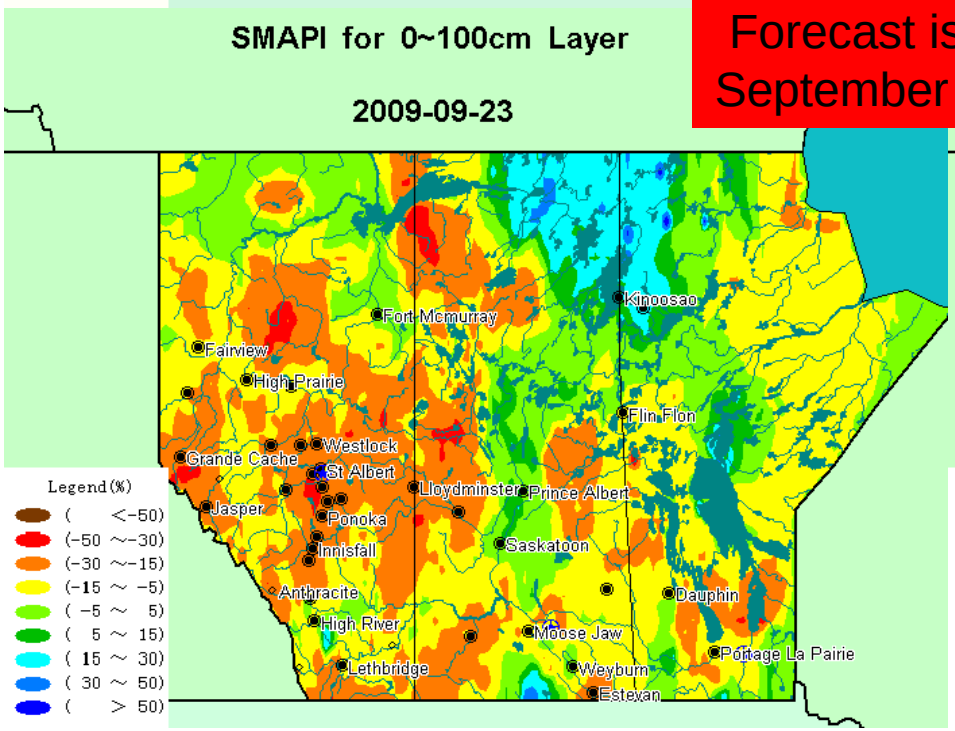

SMAPI for 0~100cm Layer
2009-08-01
SMAPI for 0~100cm Layer
2009-08-02
SMAPI for 0~100cm Layer
2009-08-01
SMAPI for 0~100cm Layer
2009-08-02
SMAPI for 0~100cm Layer
2009-08-03
Forecast issued on July 1, 2009
SMAPI for 0~100cm Layer
2009-08-04
SMAPI for 0~100cm Layer
2009-08-03
Forecast issued on July 11, 2009
SMAPI for 0~100cm Layer
2009-08-04
SMAPI for 0~100cm Layer
2009-08-01
SMAPI for 0~100cm Layer
2009-08-02
SMAPI for 0~20cm Layer
2009-08-02
SMAPI for 0~100cm Layer
2009-08-03
Forecast issued on July 21, 2009
SMAPI for 0~100cm Layer
2009-08-04
SMAPI for 0~100cm Layer
2009-08-03
Forecast issued on August 1, 2009
SMAPI for 0~100cm Layer
2009-08-04
Legend(%)
Fort Mcmurray
Kinoosao
Fairview
High Prairie
Peace River
Grande Cache
Westlock
St Albert
Lloydminster
Prince Albert
Jasper
Ponoka
Innisfail
Saskatoon
Anthracite
High River
Dauphin
Moose Jaw
Lethbridge
Weyburn
Portage La Paine
Estevan

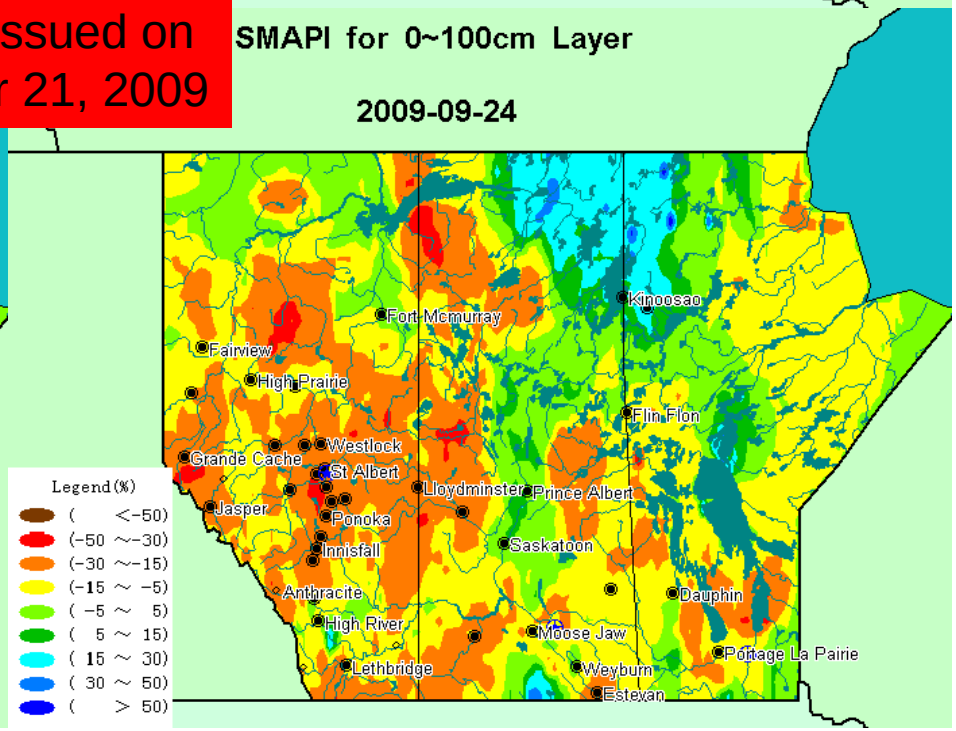

SMAPI for 0~20cm Layer
2009-08-11
SMAPI for 0~100cm Layer
2009-08-12
SMAPI for 0~100cm Layer
2009-08-11
SMAPI for 0~100cm Layer
2009-08-12
SMAPI for 0~100cm Layer
2009-08-13
SMAPI for 0~100cm Layer
2009-08-14
Forecast issued on July 11, 2009
SMAPI for 0~100cm Layer
2009-08-13
SMAPI for 0~100cm Layer
2009-08-14
Forecast issued on July 21, 2009
SMAPI for 0~100cm Layer
2009-08-11
SMAPI for 0~100cm Layer
2009-08-12
SMAPI for 0~100cm Layer
2009-08-13
SMAPI for 0~100cm Layer
2009-08-14
Forecast issued on August 1, 2009
SMAPI for 0~100cm Layer
2009-08-11
SMAPI for 0~100cm Layer
2009-08-12
SMAPI for 0~100cm Layer
2009-08-13
SMAPI for 0~100cm Layer
2009-08-14
Forecast issued on August 11, 2009

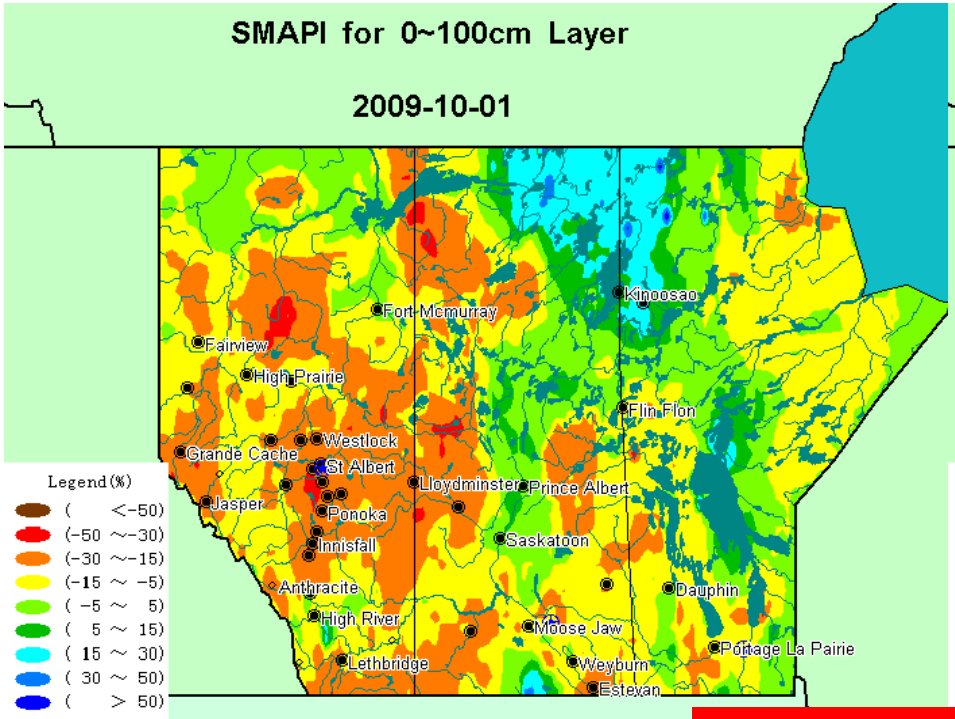


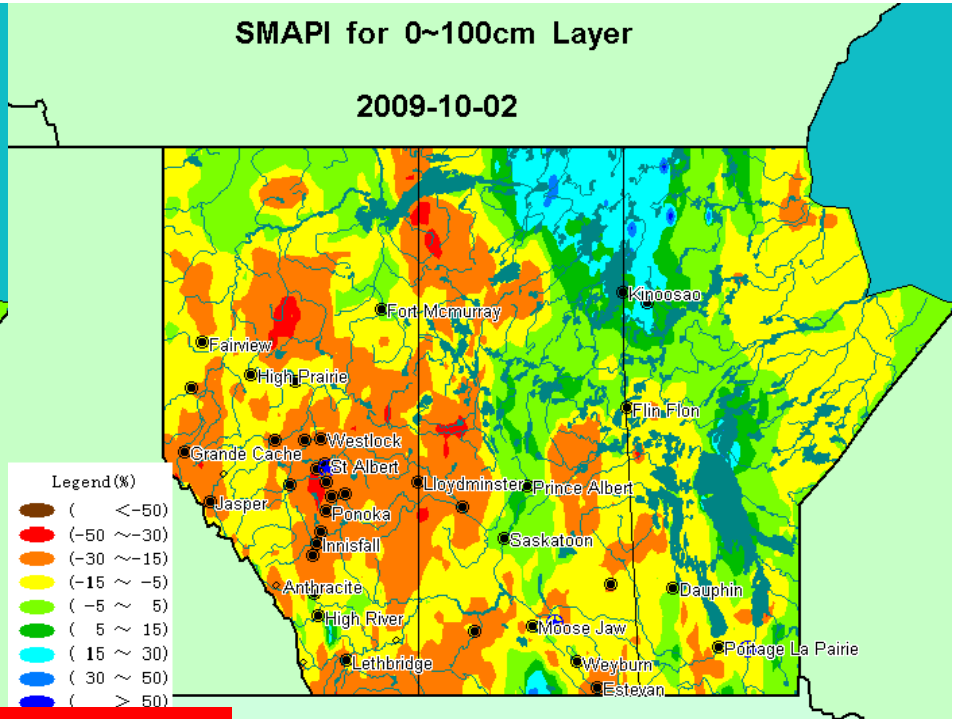


Forecast issued on
September 21, 2009

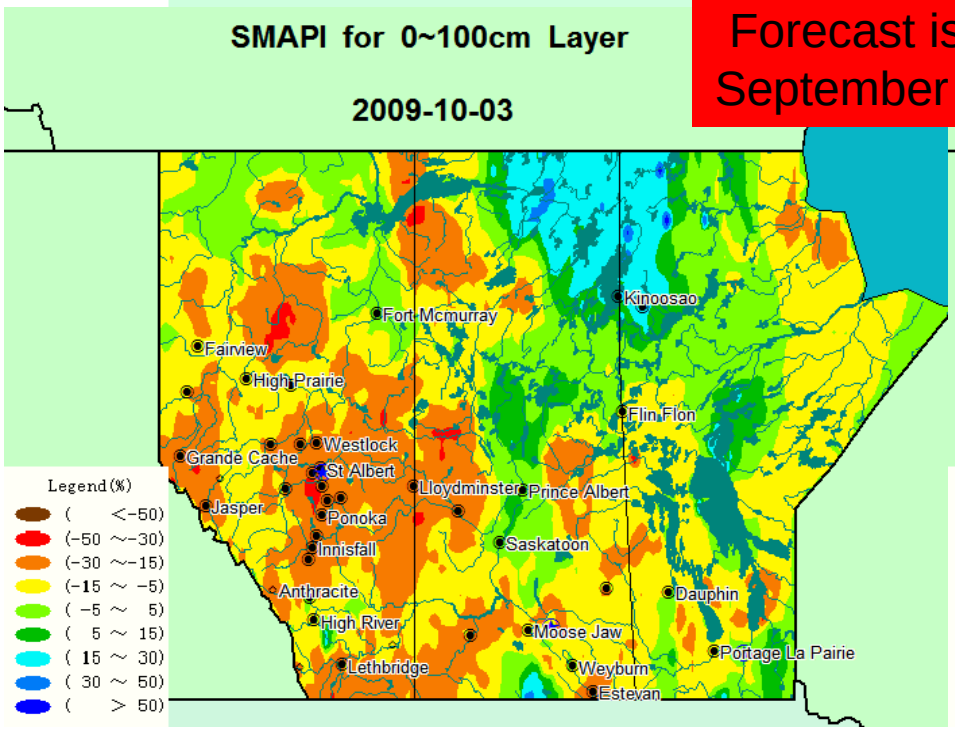


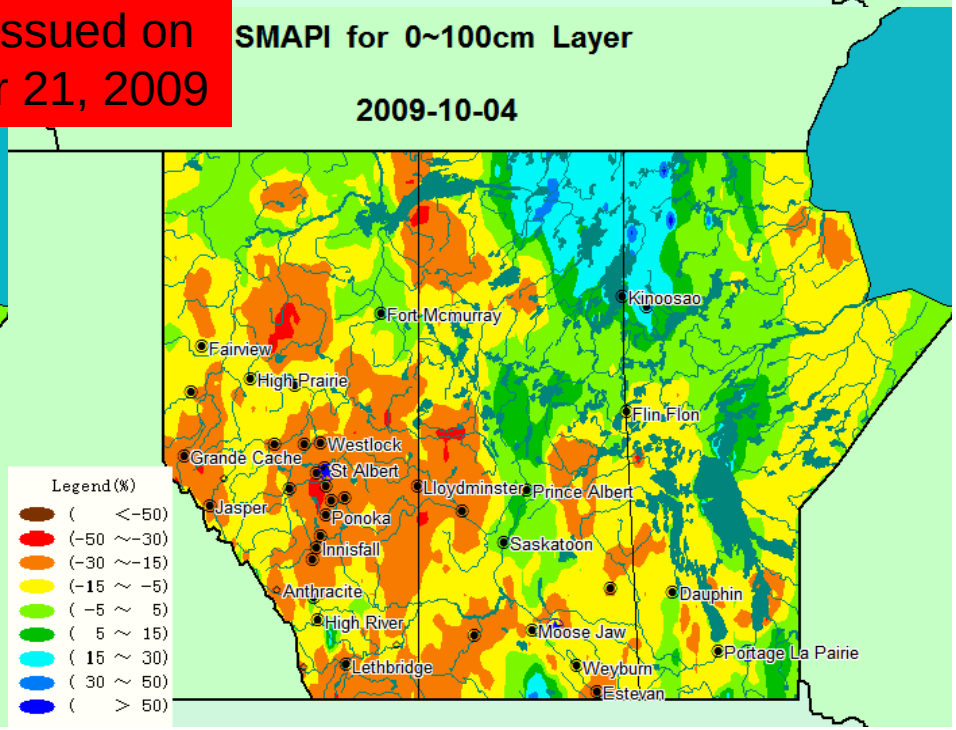


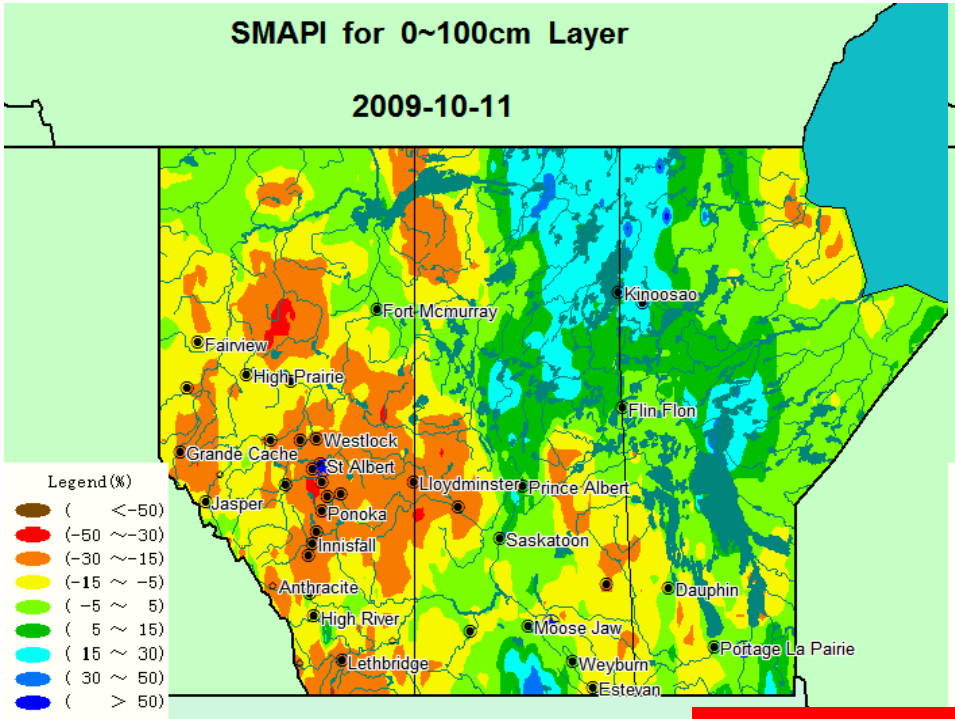


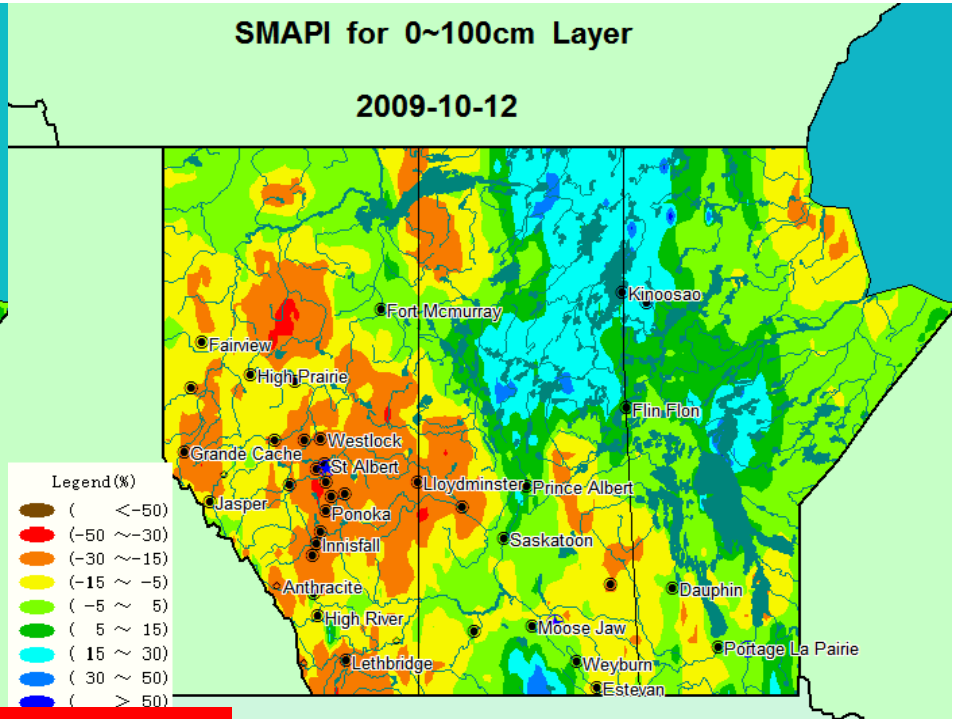


Forecast issued on
September 21, 2009

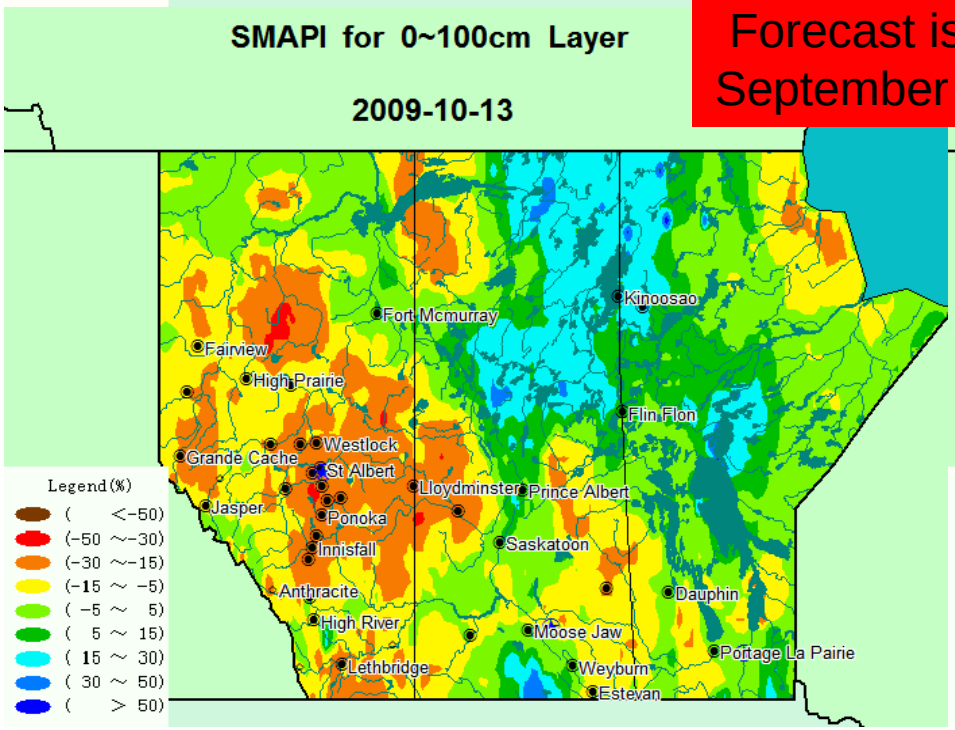


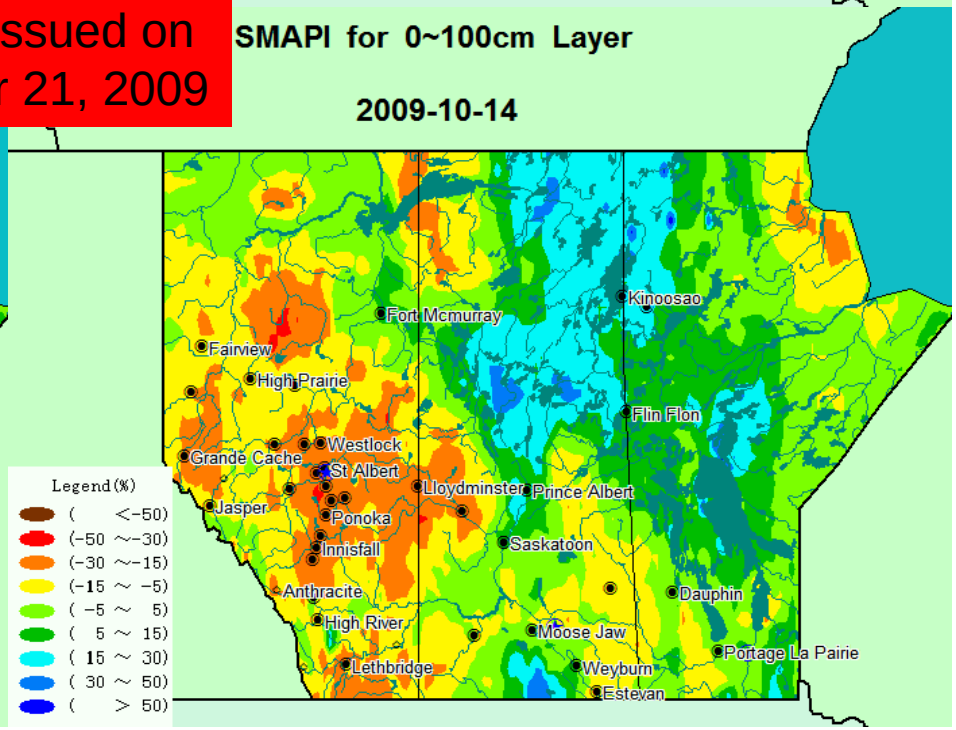


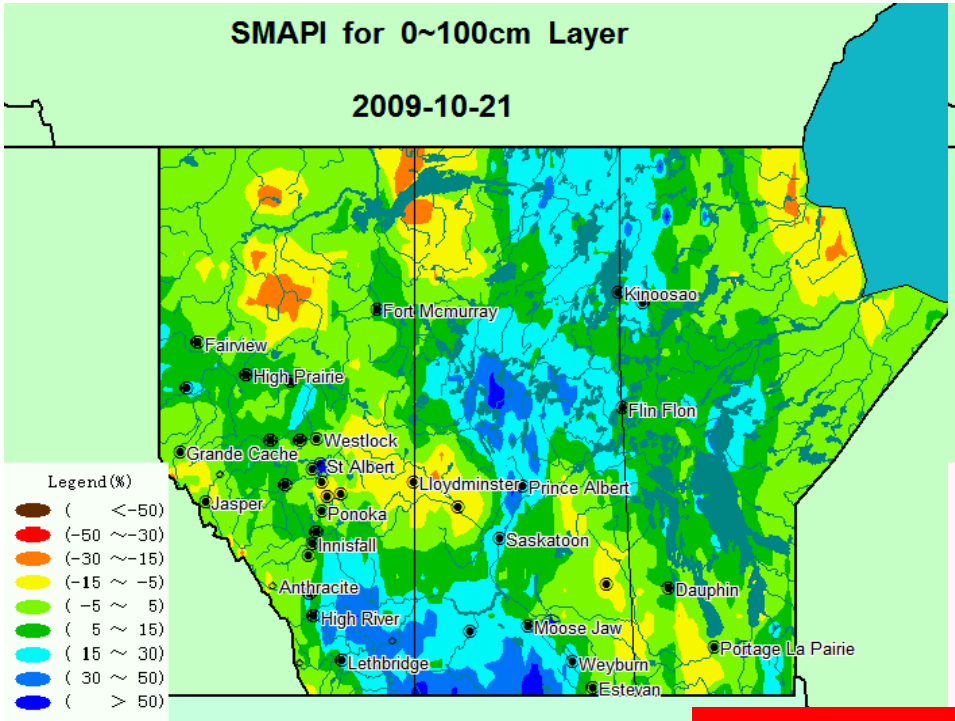


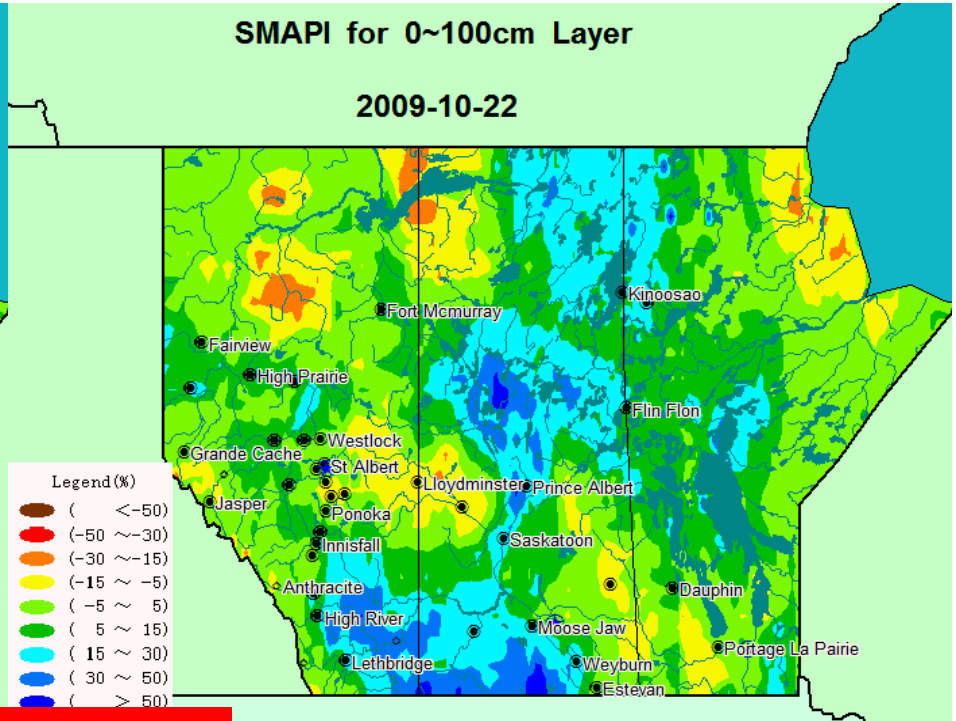


Forecast issued on
September 21, 2009

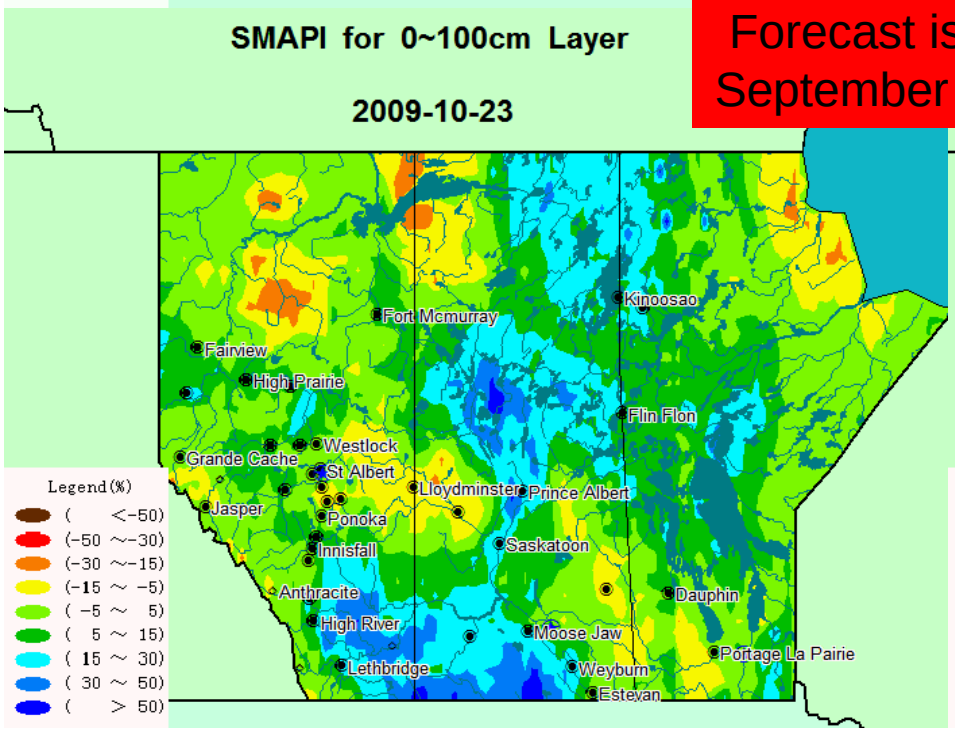


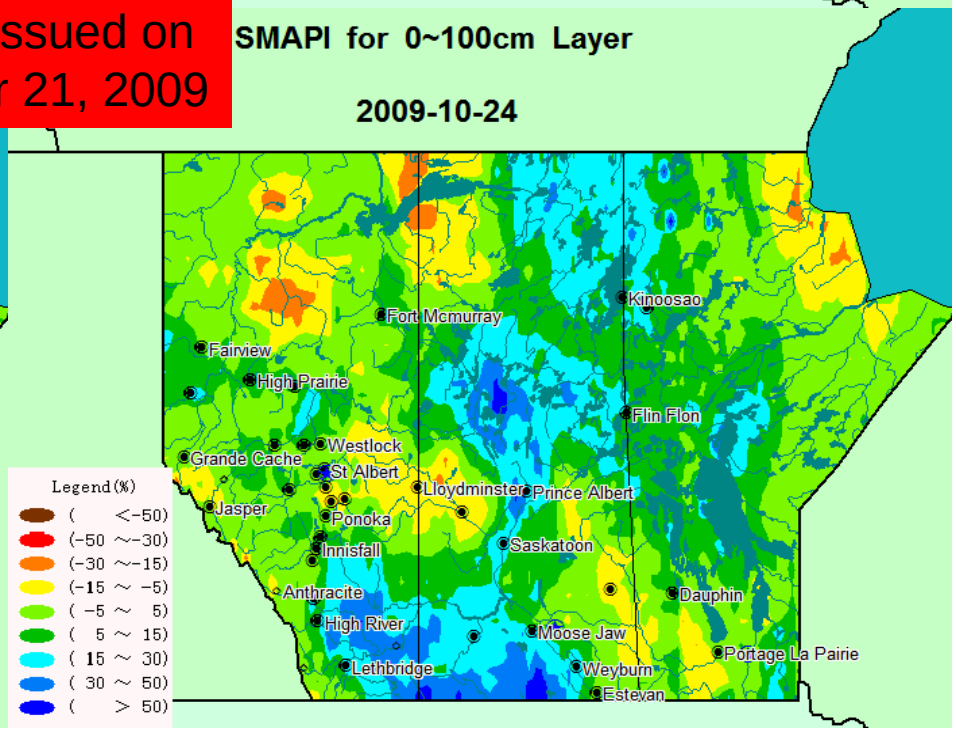






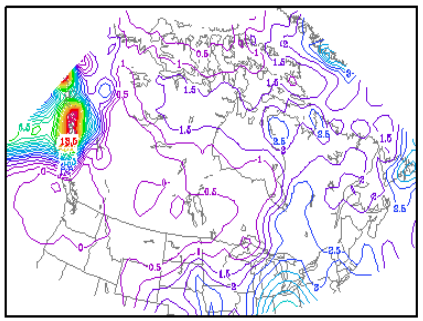
Forecast issued on
September 21, 2009



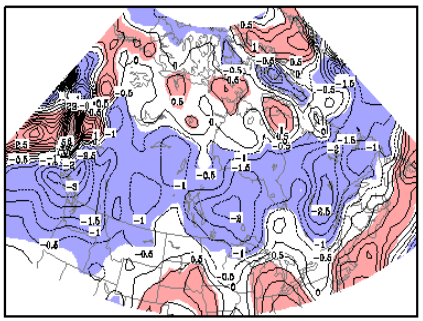


Thanks very much
Merci beaucoup!

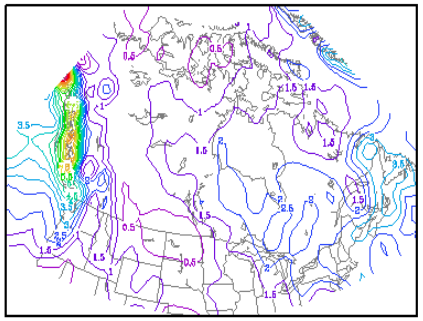
a) 1st 10-day mean PR



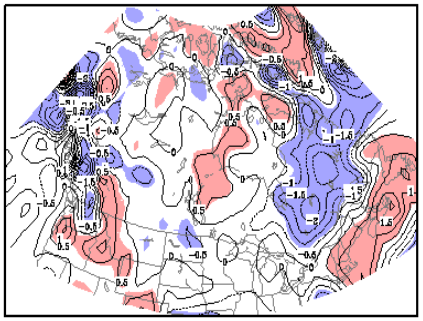
b) 1st 10-day PR anomaly



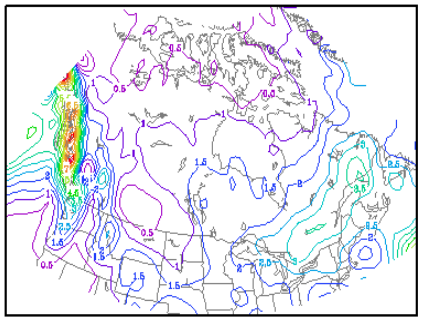
c) 2nd 10-day mean PR



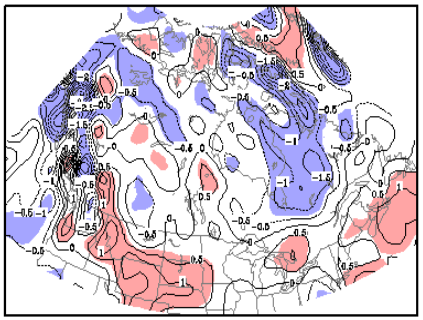
d) 2nd 10-day PR anomaly



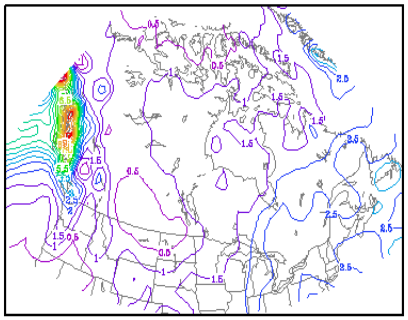
e) 3rd 10-day mean PR



f) 3rd 10-day PR anomaly



a) 30-day mean PR



b) 30-day PR anomaly