A Real Time Drought Monitoring and Forecasting System and its Application

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Objective: to develop and implement a real-time drought monitoring and seasonal prediction system for Canadian Prairies (1,964,000 km^2).

Methodology: 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.

Driving Forces: 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 (0 to 6 days) + the North American Ensemble Forecast System (NAEFS) 40-number super ensemble forecast (7 to 15 days) + the operational CMC ensemble seasonal forecast for forecasting VIC runs (16 to 35 days)

Drought Index: 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.

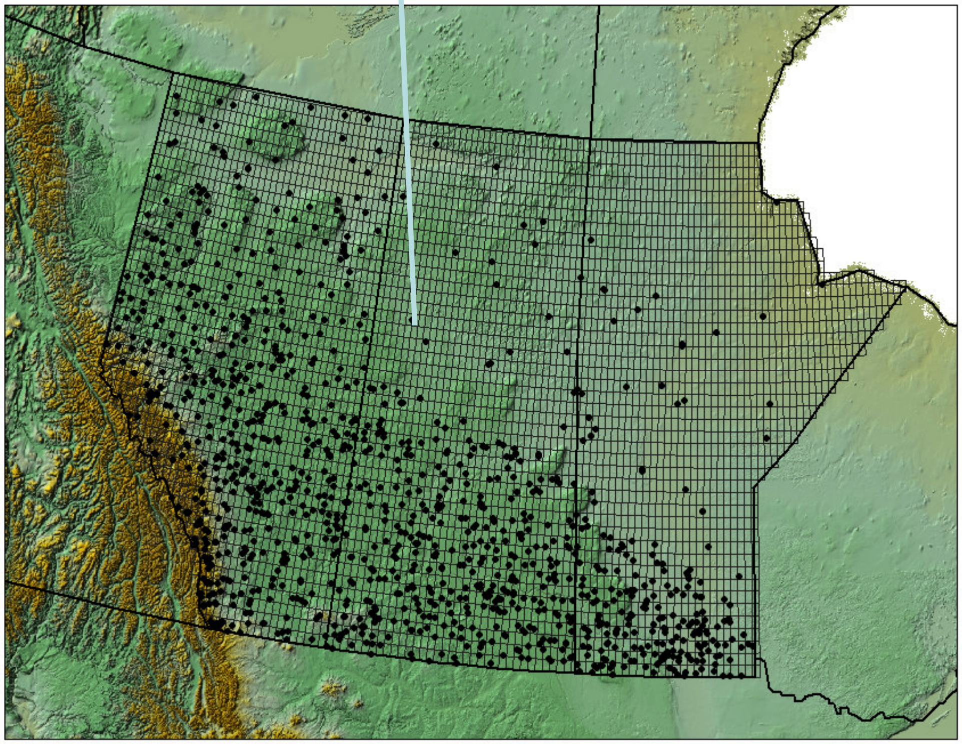
Evaluation: the reconstructed VIC SMAPI can be used to explain historical drought events in the Prairies over the past 60 years; and compares favorably with three independent drought datasets.

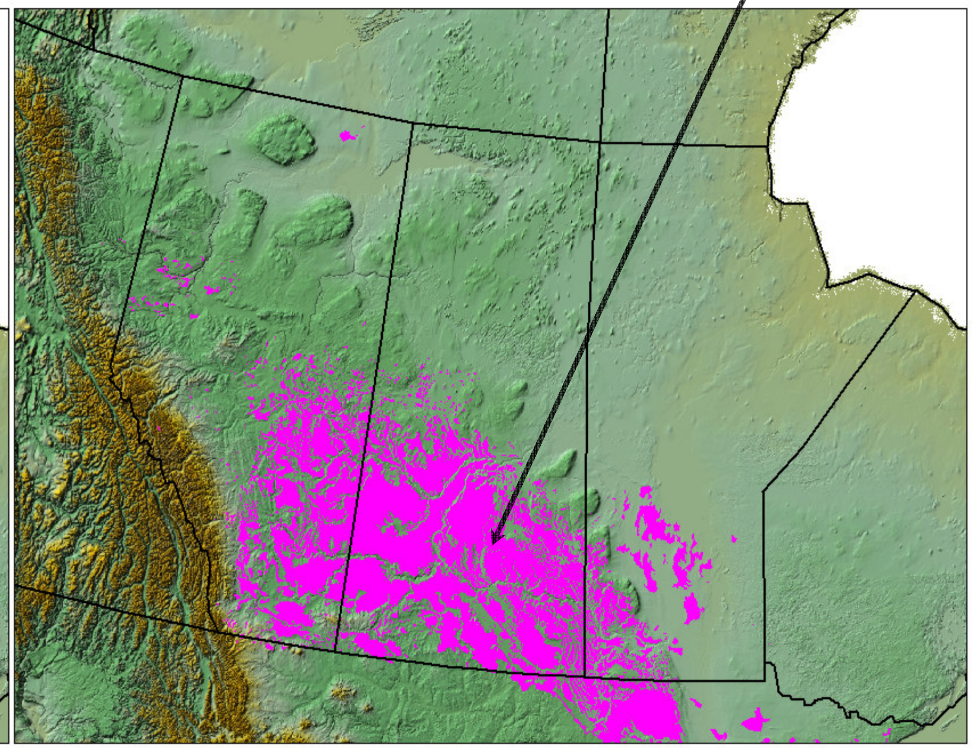
Drought Mechanism: the loss nature of soils could be another important contributing factor for prairie susceptibility to drought next to the lack of precipitation.

Availability: the system is updated daily at present; and the result of SMAPI is publicly accessible online (http://www.meteo.mcgill.ca/~leiwen/vic/prairies/)

VIC Model Application

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





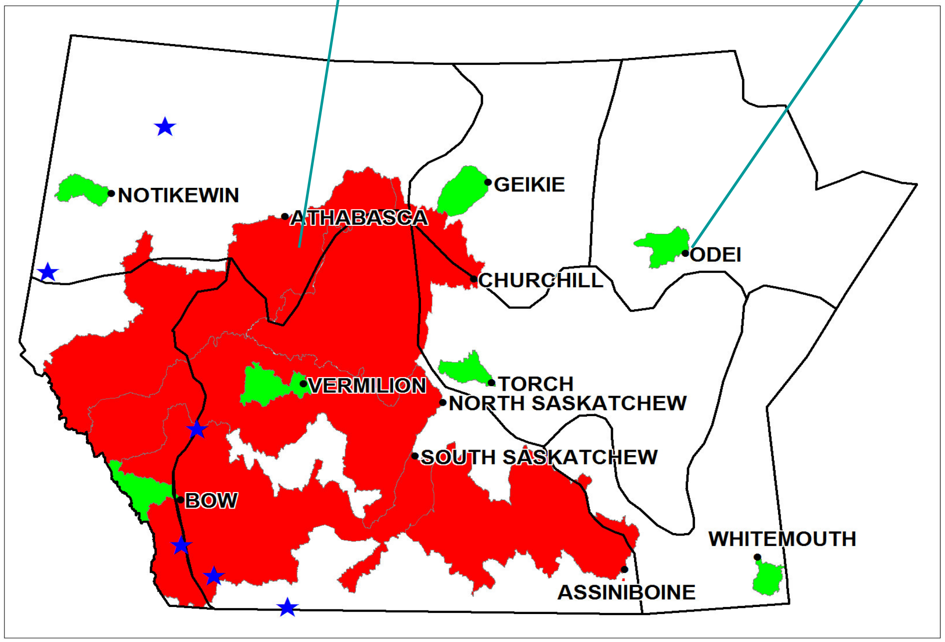
The VIC model is applied over a Prairies domain consisting of 4393 grid points with a resolution of 0.25 ° x 0.25 °

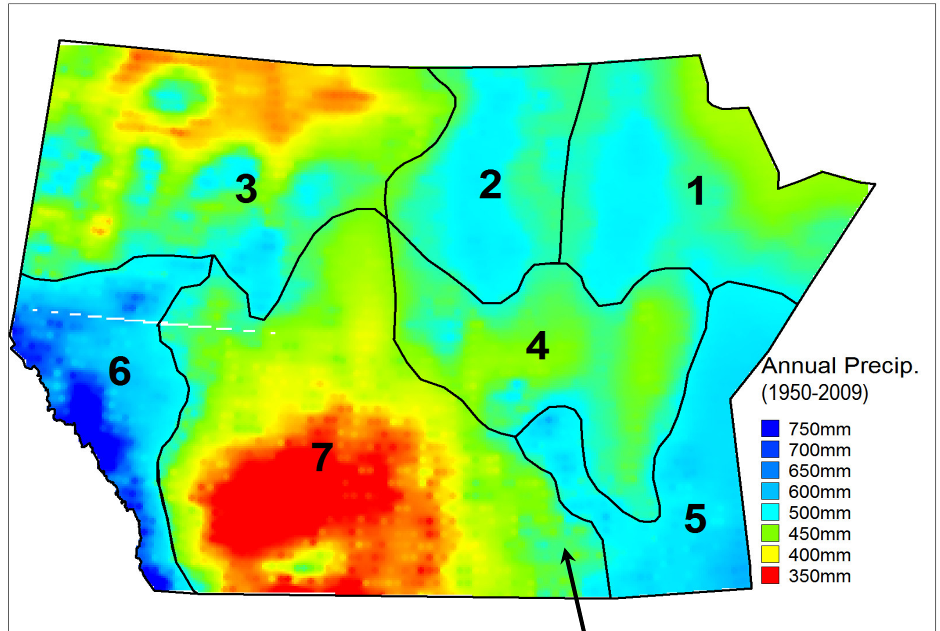
Flat terrain and non-contributing drainage areas; bring challenges to hydrological modeling

5 additional validation catchments in red

7 calibration catchments in green;

VIC calibration and validation





- 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

VIC calibration and validation over 12 catchments
from 7 hydrological simulation regions

- Calibration period 1994-1999
- Validation period 1975-2001
- Only water balance mode is used
- 24-h time step for main process
- 1-h time step for snow band solving
- VIC calibration and validation are done using observed hydrographs
- VIC is forced by observed max and min temperature and precipitation
- The IDW method is used for the driving forces interpolating
- Temperature lapse rate (C/100 m) = 0.75 ° C
- Precipitation lapse rate (%/100 m) = 5 mm

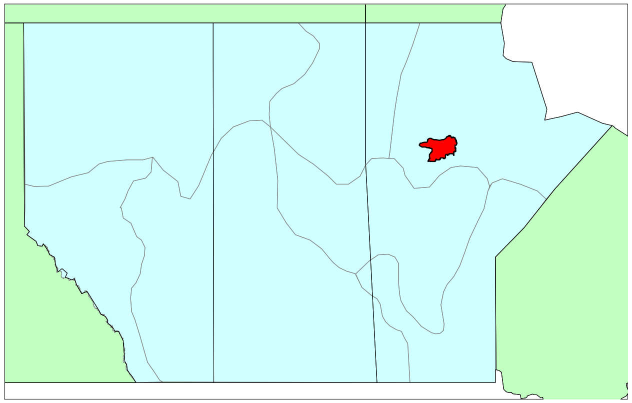
Catchments' information and VIC calibration and validation results

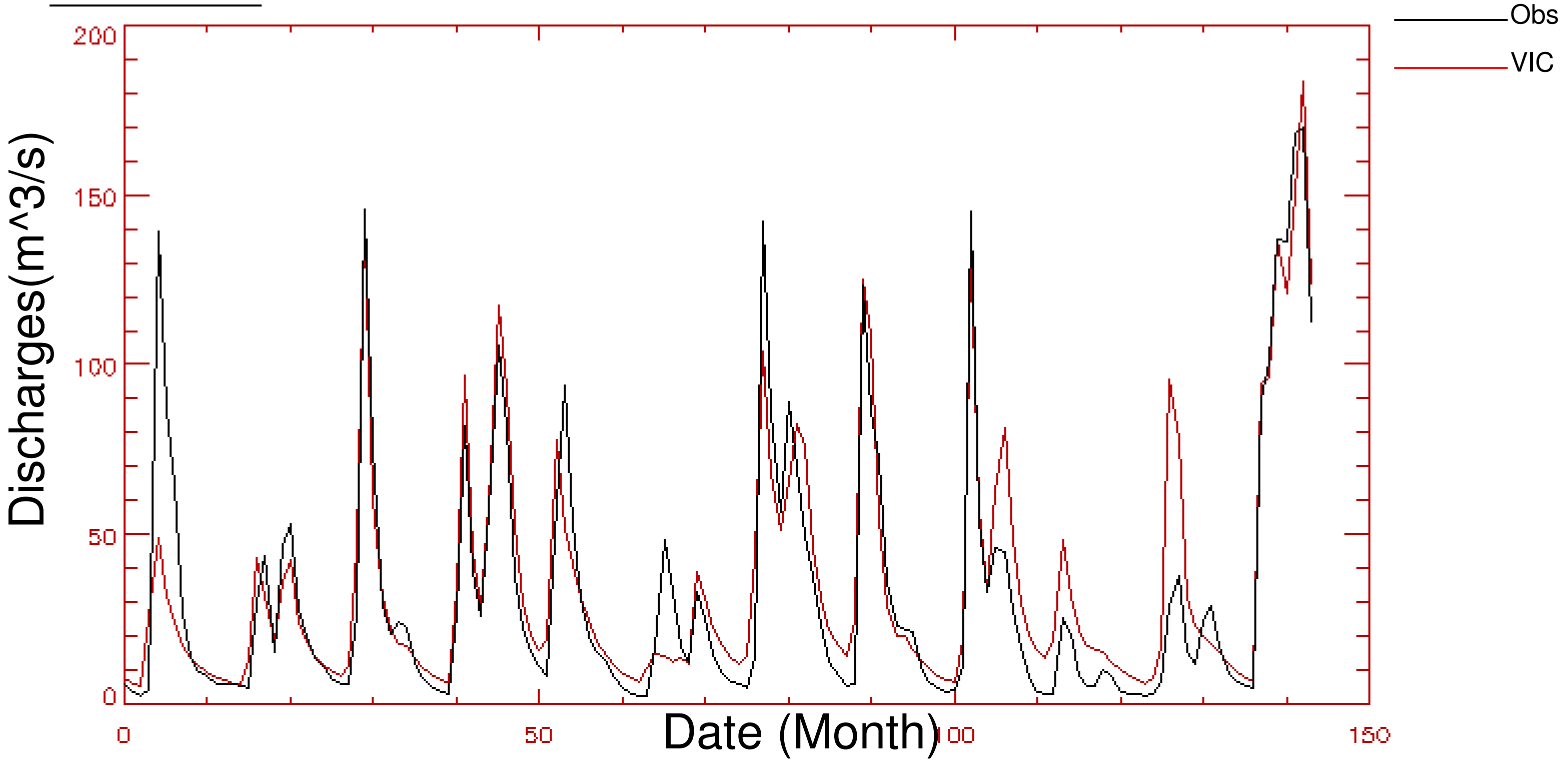
ID		River Name	Station Name	Station ID	Station Lat	Station Long	Drainage Area (km^2) Gross	Effective	(%)	ELEV	AVG_T	ANN_PREC
1		ODEI	THOMPSON	05TG003	55.996	-97.356	6110	6110	100.0	259	-3.1	508.7
2		GEIKIE	WHEELER	06DA004	57.589	-104.203	7730	7730	100.0	501	-3.4	492.7
3		NOTIKEWIN	MANNING	07HC001	56.919	-117.618	4680	4660	99.6	791	-0.8	483.0
4	Cal.	TORCH	LOVE	05KE002	53.588	-104.161	4650	4650	100.0	513	0.0	454.9
5		WHITEMOUTH	WHITEMOUTH	05PH003	49.939	-95.956	3750	3750	100.0	325	2.1	592.6
6		BOW	CALGARY	05BH004	51.050	-114.050	7870	7740	98.3	1953	-1.5	690.7
7		VERMILION	MARWAYNE	05EE007	53.491	-110.397	7270	3110	42.8	649	1.9	418.1
8		ATHABASCA	MCMURRAY	07DA001	56.781	-111.400	133000	131000	98.5	807	0.2	532.8
9	Val.	NORTH SASKATCHEWAN	PRINCEALBERT	05GG001	53.203	-105.768	131000	72300	55.2	814	1.5	465.3
10		SOUTH SASKATCHEWAN	SASKATOON	05HG001	52.140	-106.643	141000	88100	62.5	965	3.0	433.1
11		ASSINIBOINE	BRANDON	05MH013	49.871	-100.100	93700	36500	39.0	576	1.9	433.5

ID		River Name	Period	INFILT	Ds	Ds_MAX	Ws	DEPTH_2	DEPTH_3	Err. (%)	Nash (day)	Nash (Mon)
1		ODEI	1994-2005	0.04	0.026	25.5	0.31	0.68	0.62	7.3	0.73	0.82
2		GEIKIE	1994-2005	0.03	0.059	26.5	0.39	0.62	1.12	-4.8	0.75	0.77
3		NOTIKEWIN	1994-2005	0.09	0.022	2.5	0.71	0.47	0.63	2.7	0.64	0.75
4	Cal.	TORCH	1982-1987	0.03	0.031	2.0	0.92	0.72	0.33	-23.1	0.68	0.69
5		WHITEMOUTH	1994-2005	0.11	0.011	24.0	0.34	0.83	0.66	19.1	0.61	0.70
6		BOW	1990-1999	0.06	0.038	28.5	0.28	0.46	1.85	-0.4	0.80	0.87
7		VERMILION	1981-1990	0.01	0.001	0.5	0.58	0.48	0.40	31.6	0.40	0.58
8		ATHABASCA	1966-1975							13.9	0.57	0.62
9	Val.	NORTH SASKATCHEWAN	1991-2000							-5.1	0.59	0.69
10		SOUTH SASKATCHEWAN	1951-1960							-8.8	0.55	0.66
11		ASSINIBOINE	1977-1987							-5.4	0.62	0.77

Example of VIC calibration result

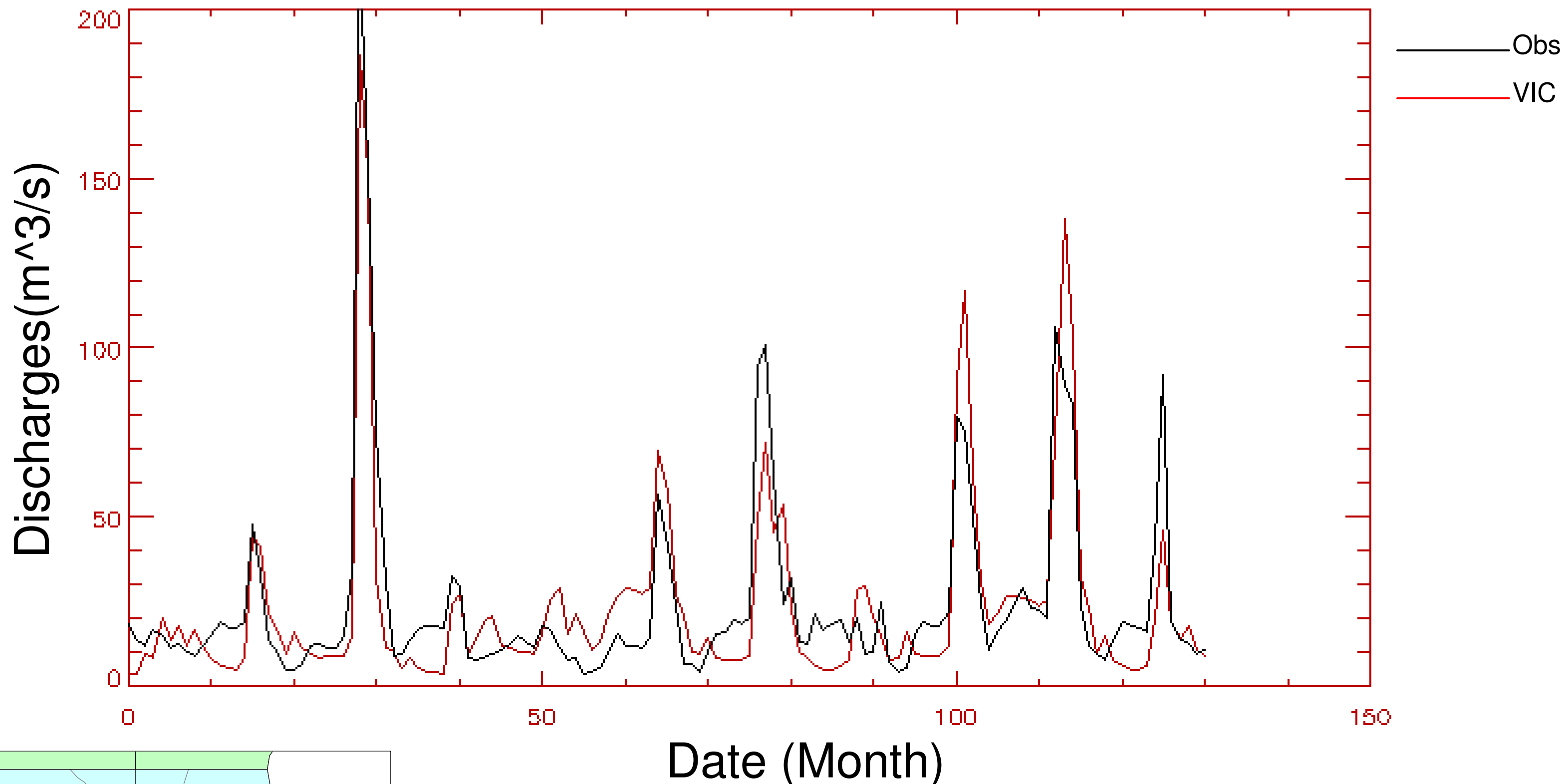
River Name	Period	Err. (%)	Nash (day)	Nash (Mon)
ODEI	1994-2005	7.3	0.73	0.82

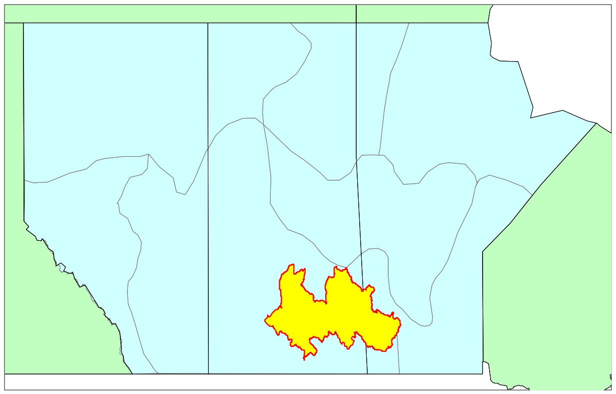




Example of VIC validation result

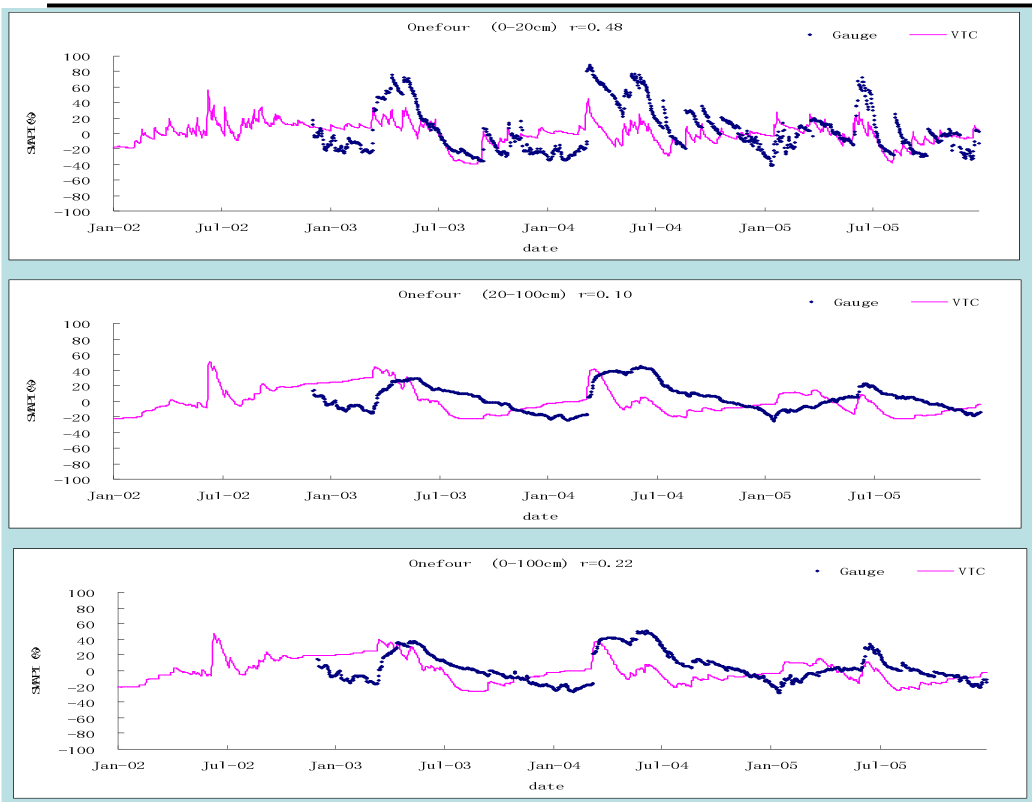
River Name	Period	Err. (%)	Nash (day)	Nash (Mon)
ASSINIBOINE	1977-1987	-5.4	0.62	0.77





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

Site	Annual Precip. (mm)	Site		VIC grid		Correlation coefficient (r)		
		Lat. (°N)	Long. (°W)	Lat. (°N)	Long. (°W)	0-20 cm	20-100 cm	0-100 cm
Fortremillion	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
Stavely	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
Onefour	335	49.12	110.47	49.13	110.38	0.48	0.10	0.22

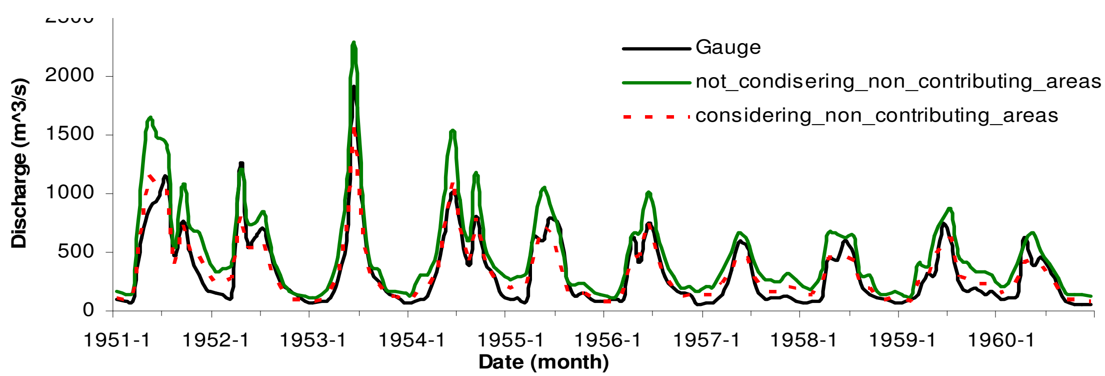


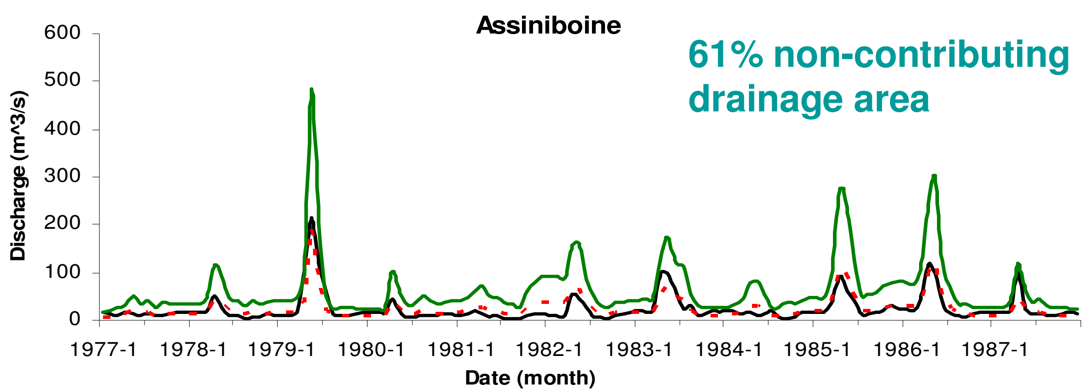
Please note: the simulated soil moisture represents the average situation of a 0.25º × 0.25º gird box. VIC is not specifically calibrated for any of these 6 grid points. Instead, we use the calibrated values for the 7 simulation regions of the Prairies in our soil moisture simulations.

Comparison results at the Onefour site

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





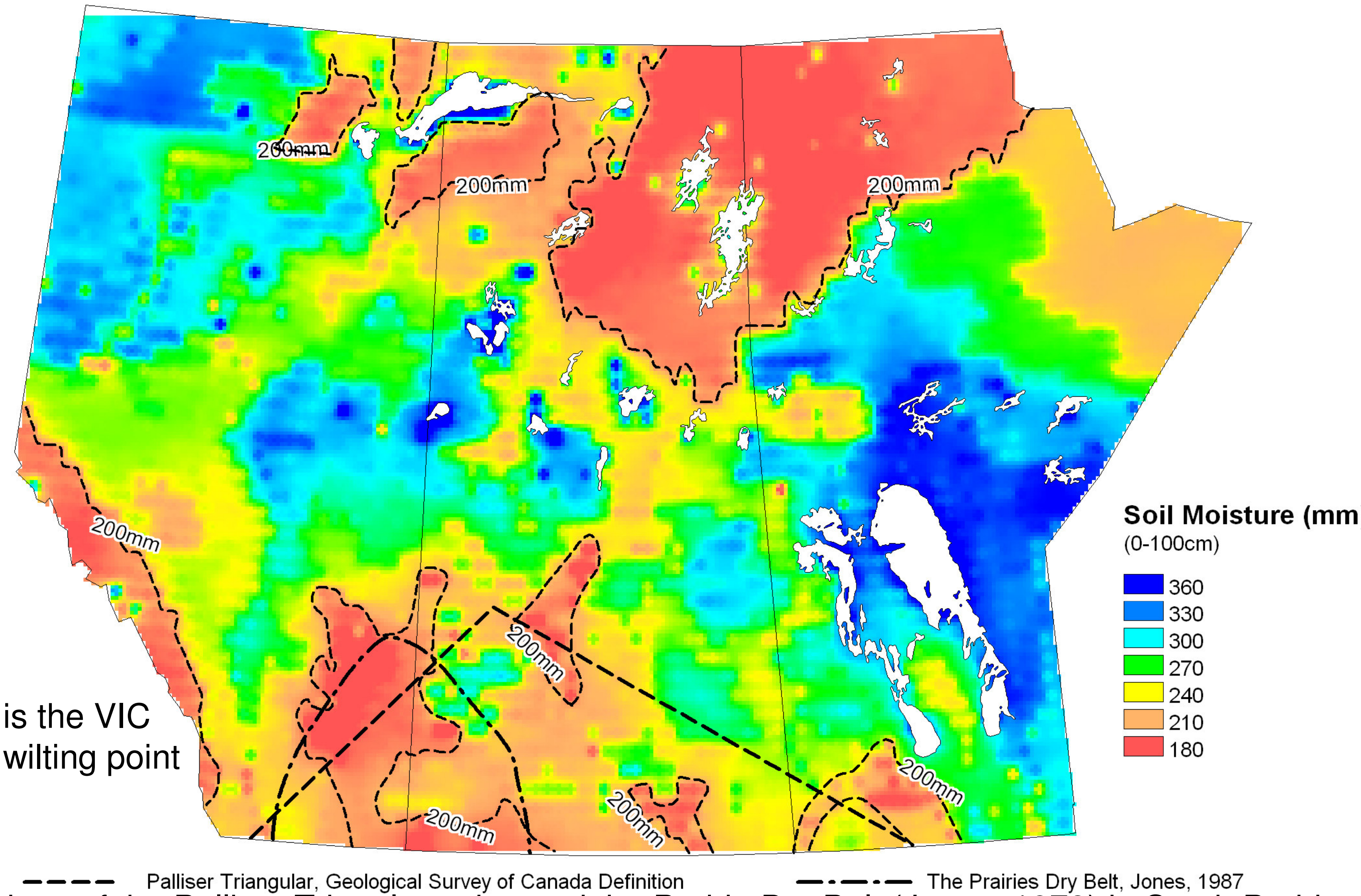
By incorporating **non-contributing drainage areas** into runoff calculations (red dashed-lines) could substantially improve the ability of hydrological models to simulate surface and sub-surface runoff in regions where the wetland is a dominant feature of land covers.

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

Application of VIC Soil Moistures

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

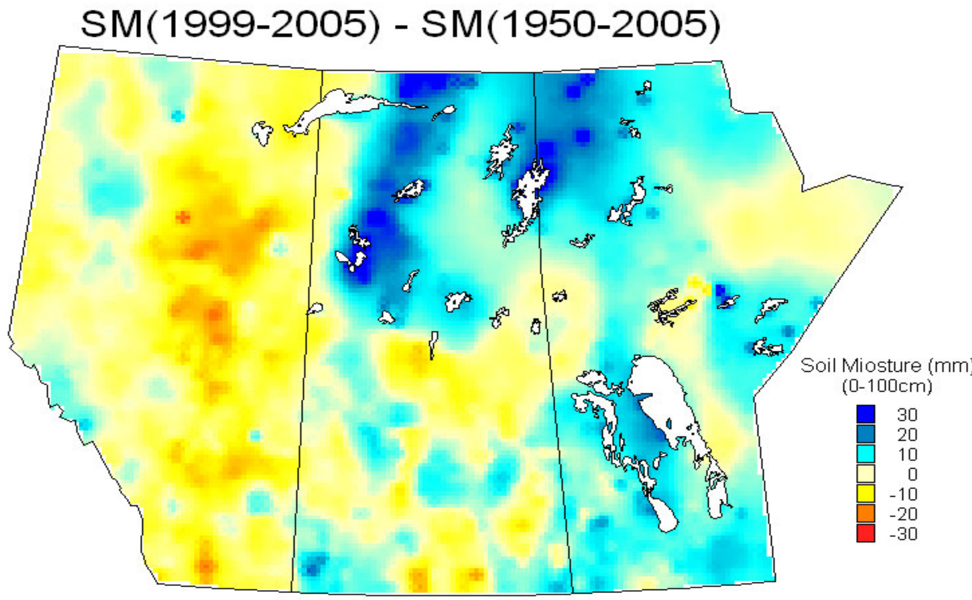
with the 200 mm soil moisture contour, showing modeled very dry areas

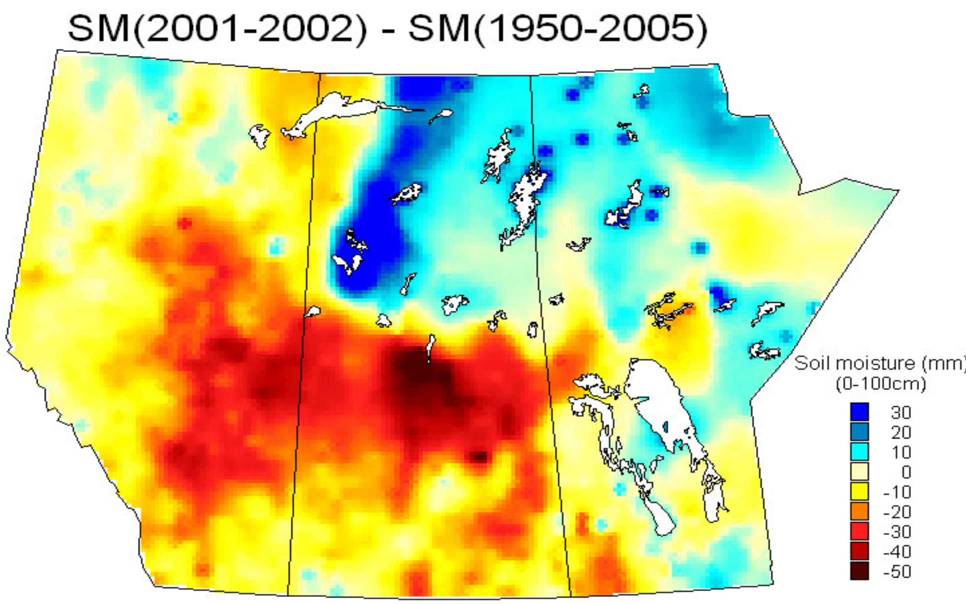


200 mm is the VIC average wilting point

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 60-year climatology:
Average of 1999-2005 (top) and 2001-2002 (bottom)



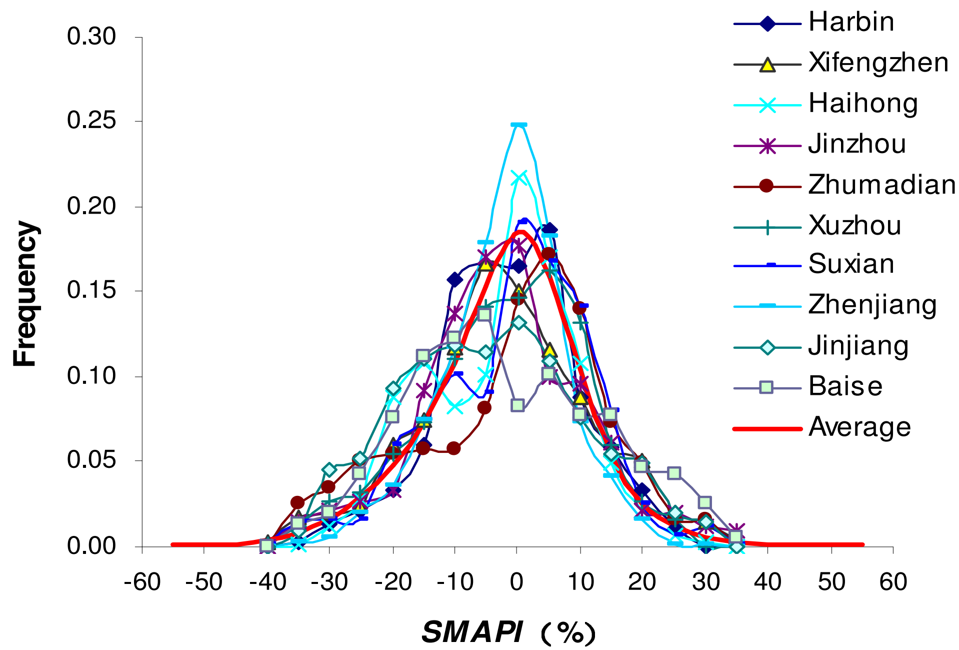


Introduction of Drought Index –

Soil Moisture Anomaly Percentage Index (SMAPI)

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

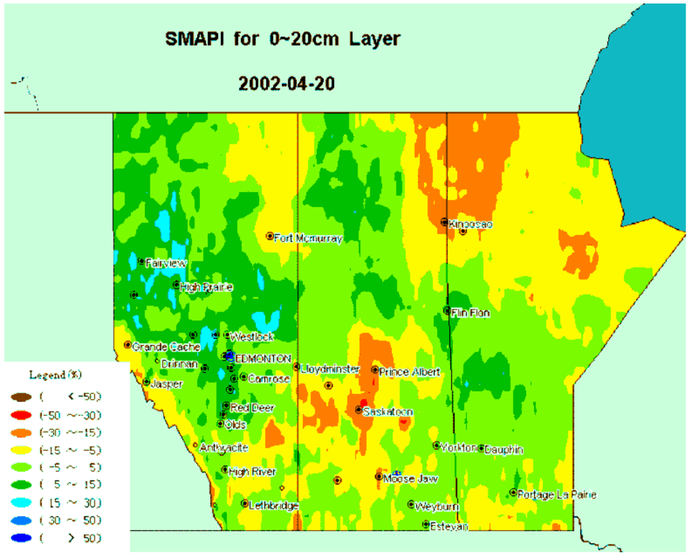
- The soil moisture climatology reflects local characteristics and mirrors the hydro-meteorological phenomena of a region
- The concept of relative soil wetness for use in measuring drought severity
- The study of Quiring and Papakryiakou (2003) indicates that the Z-index is best suited for predicting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

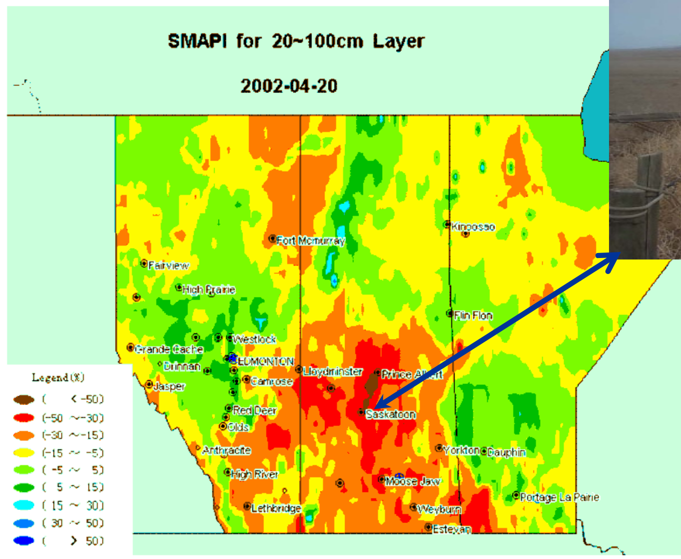


Drought classifications based on SMAPI

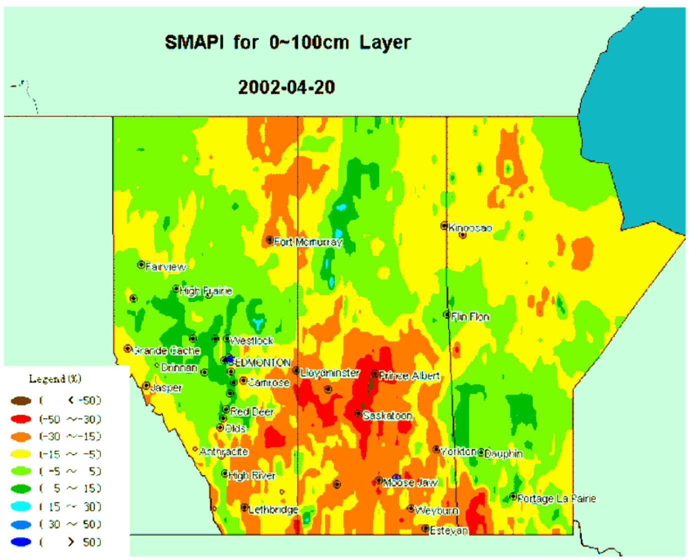
Category	SMAPI	Average Frequency
extreme drought	≤ -50%	0.005
severe drought	-50% to -30%	0.020
moderate drought	-30% to -15%	0.100
mild drought	-15% to -5%	0.200
near normal	-5% to 5%	0.350
slightly wet	5% to 15%	0.200
moderately wet	15% to 30%	0.100
very wet	30% to 50%	0.020
extremely wet	> 50%	0.005

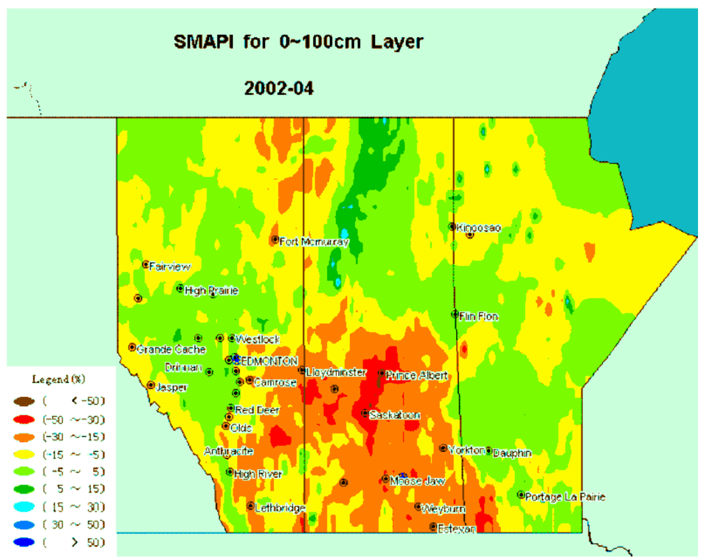
Reconstructing prairie drought history



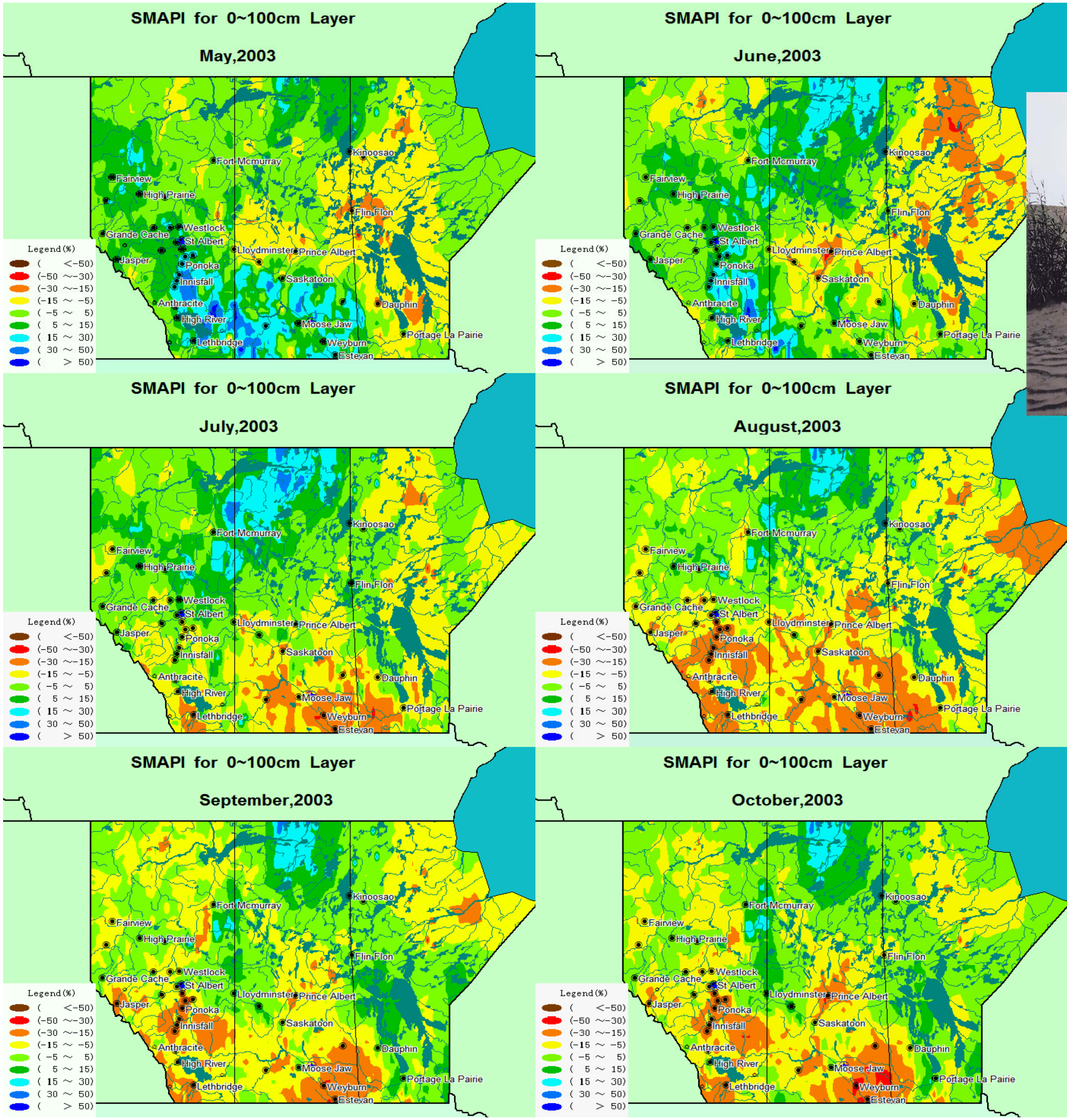


Southern Saskatchewan, April 2002; Taken from Stewart





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

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

Intensity:

- D0 Abnormally Dry
- D1 Drought - Moderate
- D2 Drought - Severe
- D3 Drought - Extreme
- D4 Drought - Exceptional

Drought Impact Types:

Delineates dominant impacts

A = Agriculture

H = Hydrological (Water)

(No type = Both impacts)

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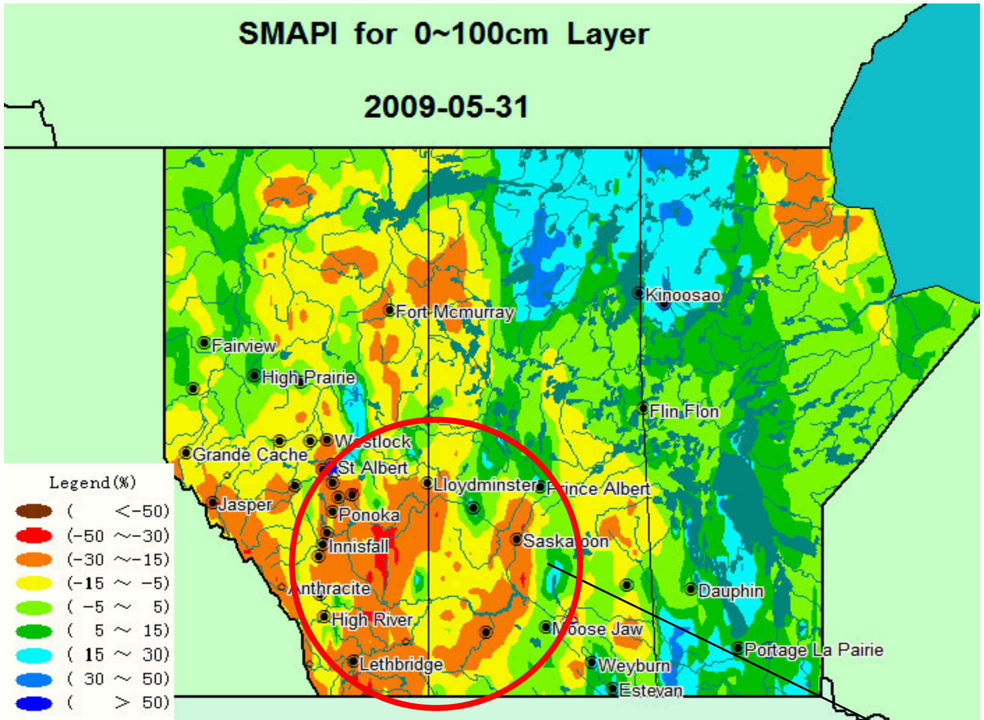
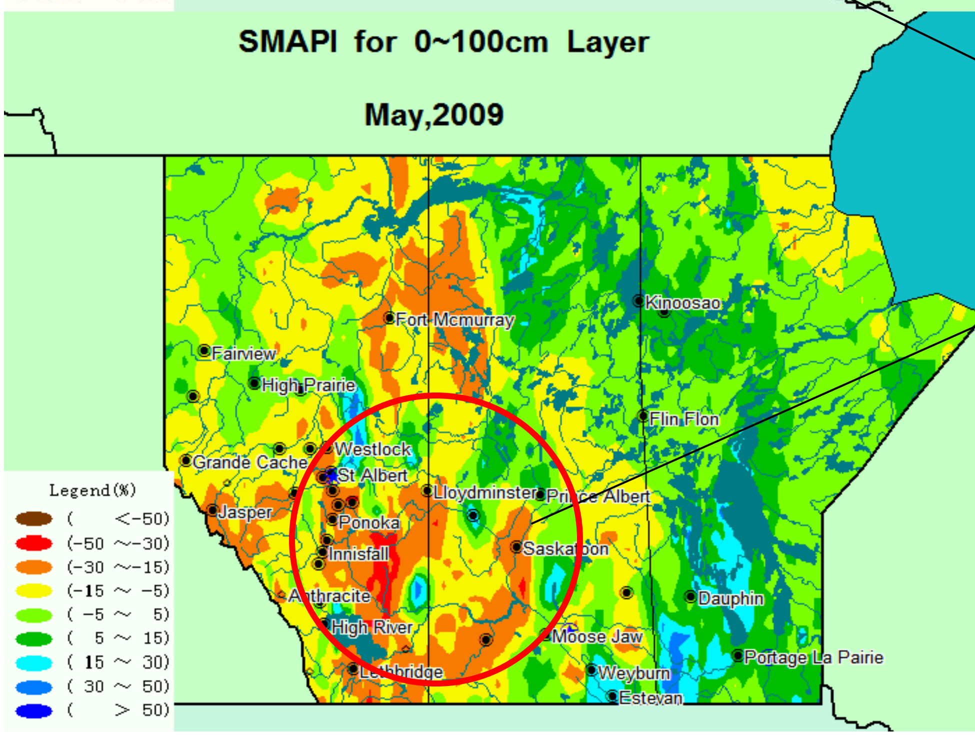
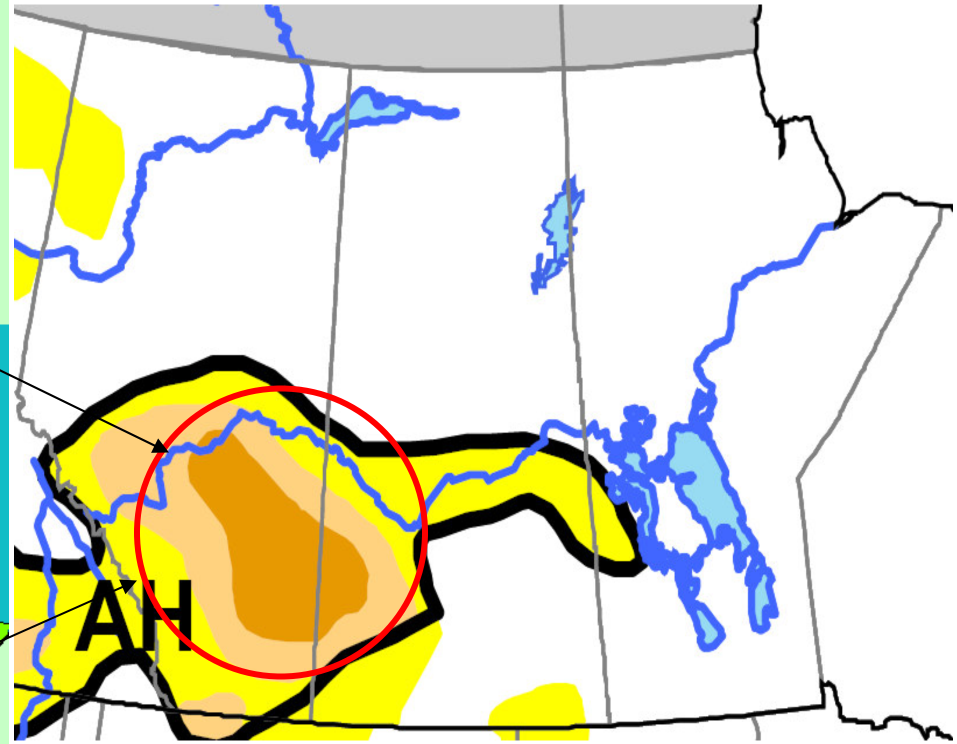
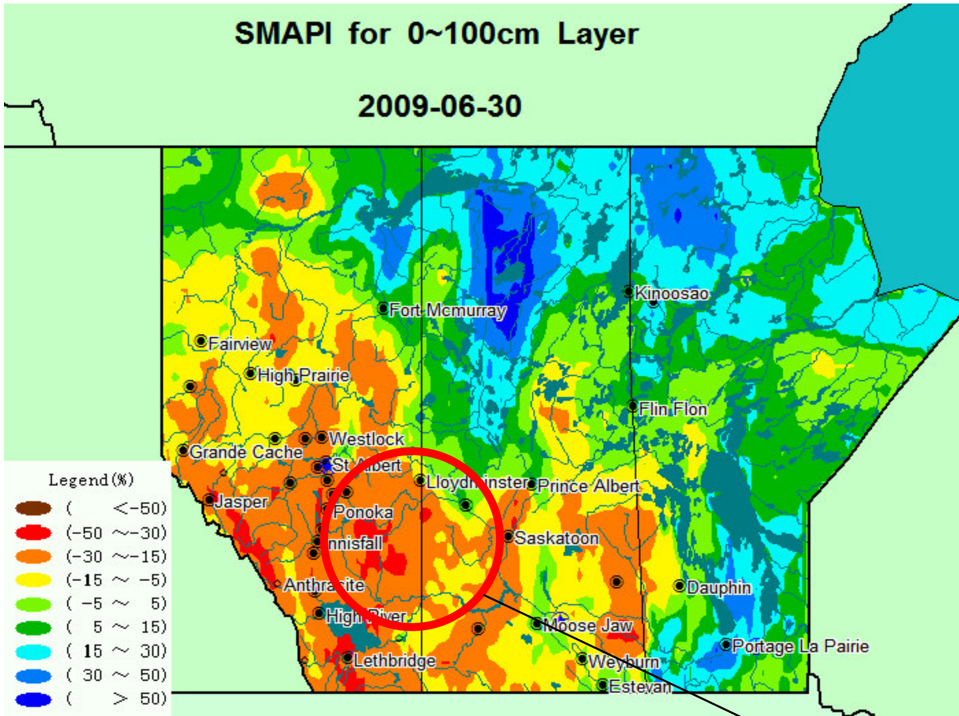
very wet	30% to 50%	0.020
extremely wet	> 50%	0.005



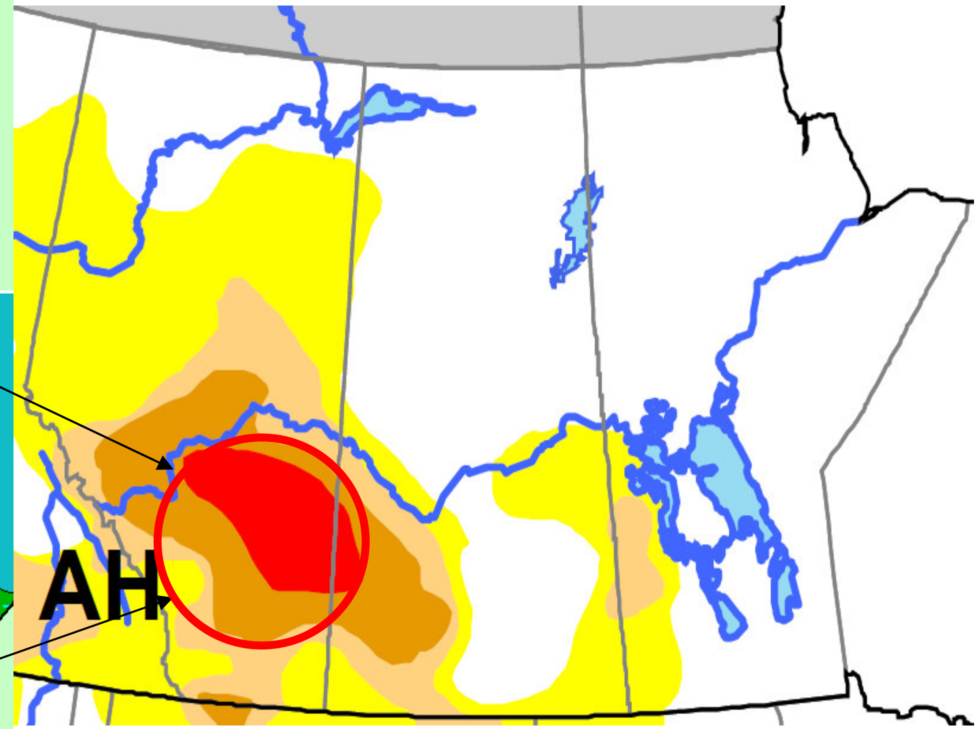


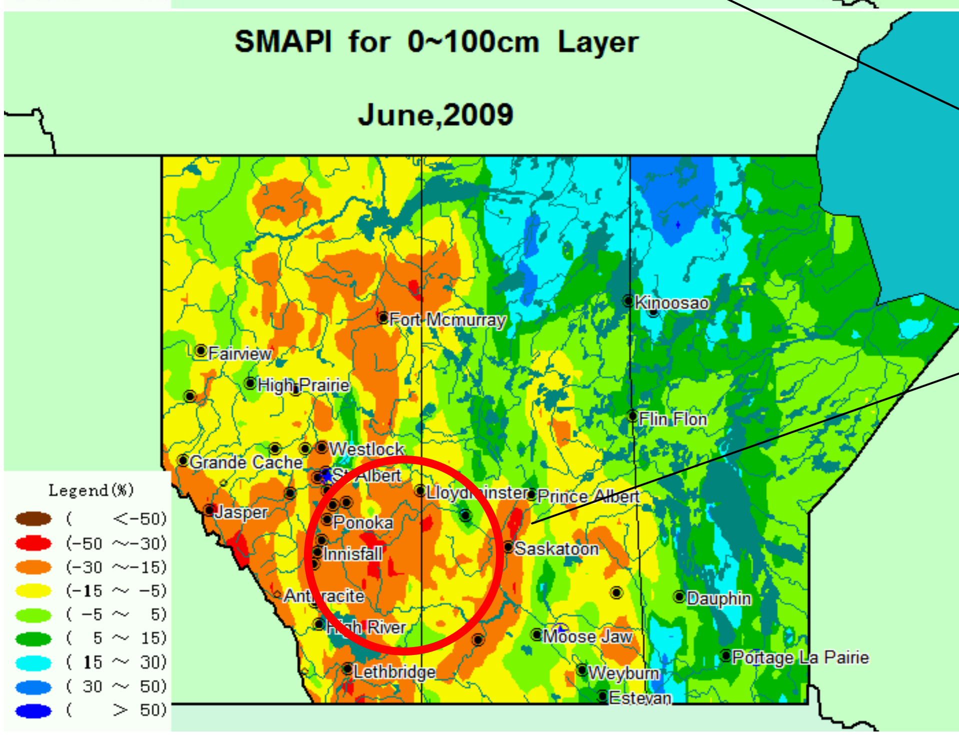


Our VIC forecast for May-2009 average

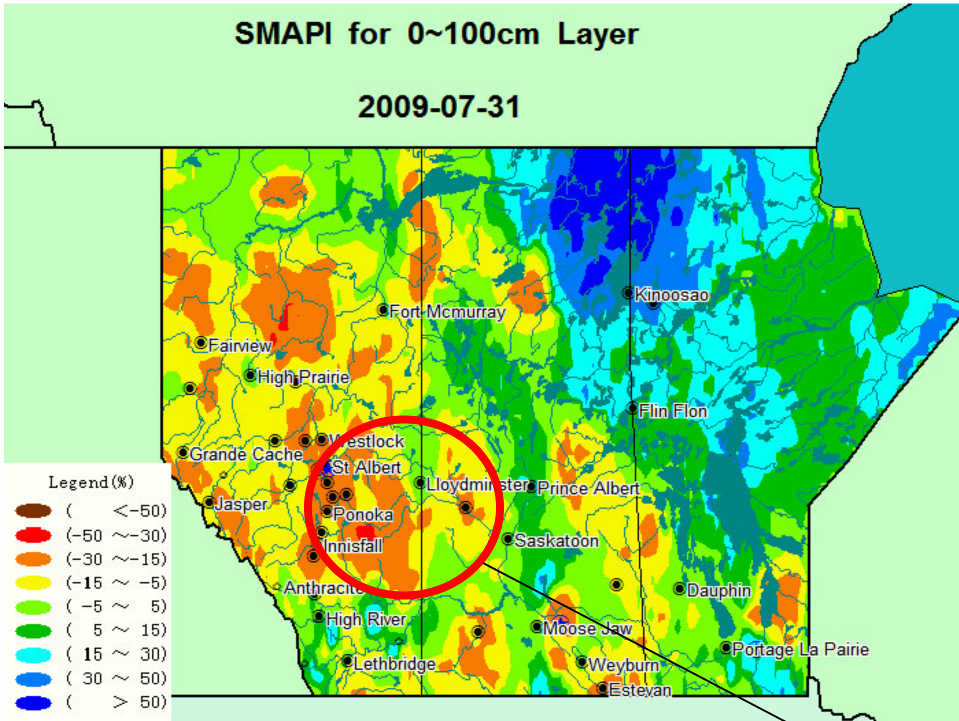


Our VIC forecast for June 30, 2009

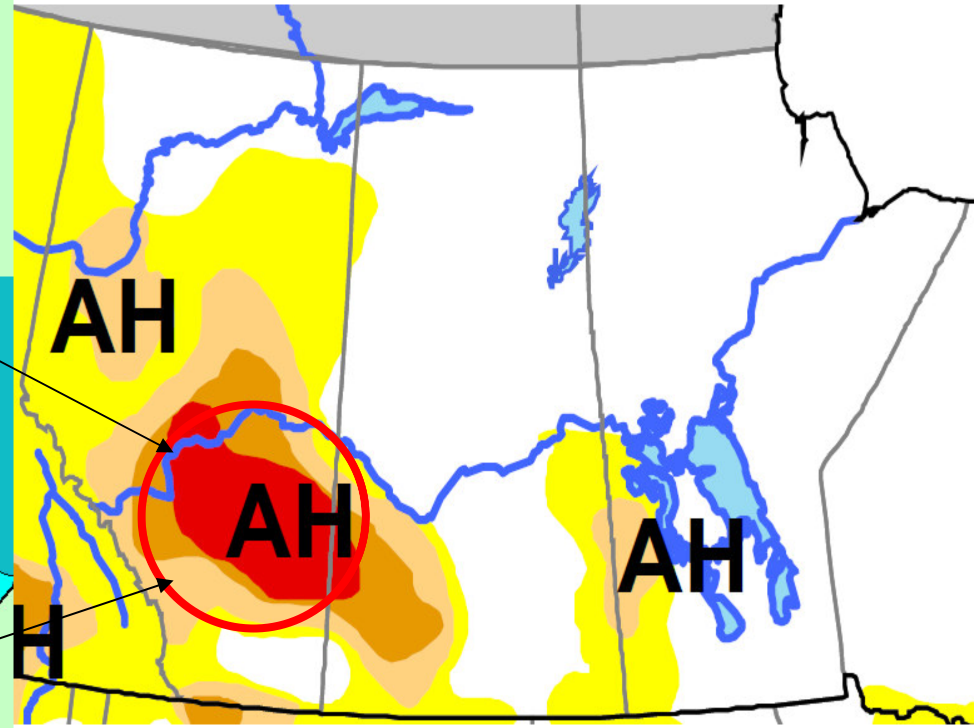


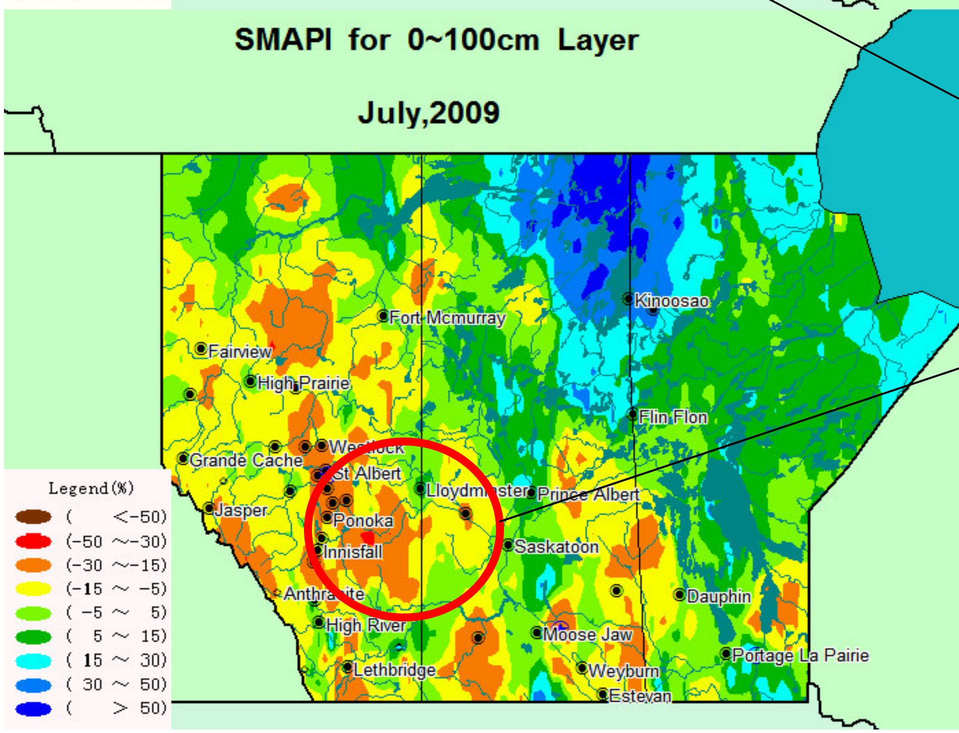


Our VIC forecast for June-2009 average

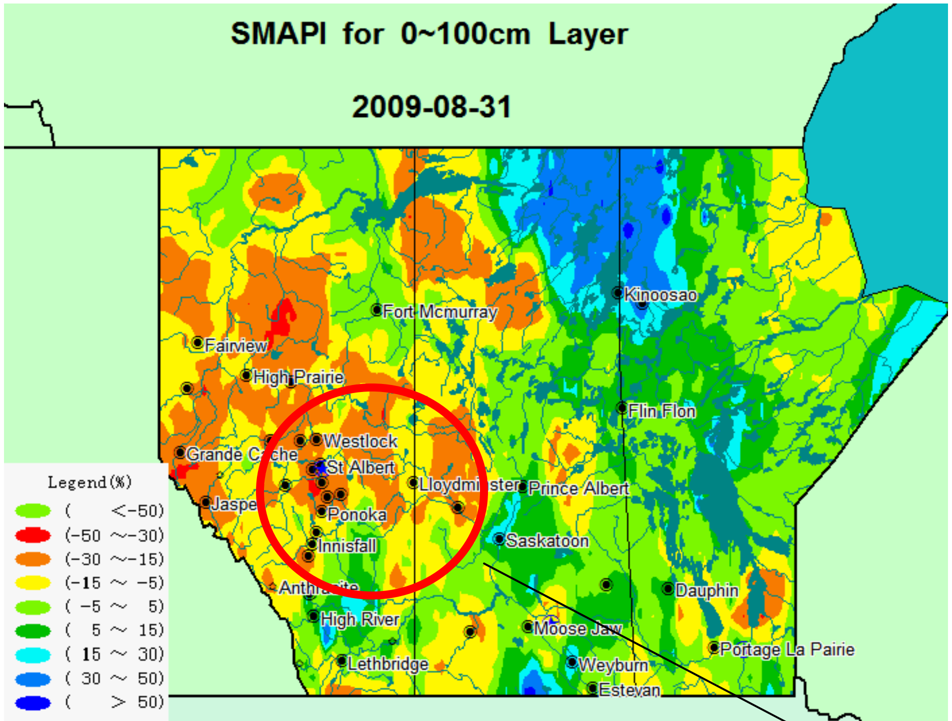


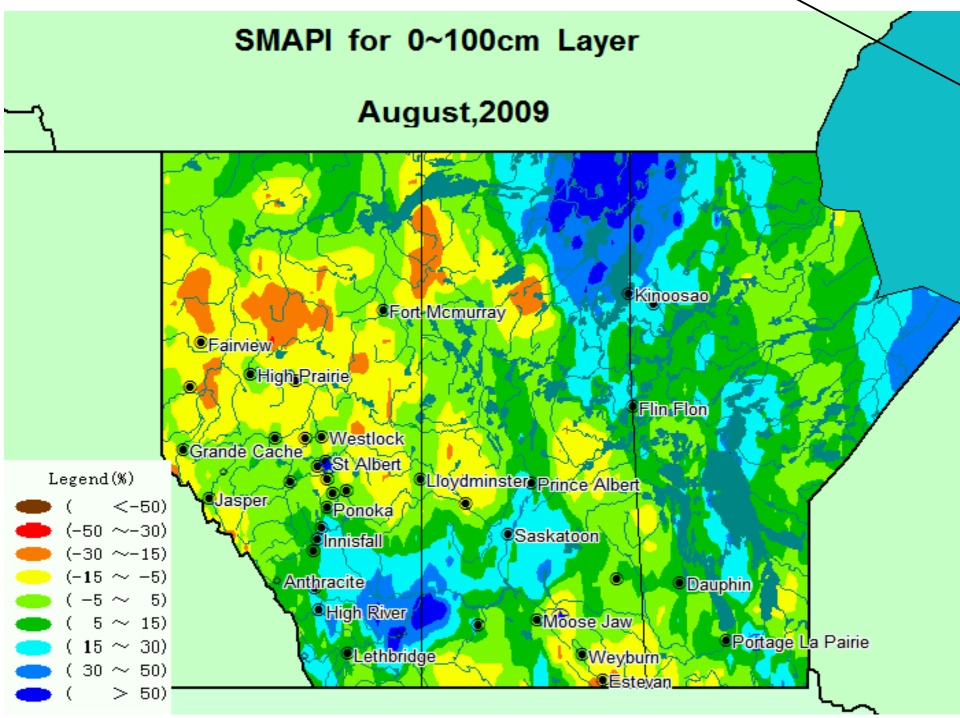
Our VIC forecast for July 31, 2009

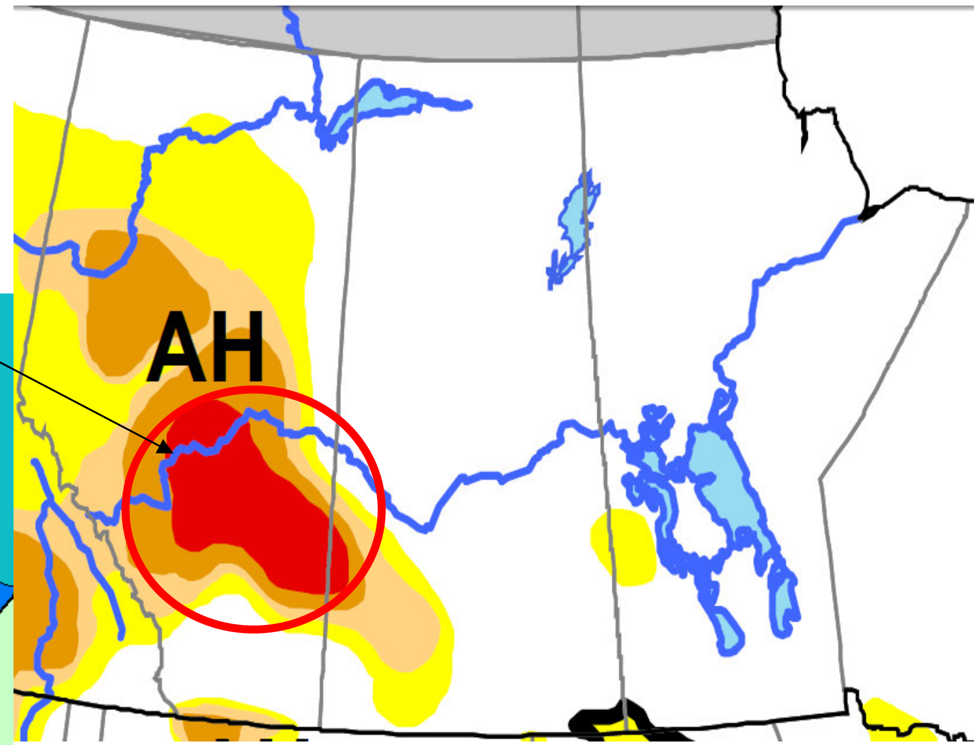




Our VIC forecast for July-2009 average



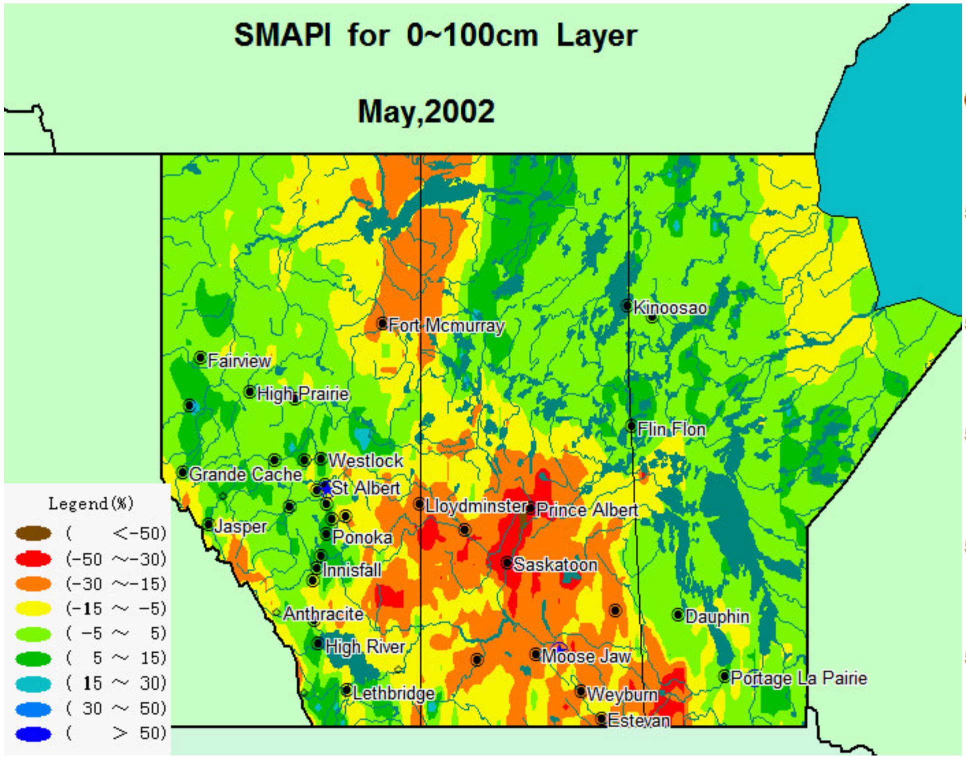


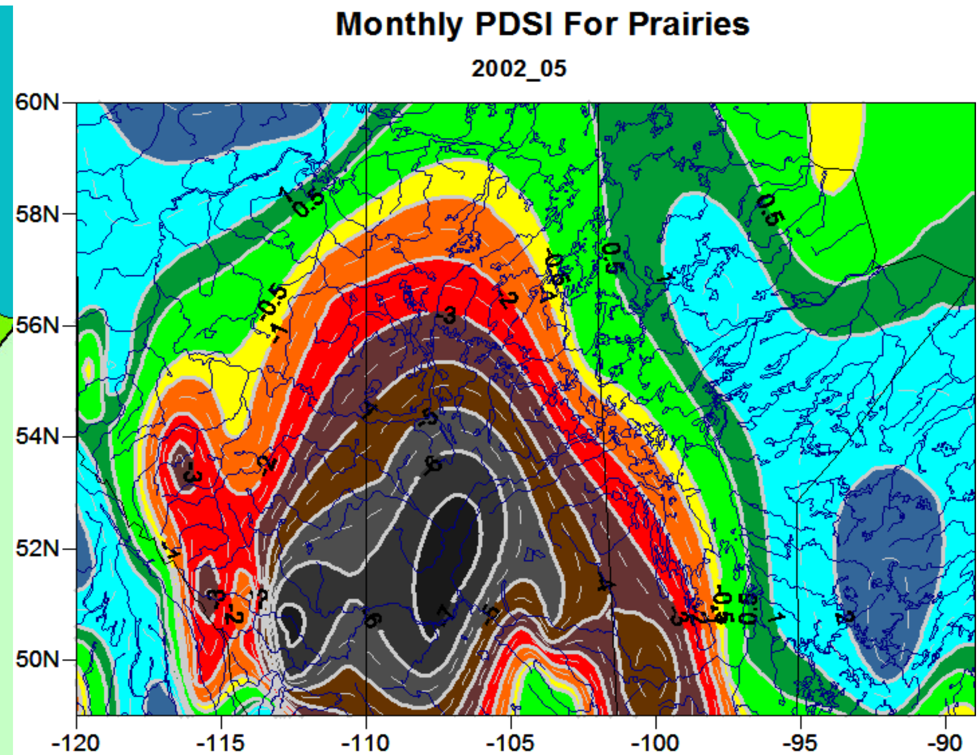


Our VIC forecast for August-2009 average

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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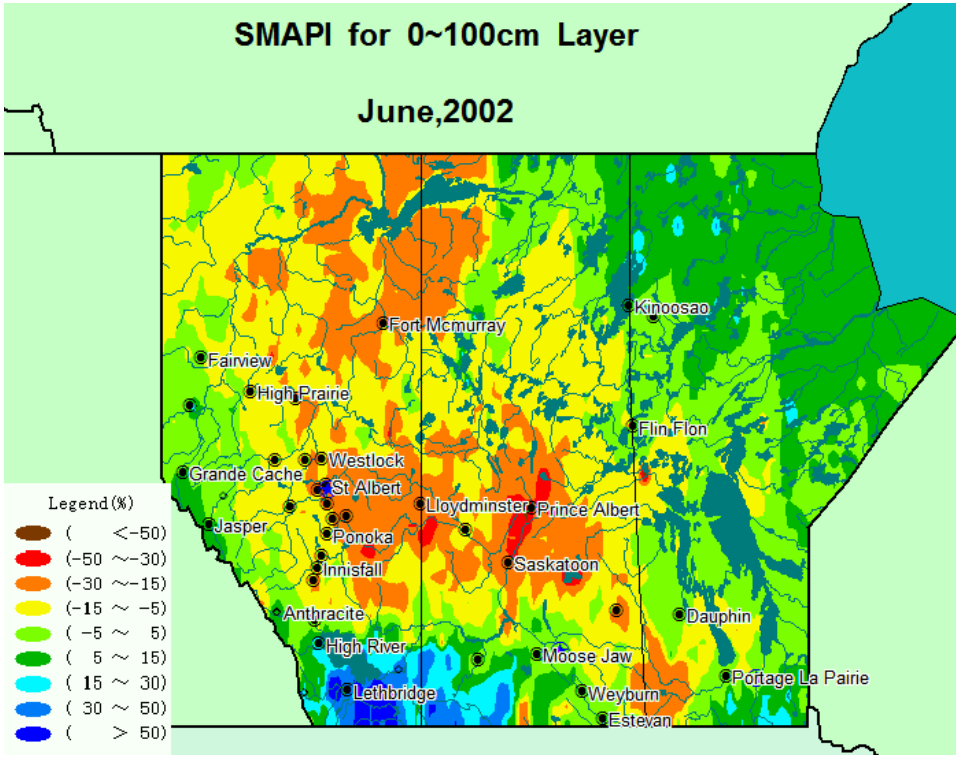

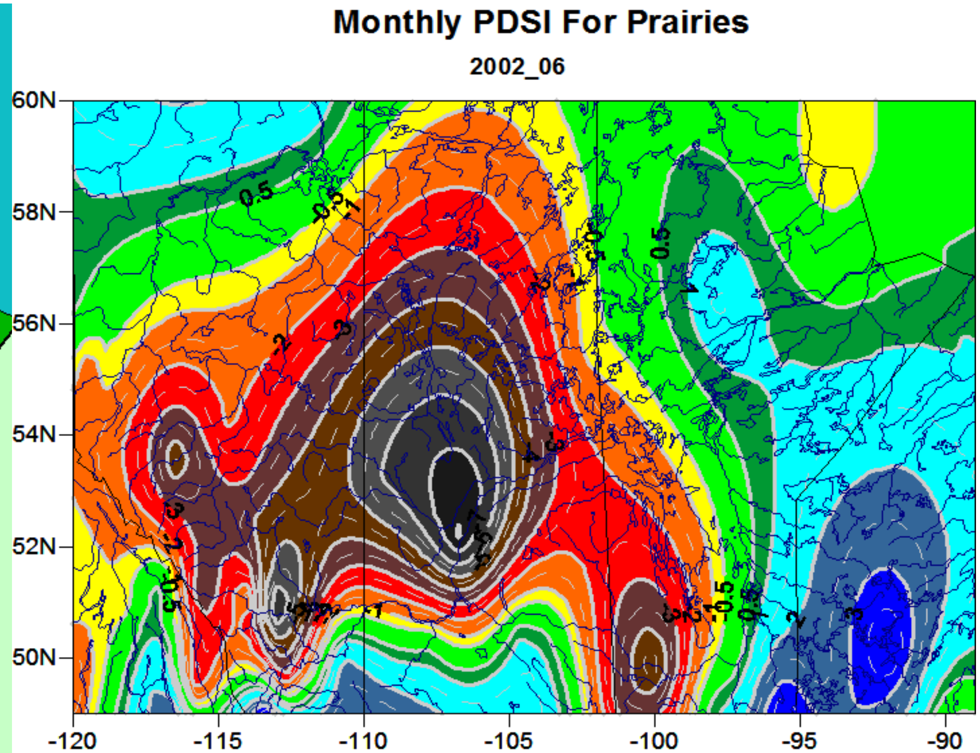

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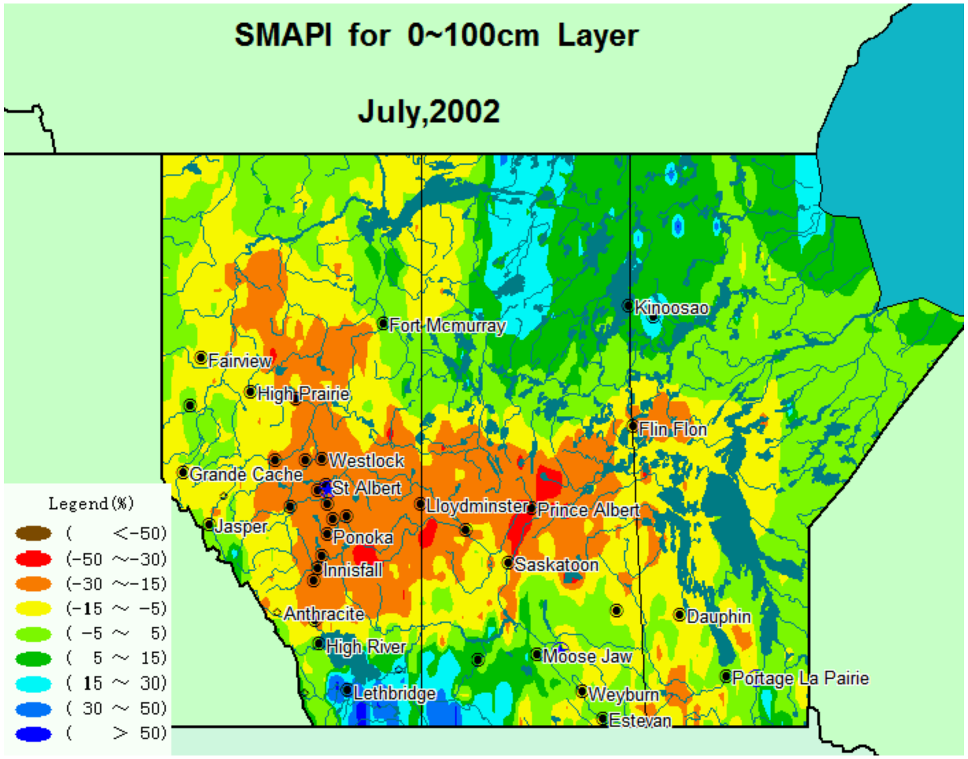

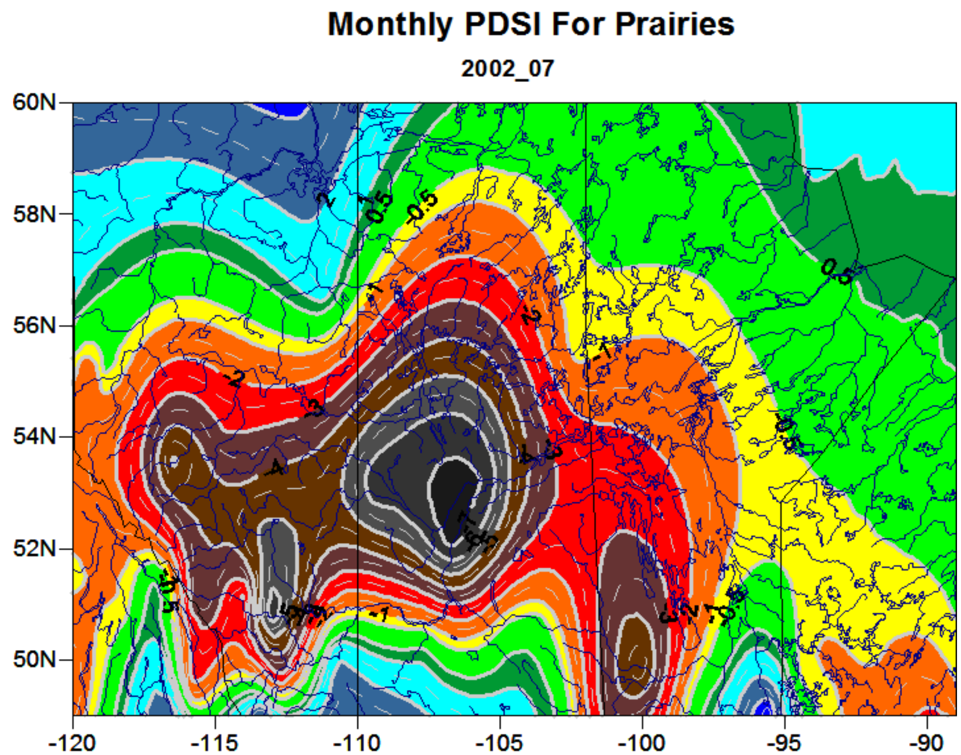

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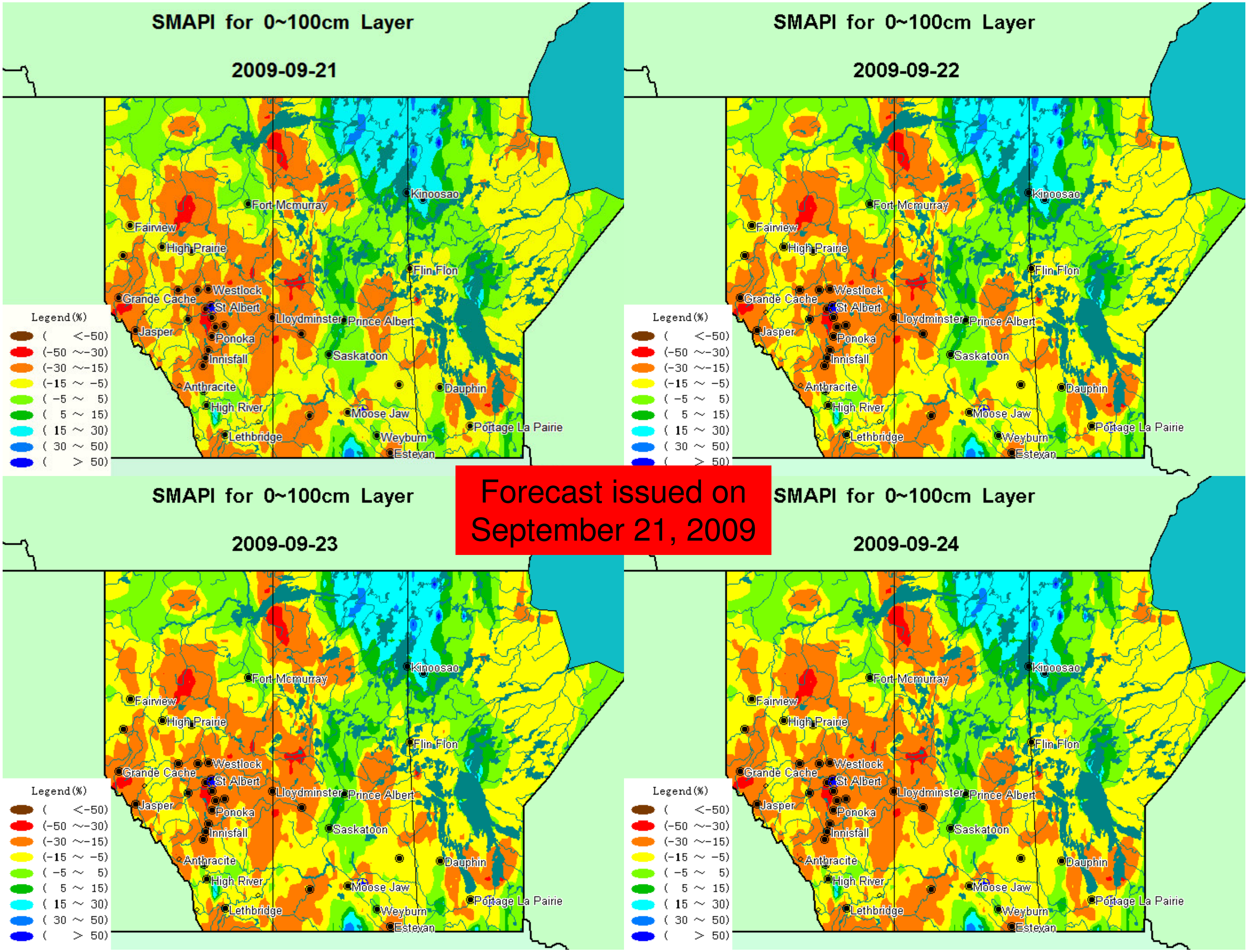
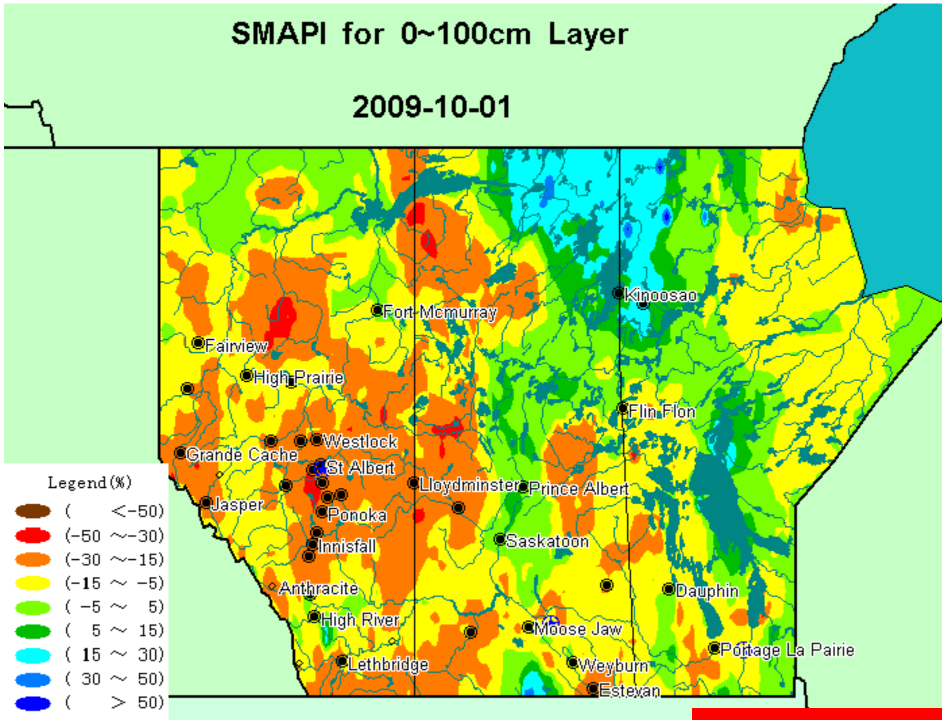
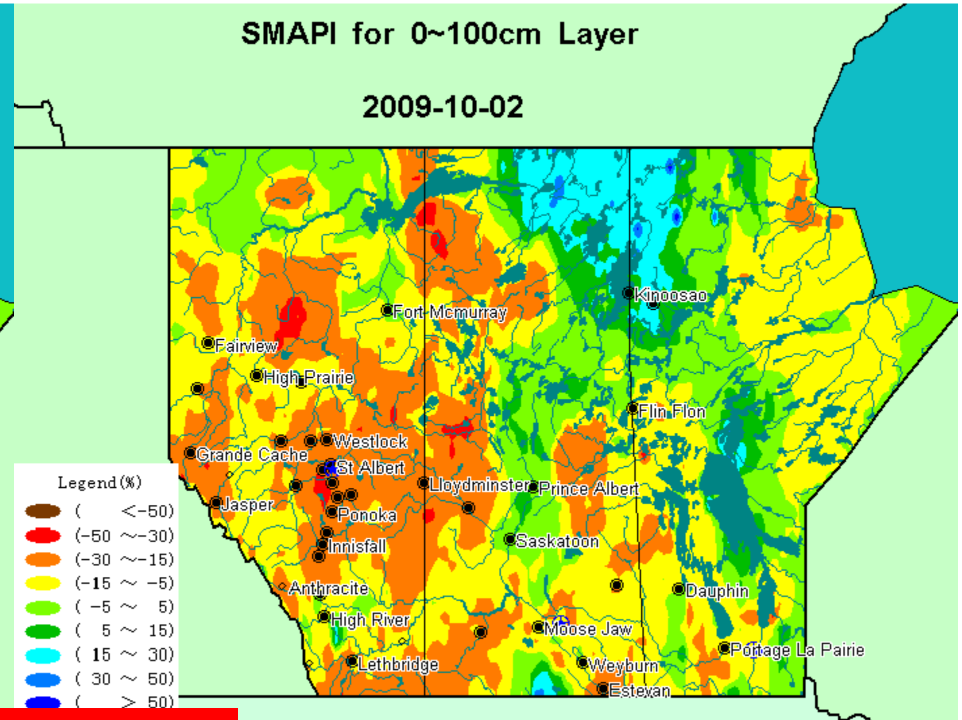
very wet	30% to 50%	0.020
extremely wet	> 50%	0.005

Real-time prairie drought/flood monitoring and forecasting

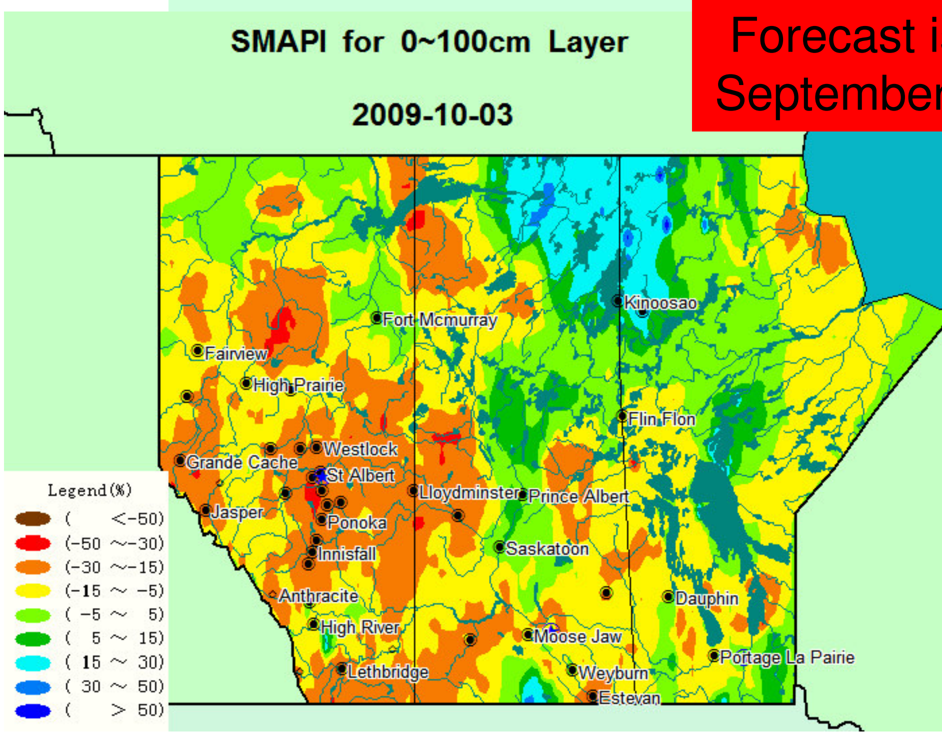
(starting date: May 1, 2009; and updated daily)

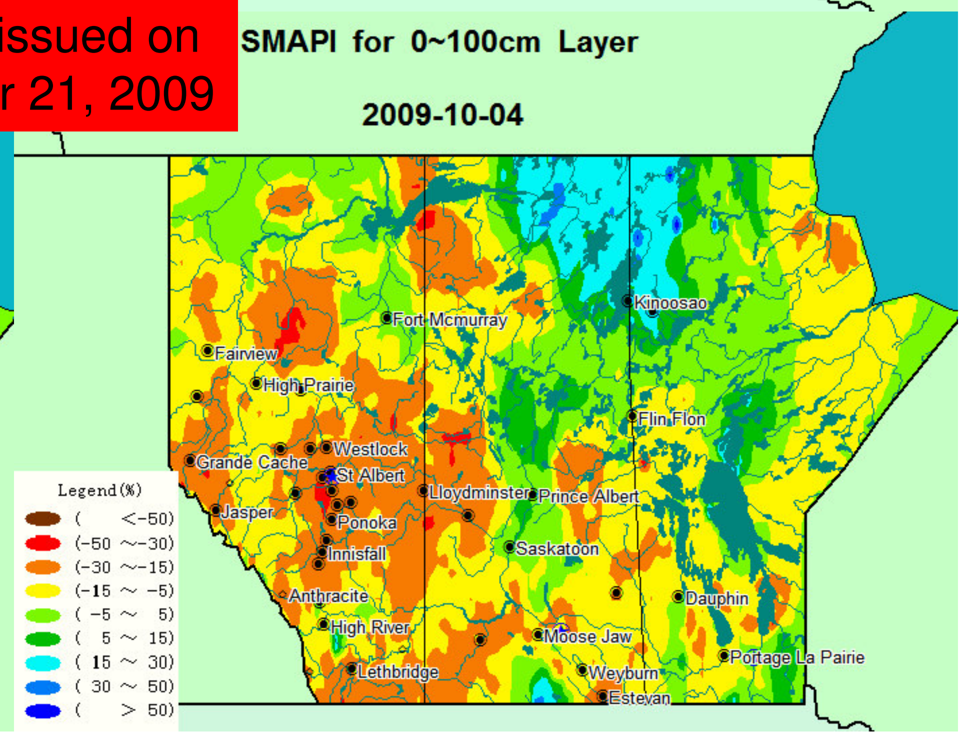

SMAPI for 0~100cm Layer
2009-09-21
SMAPI for 0~100cm Layer
2009-09-22
SMAPI for 0~100cm Layer
2009-09-23
SMAPI for 0~100cm Layer
2009-09-24
Forecast issued on September 21, 2009
Legend(%)
(<-50)
(-50 ~-30)
(-30 ~-15)
(-15 ~ -5)
(-5 ~ 5)
(5 ~ 15)
(15 ~ 30)
(30 ~ 50)
(> 50)
Fort Mcmurray
Kinoosao
Fairview
High Prairie
Flin Flon
Grande Cache
Westlock
St Albert
Lloydminster
Prince Albert
Jasper
Ponoka
Innisfall
Saskatoon
Anthracite
Dauphin
High River
Moose Jaw
Portage La Pairie
Lethbridge
Weyburn
Estevan

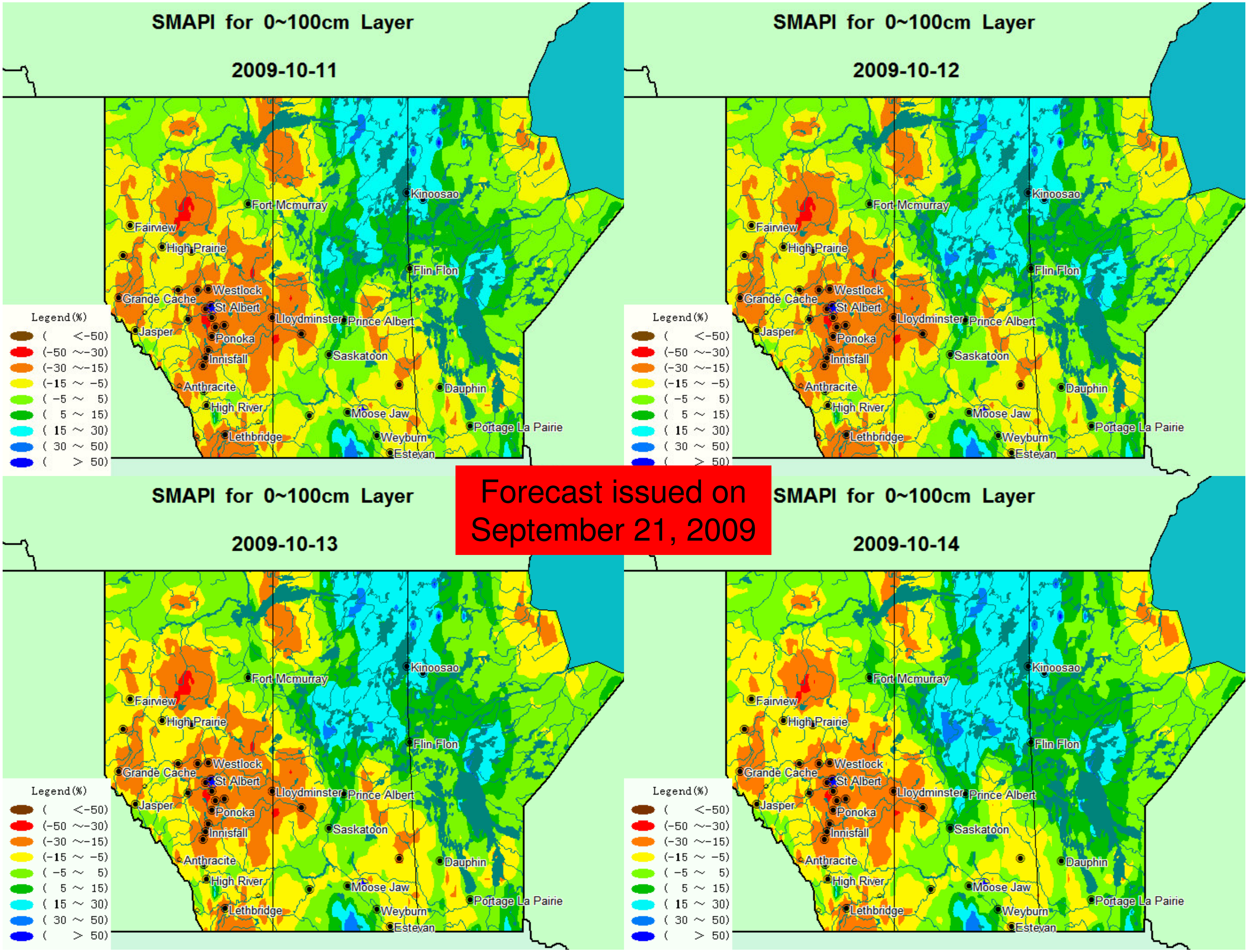




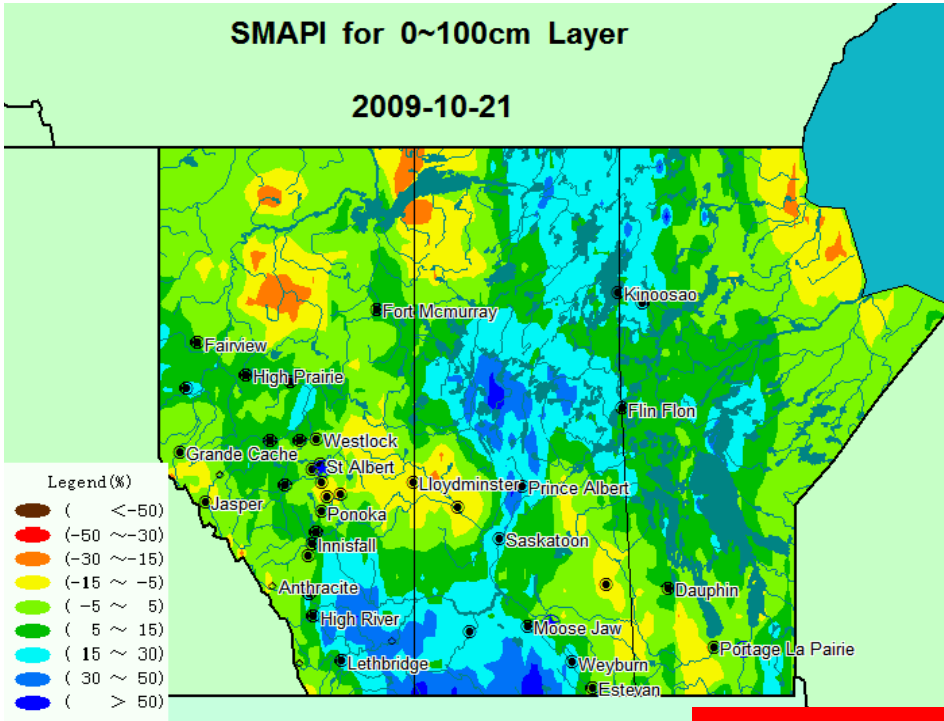
Forecast issued on
September 21, 2009

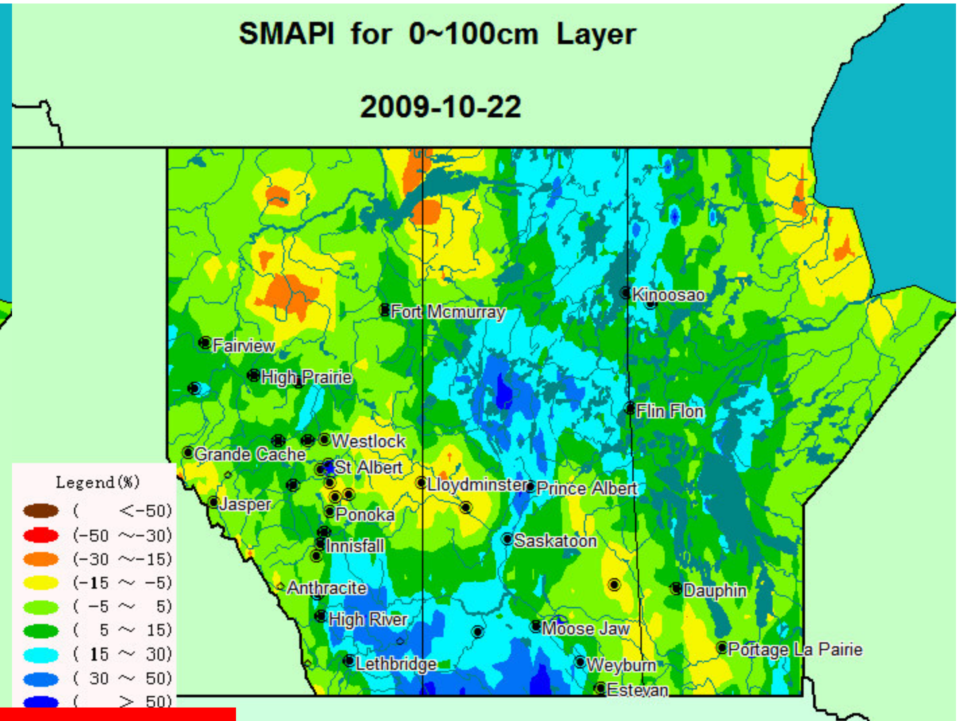




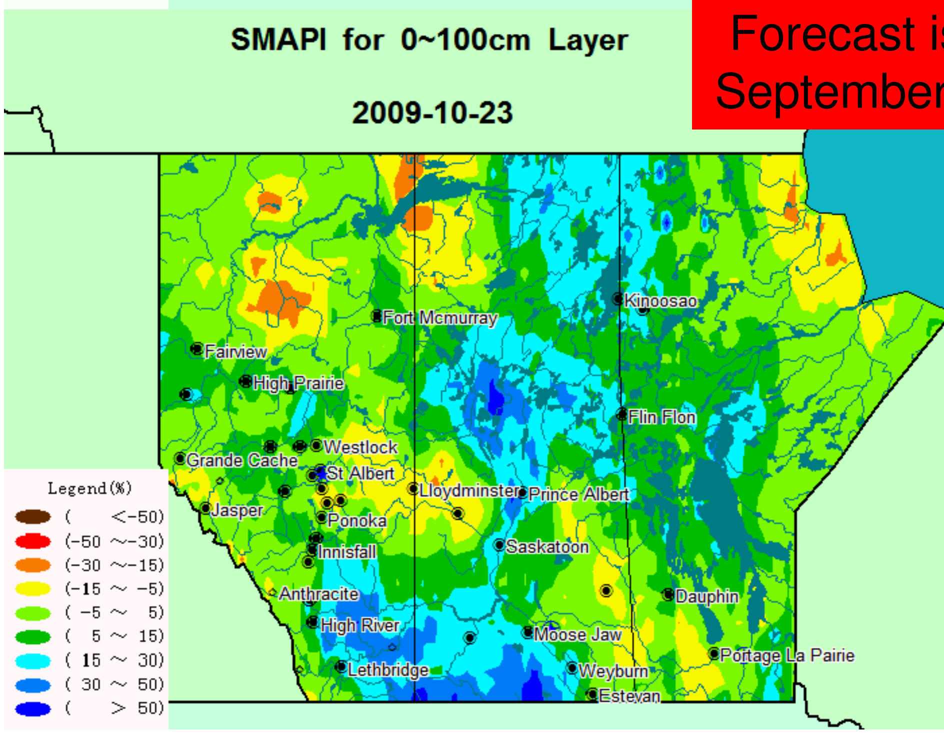


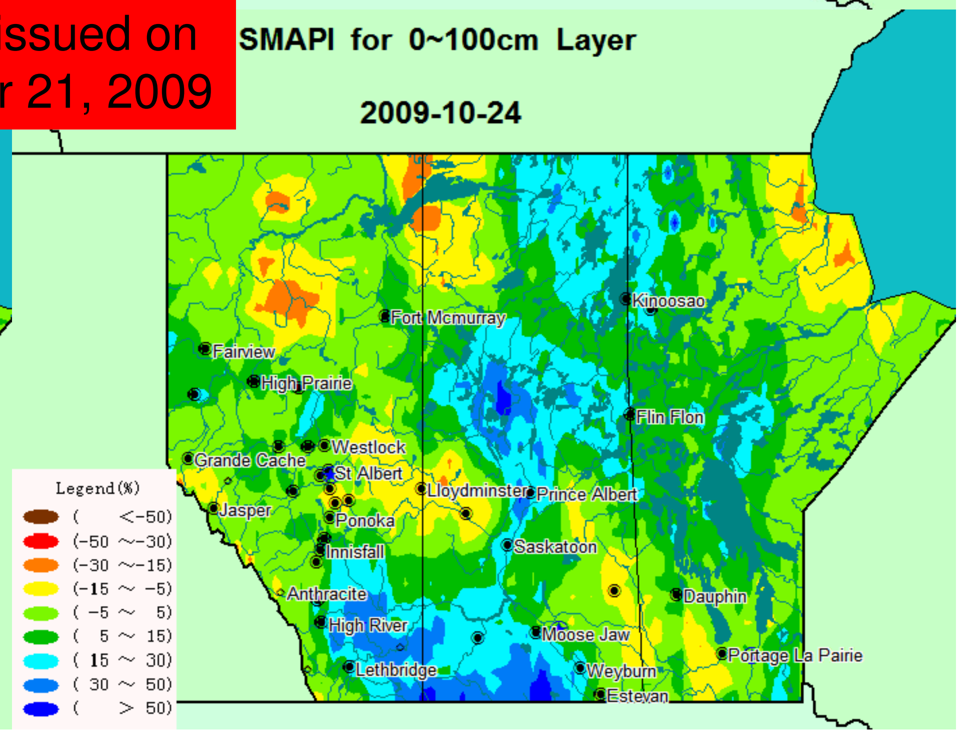
Forecast issued on September 21, 2009

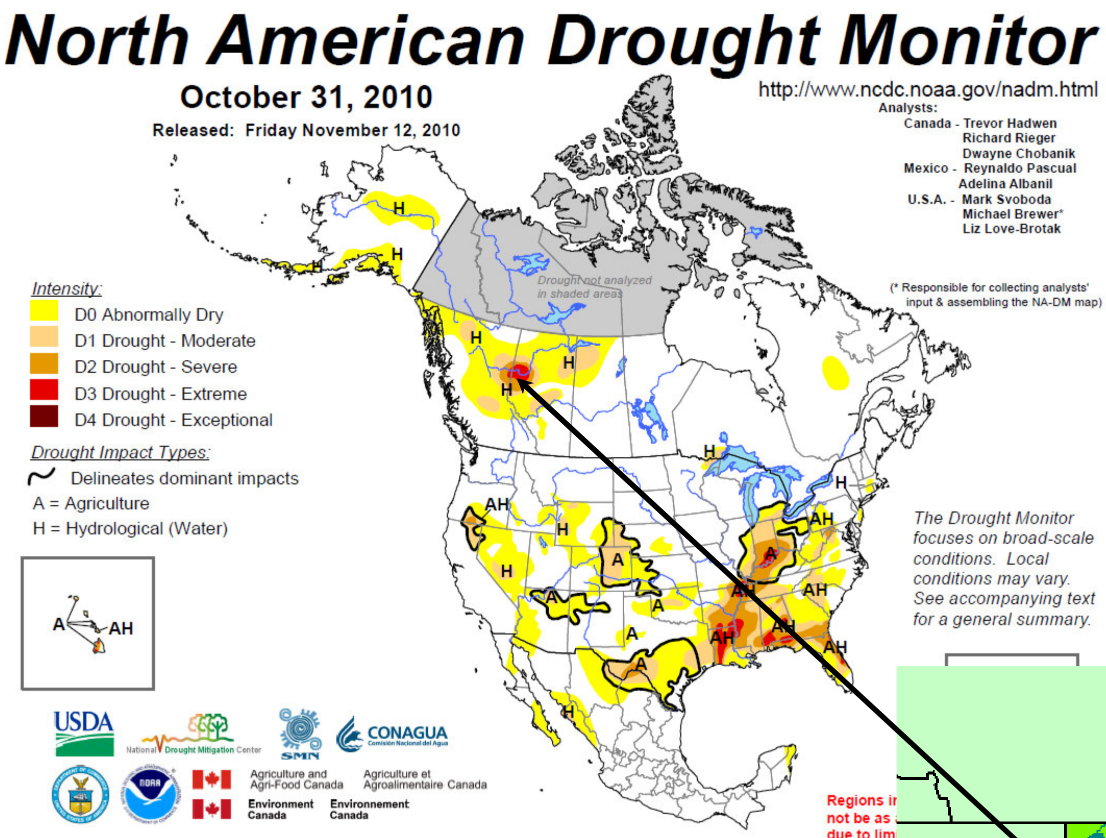




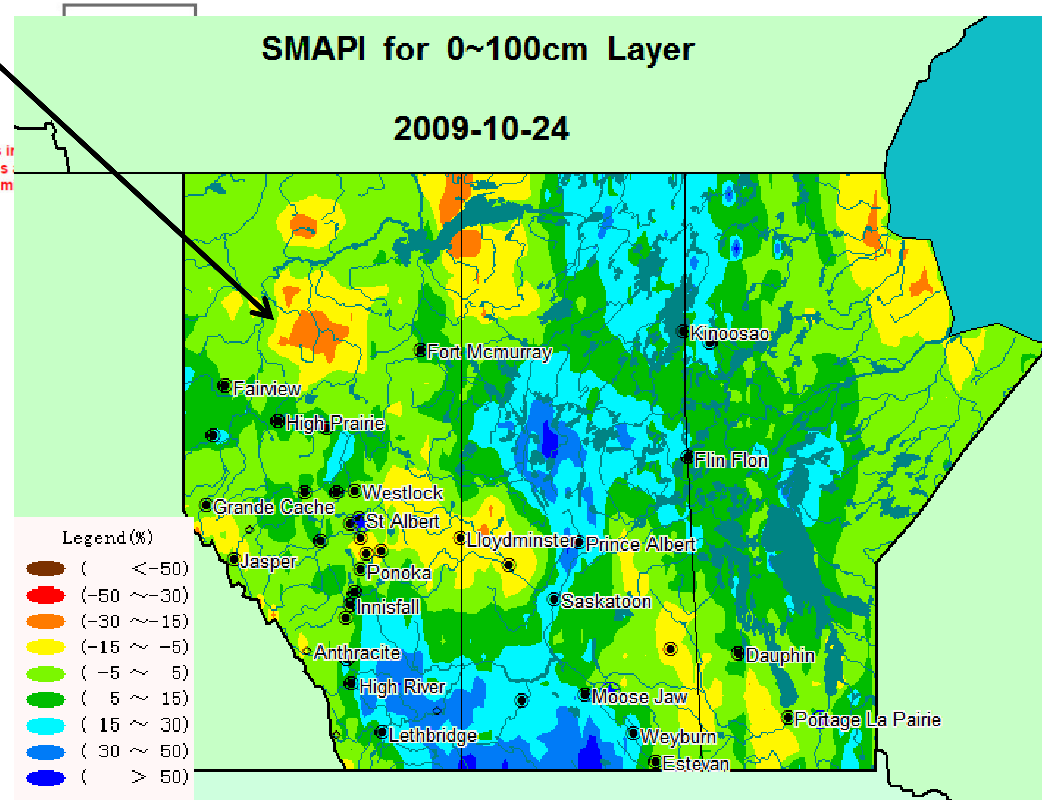
Forecast issued on September 21, 2009

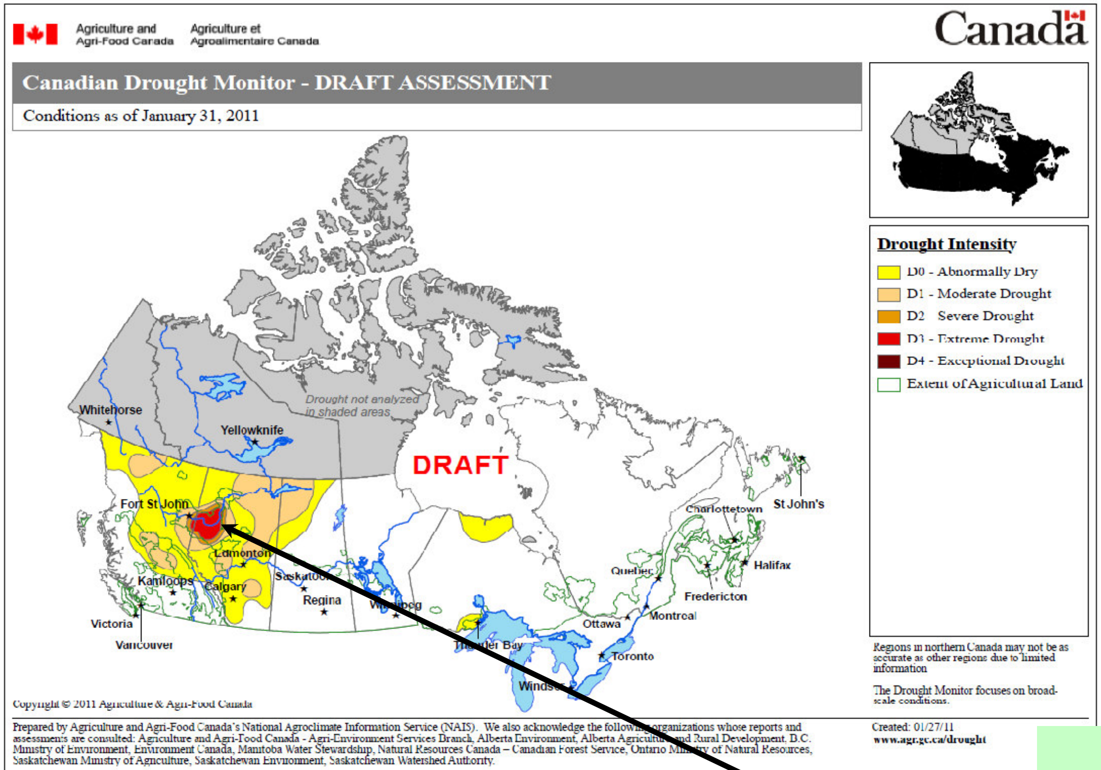


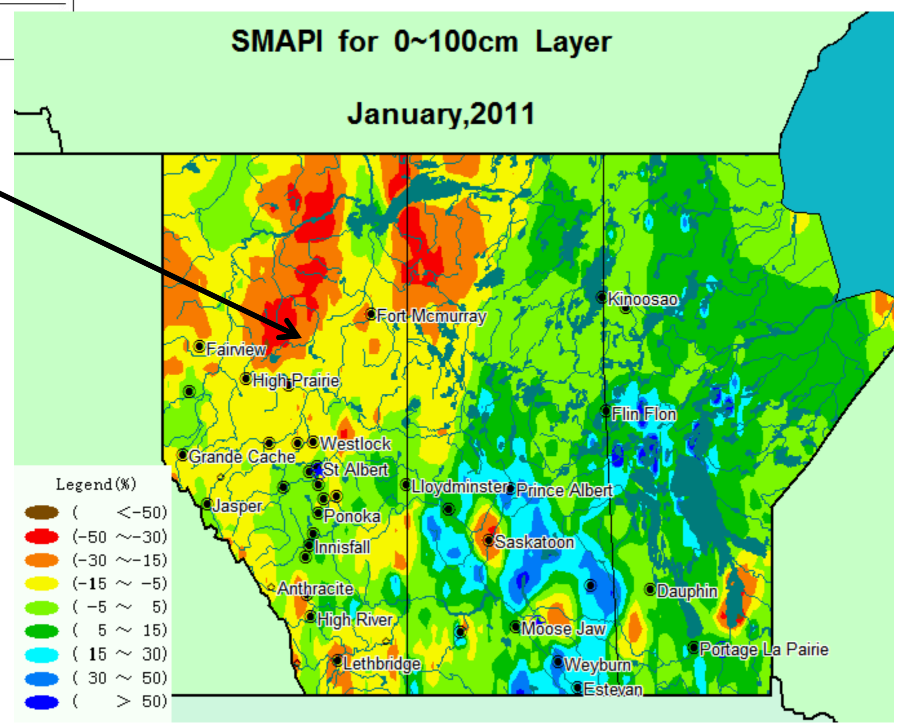




VIC forecast with a lead time of 34d

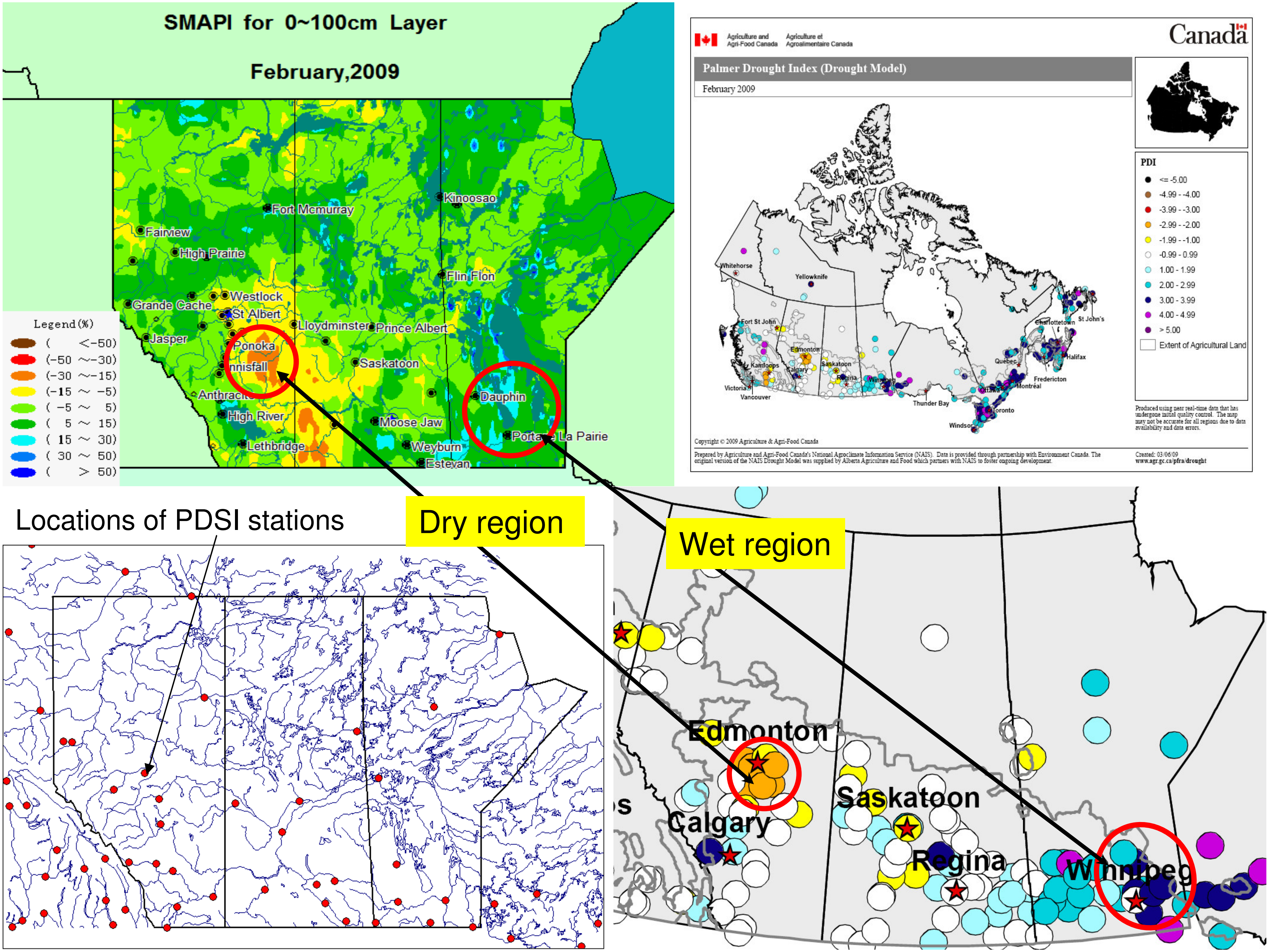


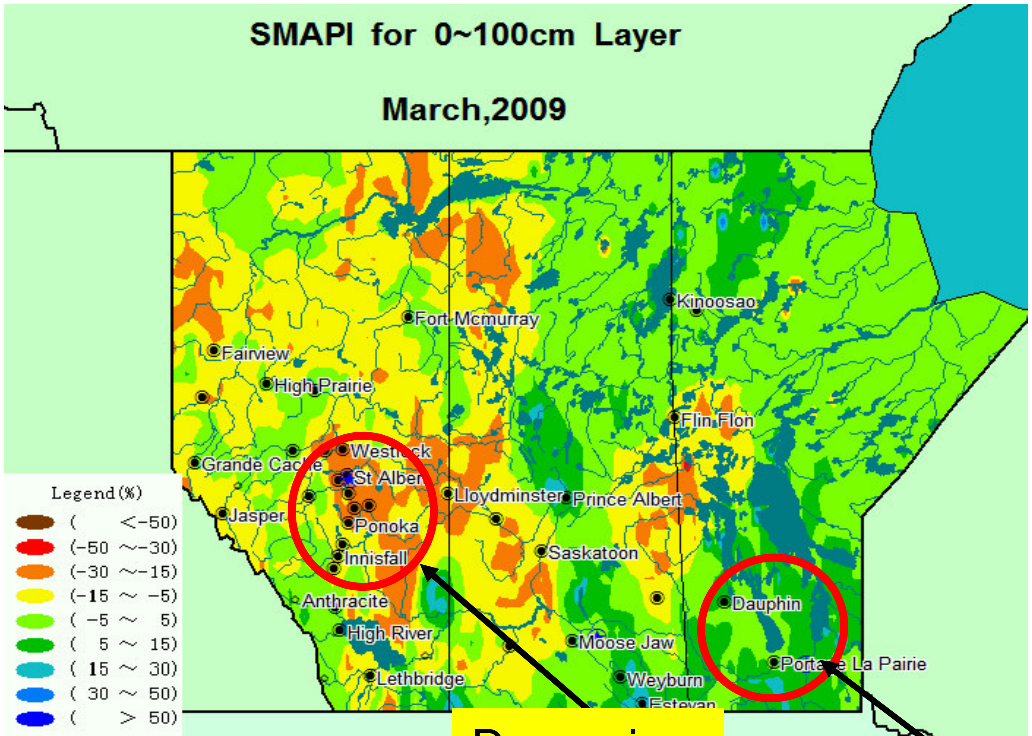


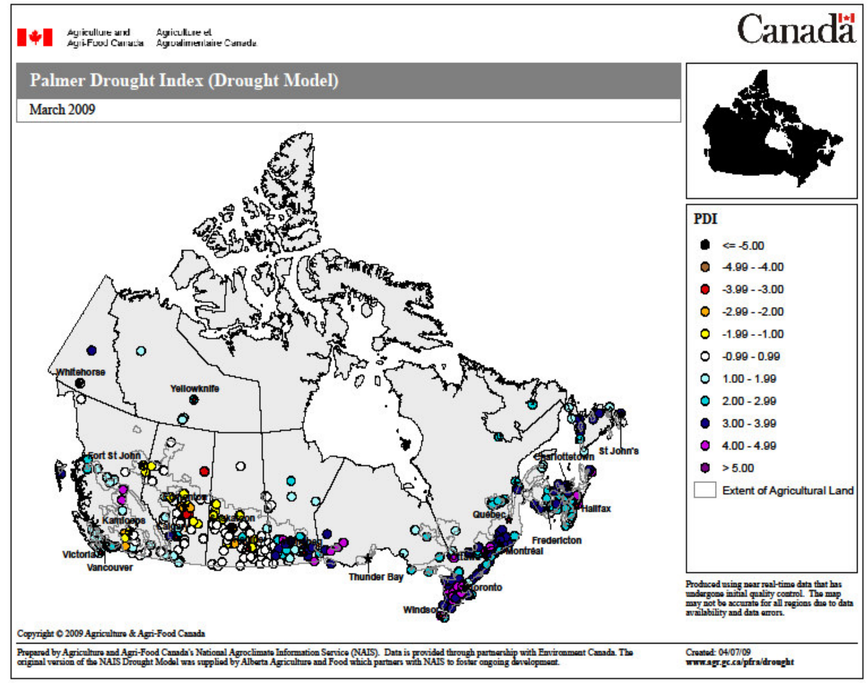


Current Prairie Drought Conditions

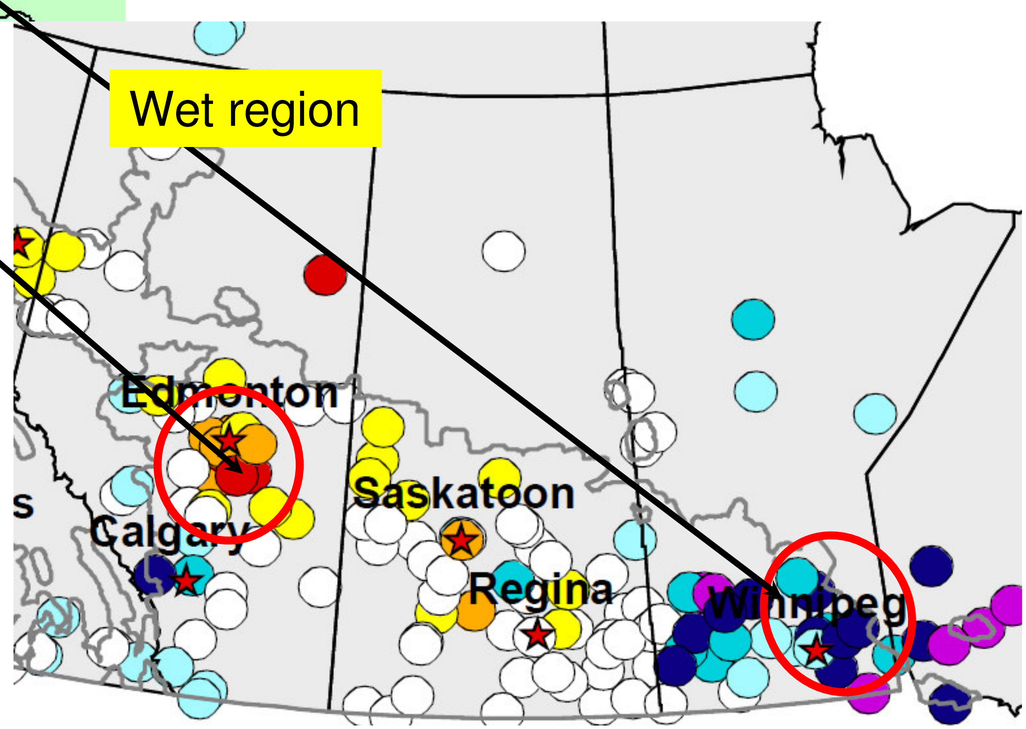
Real-time forecasting Winnipeg 2009 spring flood

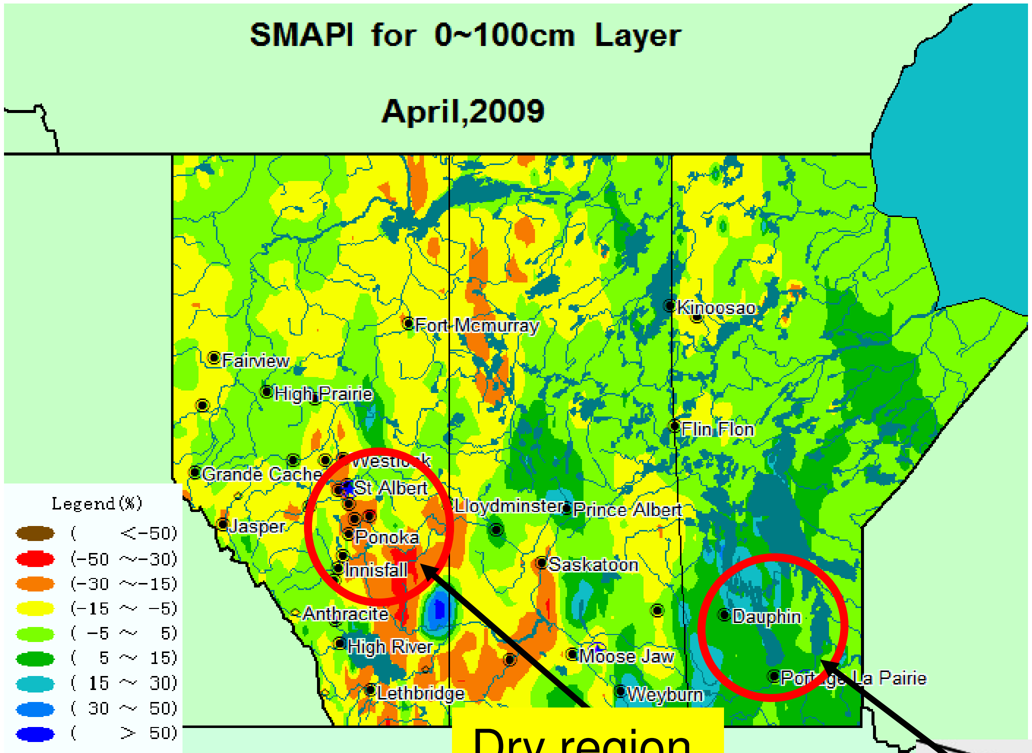

SMAPI for 0~100cm Layer
February,2009
Legend(%)
(<-50)
(-50 ~-30)
(-30 ~-15)
(-15 ~ -5)
(-5 ~ 5)
(5 ~ 15)
(15 ~ 30)
(30 ~ 50)
(> 50)
Fort Mcmurray
Kinoosao
Fairview
High Prairie
Flin Flon
Westlock
Grande Cache
St Albert
Lloydminster
Prince Albert
Jasper
Ponoka
Saskatoon
Dauphin
High River
Moose Jaw
Portage La Pairie
Lethbridge
Weyburn
Estevan
Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada
Canada
Palmer Drought Index (Drought Model)
February 2009
PDI
<= -5.00
-4.99 - -4.00
-3.99 - -3.00
-2.99 - -2.00
-1.99 - -1.00
-0.99 - 0.99
1.00 - 1.99
2.00 - 2.99
3.00 - 3.99
4.00 - 4.99
> 5.00
Extent of Agricultural Land
Whitehorse
Yellowknife
Fort St John
Edmonton
Saskatoon
Winnipeg
Thunder Bay
Quebec
Montreal
Toronto
Halifax
Fredericton
St John's
Vancouver
Victoria
Copyright © 2009 Agriculture & Agri-Food Canada
Locations of PDSI stations
Dry region
Wet region
Edmonton
Calgary
Saskatoon
Regina
Winnipeg

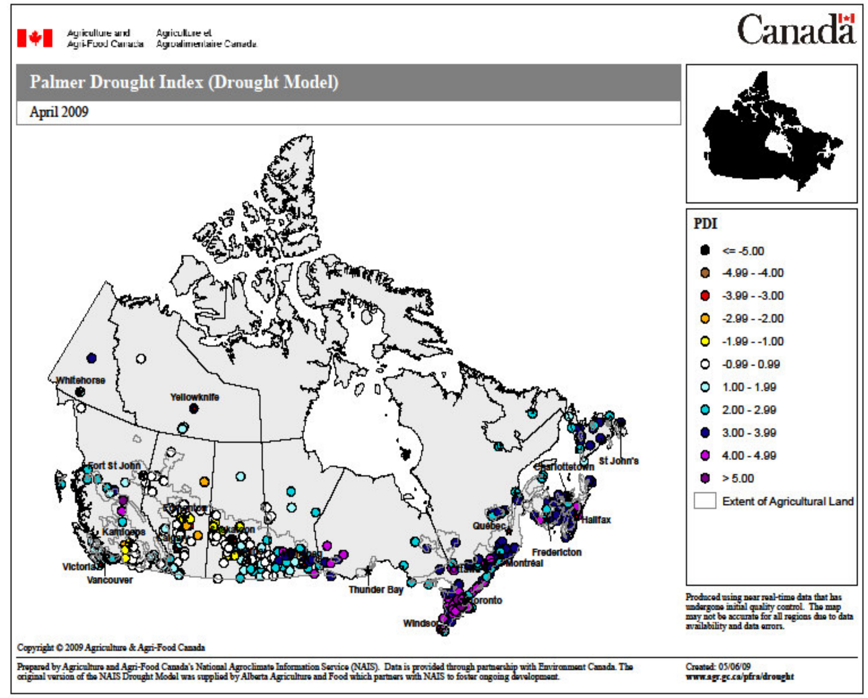


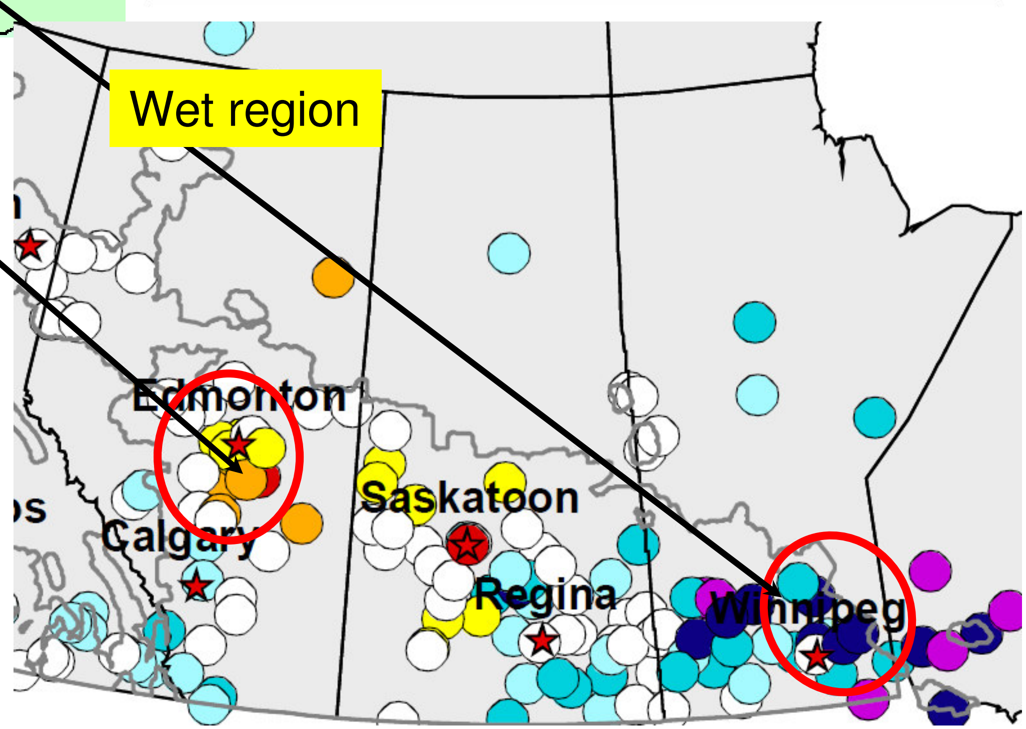


Category	SMAPI	Average Frequency
extreme drought	≤-50%	0.005
severe drought	-50% to -30%	0.020
moderate drought	-30% to -15%	0.100
mild drought	-15% to -5%	0.200
near normal	-5% to 5%	0.350
slightly wet	5% to 15%	0.200
moderately wet	15% to 30%	0.100
very wet	30% to 50%	0.020
extremely wet	> 50%	0.005









Category	SMAPI	Average Frequency
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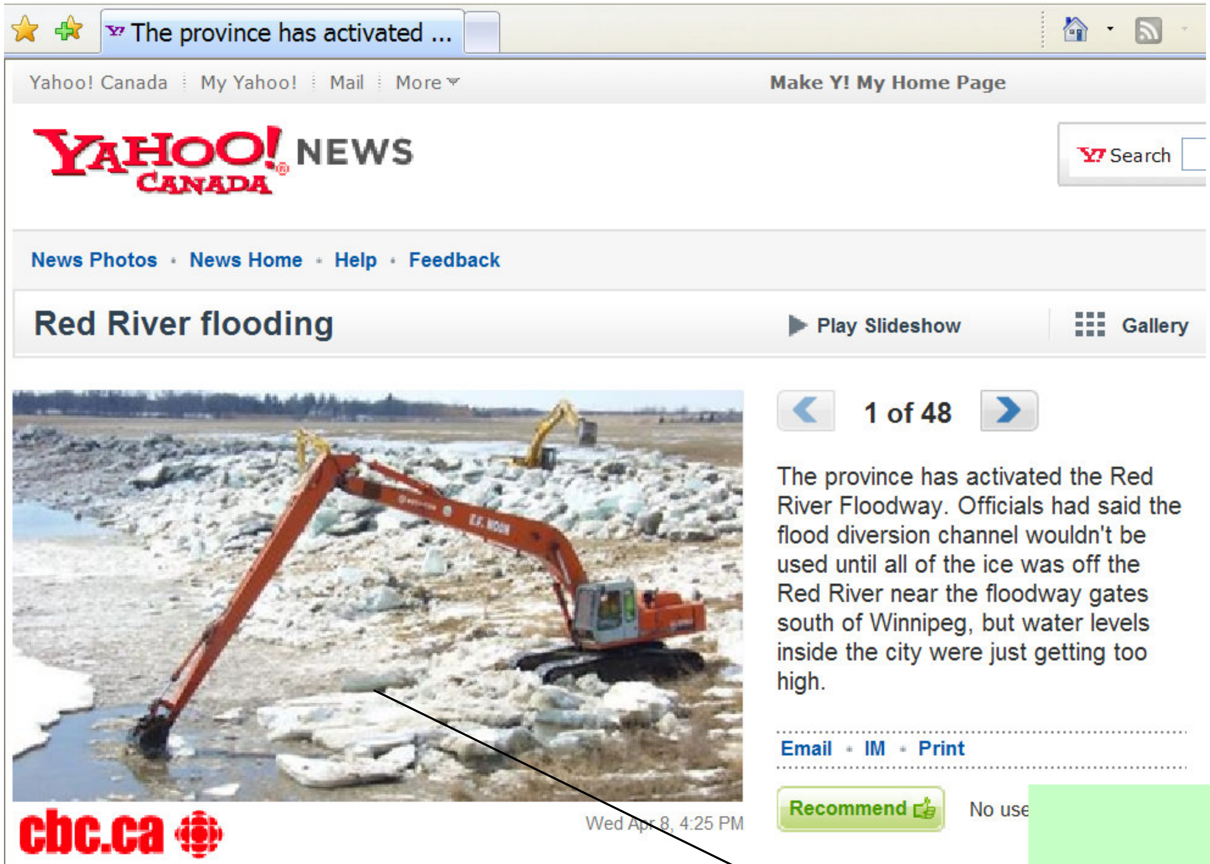
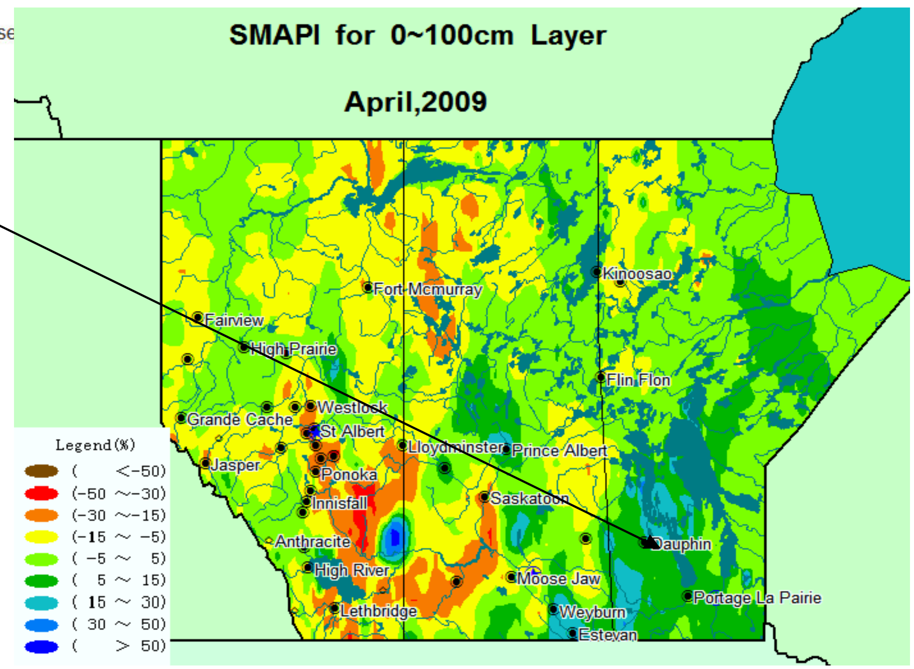
NOW!

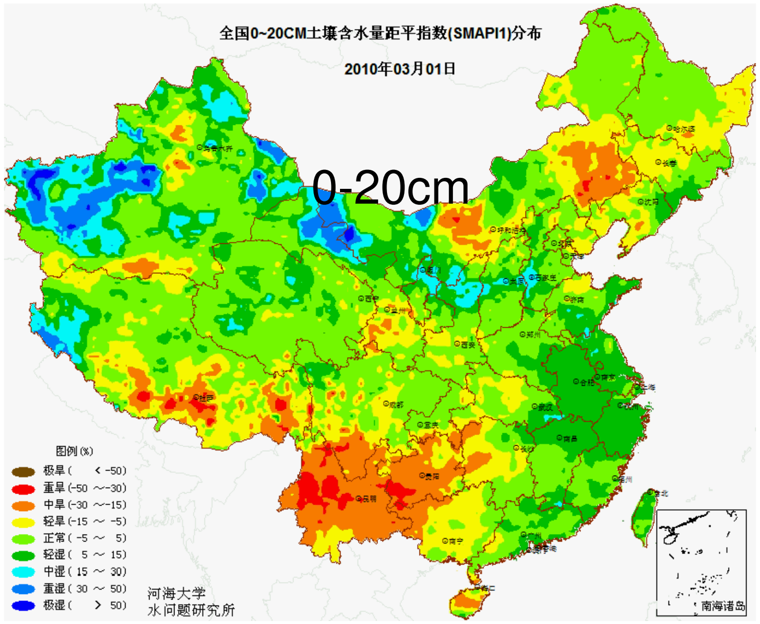
Monitoring and forecasting prairie flooding

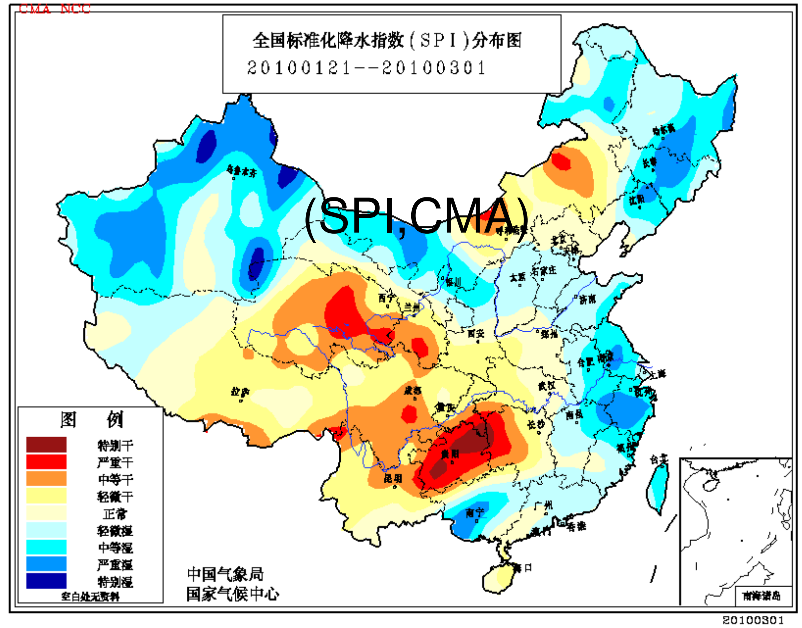


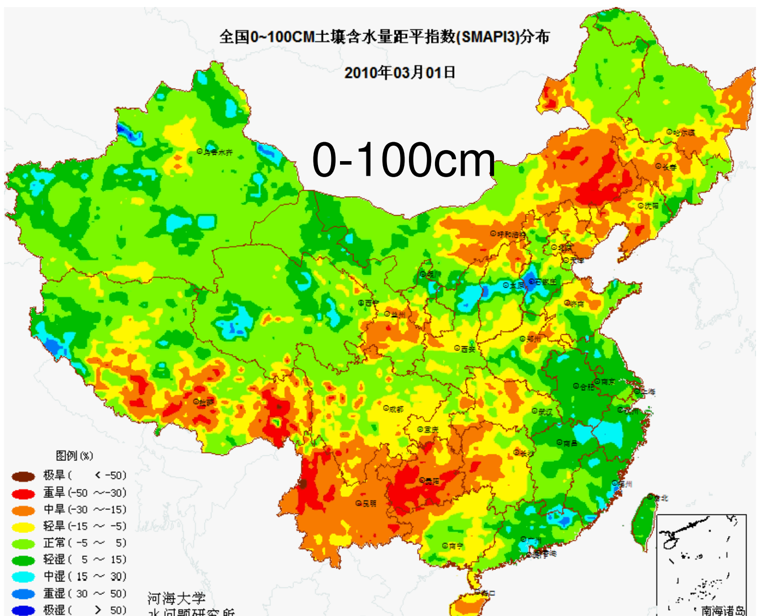


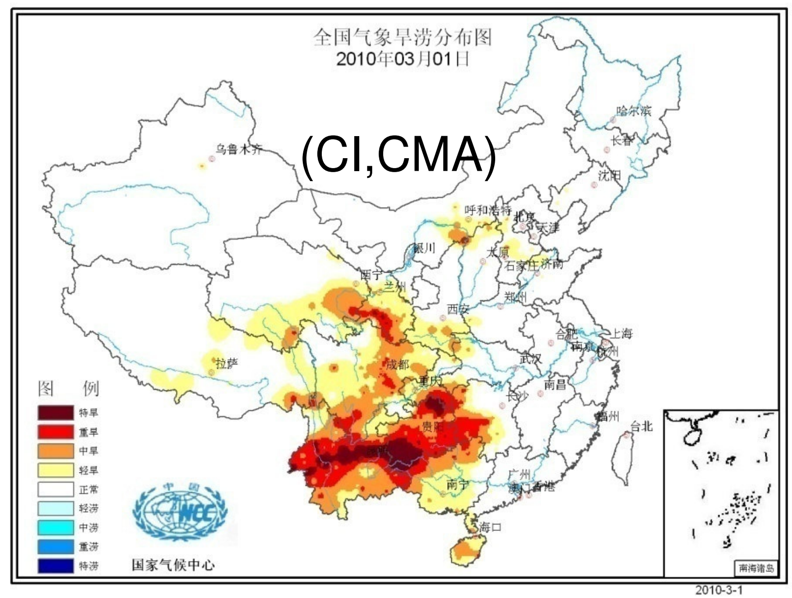
2010 South-west China Drought

China Drought monitoring, Mar. 1, 2010



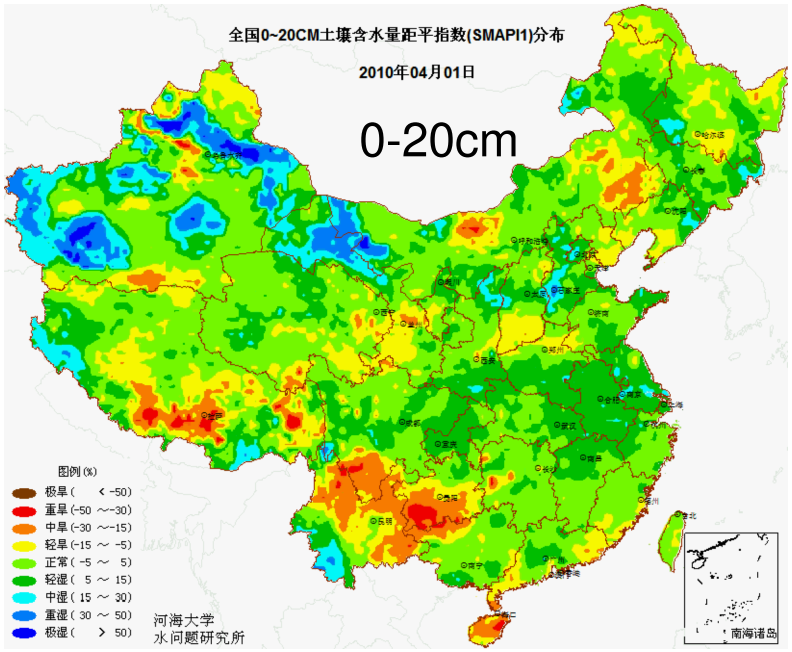


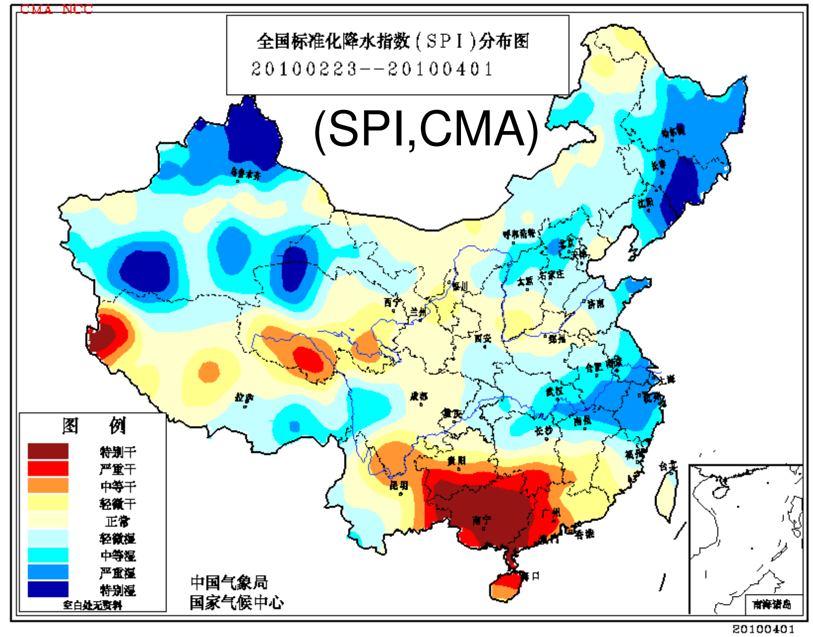


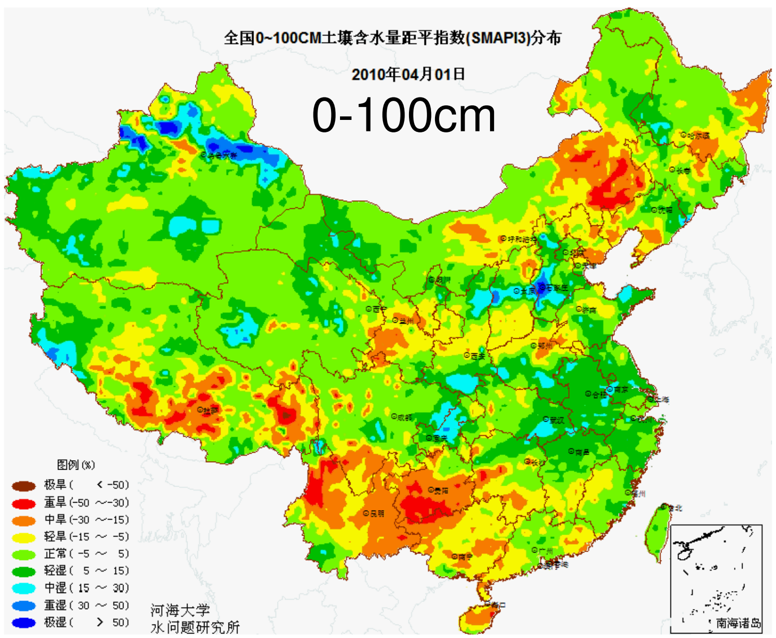


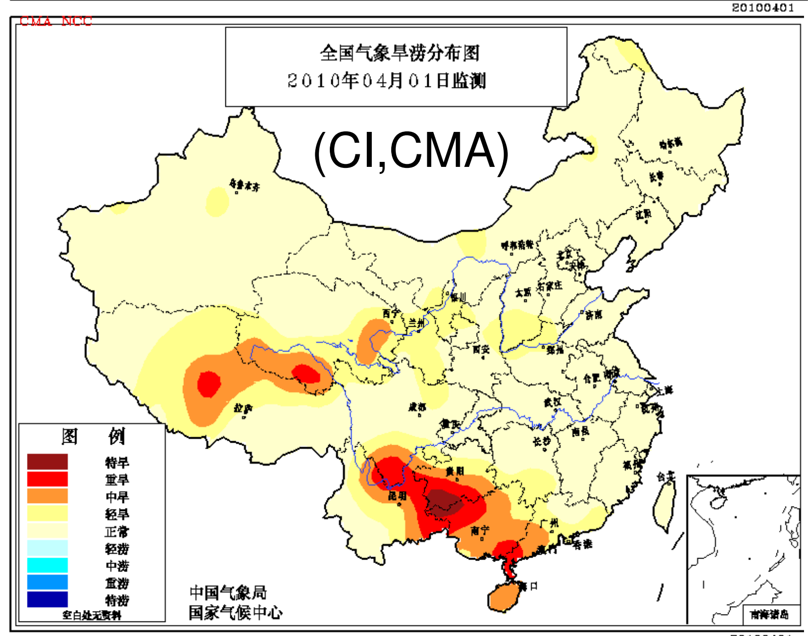
http://cmdp.ncc.cma.gov.cn/influ/dust.php?dateStr=2010-4#calendar

China Drought monitoring, Apr. 1, 2010



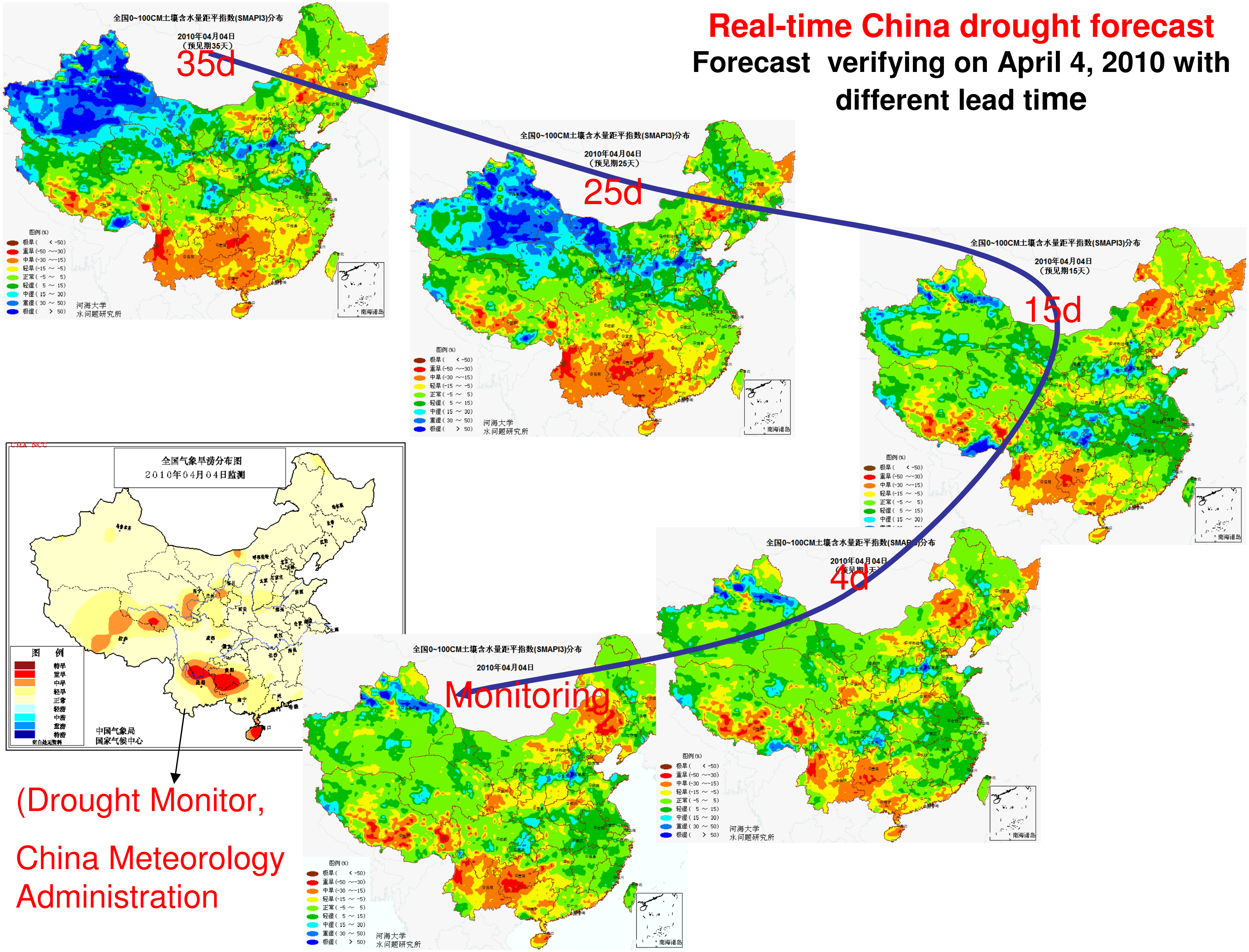






Real-time China drought forecast

Forecast verifying on April 4, 2010 with different lead time



Potential Applications

1. Runoff assessment
2. Water resources trend study
3. Supplementary information to observation over Northern regions
4. Many others

Thanks very much
Merci beaucoup!