Prairie Water and Energy Cycling: Budget Assessments, Modeling and Process Diagnostics

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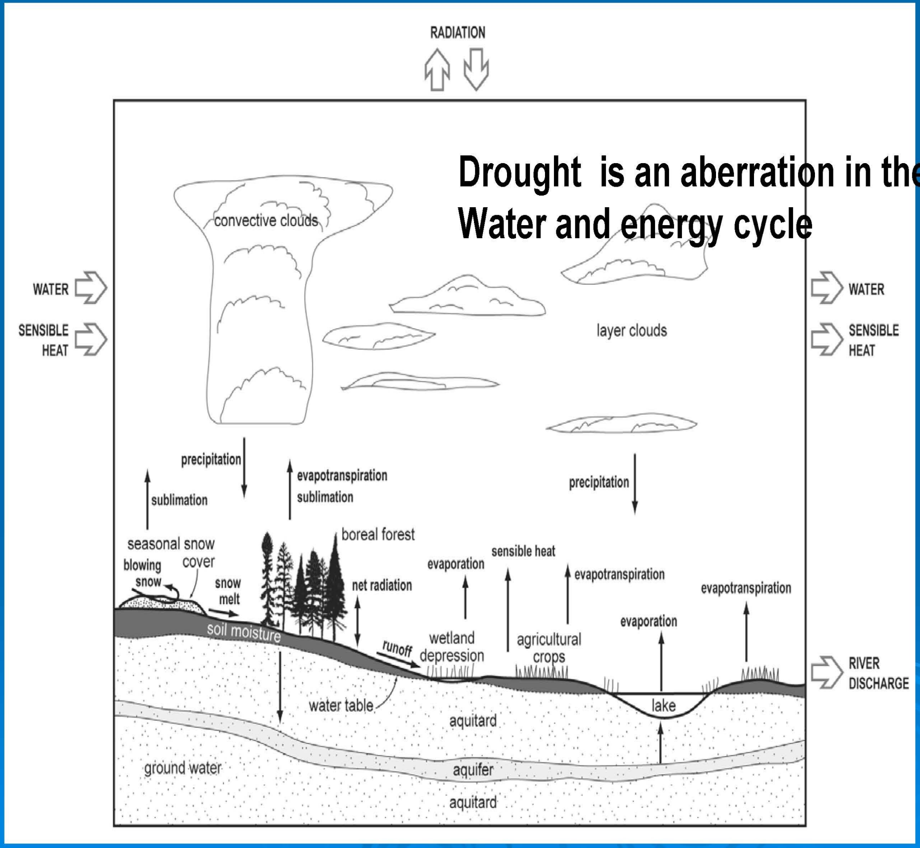
Why Study Water and Energy Cycling?

WATER AND ENERGY CYCLING



Drought is an aberration in the Water and energy cycle

Study Foci:

2. Budget assessments
3. Modeling
4. Process diagnostic studies

Budget Assessments Objectives:

- To develop comprehensive baseline climatologies of W+E budgets for the Prairie region by using various quasi-independent datasets
- To assess the relative merits of the various datasets in representing the budgets and to explore implications of the assessment results to the use of these datasets in drought monitoring, model validation and process study applications

Water and Energy Budgets

Atmospheric Water

$$\frac{\partial Q}{\partial t} = E - P + MC + RESQ$$

Surface Water

$$\frac{\partial W}{\partial t} = P - E - N + RESW$$

Atmospheric Temperature

$$C_p \frac{\partial \{T\}}{\partial t} = QR + LP + SH + HC + REST$$

Surface Temperature

$$Cv \frac{\partial \{Ts\}}{\partial t} = QRS - LE - SH + G$$

Source: John Roads

Q=Atmospheric Precipitable Water, mm
W=Surface Water (M+S), mm
M=Soil Moisture, mm
S=Snow, mm
T=Atmospheric Temperature, K
Ts=Surface Skin Temperature, K
T2=Surface Air Temperature (at 2m), K
E=Evaporation, mm/day
P=Precipitation, mm/day
MC=Moisture Convergence, mm/day
N=Runoff, mm/day
LP=Latent Heat of Condensation, W/m**2
SH=Sensible Heat (which is positive upward), W/m**2
HC=Dry Static Energy Convergence, W/m**2
LE=Latent Heat of Evaporation (which is positive upward), W/m**2
QR=Atmospheric Radiative Heating (which is negative), W/m**2
QRS=(NSW+NLW)=Surface Radiative Heating, W/m**2
NSW=Net Shortwave Radiation at the Bottom of Atmosphere (BOA), W/m**2
NLW=Net Longwave Radiation at the Bottom of Atmosphere (BOA), W/m**2
NSW (0)=Net Shortwave Radiation at the Top of Atmosphere (TOA), W/m**2
NLW (0)=Net Longwave Radiation at the Top of Atmosphere (TOA), W/m**2
RESQ=Atmospheric Residual Water Forcing, mm/day
RESW=Surface Residual Water Forcing, mm/day
REST=Atmospheric Residual Dry Static Energy Forcing, W/m**2
G=Surface Residual Temperature Forcing, W/m**2

Datasets

Local (L), regional (R) and global (G) observations

Parameter	Source	Resolution	Coverage Period
Precipitable Water	Rawinsondes (L)	Sites	Various - Current
	GVAP/NVAP (G)	1 deg	1988-1999
Snow	SSMI (R)	25 km	1978 Dec - 2003 Mar (Dec-Mar)
Surface Air Temperature	CANGRID (R)	50 km	1895 - 2003 Dec
Atmospheric Enthalpy	Rawinsondes (L)	Sites	Various - Current
Precipitation	CANGRID (R)	50 km	1895 - 2003 Dec
	CMAP (G)	2.5 deg	1979 - 2003 Sep
	GPCP (G)	2.5 deg	1979 – 2003 Dec
Discharge	WSC (L)	sites	1913 - Current (The Pas)
Radiative Fluxes	ISCCP FD (G) BERMS (L)	280 km Sites	1983 Jul - 2001 Jun 1994 - Current
Sensible/Latent Heat Flux	BERMS (L)	Sites	1994 - Current
Cloud Cover	Surface Obs (L/R)	Sites	Various - Current

Global (G) and regional (R) analysis and model datasets

Dataset	Resolution	Coverage period
CRCM (R)	51 km	1997 Apr - 2003 Dec
CMC (R)	35/24 km	1997 Mar - Current
NARR (R)	32 km	1979 Jan - Current
NCEP-R2 (G)	2.5 deg	1979 Jan - Current
ERA-40 (G)	2.5 deg	1957 Sep - 2002 Aug

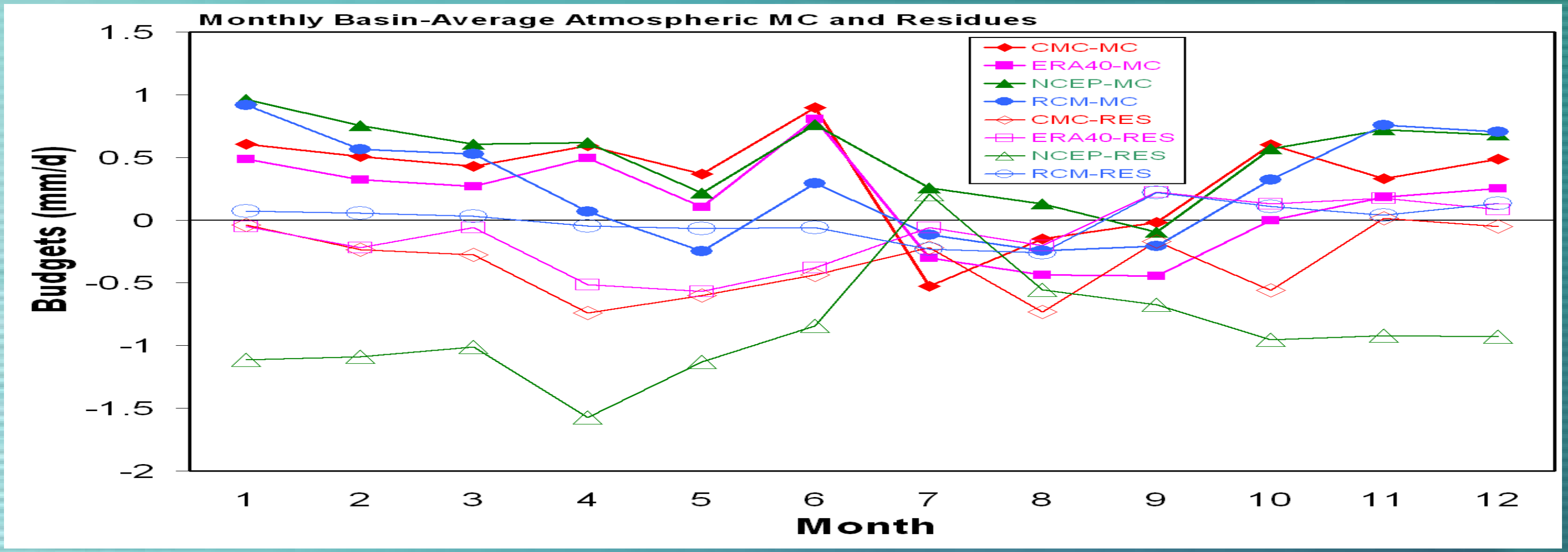
Summary of annual basin-average water and energy budgets for the SRB 1997-2002

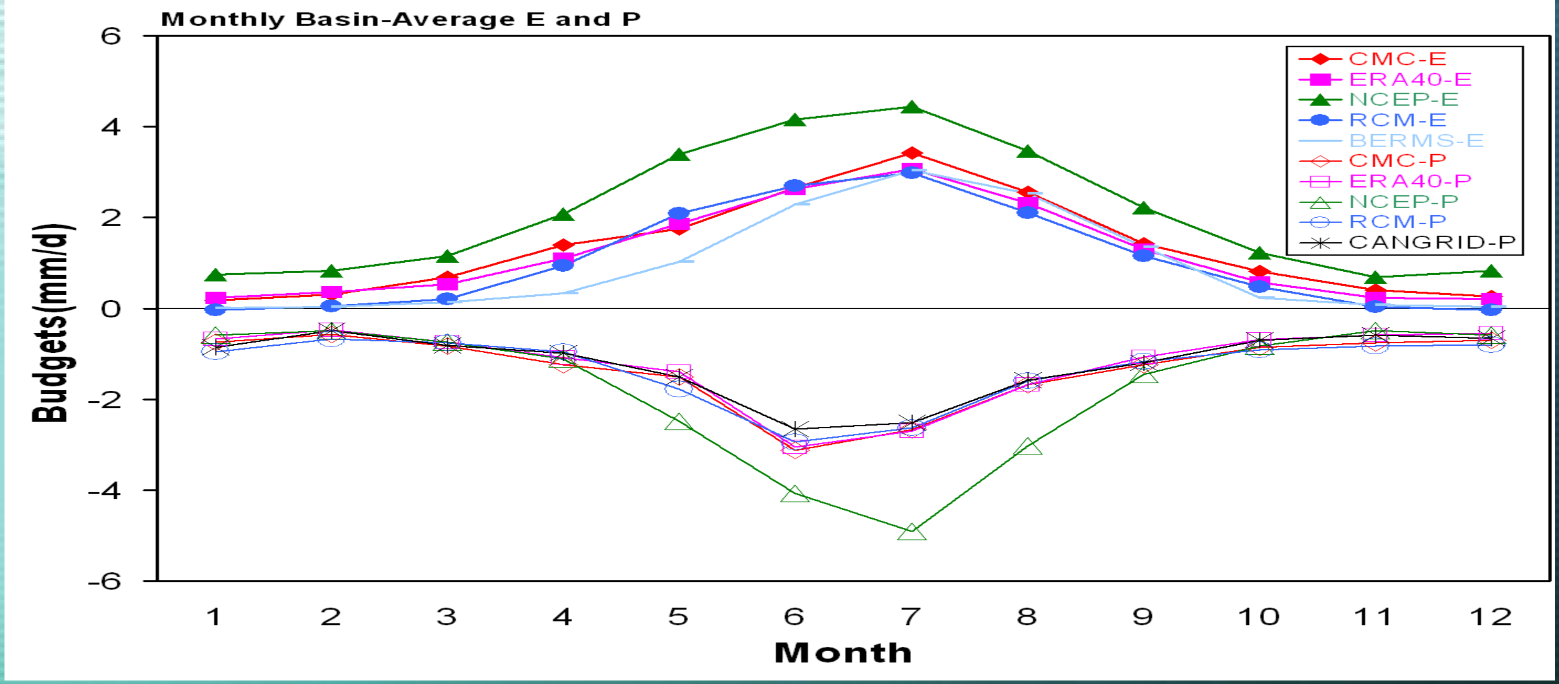
Data\Para	Q	M	SWE	T2m	H	P	E	MC	N	HC	SH	RESQ	REST
NCEP	10.63	318.3	14.95	276.1	2.26	1.73	-2.09	0.51	-0.53	0.34	-0.15	-0.88	0.23
CMC	10.94	224.6	15.55	275.8	2.30	1.32	-1.32	0.34	-0.01	0.17	0.12	-0.34	0.21
CRCM	10.68	218.8	30.29	273.7	2.30	1.33	-1.05	0.28	-0.31	0.41	0.12	0.00	-0.01
ERA-40	10.85	382.3	15.09	276.6	2.27	1.22	-1.20	0.14	-0.36	0.14	0.13	-0.16	0.35
Reg Obs	10.64		23.84	276.2	2.31	1.20	-0.93		-0.12		0.21		
Globl Obs	10.81					1.00							
						1.07							
Average	10.76	286.0	19.9	275.7	2.29	1.30	-1.32	0.32	-0.27	0.27	0.09	-0.35	0.19
ERA Avg 79-98	10.84	383.2	15.2	276.0	2.27	1.21	-1.21	0.26	-0.38	0.07	0.14	-0.26	0.40
Average(MRB)	9.27	276.1	44.5	270.0	2.33	1.32	-1.14	0.55	-0.58	0.39	-0.01	-0.29	0.16
%Error	1.18	27.53	34.56	0.40	0.95	18.61	34.59	48.27	76.89	49.35	160		
%Error(MRB)	4.51	14.68	36.96	0.55	1.29	18.71	38.08	17.42	48.34	22.42	3475		

Data\ Parameter	LP	QRS	QR	TOA SWD	TOA SWU	TOA LWU	BOA SWD	BOA LWU	BOA SWU	BOA LWD	Cloud cover	RESW	RESG
NCEP	0.46	0.56	-0.88	2.56	0.81	2.08	1.60	3.10	0.36	2.42	43	0.89	-0.15
CMC	0.36	0.46	-0.85	2.49	0.85	2.03	1.46	3.05	0.36	2.41	48	0.00	0.02
CRCM	0.35	0.43	-0.87	2.54	0.99	1.99	1.47	2.93	0.37	2.26	47	0.03	-0.03
ERA-40	0.33	0.53	-0.94	2.56	0.88	2.10	1.39	3.13	0.29	2.56	59	0.34	-0.07
Reg Obs		0.56					1.35	2.91	0.15	2.43	60		
Globl Obs		0.51	-0.87	2.55	0.95	1.95	1.40	3.14	0.31	2.57	68		
Average	0.38	0.51	-0.88	2.54	0.90	2.03	1.45	3.04	0.31	2.44	54	0.32	-0.06
ERA Avg79-98	0.33	0.53	-0.92	2.56	0.87	2.09	1.38	3.10	0.28	2.54	59	0.39	-0.06
Average(MRB)	0.25	0.36	-0.93	2.12	0.80	1.89	1.12	2.77	0.25	2.27	61	0.25	-0.03
%Error	15.47	10.51	3.88	1.15	8.19	3.06	6.11	3.02	24.74	4.27	16.16		
%Error(MRB)	17.03	13.66	5.80	1.13	9.70	3.11	8.78	3.18	21.46	5.16	12.31		

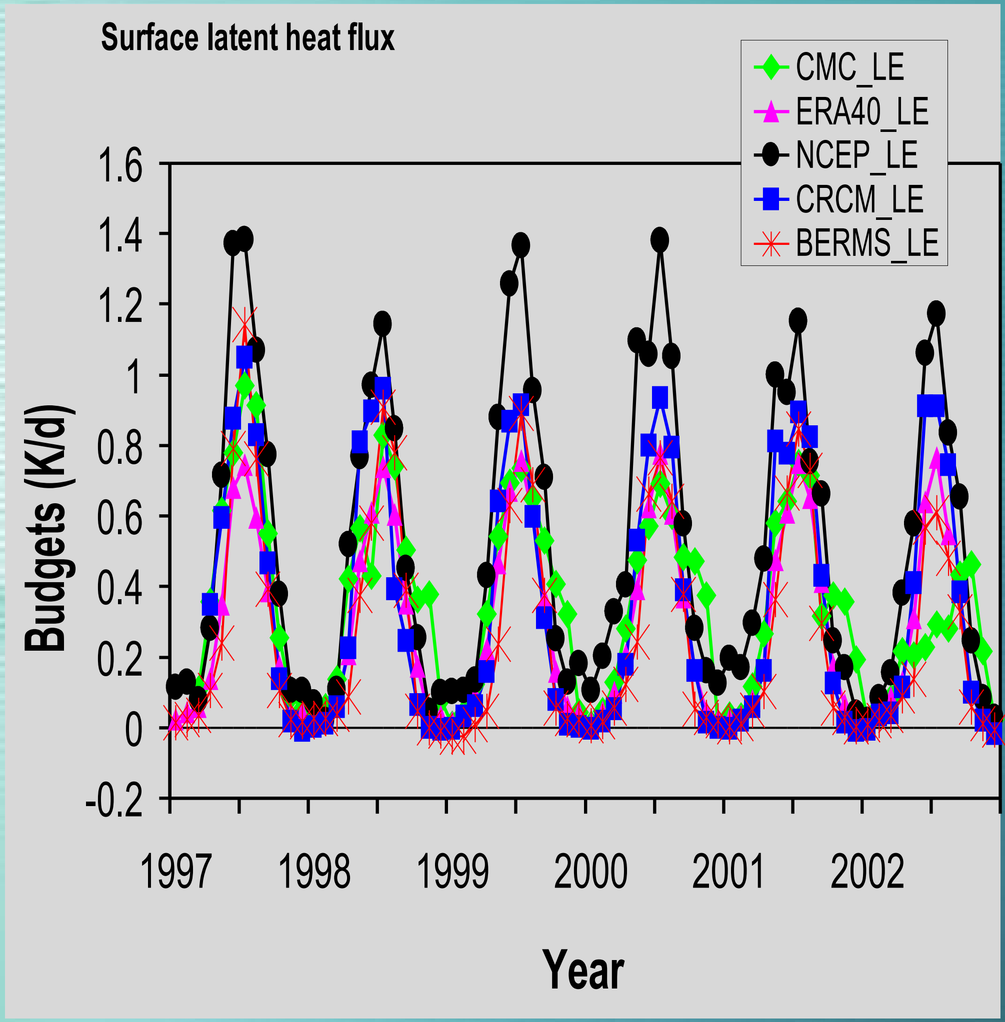
All water storage terms are in mm,
T2m in K, enthalpy (H) in 10^9J/km2,
moisture fluxes in mm/day
energy fluxes in K/day.

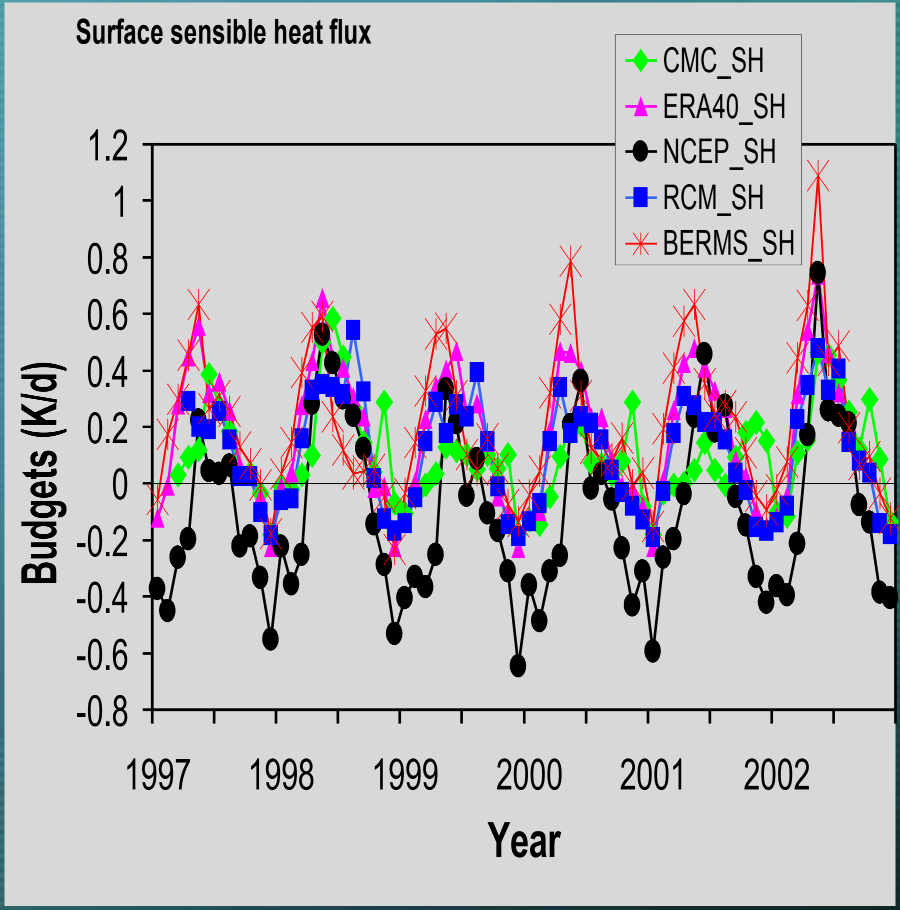
Variability among Budgets Assessments - Annual Cycles of Atmospheric Water Budgets





Variability among Budgets Estimates ….cont…. Surface SH and LE near BERMS Site



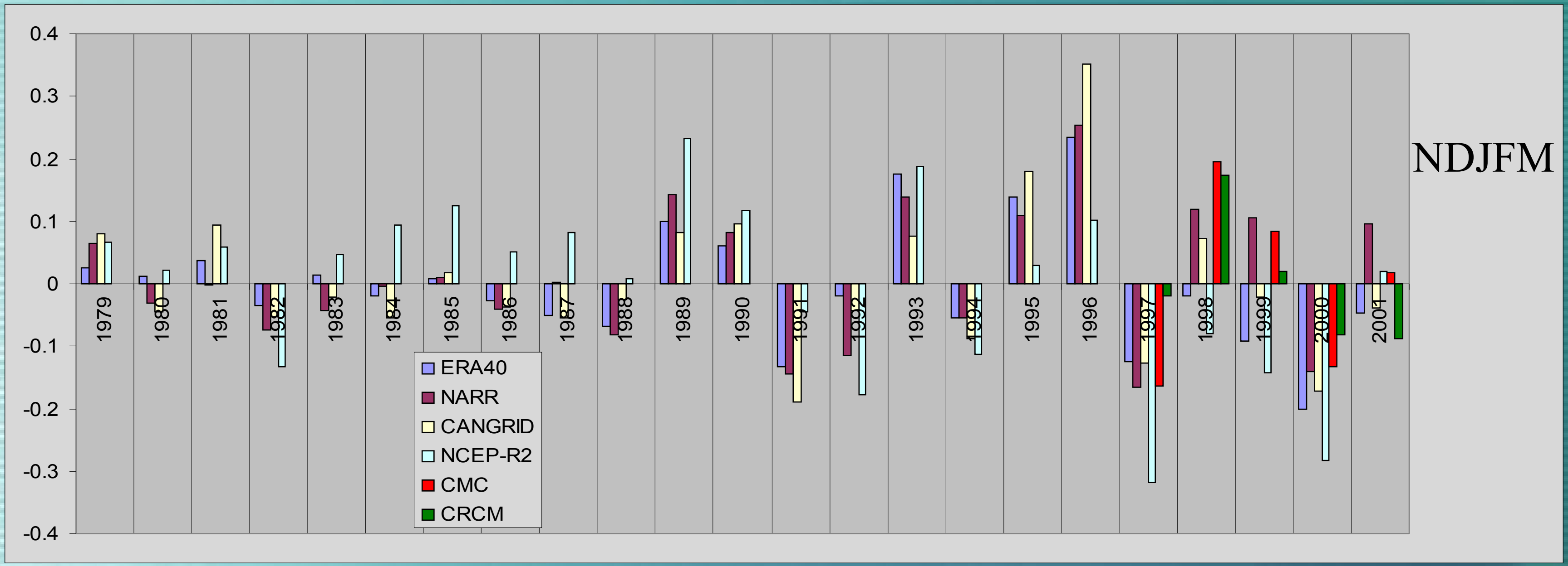


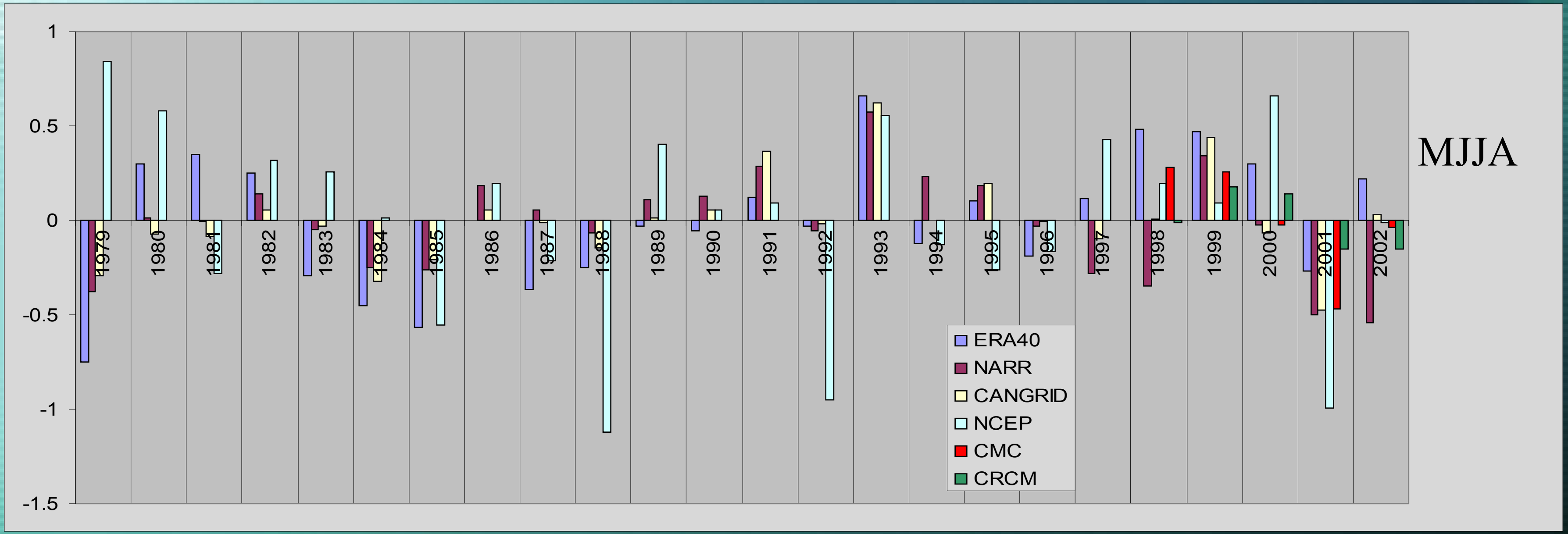
Summary of mean budget results

- Some estimates of budget components compare well to obs but residuals in the balance are often as large as the budget components in all datasets
- Budgets from analysis datasets based on more "modern" assimilation systems (CMC, NARR, ERA-40) compared the best to obs
- NCEP-R2 over-predicts warm-season water cycling for the region
- Strong cold bias in CRCM affects its capability to accurately simulate drought in the region
- Water closure problem (MC >> obs discharge)

Szeto, *J. Met. Soc. Jap*. 2007, 167-186.
Szeto et al., *J. Hydromet*., 2008, 96-115.

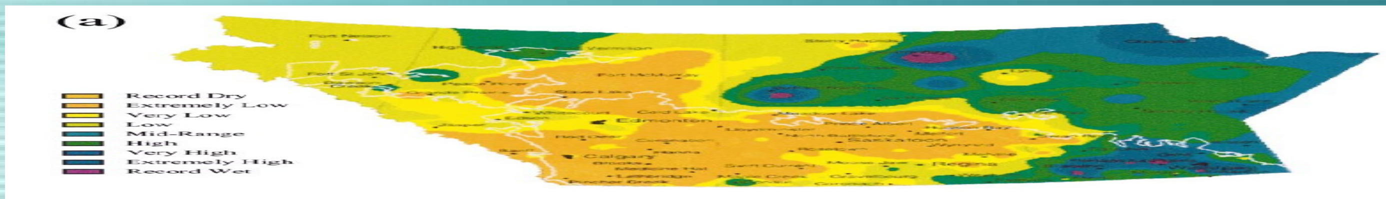
Variability among Budget Estimates - Seasonal P anomaly Timeseries



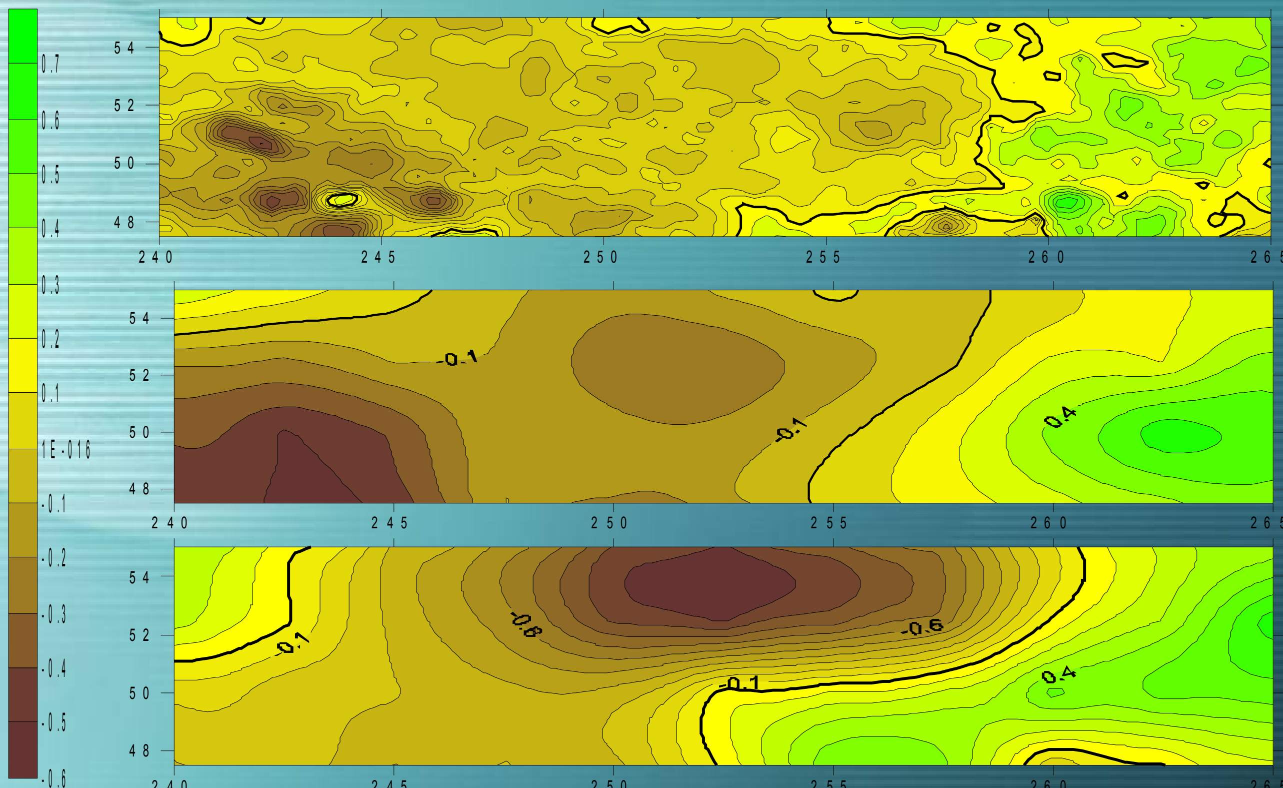


Spatial Variability of P Anomalies: Observed vs Analyzed

00-01WY



PFRA Obs P’



NARR P’

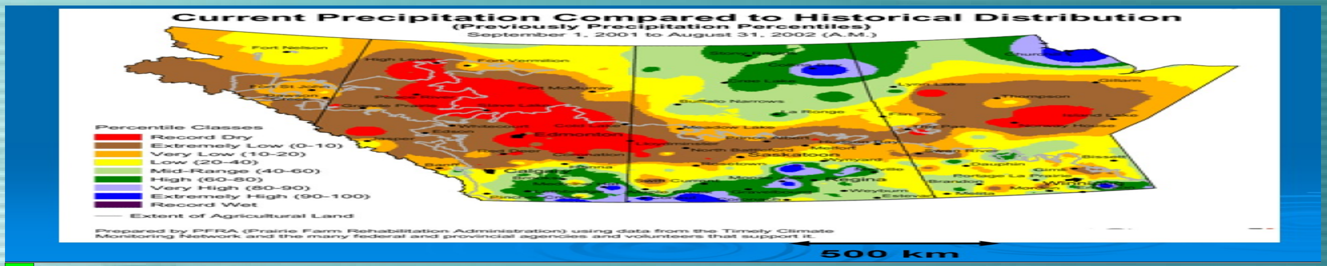
ERA40 P’

NCEP-R2 P’

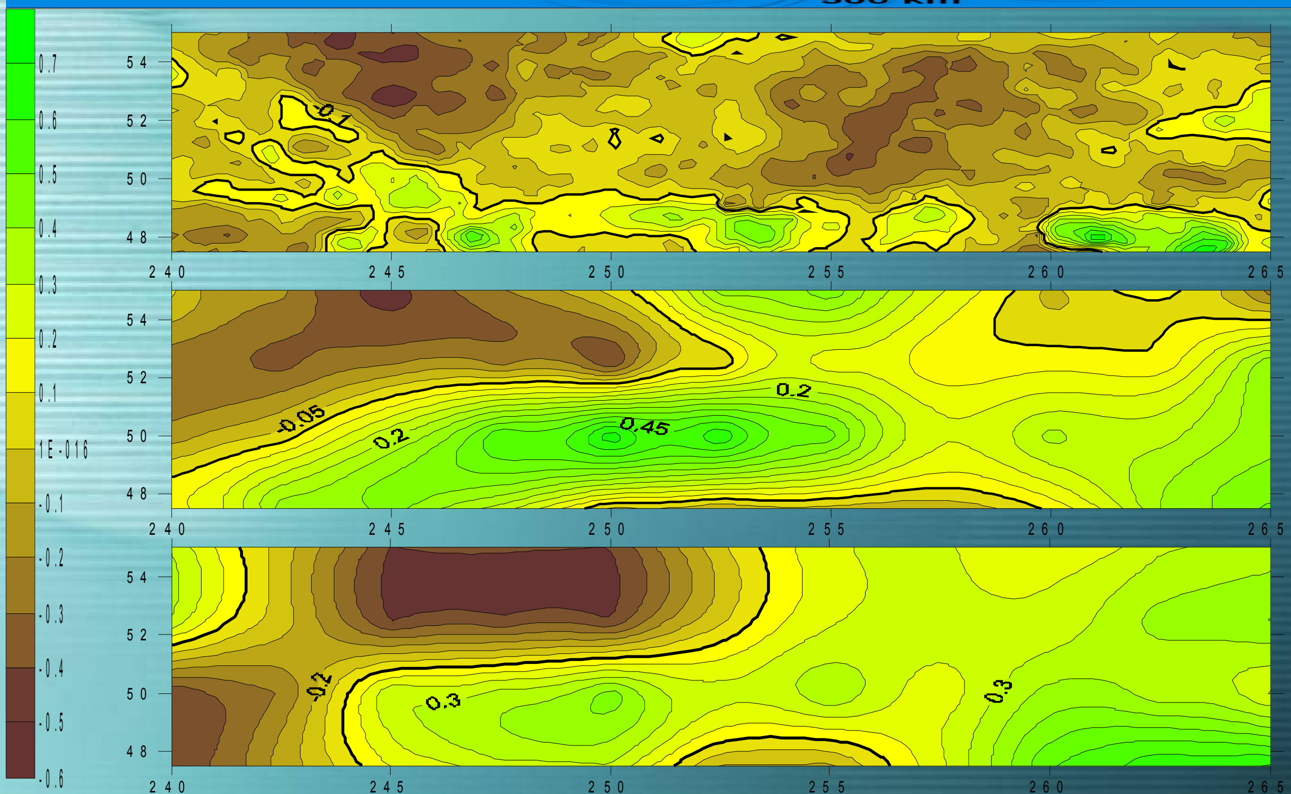
P’ (mm/d)

Spatial Variability of P Anomalies: Observed vs Analyzed

01-02WY



PFRA Obs P’



NARR P’

ERA40 P’

NCEP-R2 P’

P’ (mm/d)

Regional climate model simulations of the 1999-2005 Prairie drought:

A model inter-comparison study

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[6] Scripps Inst of Oceanography

Objectives of Study

- To assess the capability and readiness of dynamical predictions of Prairie droughts through a critical evaluation of simulations of the 1999-05 drought with several state-of-the-art RCMs

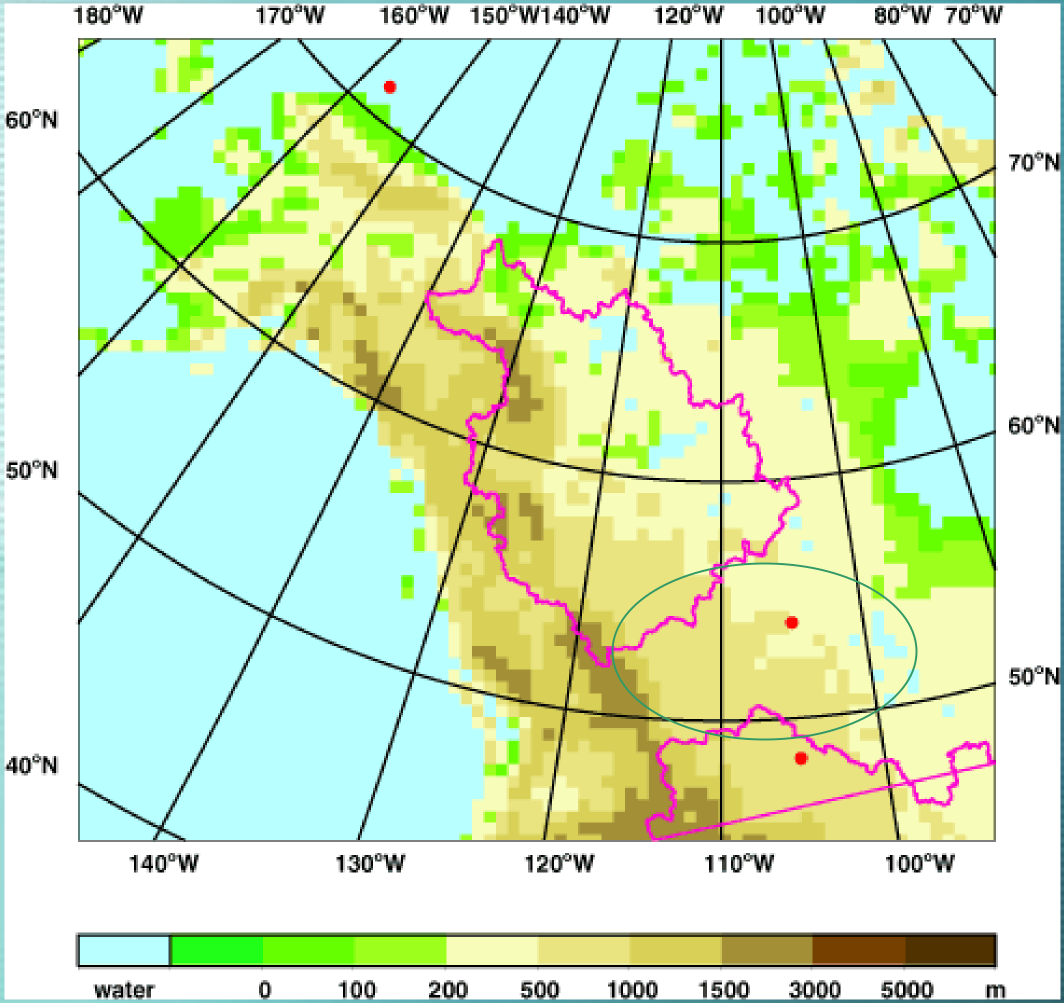
- To assess the viability of using RCMs as tools for studying Prairie droughts

- To identify major problems that affected the simulations in the different models and to diagnose their causes

Models

Model	Description	Institute	Notes
CRCM-041	Canadian Regional Climate Model	OURANOS	V. 4.1 – CGCM3, CLASS 2.7, K-F
CRCM-027	“ “ “	EC	CGCM3 - CLASS 2.7, Z-M
CRCM-032	“ “ “	EC	CGCM3 - CLASS 3.2, Z-M
GEMLAM	Global Environmental Multiscale Limited Area Model	EC	RPN, ISBA, K-F, Sunq
CLM	Climate version of the "Lokal Modell"	GKSS (Germany)	TERRA3D, K-F
RSM	Regional Spectral Model	ECPC (US)	GSM, Noah, A-S

Simulations



Model domain with elevation

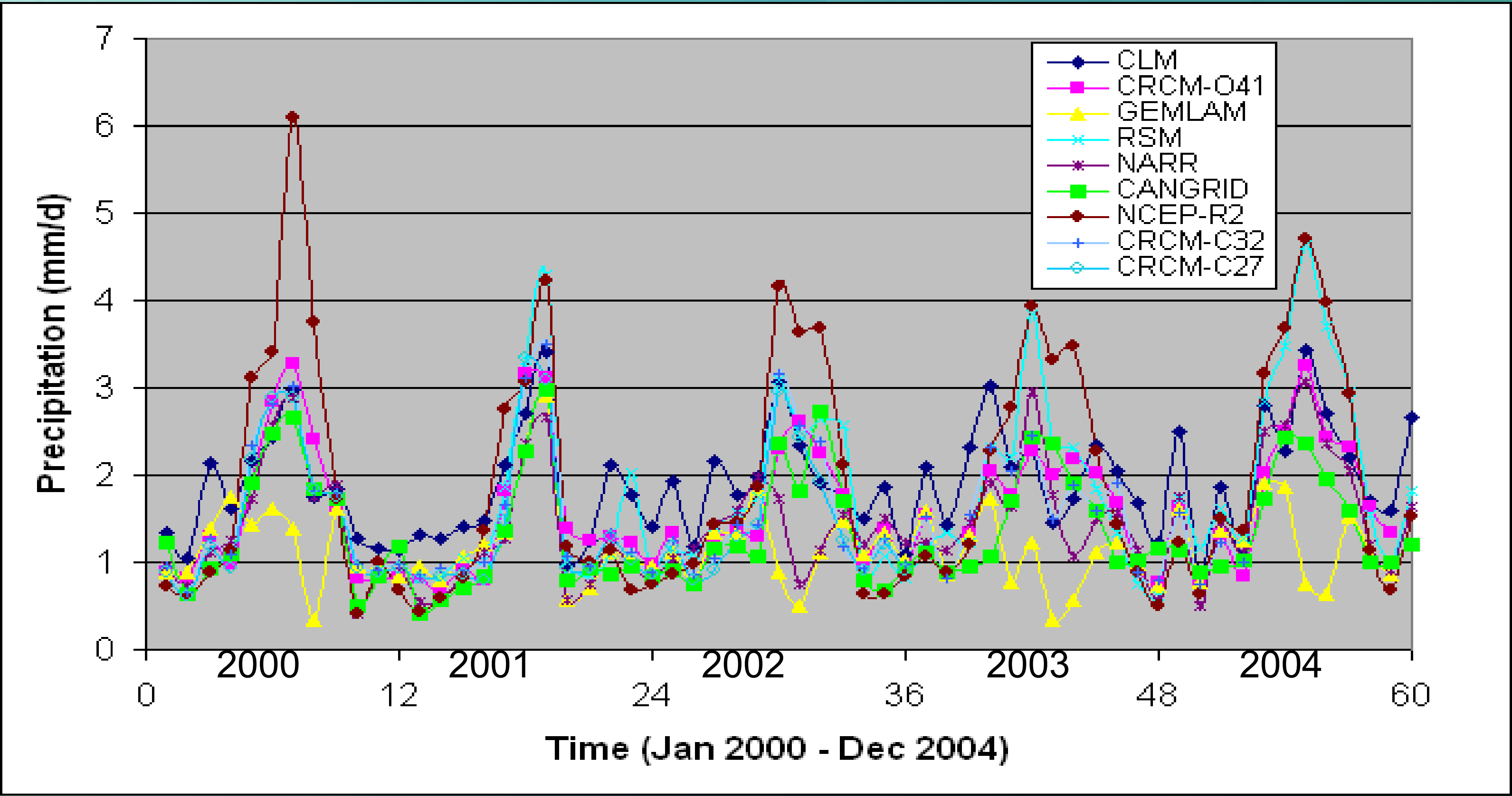
"Climate mode" simulations

Simulation period: 07/1999-12/2004
except 04/97-12/04 for
CRCM C27 and C32

Horizontal resolution: ~50km

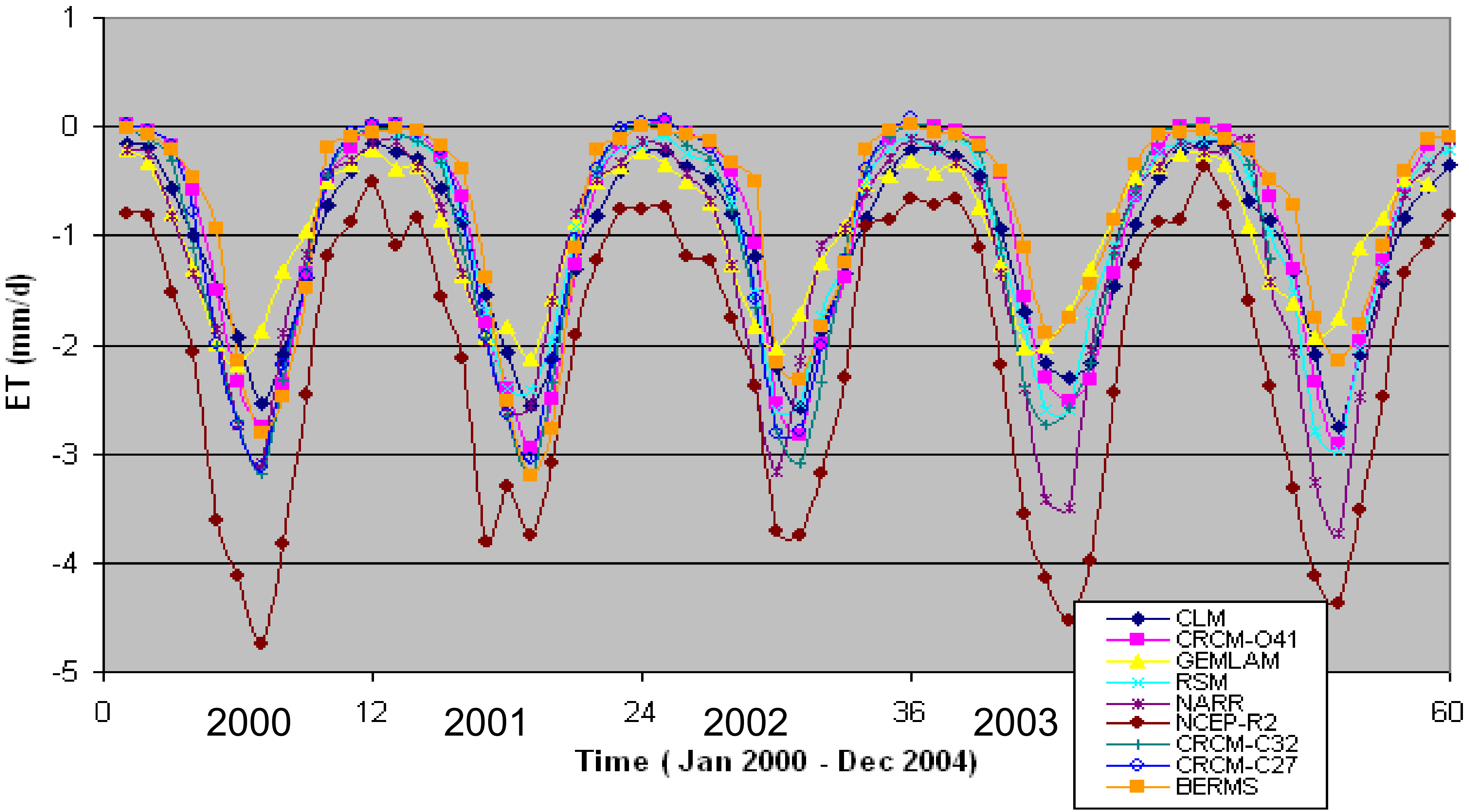
Initial/boundary data: NCEP-R2
except CMC global analysis for
CRCM C27 and C32

Monthly Timeseries of Areal Mean Precip



- All models captured the low precip of 2000/2001 winter and 2001 summer
- NCEP-R2 and sometimes RSM severely overpredict summer P
- GEMLAM and occasionally NARR severely underpredicts summer precip
- CLM, and to a lesser degree, most models, overpredict winter P (obs could be wrong!)
- CRCM P agrees well with observation, including the general interannual variability of P during the drought
- dependencies of model bias on large-scale conditions

Monthly Timeseries of ET



- Observed Interannual variability of ET captured quite well by most models
- When compared to BERMS data, most models (except GEMLAM) over-predict ET during the later drought period
- NCEP-R2 severely over-predicts ET
- NARR over-predicts summer ET during 03/04
- GEMLAM under (over)-predicts summer (winter) ET

Summary

- All models captured, to varies degree, the meteorological drought conditions developed during 2000/2001 and the subsequent drying of the surface
- All models also captured the gradual termination of the drought after 2002
- The quality of the predictions are impaired by different deficiencies in the models that need to addressed before improved drought predictions can be expected from the models

Water and Energy Cycling Processes

Main issues of interest:

What intermediate physical mechanisms are involved in determining the hydrometeorological response of the Canadian Prairies to variations in the large-scale circulation

1. During the winter and 2. during the summer

Some discussions related to (1) can be found in:

Szeto et al. *BAMS*, 2007, 1411-1425.

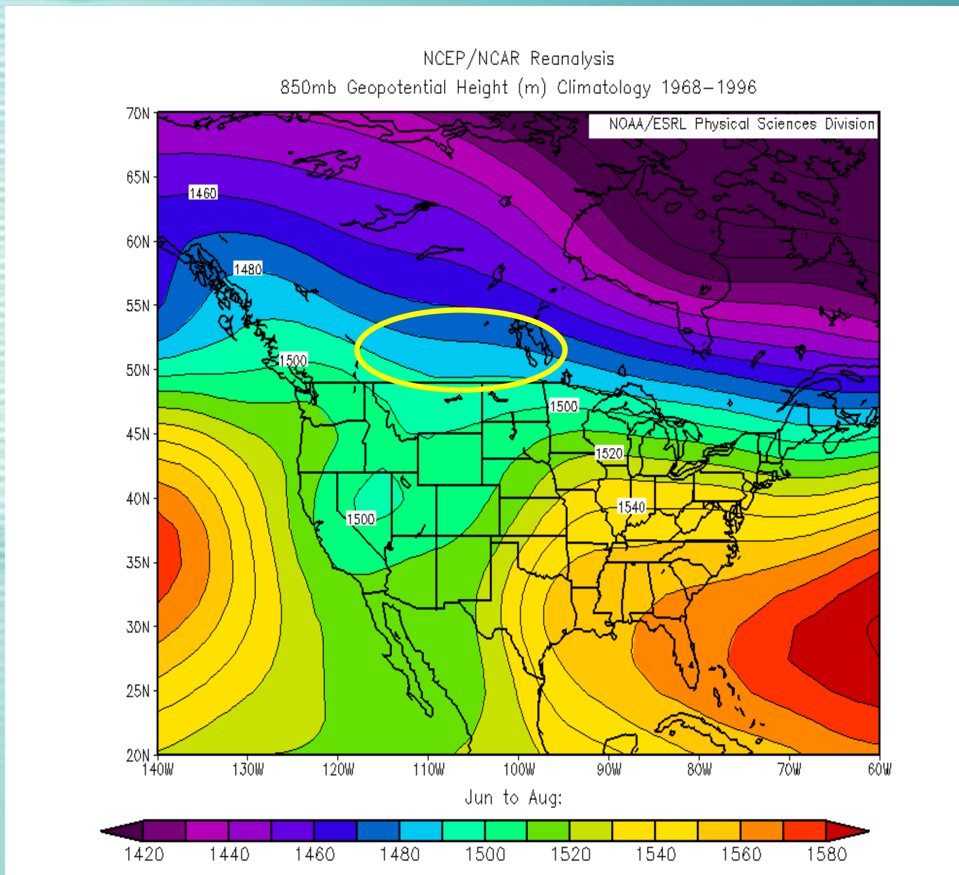
Szeto, *J. Climate*, 2008, 94-113

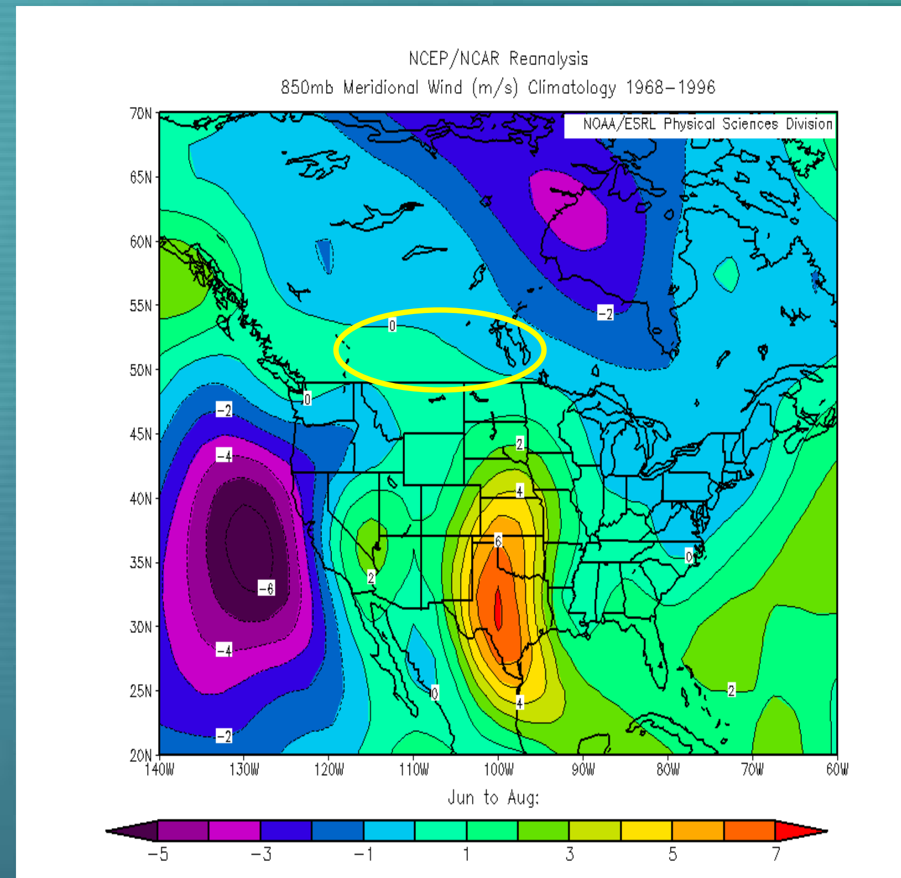
Basin	Mackenzie (JJA)	Mississippi (MJJA)	SRB (JJA)
Parameter	P	P	P
E	0.34	0.61	0.21
Fx	-0.26	-0.10	-0.19
Fy	0.58	0.44	0.25/0.63*
ρ	0.17	-0.19	0.00

Correlation coefficients between key JJA ERA-40 water cycle variables and P for Prairies computed over 1979-1999: P (precipitation), E (evaporation), Fx (zonal moisture flux), Fy (meridional moisture flux), ρ (recycling ratio). Correlations exceeding the 95% significance level are highlighted

* - correlation between P and seasonal average southerly moisture flux component across 50°N over eastern Prairies

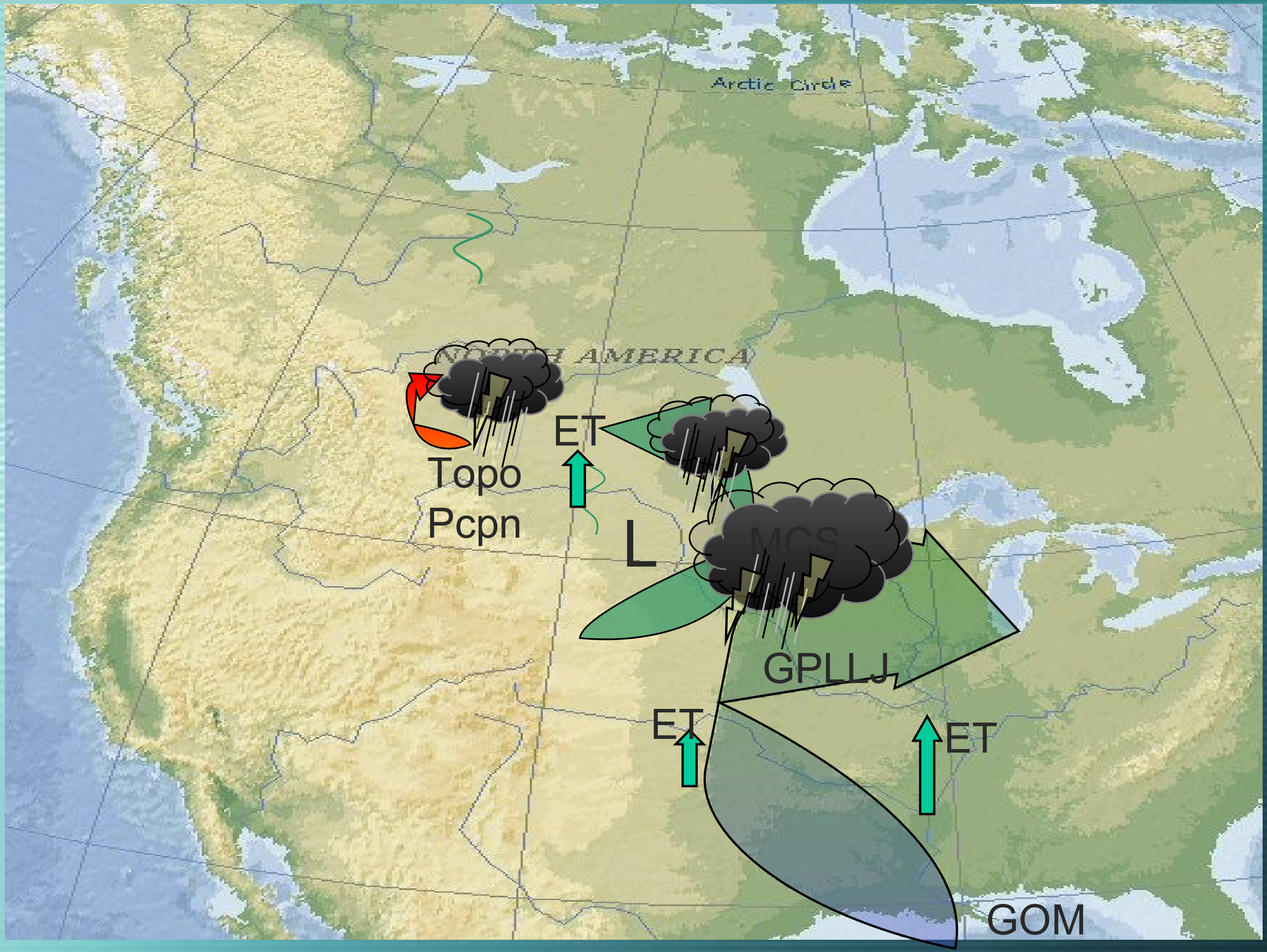
JJA mean circulation at 850 hPa





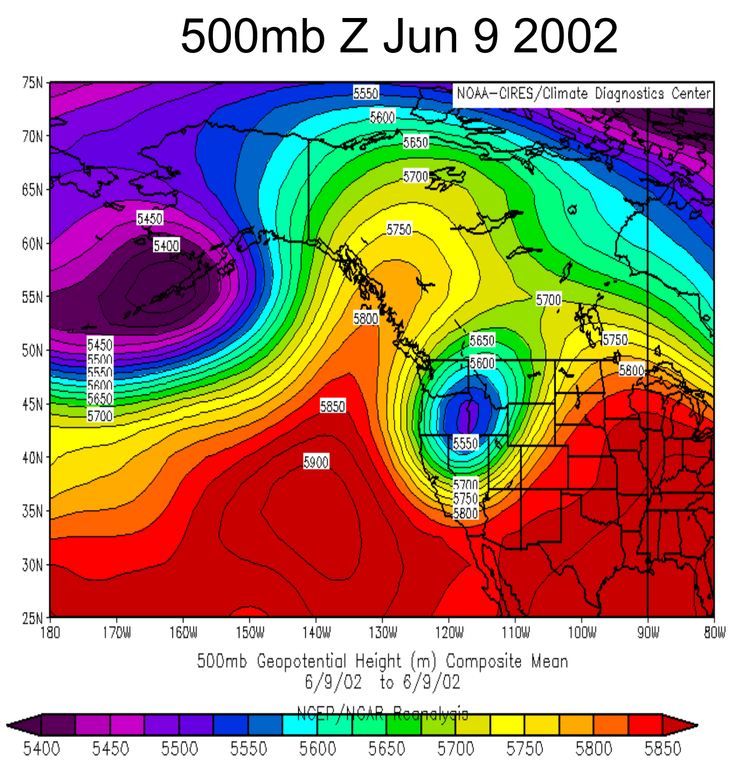
Mean meridional flow over the prairies is northerly –> mean southerly moisture transports into the Prairies must be accounted for by eddy transports

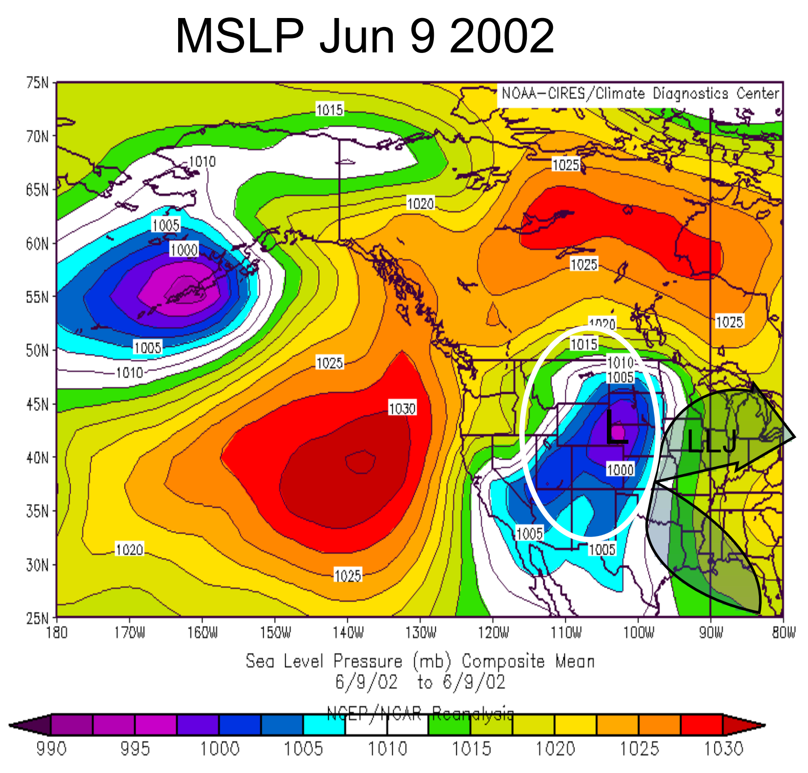
Warm-season Water Transport & Cycling from GOM to SRB



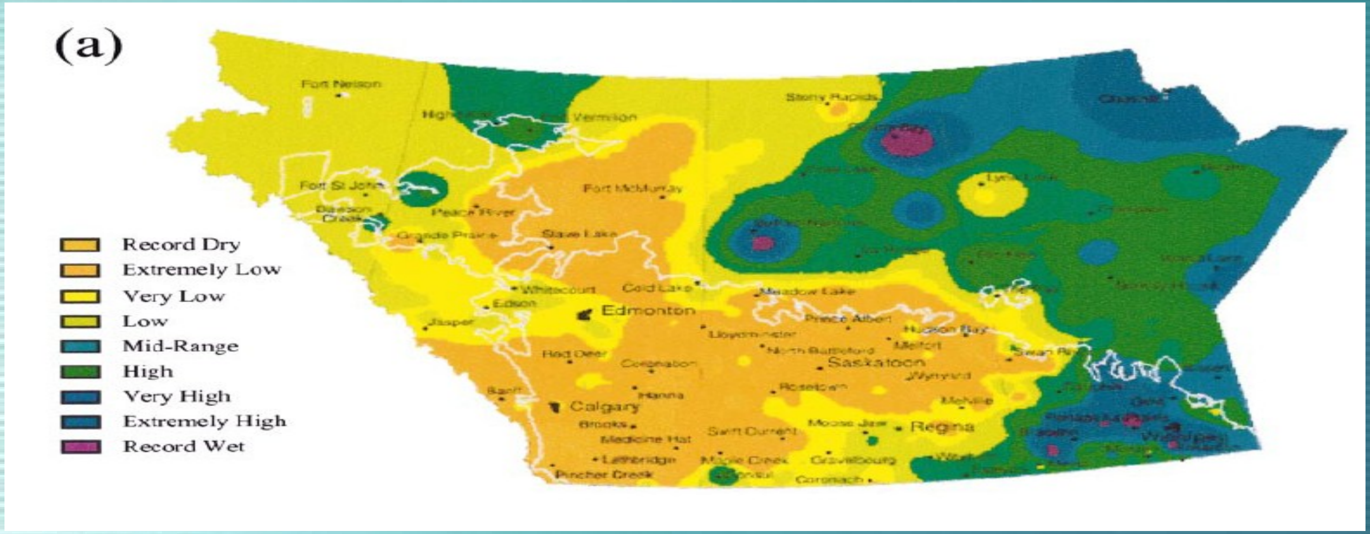
A flood within a drought

A recording-breaking Prairie rain event during Jun 8-11, 2002 that gave a several-month long break for the record-breaking 1999-2004 Prairie drought



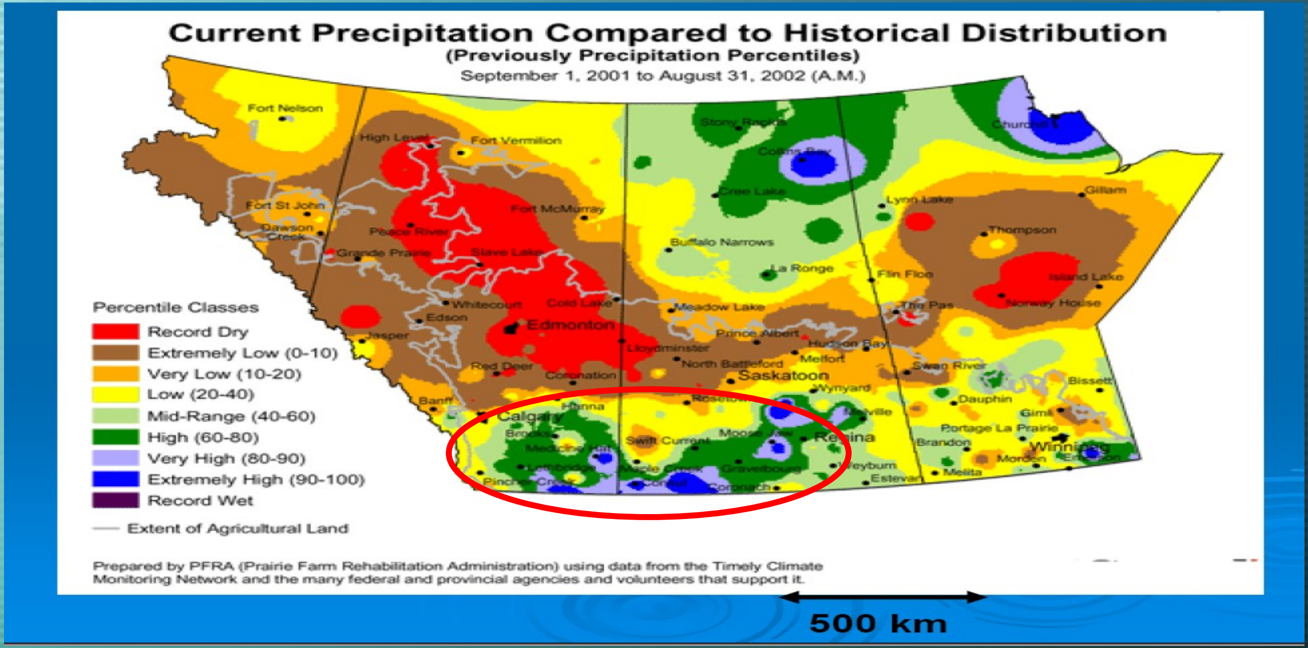


That one rain event gave a several months break to the 99-04 drought over the southern Prairies



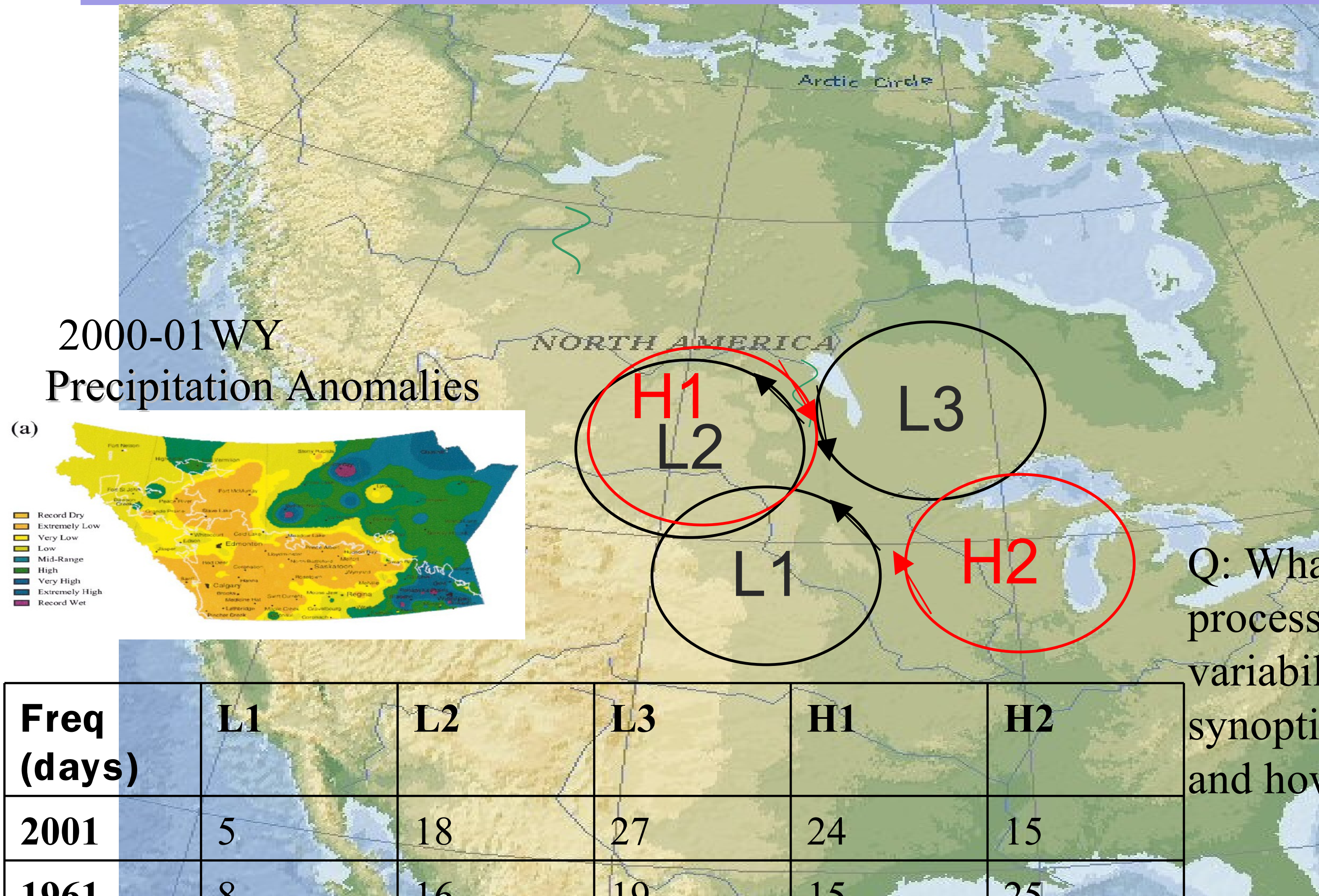
Precipitation Anomalies

2000-01



01-02

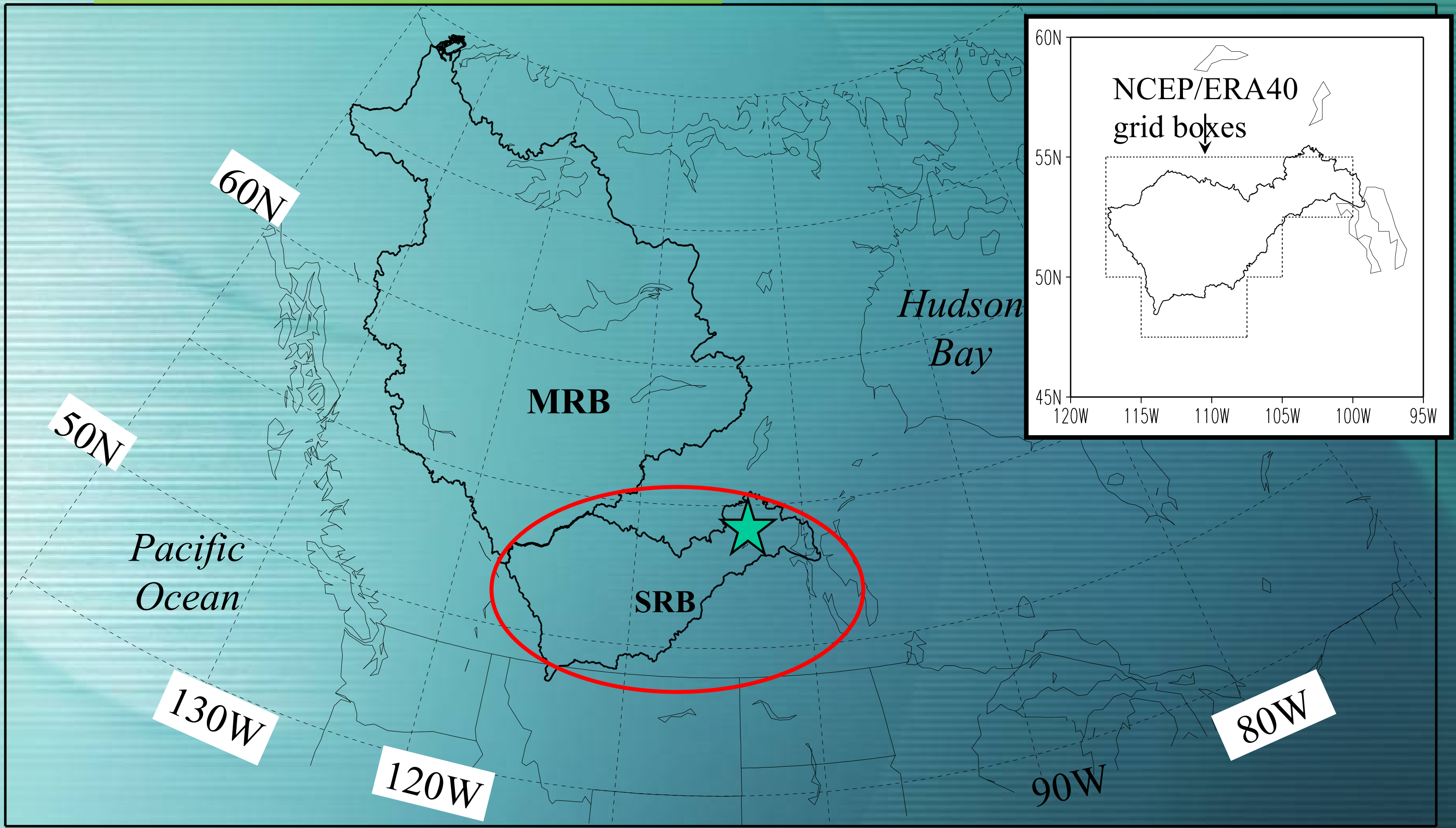
Synoptic Patterns Affecting Summer Moisture Flux and P over the Prairies



Q: What largescale process control the variability of summer synoptic activities and how?

Freq (days)	**L1**	**L2**	**L3**	**H1**	**H2**
2001	5	18	27	24	15
1961	8	16	19	15	25
1988	14	17	21	19	17
1993	14	17	22	21	27

The Canadian Prairies



Study period: 1997-2002 for the formation and mature phases of the drought, and for the maximum overlap of available datasets

Longer-term budget climatologies from ERA-40, NCEP-R2, NARR and available observations