Water Cycling and Drought in 3 North American River Basins

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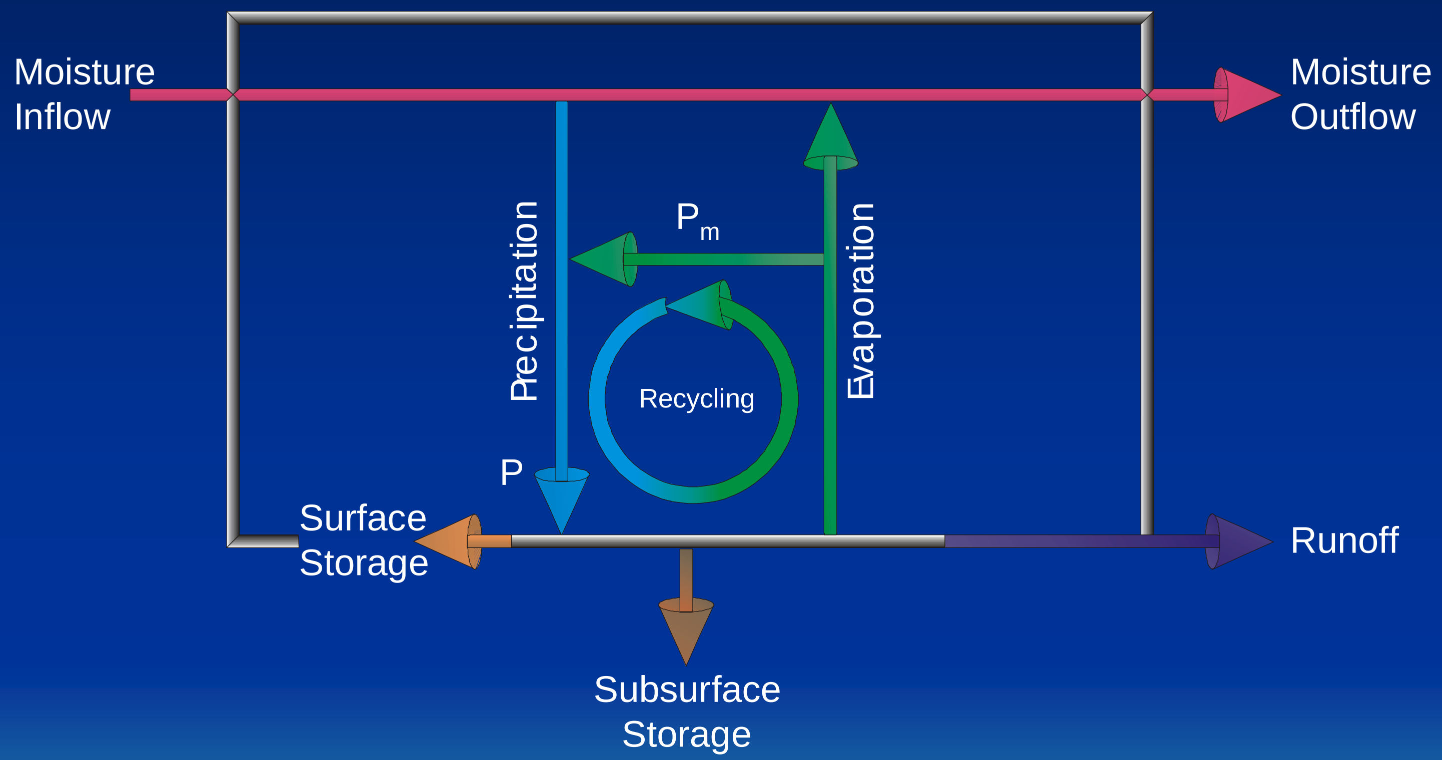
Schematic of the Regional Water Cycle



Recycling ratio = ρ = P_m/P

Air-land Coupling and Precip Recycling Feedback

Increases soil moisture → Increases surface evaporation → modifies atmospheric conditions → Enhances precip → Increases soil moisture

→ Spatial and temporal correlations between P and E

Feedback loop might beak due to complicating factors:

- Surface moisture supply might not depend on P
- Increased ET alone might not be sufficient to enhance P
- Re-distribution of evaporated moisture by airflow and spatial dislocation of P and E
  - Enhanced P might contribute to runoff rather than wetting surface

Objective of Study

– To elucidate water cycling processes in different climate regions of NA, and in doing so, gain insights into the development of hydrometeorological extremes, particularly drought in western Canadian regions

- Focus on linkages between
  – Cold and warm season processes
  – Regional and larger-scale processes

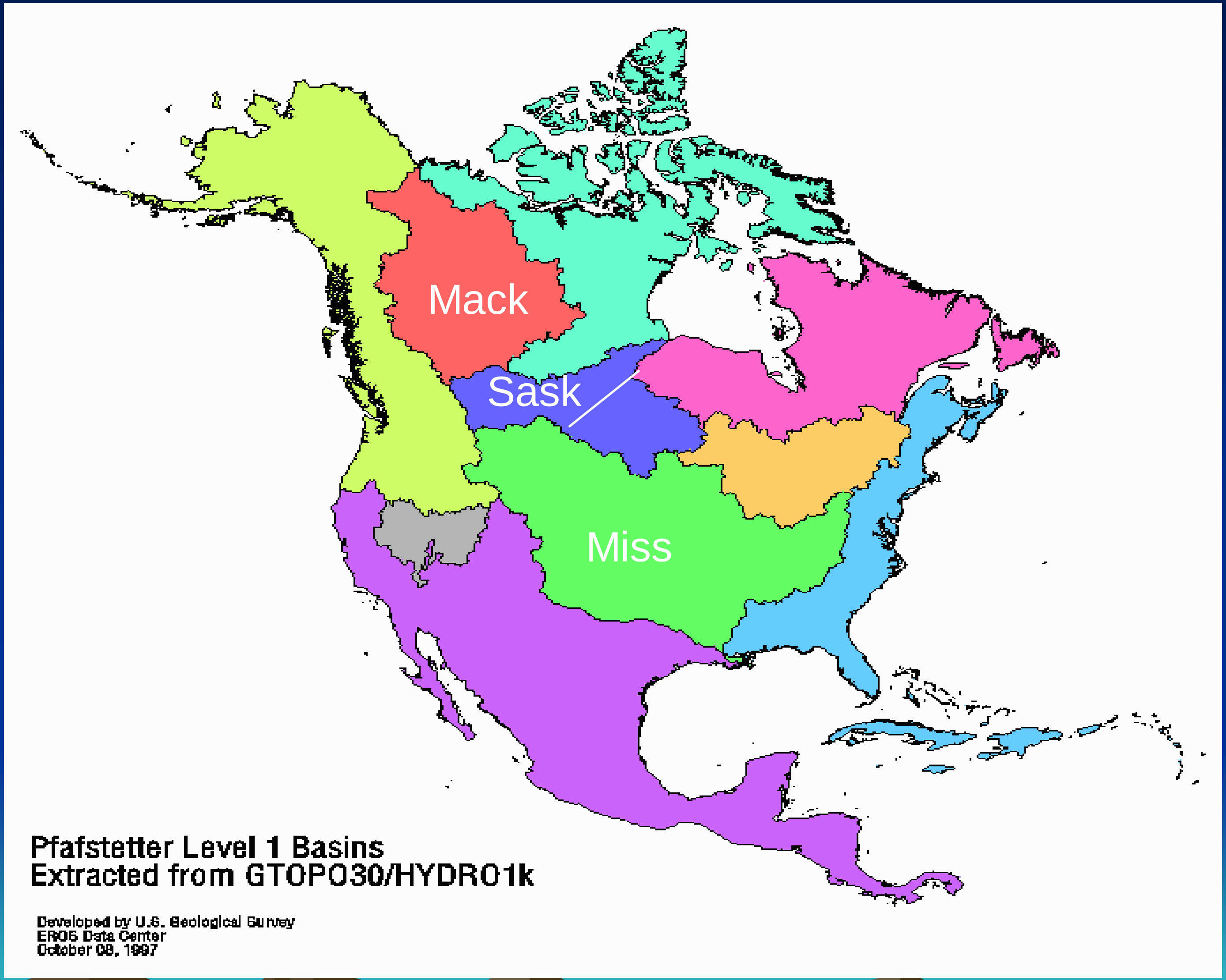
Approach

– Quantification of atmospheric water cycling variables (water vapor flux, P, E, and recycling ratio) for 3 major river basins located to the lee of the Western Cordillera by using reanalysis data (mainly ERA-40 but also others)

– Interpret the results by examining the processes that govern water cycling under “normal” conditions in the regions

– Investigate regional hydrometeorological response to changes in synoptic and large-scale atmospheric conditions and relate the results to interannual variability and development of extremes in the regional water cycle

NA Drainage Basins



Datasets

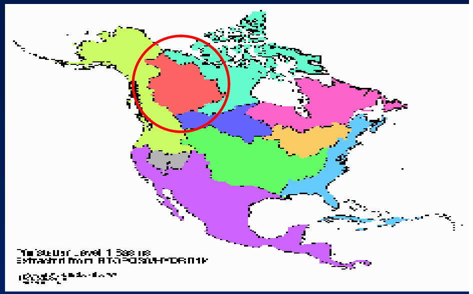
Global (G) and regional (R) analysis and model datasets

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

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

Merits of ERA-40 in representing water and energy fluxes in western Canadian regions are shown in Szeto (2007) and Szeto et al. (2007).

Mackenzie Basin



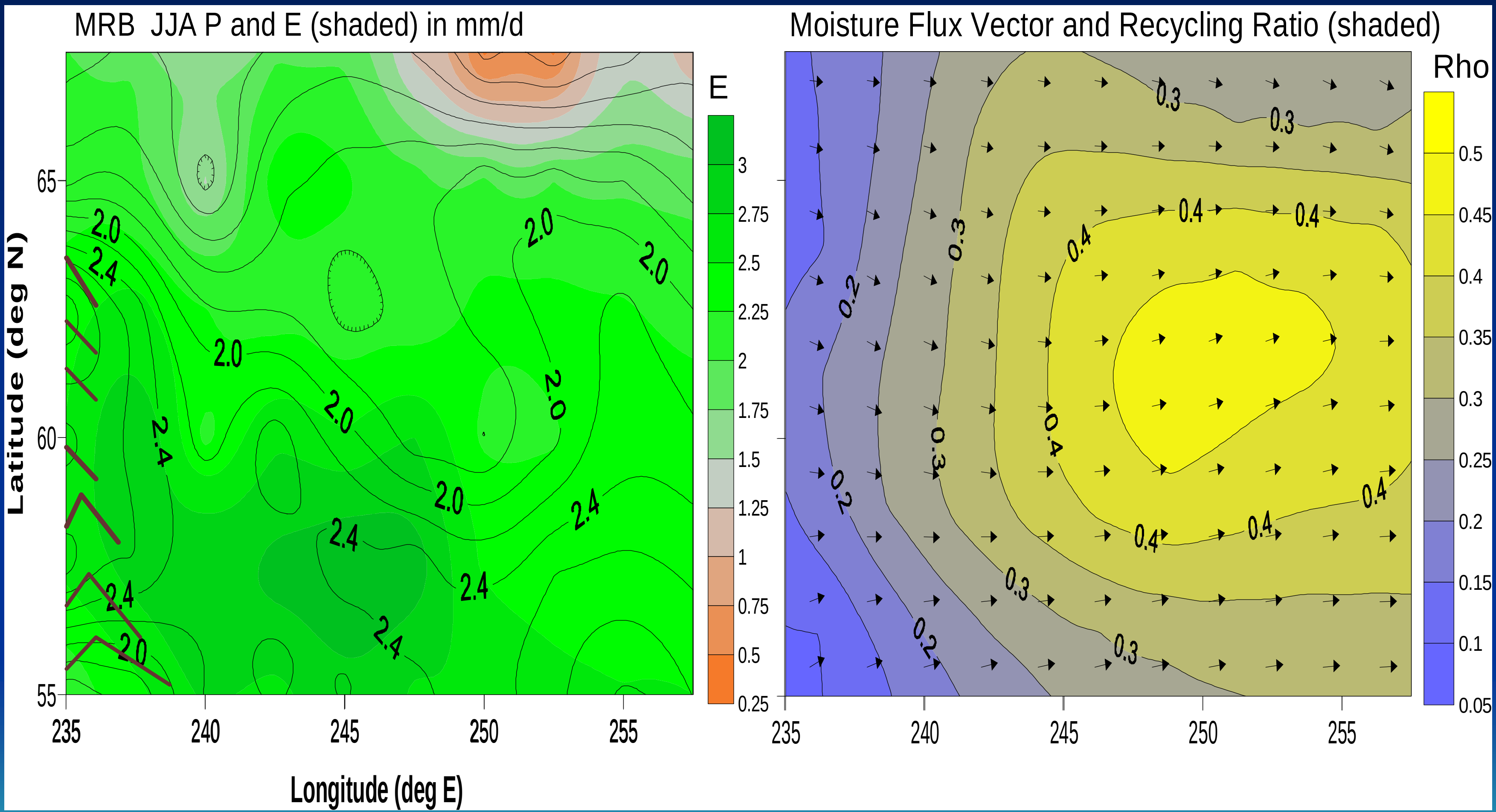
•Sub-arctic, located to the lee of Western Cordillera - cold winter with light precip that accumulates on surface

• Extensive frozen soil and organic active layer affect spring recharge and runoff from snowmelt – wet topsoil and surface water over extensive areas – a spring time condition that is not sensitive to normal variations in winter P

•Long hours of solar heating during summer + abundant surface moisture create favourable conditions for strong ET and convective activities that recycle the accumulated winter P to produce summer P

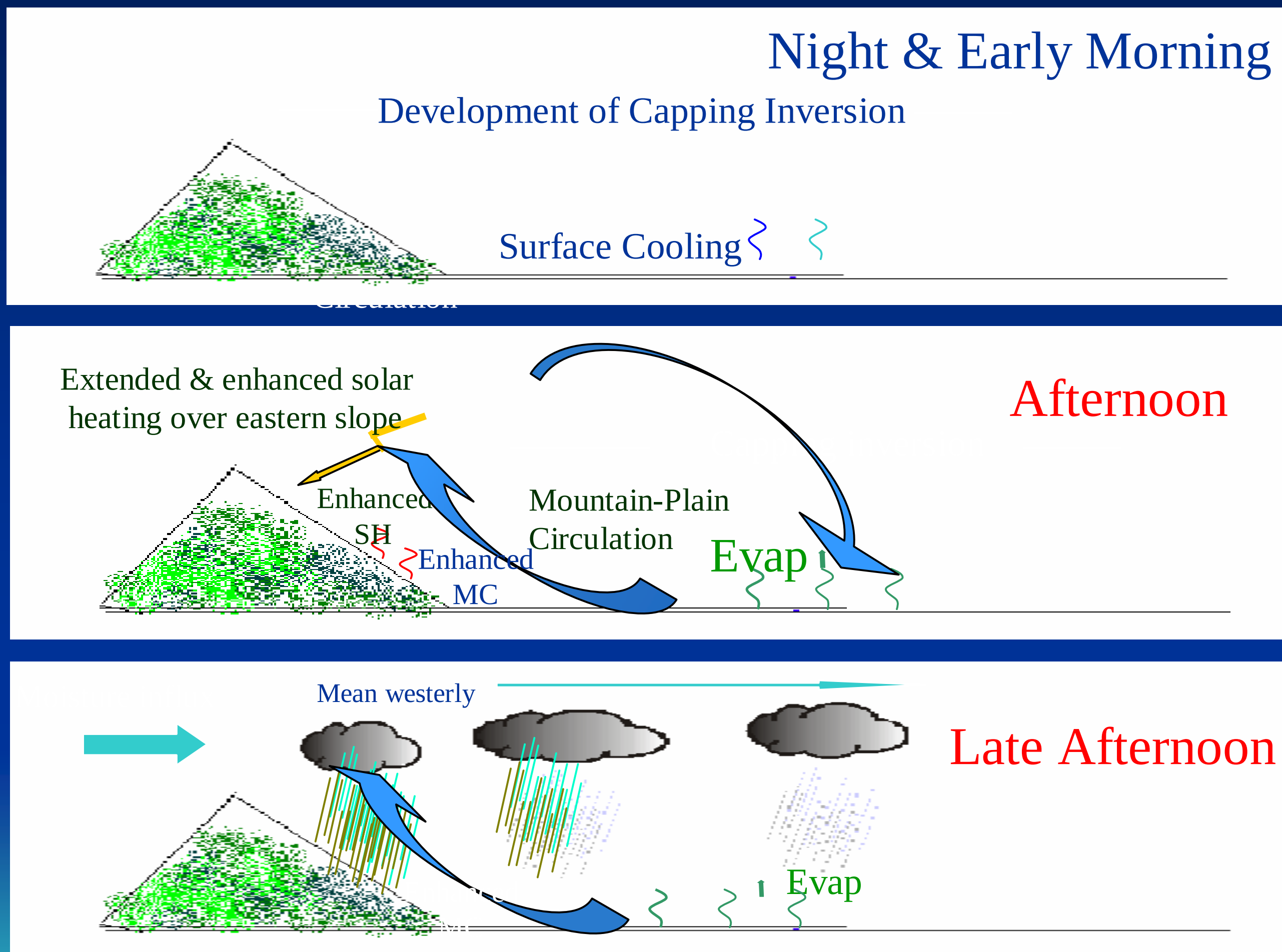
•Lee-side location and open SE basin boundary allow for interactions between synoptic and regional processes to exert strong effects on its warm-season water cycling

MRB – JJA water cycling

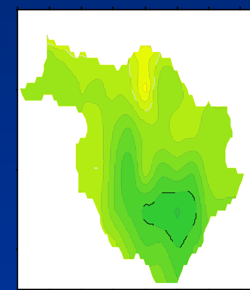


JJA basin average ρ = 33 %

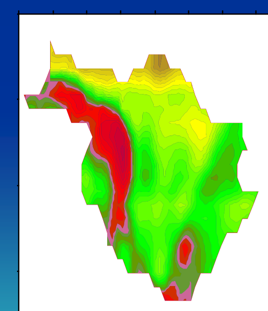
Diurnal Variations of Summer Atmospheric Conditions over the MRB and Precipitation Development



Mean ERA JJA E



Mean Obs JJA Precip



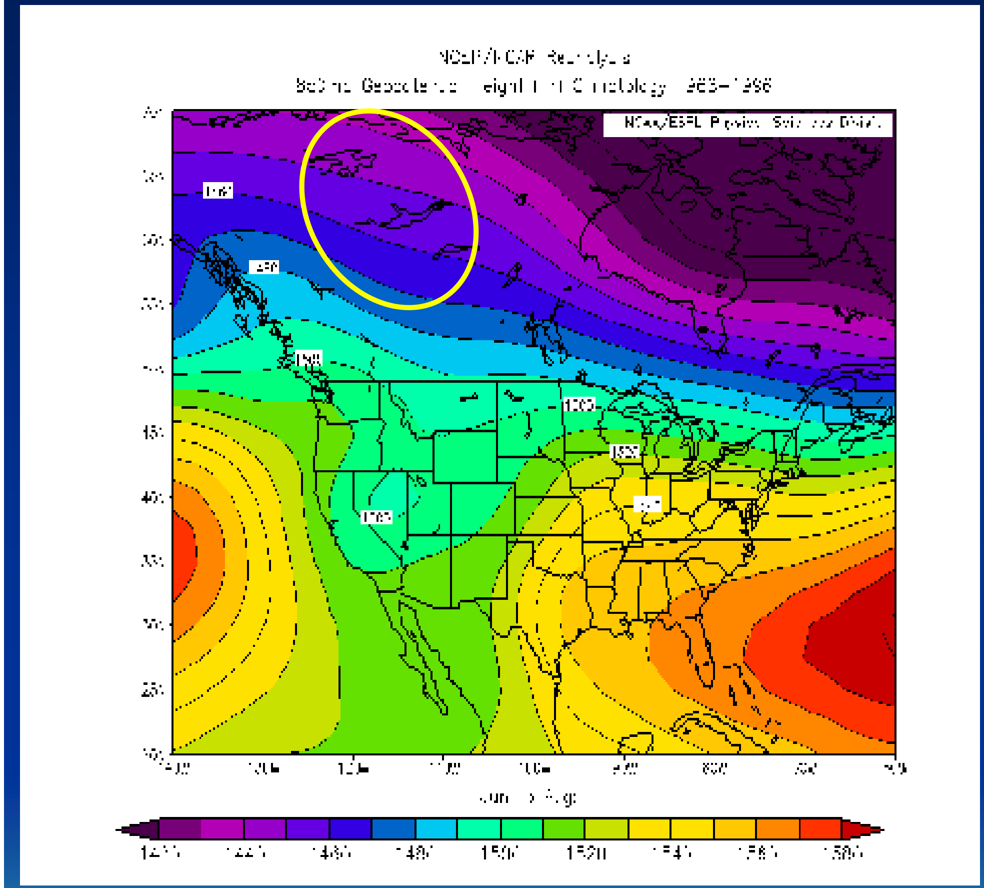
Rockies Foot Hills   Mackenzie Basin

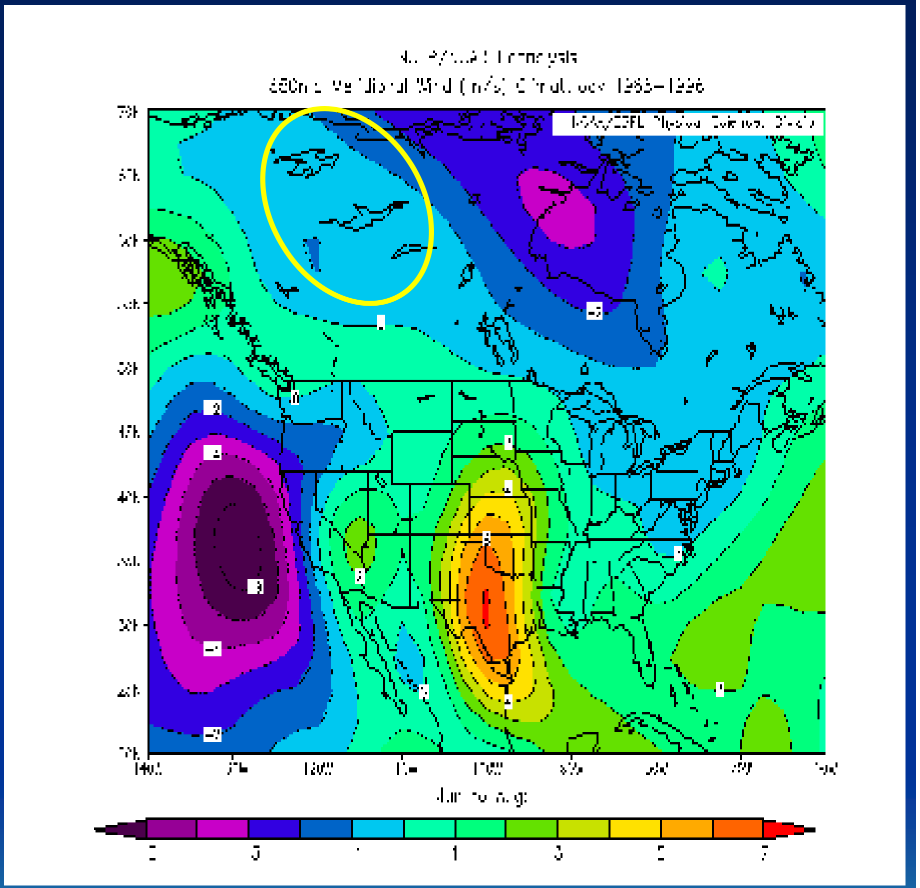
Substantial portion of the precip is lost through runoff in the mountainous region and part of it falls back onto the plains for recycling

Basin	Mackenzie
Months n/ Variables	P_{n-1},E_n
May, Jun	-0.37
Jun, Jul	0.36
Jul, Aug	0.52

1-month lagged correlation between monthly basin-average P and E during the rainy season. Correlations exceeding the 95% significance level are high-lighted

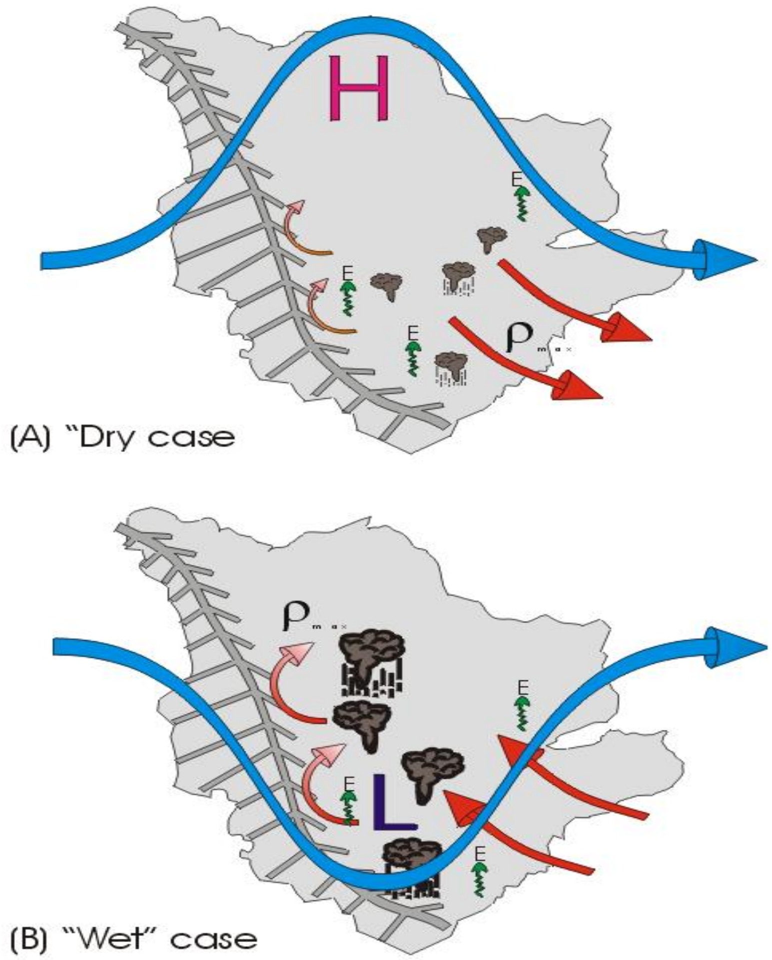
JJA mean circulation at 850 hPa





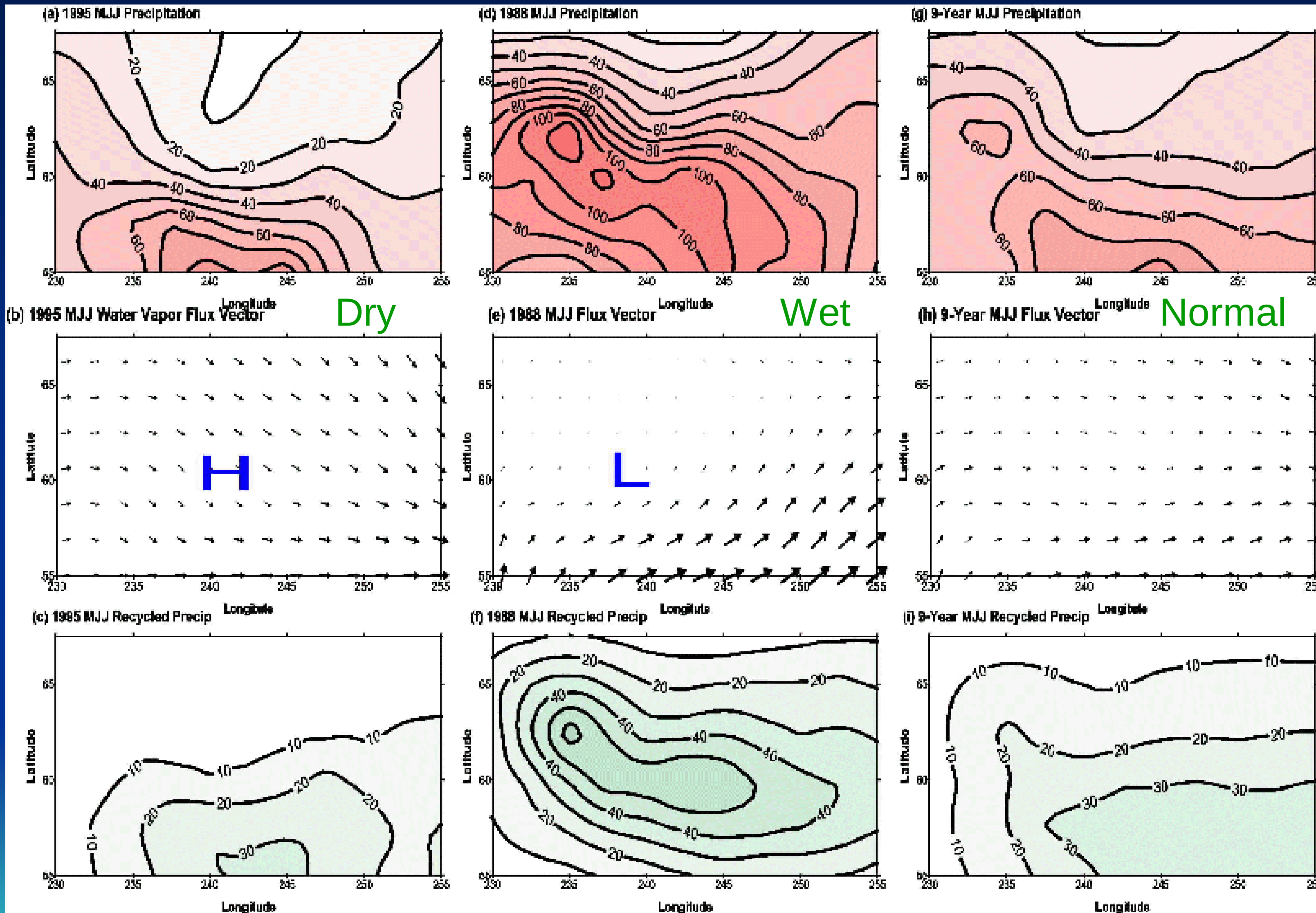
Northerly moisture transport by mean meridional flow over the MRB –> mean southerly moisture transports into the MRB must be accounted for by eddy transports

Schematic illustrating interactions between large-scale atmospheric conditions, geographical features & recycling over MRB



Schematics showing the responses of precipitation and its recycling over the MRB to variations in large-scale atmospheric conditions: (a) a dry summer characterized by a enduring large-scale high pressure anomaly, (b) a wet summer characterized by an enduring low pressure anomaly, and moist southerly flows.

MRB water cycling parameters during two extreme Summers

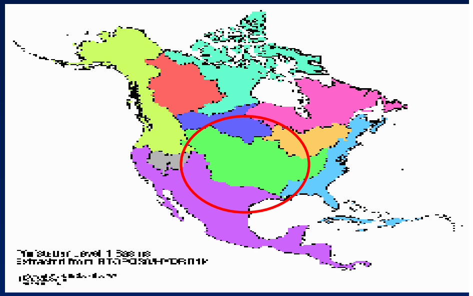


The May, June and July average precipitation, vertically-integrated moisture flux vectors and recycled precipitation over the MRB for 1995 (a-c), 1988 (d-f) and the nine year (1988-1996) mean (g-i).

Basin	Mackenzie (JJA)
Parameter	P
E	0.34
Fx	-0.26
Fy	**0.58**
r	0.17

Correlation coefficients between JJA-average water cycle variables for the MRB 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.

Mississippi Basin



•Temperate region located to the lee of Western Cordillera

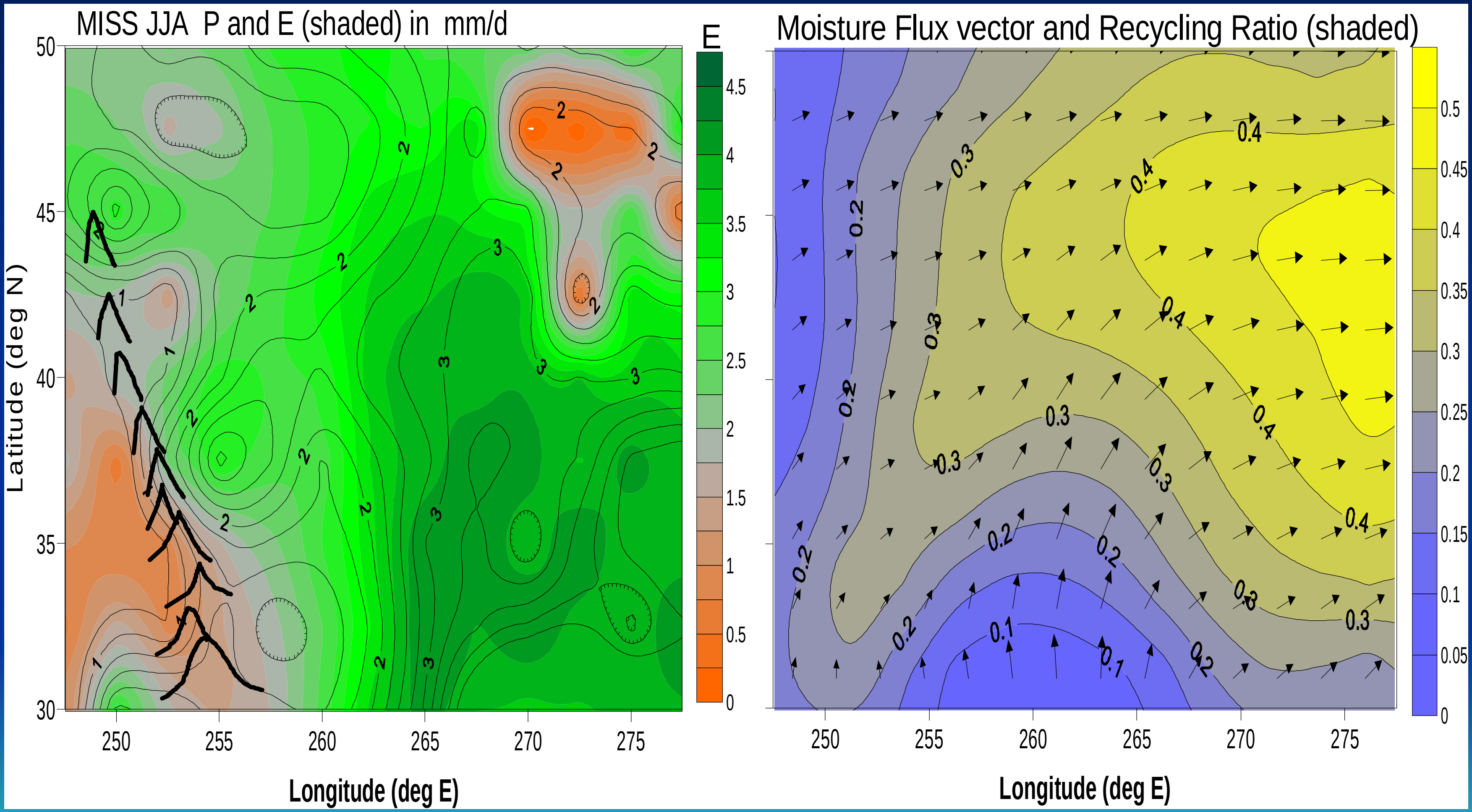
• Large areas, especially in the southern basin, is snow-free during the winter

• Without snowcover, spring soil wetness depends critically on pre-season precip

• Lee-side location and vicinity to the Atlantic ocean allow for the development of the GPLLJ, which along with the openness of the basin to the Gulf of Mexico facilitate strong moisture transport into the central and eastern Basin during the warm season

• Potential for strong air-land coupling over the dry western basin

Miss R.B. – JJA water cycling

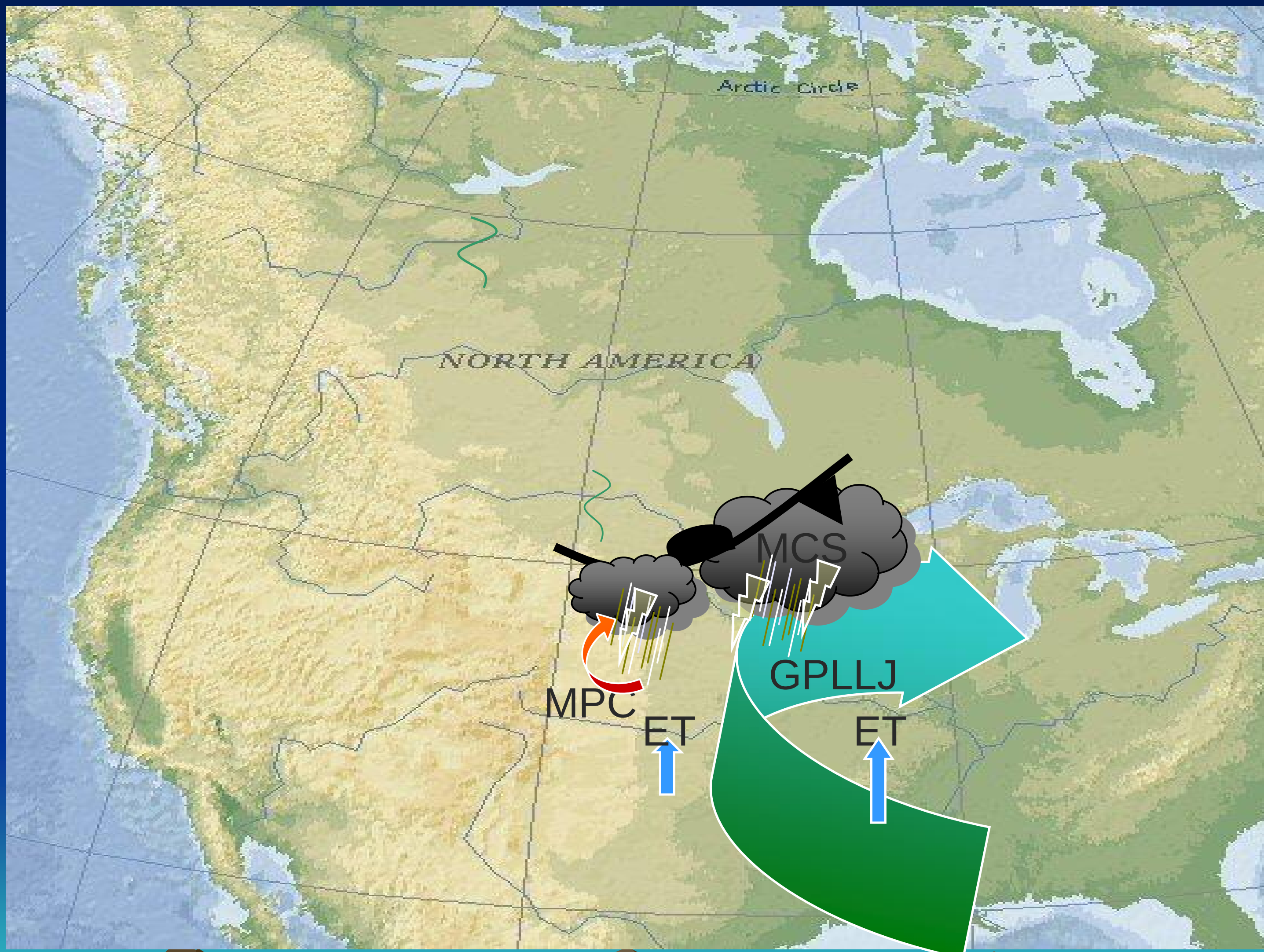


JJA basin average ρ = 31 %

Basin	Mackenzie	Mississippi
Months n/ Variables	P_{n-1},E_n	P_{n-1},E_n
May, Jun	-0.37	0.65
Jun, Jul	0.36	0.54
Jul, Aug	0.52	0.20

1-month lagged correlation between monthly basin-average P and E during the rainy season. Correlations exceeding the 95% significance level are high-lighted

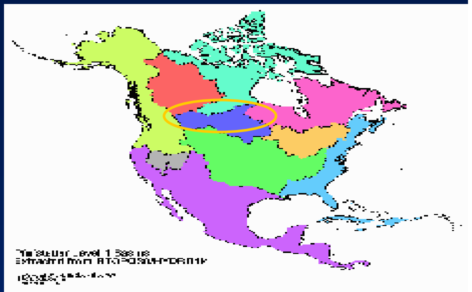
Warm-Season Precip Mechanisms over Miss. Basin



Basin	Mackenzie (JJA)	Mississippi (MJJA)
Parameter	P	P
E	0.34	0.61
Fx	-0.26	-0.10
Fy	0.58	0.44
r	0.17	-0.19

Correlation coefficients between rainy season water cycle variables for the MRB and Missip Basin 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

Saskatchewan Basin



•Mid-latitude, located to the lee of Western Cordillera - cold winter with light-moderate precip

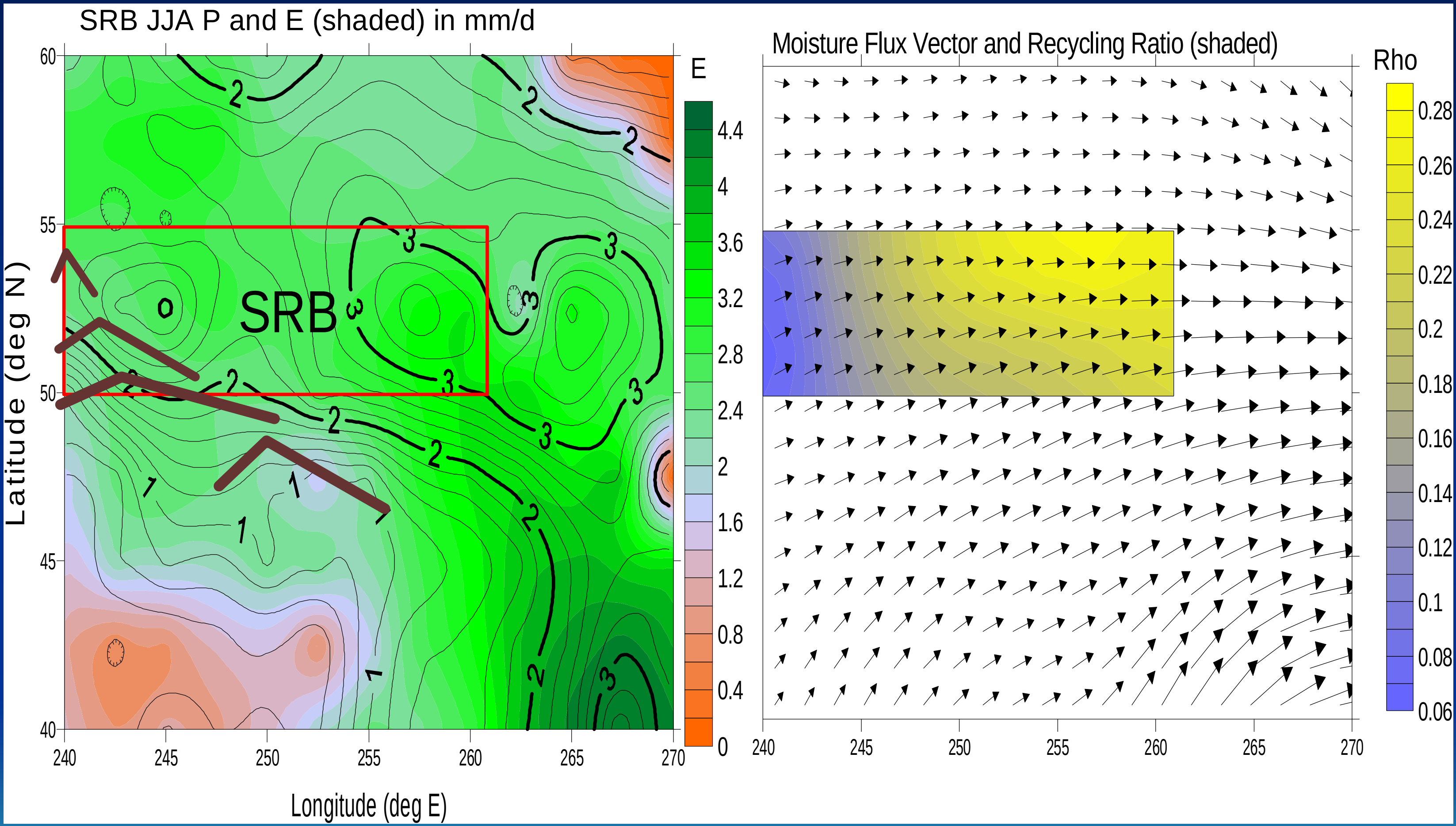
• Unlike the MRB, surface snow can be removed by blowing snow sublimation, chinook, etc., leading to large interannual variability in snowcover and spring soil wetness – potentially stronger linkages between summer P and previous winter conditions than in MRB

• With topographic settings that are similar to the MRB, MPC and recycling can be important for P production and interactions between regional and synoptic scale processes can exert strong control on water cycling processes

• Being just north of the Miss.RB, southerly moisture transport into region plays a more significant role in governing its warm-season water cycle than for the MRB

•Water cycling is more complicated in the SRB than in either the MRB or MissRB

SRB – JJA water cycling

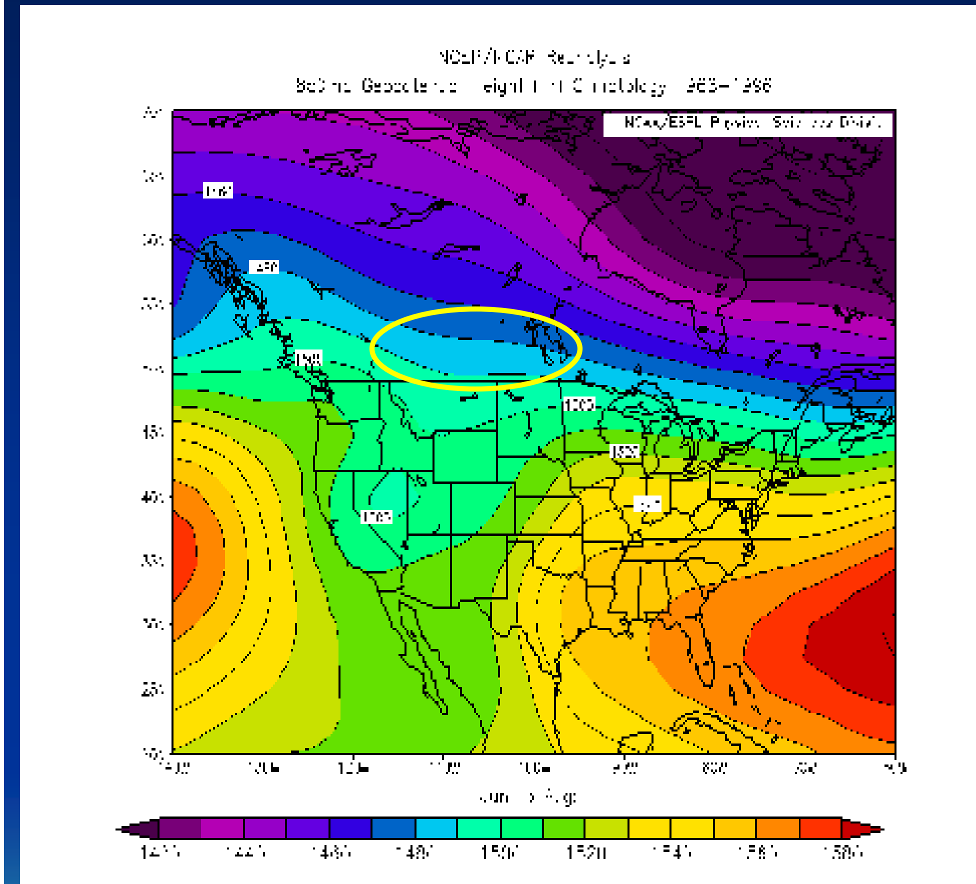


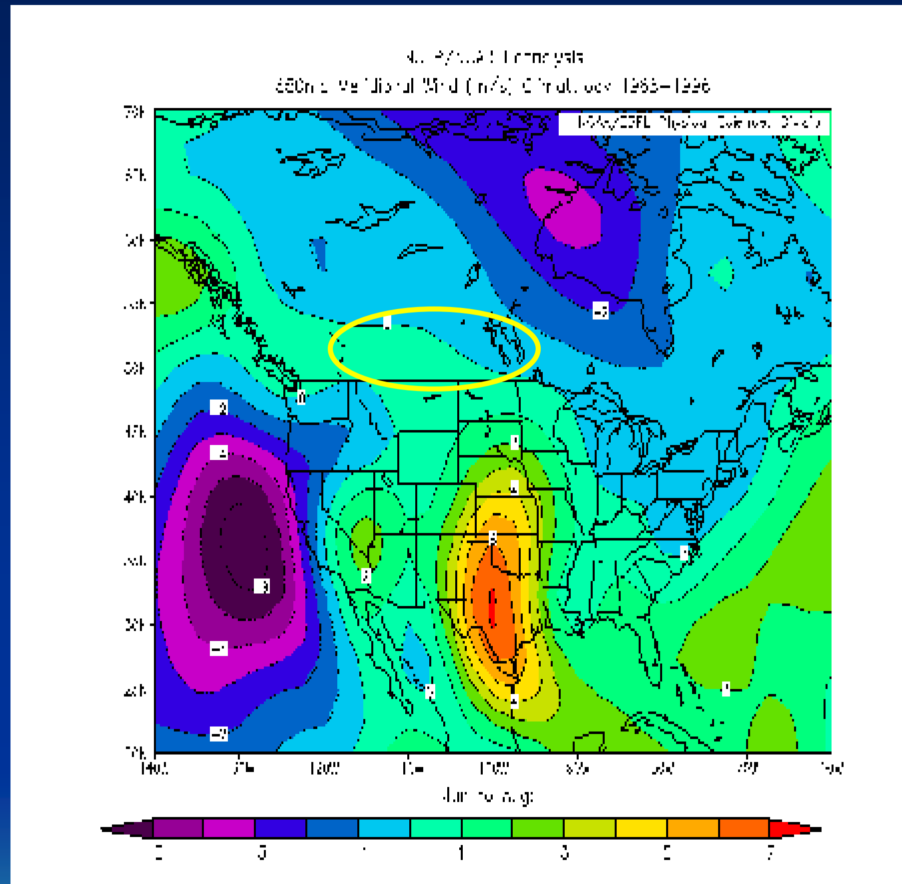
JJA basin average ρ = 20%

Basin	Mackenzie	Mississippi	Saskatchewan
Months/ Variables	P_{n-1},E_n	P_{n-1},E_n	P_{n-1},E_n
May, Jun	-0.37	0.65	0.44
Jun, Jul	0.36	0.54	0.60
Jul, Aug	0.52	0.20	0.43

1-month lagged correlation between monthly basin-average P and E during the rainy season. Correlations exceeding the 95% significance level are high-lighted

JJA mean circulation at 850 hPa



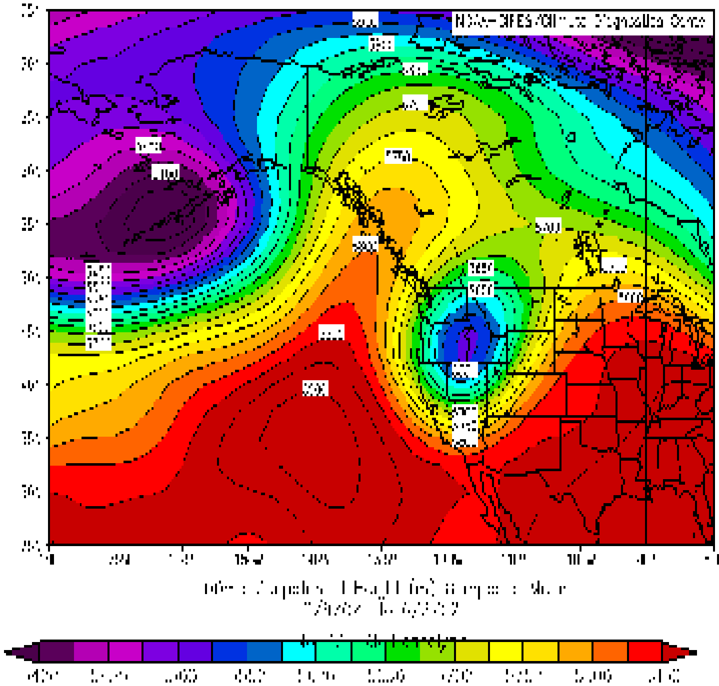


Northerly moisture transport by mean meridional flow over the prairies –> mean southerly moisture transports into the Prairies must be accounted for by eddy transports

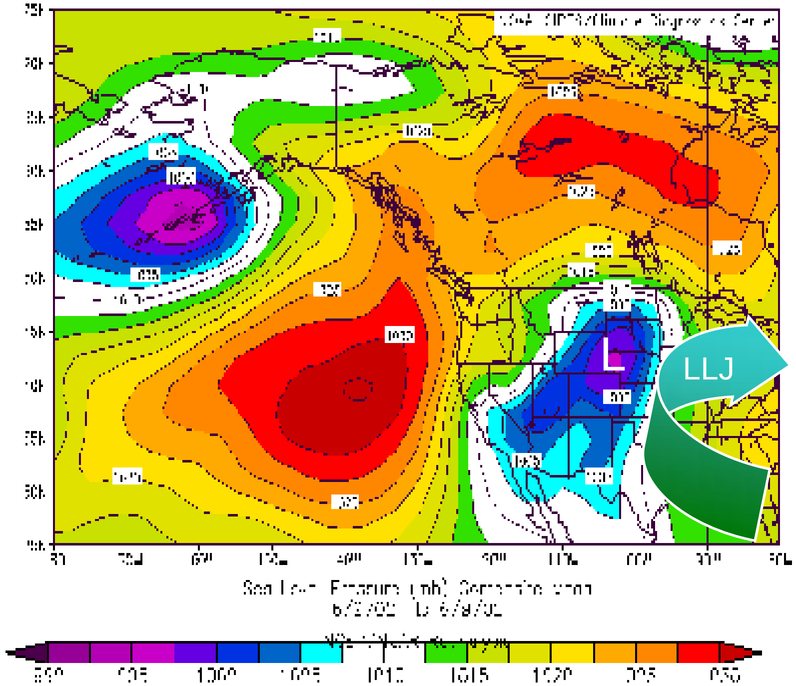
A flood within a drought

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

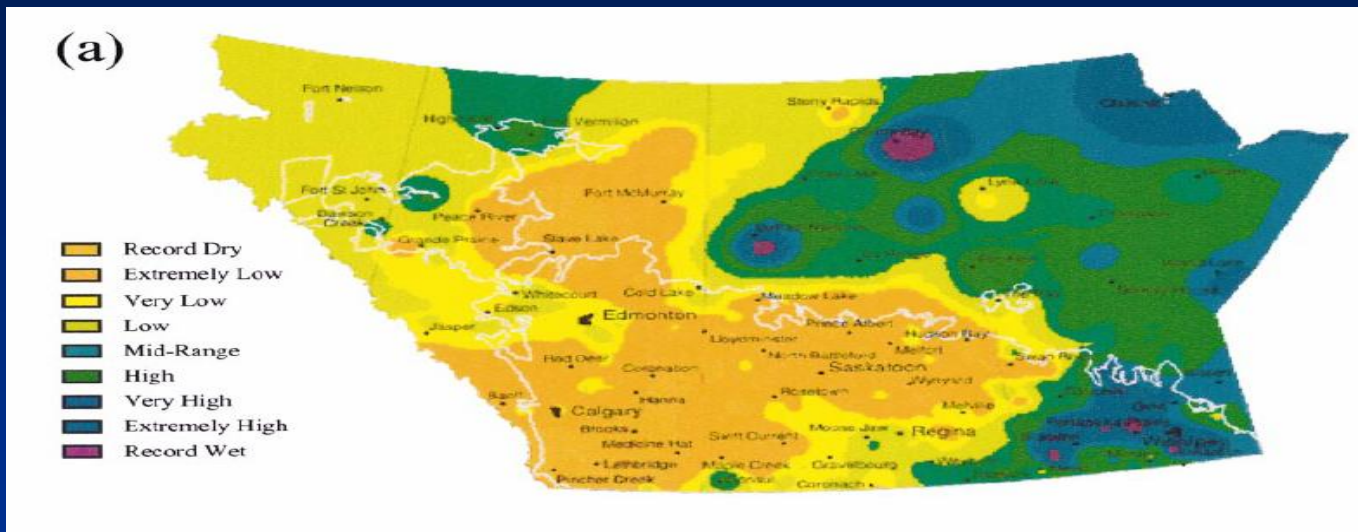
500mb Z Jun 9 2002



MSLP Jun 9 2002

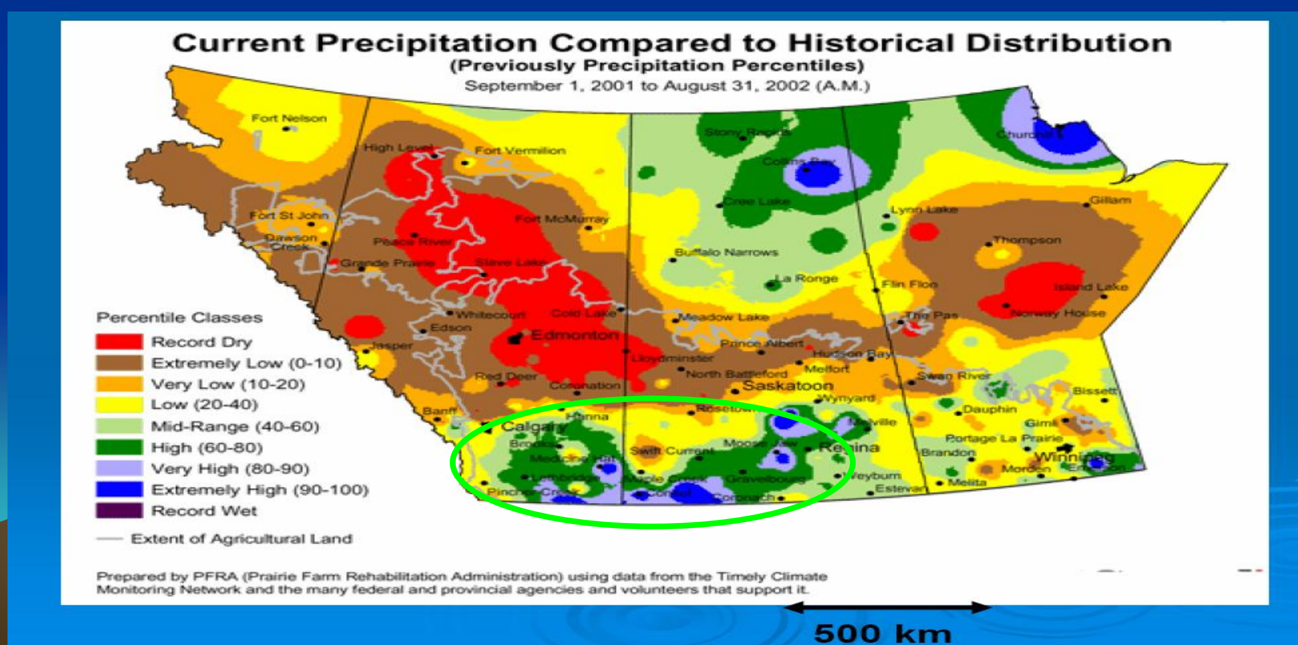


One rain event can drastically change the annual P



Precipitation Anomalies

2000-01



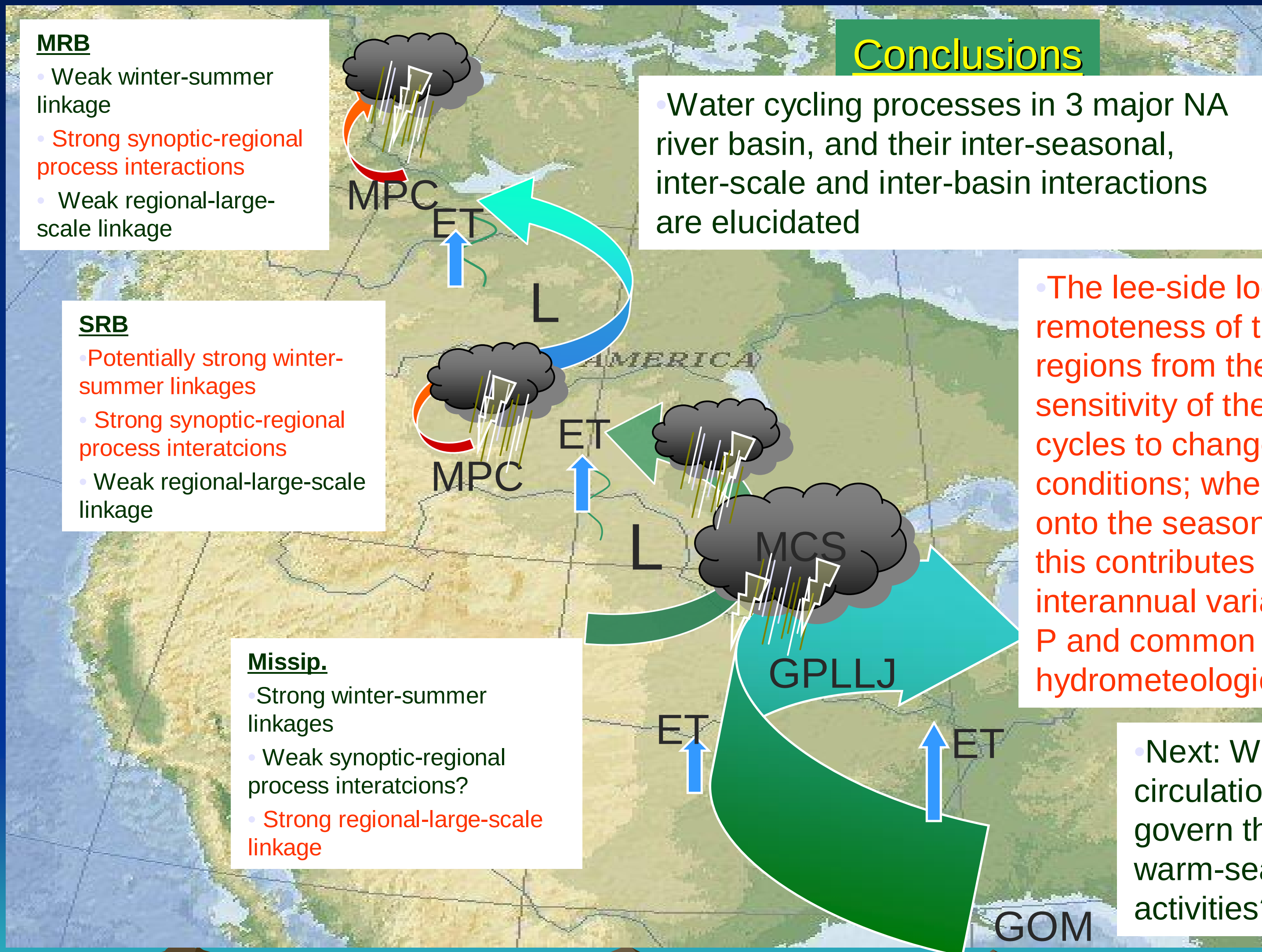
01-02

Basin	Mackenzie (JJA)	Mississippi (MJJA)	Saskatchewan (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*
r	0.17	-0.19	0.00

Correlation coefficients between rainy-season water cycle variables for the study basins 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 positive vq across 50^{o}N over eastern Prairies

Warm-season Water Transport & Cycling from GOM to MRB



MRB
- Weak winter-summer linkage
- Strong synoptic-regional process interactions
- Weak regional-large-scale linkage

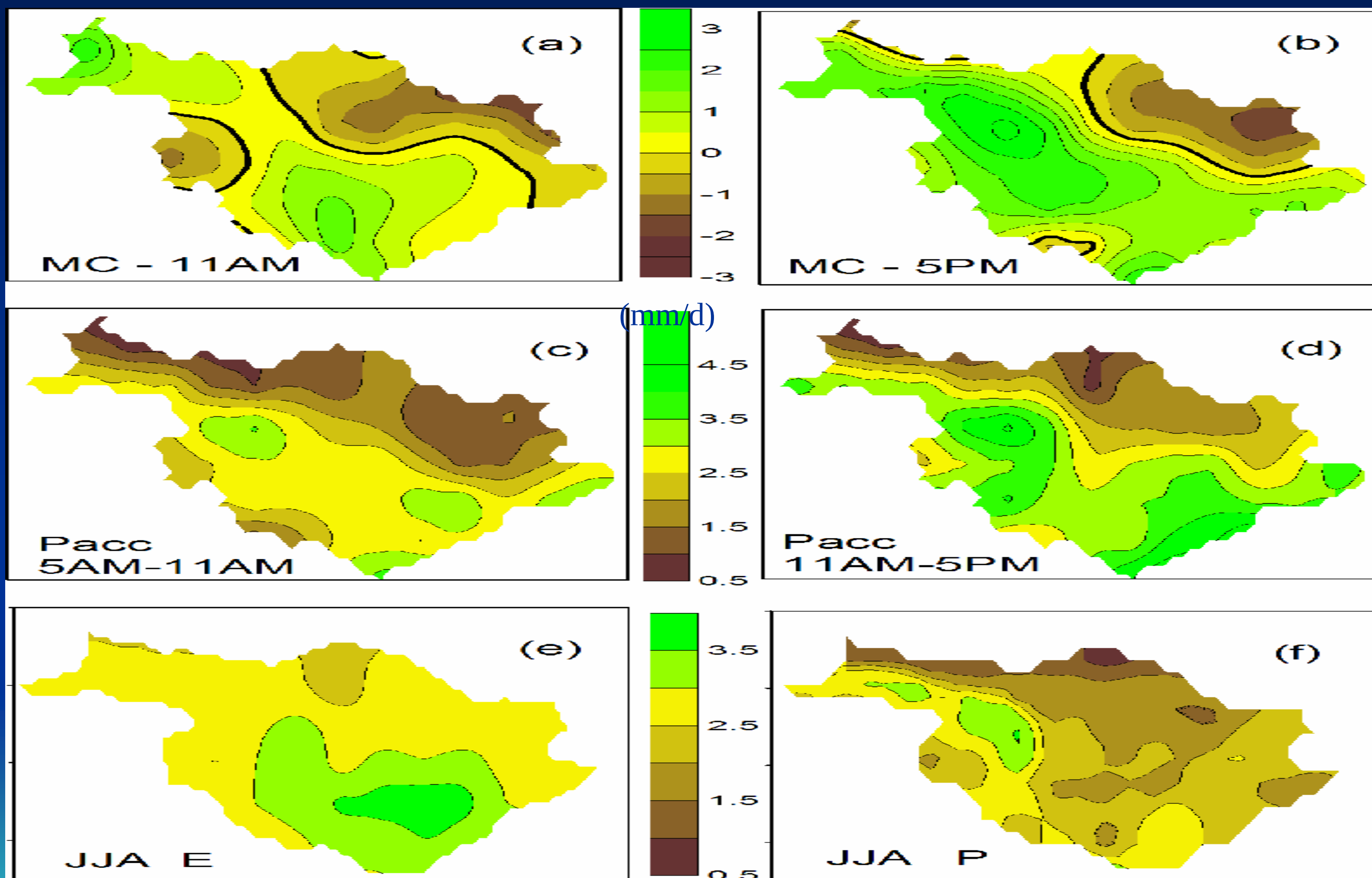
SRB
- Potentially strong winter-summer linkages
- Strong synoptic-regional process interatcions
- Weak regional-large-scale linkage

Missip.
- Strong winter-summer linkages
- Weak synoptic-regional process interatcions?
- Strong regional-large-scale linkage

Conclusions

- Water cycling processes in 3 major NA river basin, and their inter-seasonal, inter-scale and inter-basin interactions are elucidated
- The lee-side locations and remoteness of the Canadian regions from the GOM enhance sensitivity of their regional water cycles to changes in synoptic conditions; when aggregated onto the seasonal timescale, this contributes to the strong interannual variability of summer P and common occurrence of hydrometeological extremes
- Next: What large-scale circulation features govern the variability of warm-season synoptic activities?

Mean Diurnal Variations of July Water Cycling Variables in ERA40



Correlation between JJA v and NAO index