Land ABL: Observations and Models

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Climatological and Global Modeling Perspective

- **BLs are a fully coupled system**
  - *Models must represent the real world*
  - *Observations tell us how the real world works*

- **Data collection without a forecast model framework is of limited value**
  - *Unless it can answer critical questions about how the coupled system works*
  - *So our forecast and climate models can be improved*

ECMWF model

- ***Spatial Resolution***

  9km at highest forecast resolution (HiRes)

  18km for the ensemble, and the analysis

- **Ocean**
  - **fully coupled wave model: wave height, spectrum analysis**
  - **58 output fields; extreme wave FX**
  - **Ensemble has ocean coupled:0.25x0.25; 75 levels**
  - **Not yet coupled in HiRes: small overprediction of hurricane intensity**
  - **Hurricane track forecasts excellent**

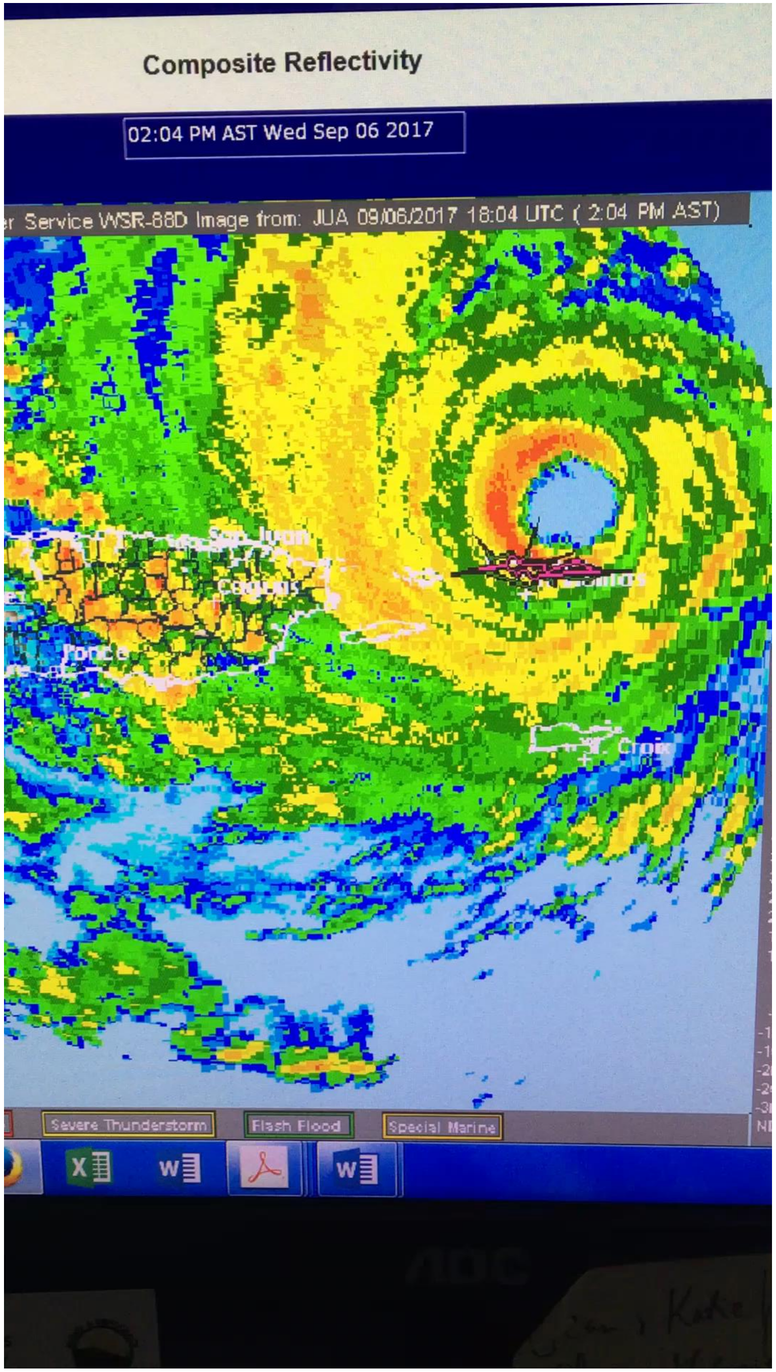
2pm Sept. 6

*Category 5**

IRMA

grazing

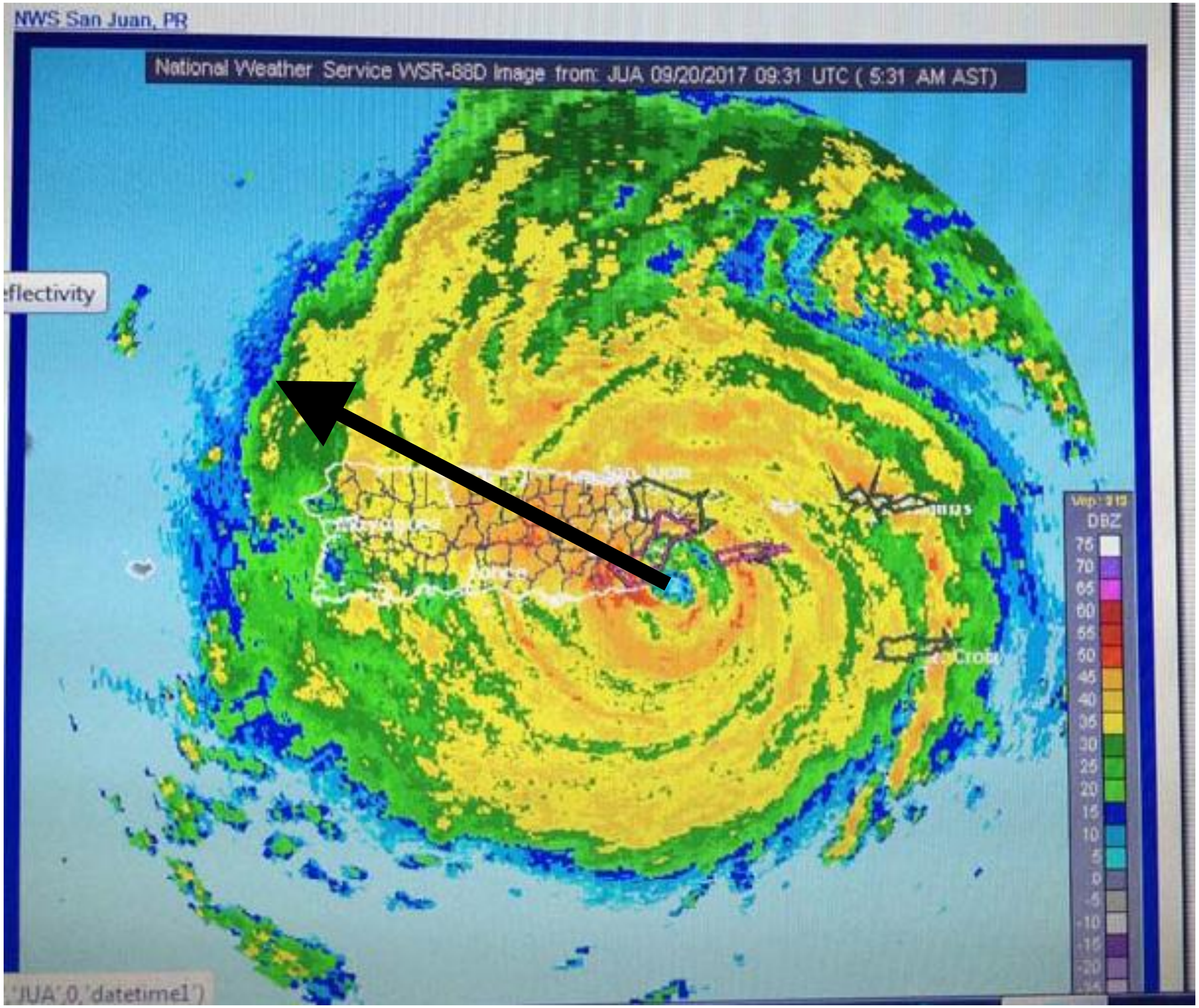
St Thomas



Cat 5 >155mph

IRMA >180mph

Maria: *5:30am Sept. 20*
Category 4 *hits Puerto Rico*



Cat 4
>130mph
Maria
>150mph

ECMWF model

- **Land**
  - **Land types/land cover are aggregated for each grid size from 1km data, into 16 vegetation classes, which are represented for each cell by one low and one high vegetation type, bare soil, snow and lake fractions and an interception reservoir**
- **Land conceptual issues**
  - **BL is diurnally driven by SW and LW radiative processes, coupled to turbulent transport processes & local cloud field**
  - **We can only model the fully coupled system with errors/biases**
  - **Disaggregating biases to separate components is tricky**
  - ***<u>Issues</u>: surface roughness, canopies and forests, intermittent turbulence, ground coupling, cloud radiative and BL flux coupling with heterogeneity***

Land discussion

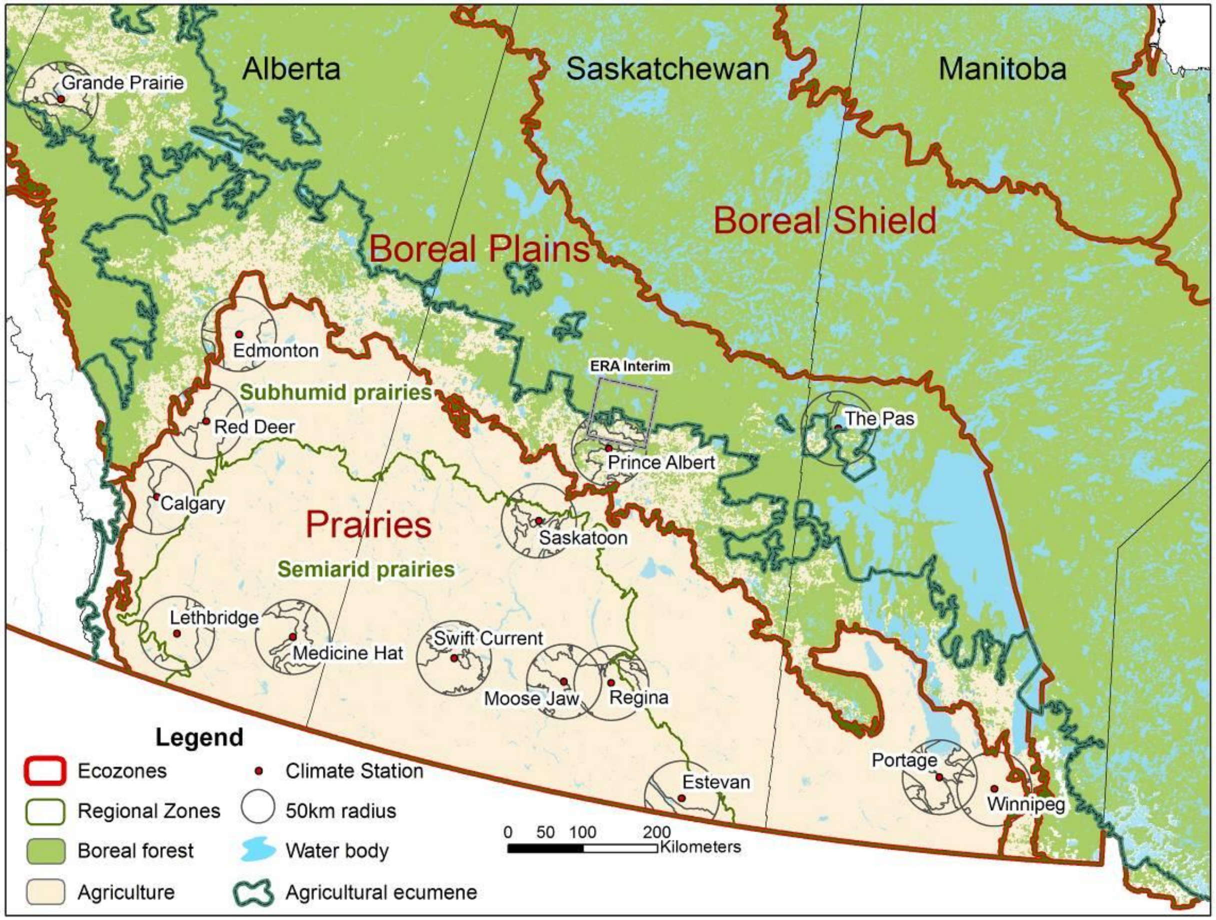
- **Northern latitude climate**
  - **Large seasonal cycle**
  - **Observational/climatological analysis**
  - **Observational evaluation of reanalysis**
    - **By cloud and seasonal regime**

- **Contrast this climatological frame with collection of a few months/years of high resolution data**

Recent Prairie studies

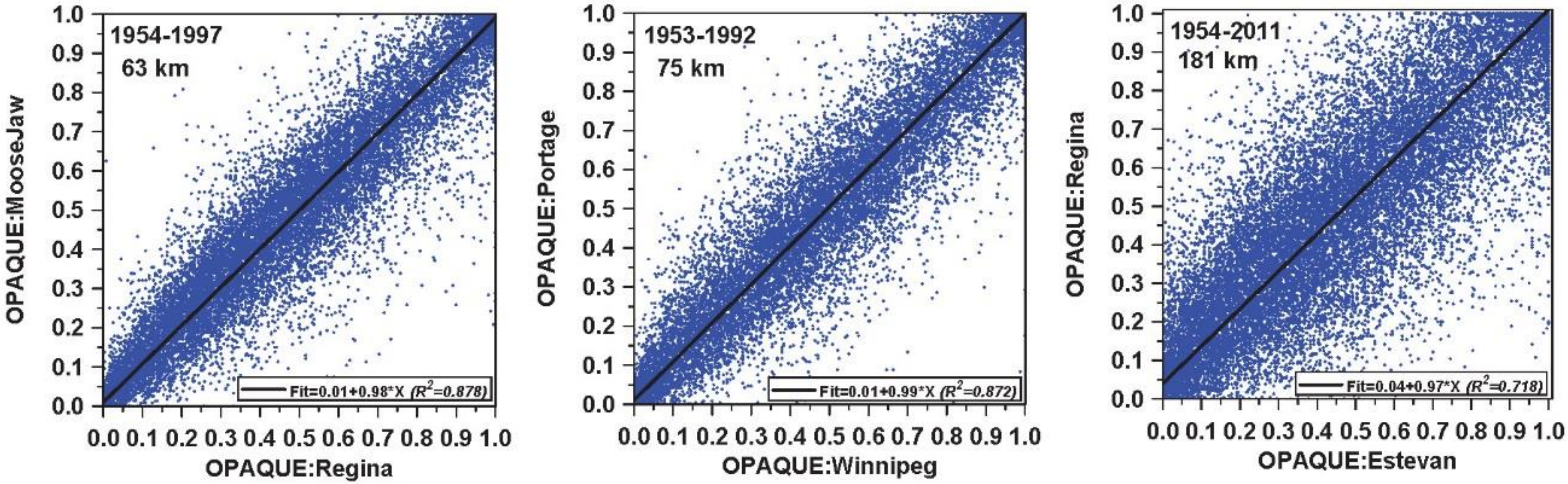
- ***Background:*** ***Remarkable 55-yr hourly Prairie data set with opaque/reflective cloud observations***
- **Northern latitude climate**
  - **Cloud forcing is the dominant BL driver**
  - **Cloud radiative forcing changes from negative to positive with snow cover**
  - **Snow cover is a <u>fast climate switch</u> between cloud-coupled unstable and stable BLs <u>with distinct non-overlapping climates</u>**

15 Prairie stations: 1953-2011

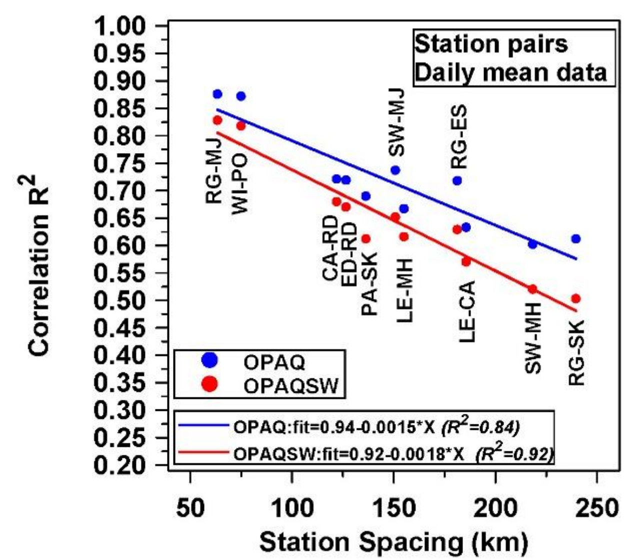


- ***Hourly*** **p, T, RH, WS, WD, <u>Opaque Cloud</u> by level, (SW_{dn}, LW_{dn})**
- ***Daily*** **precipitation and snowdepth**
- **Ecodistrict crop data since 1955**
- **Albedo data (MODIS/CCRS: 250m, after 2000)**

Opaque Cloud (Observers)



- **Daily means unbiased**
- **Correlation falls with distance**
- **Good data!**



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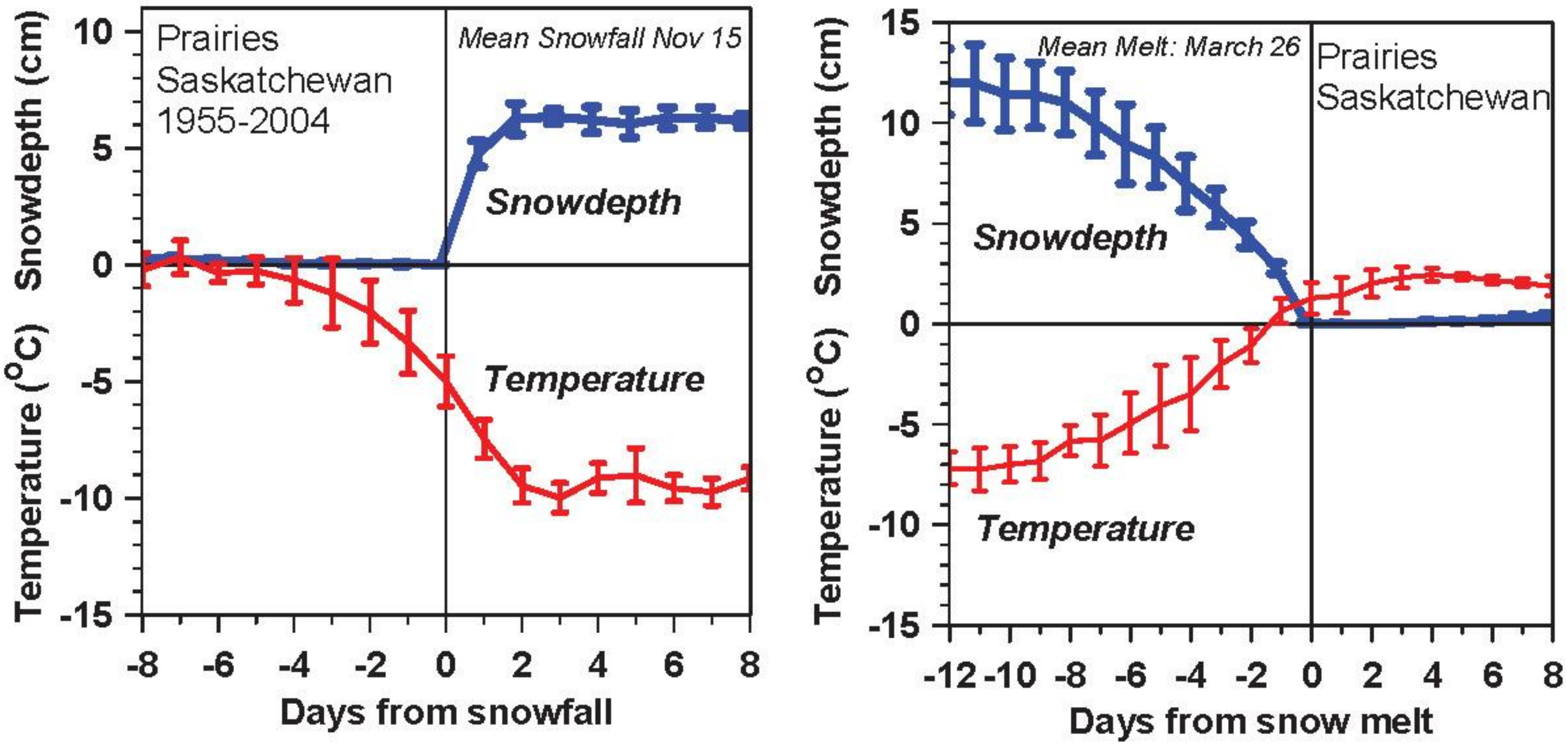
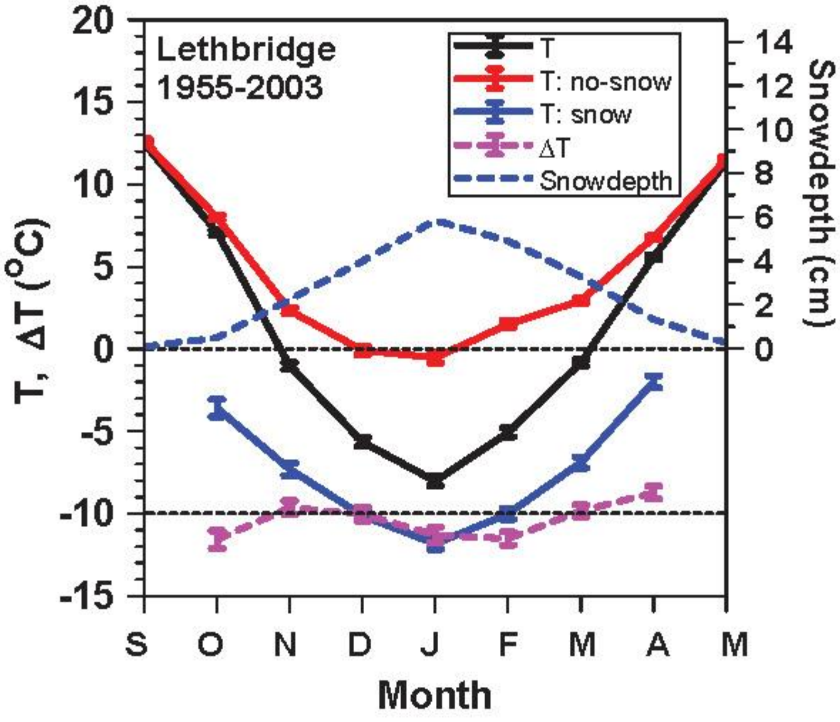
Snowfall and Snowmelt
ΔT Canadian Prairies

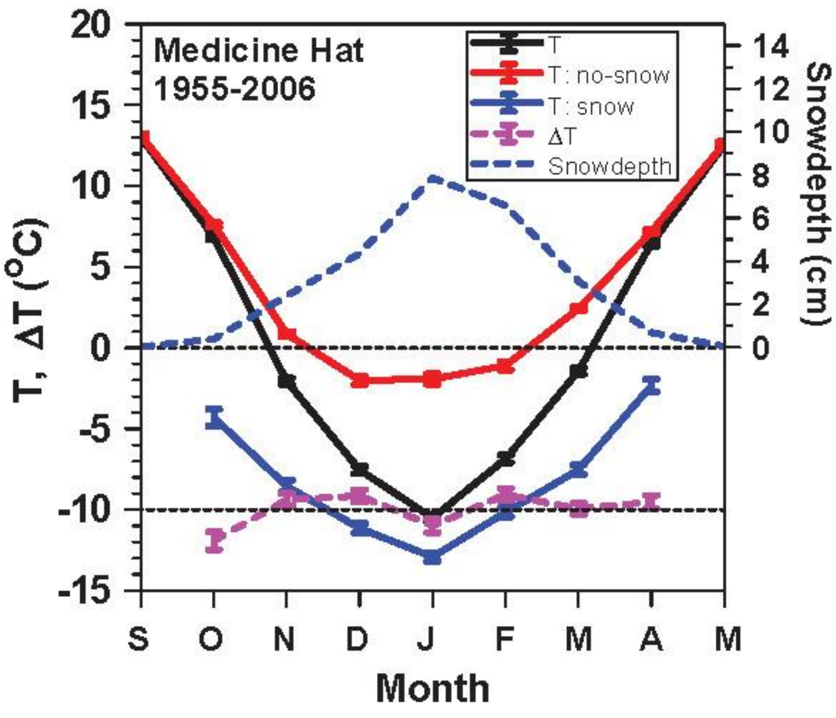


- **Temperature falls/rises 10K with first snowfall/snowmelt**
  - ***Local climate switch* between warm and cold seasons, and BL structure**

Betts et al. 2014

Impact of Snow on Climate





Separate mean climatology into days
with no-snow and snowdepth >0

ΔT = T:no-snow –T:snow = -10.2(±1.1)°C

Betts et al. (2016)

Interannual variability of T coupled to Snow Cover

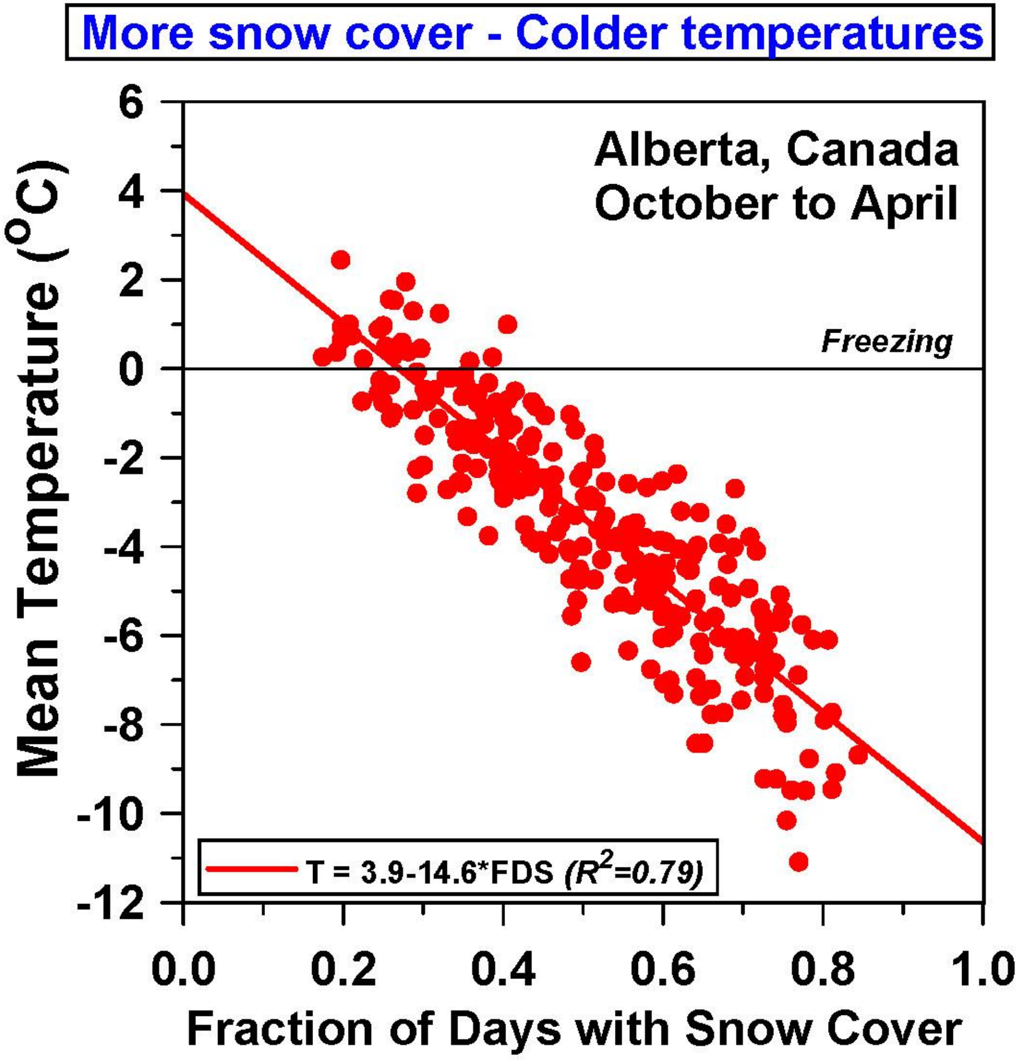
- **Alberta: 79% of variance**
- **Slope T_m - 14.7 (± 0.6) K**

10% fewer snow days

= 1.5K warmer

on Prairies

Snow: climate switch



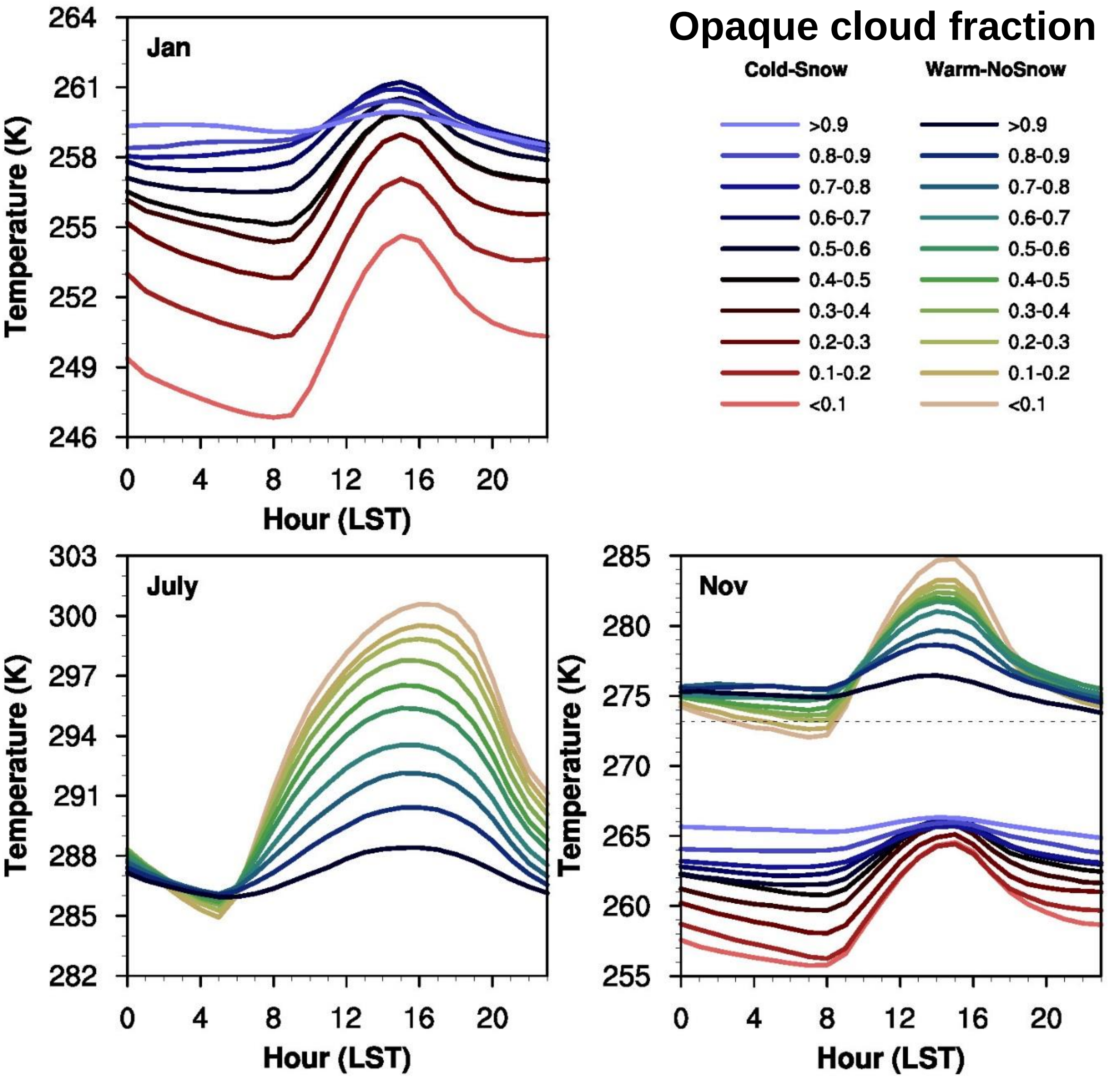
Diurnal cycle: Clouds & Snow

Canadian Prairies
660 station-years of data

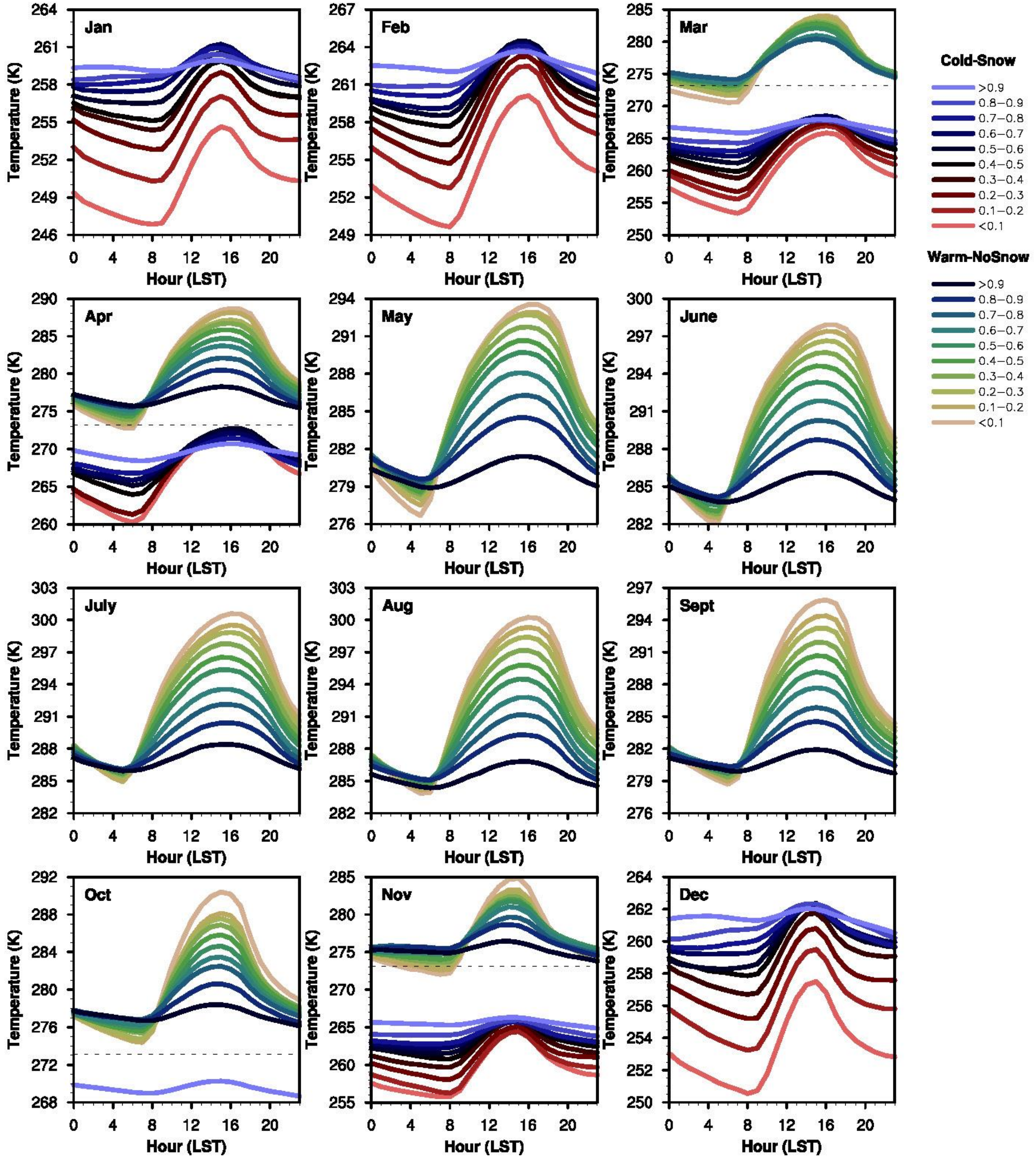
Winter climatology
- Colder when clear
- LWCF dominant with snow

Summer climatology
- Warmer when clear
- SWCF dominant: no snow

Transition months:
- Show both climatologies
- With 11K separation
- Fast transitions with snow
- Snow is "Climate switch"



Monthly diurnal climatology (by snow and cloud)

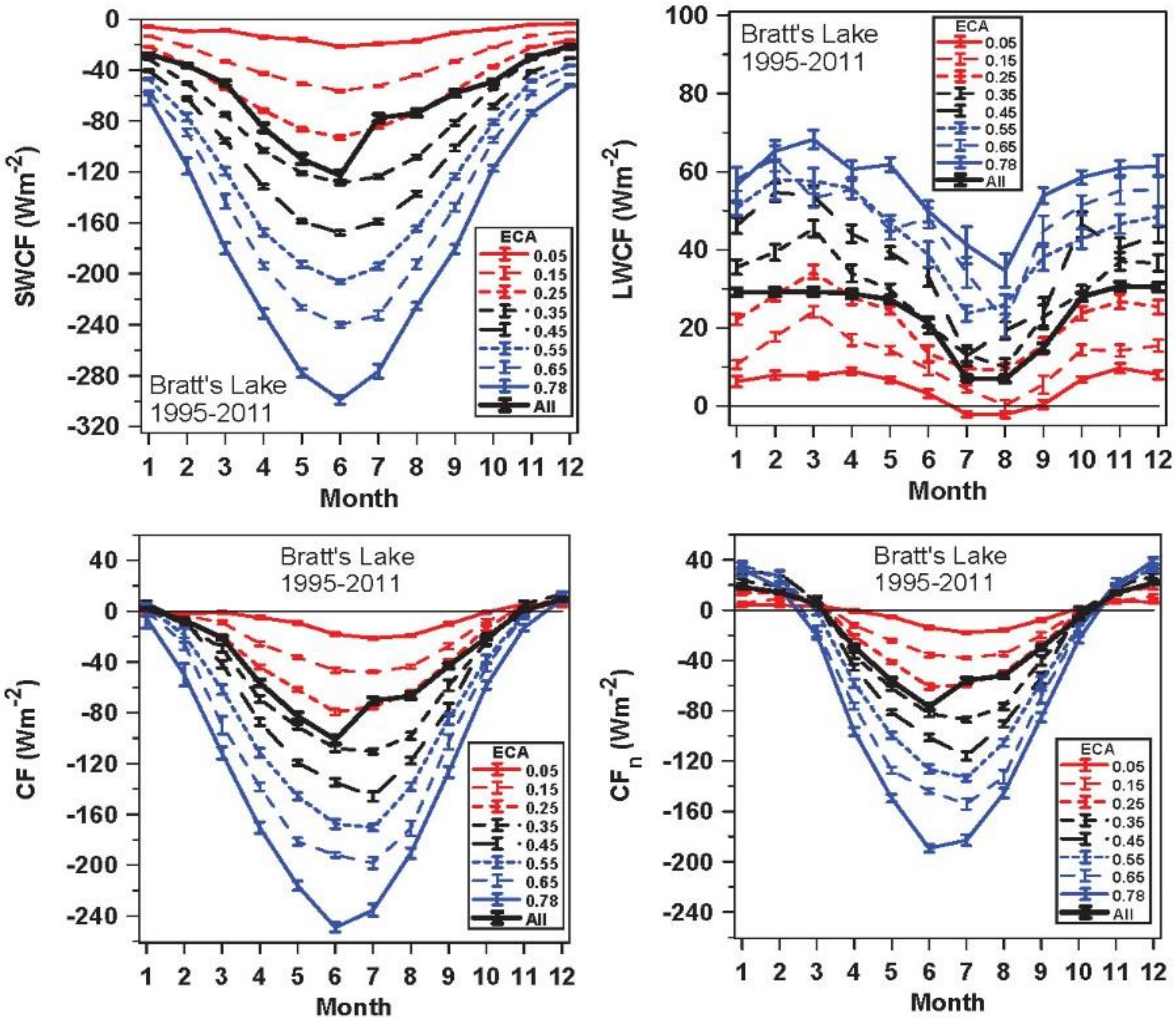


SW and LW ‘Cloud Forcing’

BSRN at Bratt’s Lake, SK

- **“Cloud Forcing”**
  - ***Change from clear-sky flux***
- **Clouds reflect SW**
  - ***SWCF***
  - ***Cool***
- ***Clouds trap LW***
  - ***LWCF***
  - ***Warms***
- ***Sum is CF***
- ***Surface albedo reduces SW_n***
  - ***Net is CF_n***
  - ***Add reflective snow, and CF_n goes +ve***
- ***<u>Regime change</u>***

(Betts et al. 2015)



Impact of Snow

- **Distinct warm and cold season states**
- **Snow cover is the <u>“climate switch”</u>**
- **<u>Prairies:</u> ΔT = -10^{o}C (winter albedo = 0.7)**
- **<u>Vermont:</u> ΔT = -6^{o}C (winter albedo 0.3 to 0.4)**

- **Snow transforms BL cloud coupling**
  - **No-snow ‘Warm when clear’ - convective BL**
  - **Snow   ‘Cold when clear’ - stable BL**

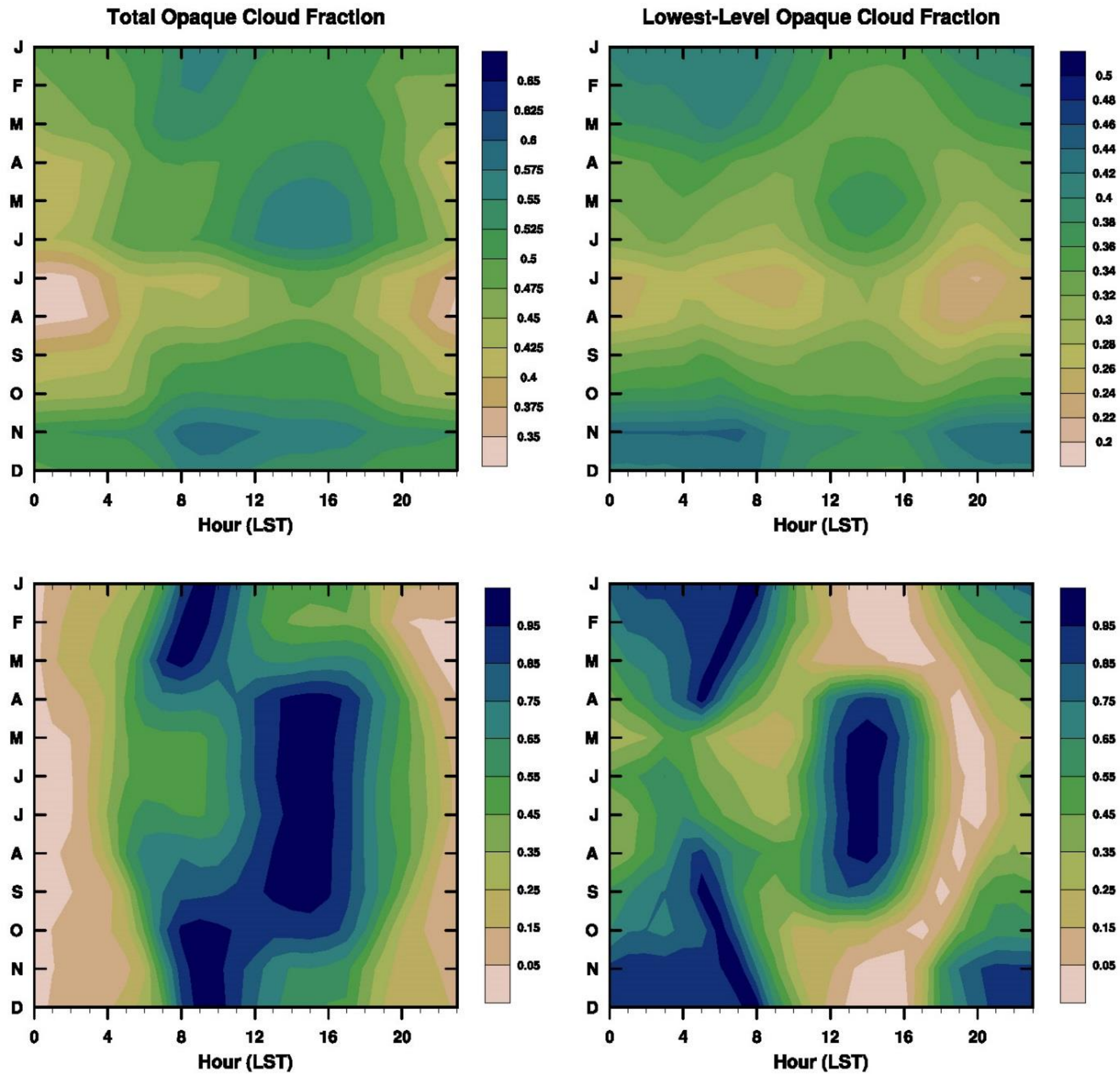
- **<u>Don’t average snow/no-snow climates</u>**
  - **Or extrapolate vertically with climatological mean**

Annual/Diurnal Opaque Cloud

- **Total opaque cloud fraction and lowest-level opaque cloud**

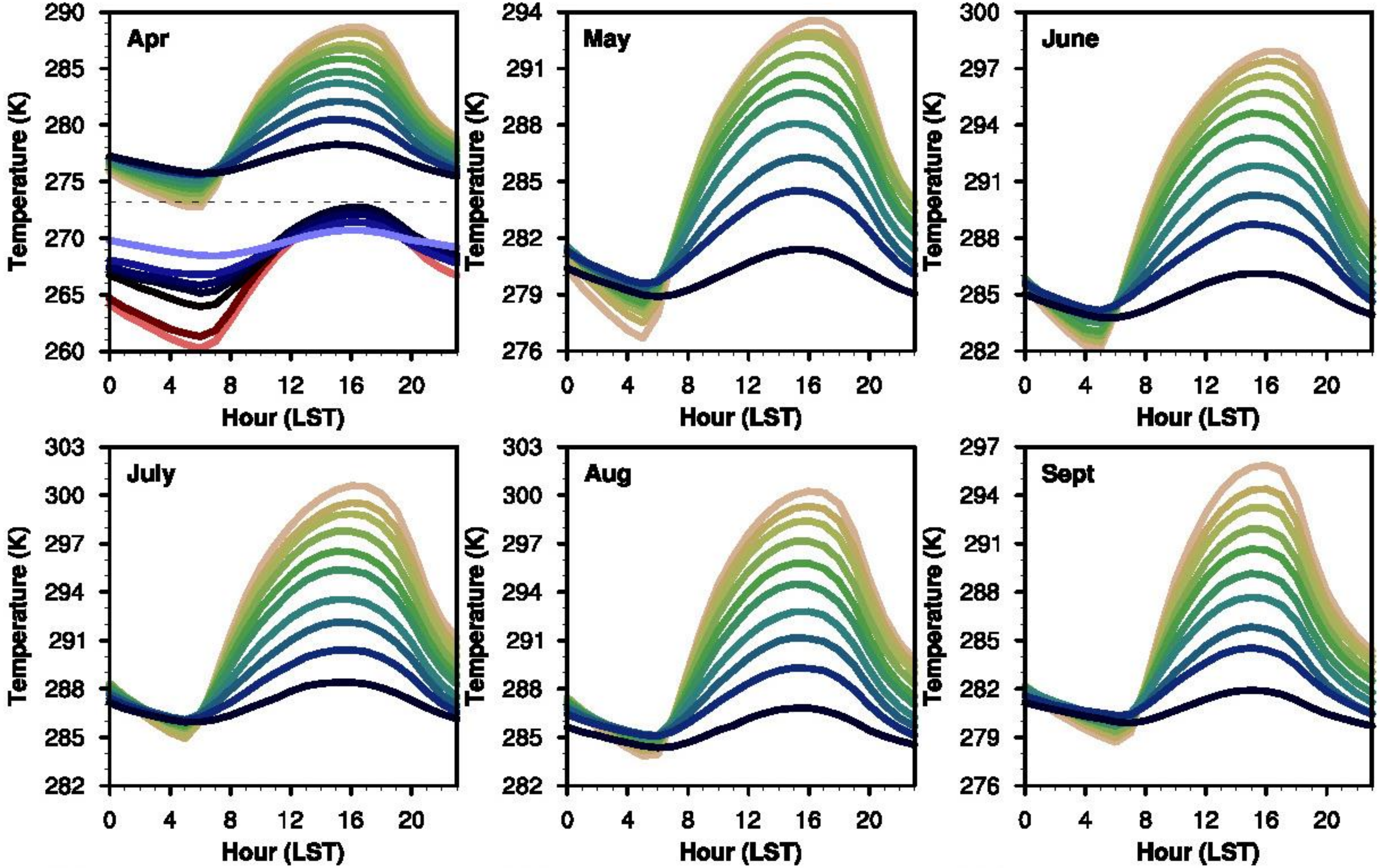
- **Normalized diurnal cycles (where 1 is the diurnal maximum and 0 is the minimum).**

- **Regime shift between cold and warm seasons: Why? Cloud forcing changes sign**



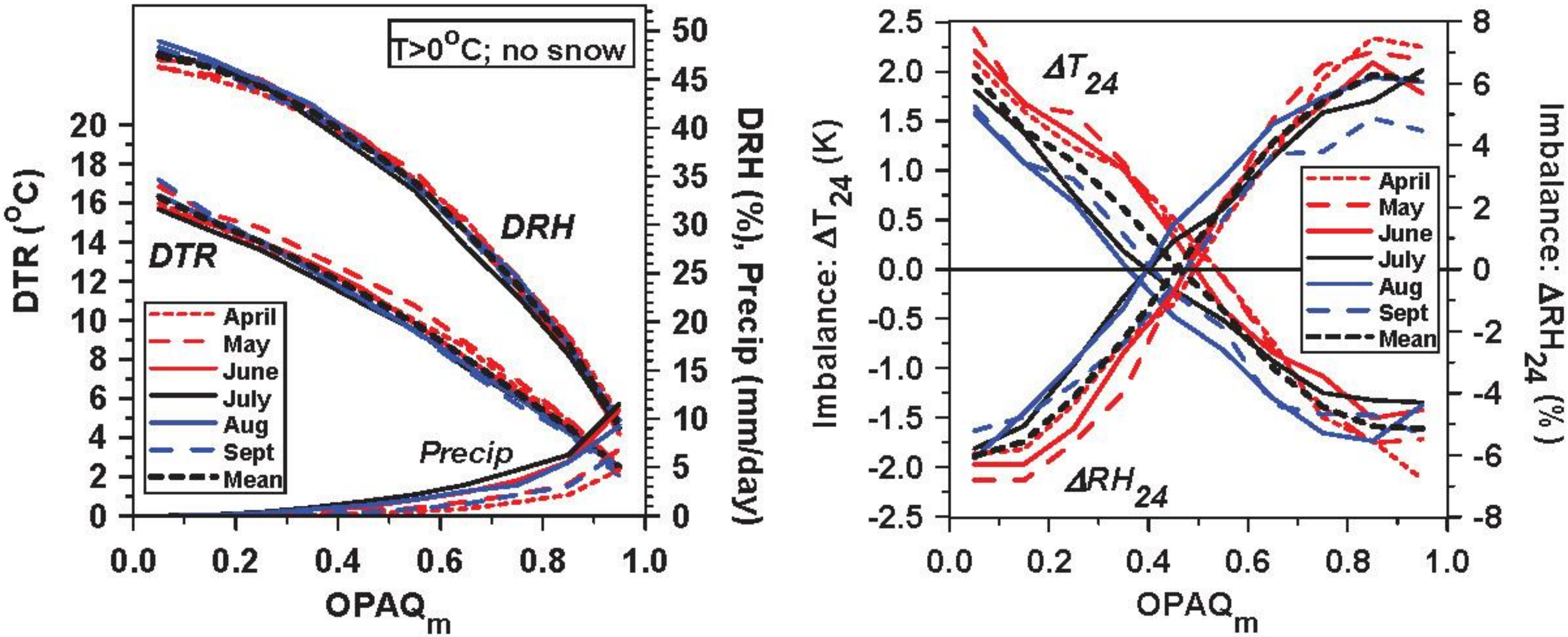
Monthly Diurnal Climatology:

Dependence on opaque cloud



Q: How much warmer is it at the end of a clear day?

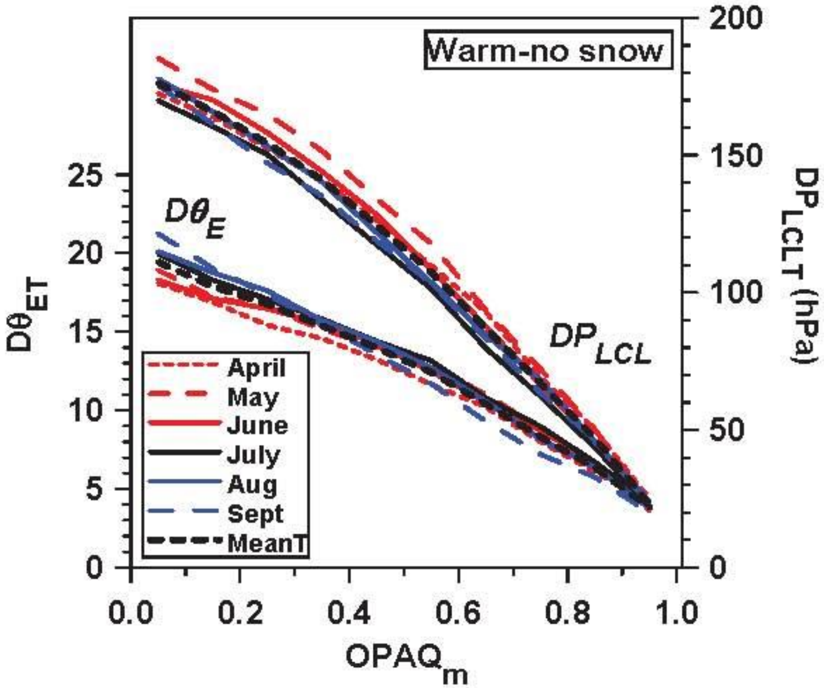
Diurnal Ranges & Imbalances

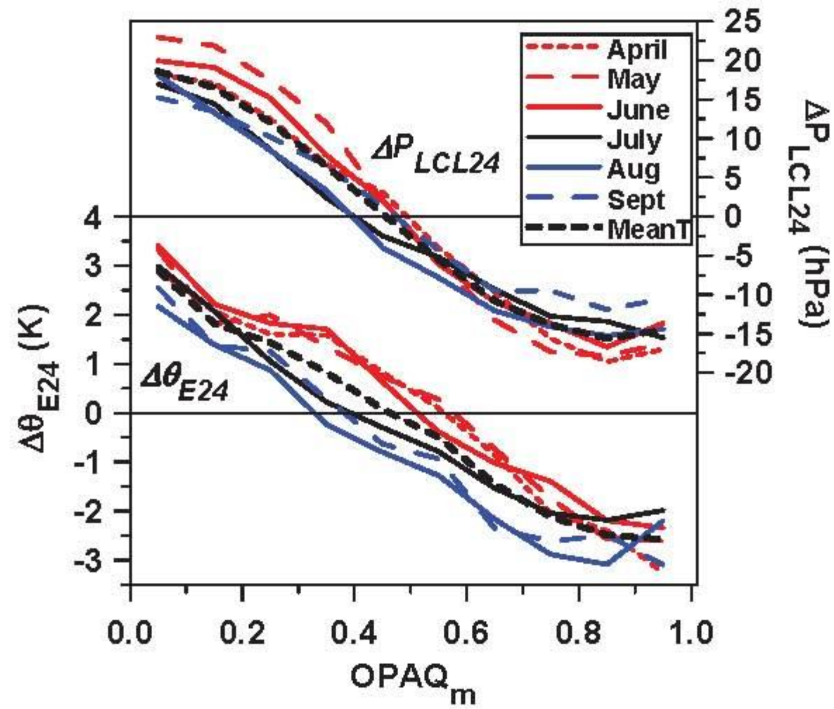


- **April to Sept: *<u>same coupled structure</u>***
- **Clear-sky: warmer (+2°C), drier (-6%)**

(Betts and Tawfik 2016)

Diurnal Ranges & Imbalances





- **April to Sept: *<u>same coupled structure</u>***
- **Clear-sky: θ_E (+3K), P_{LCL} (-18hPa)**

(Betts and Tawfik 2016)

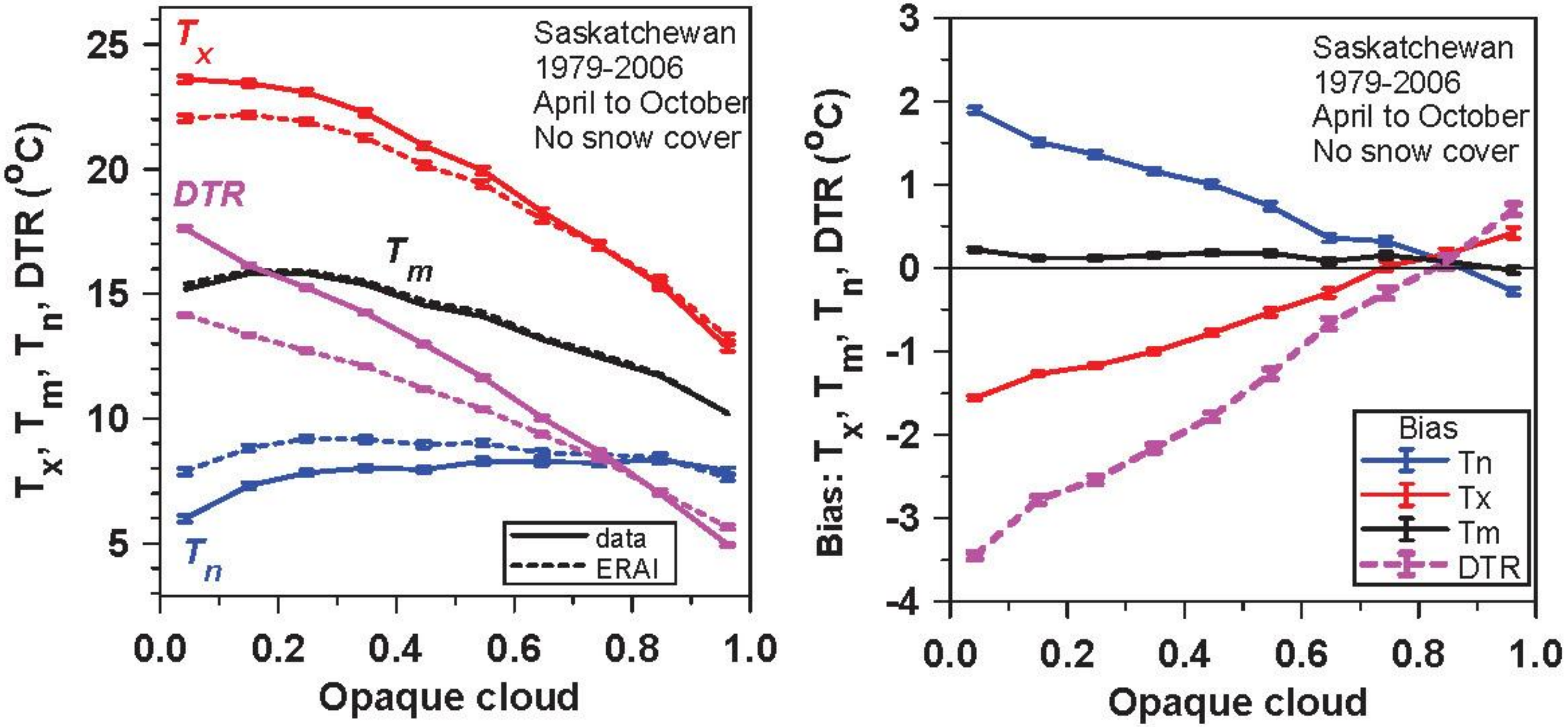
ERA-Interim 2-m Temperature Biases

- **Referenced to <u>daily</u> hourly data**
  - **Bias:T_x = T_x:ERAI –T_x:2m**
  - **Bias:T_n = T_n:ERAI –T_n:2m**
  - **Bias:T_m = T_m:ERAI –T_m:2m**
  - **Bias:DTR = DTR:ERAI –DTR:2m**
    - **Conventional DTR (daily)**
- **Stratified by Opaque cloud (data)**
- **Partitioned**
  - **Cold season with snow (MDJFM)**
  - **Warm season (no snow) (AMJJASO)**

Four stations in Saskatchewan

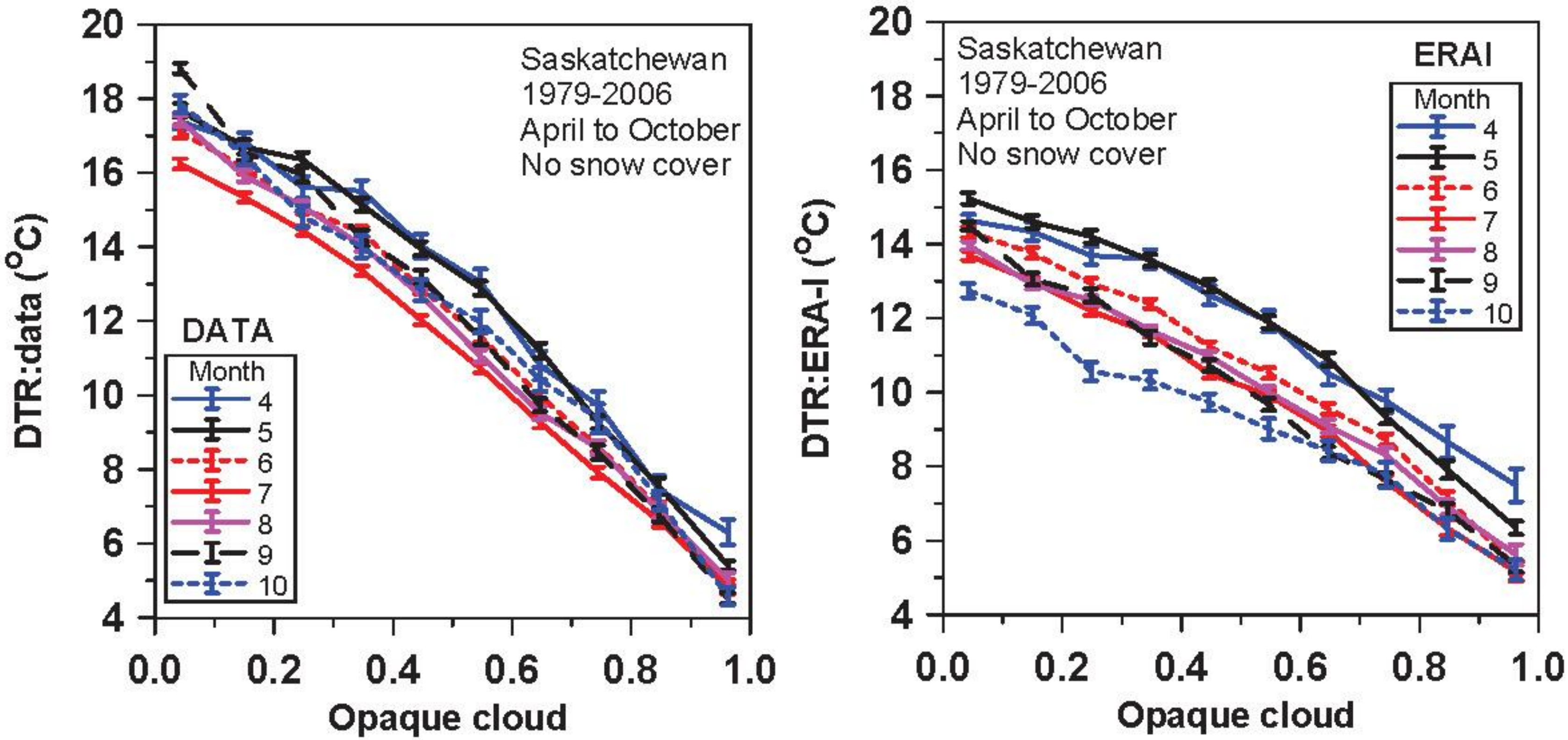
- Estevan, Regina, Saskatoon, Prince Albert
- 1979-2006
  - cold season (MDJFM) 12465 days
  - Warm season (AMJJASO) 17927 days
  - 84 station-years
- 10 bins of daily mean opaque cloud

ERA-Interim Biases



- **Warm season: linear in opaque cloud**
  - ***T_x cold, T_n warm; DTR too small***

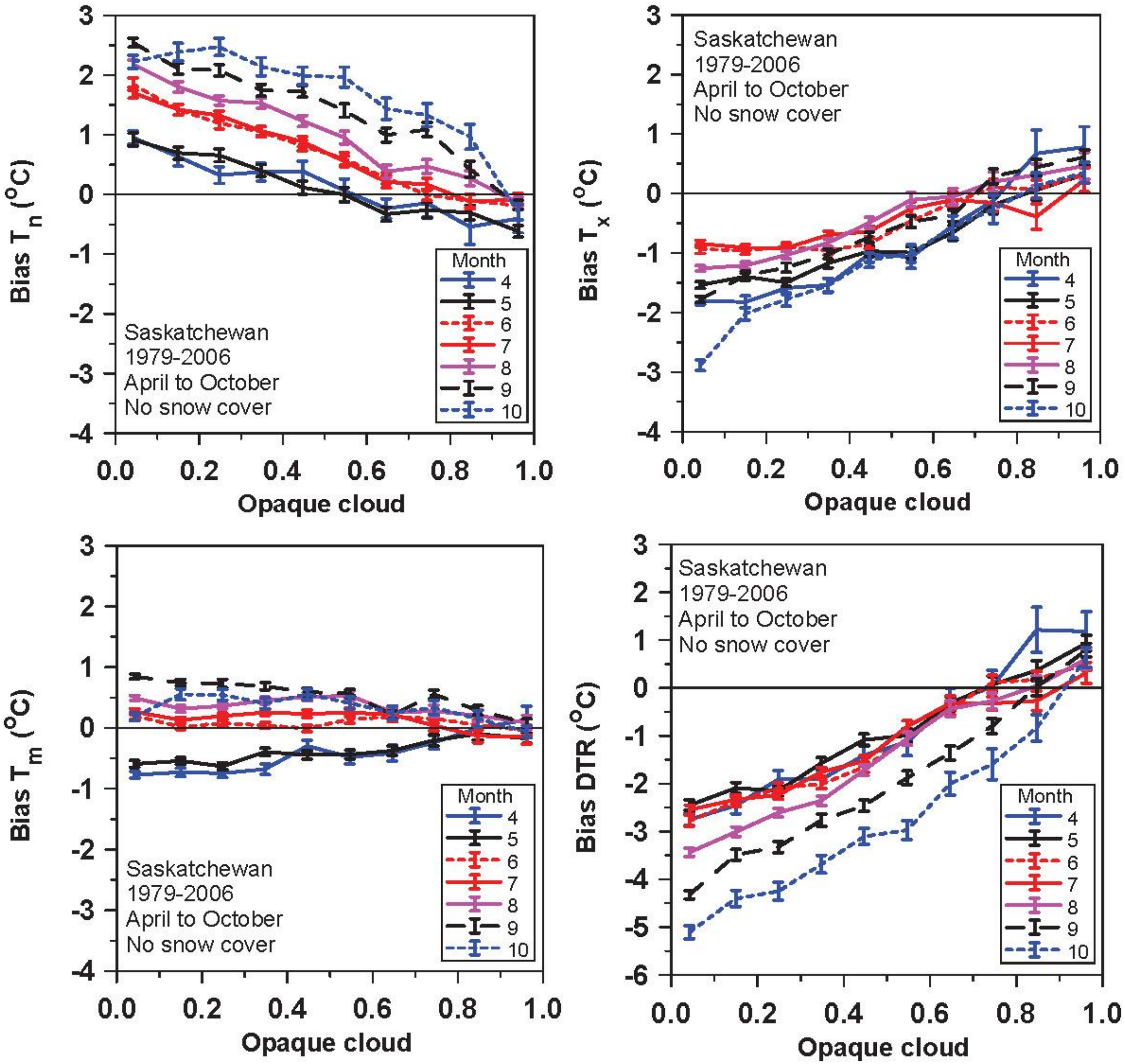
Compare monthly DTR



- **DTR: ERAI wider spread, different seasonal structure**

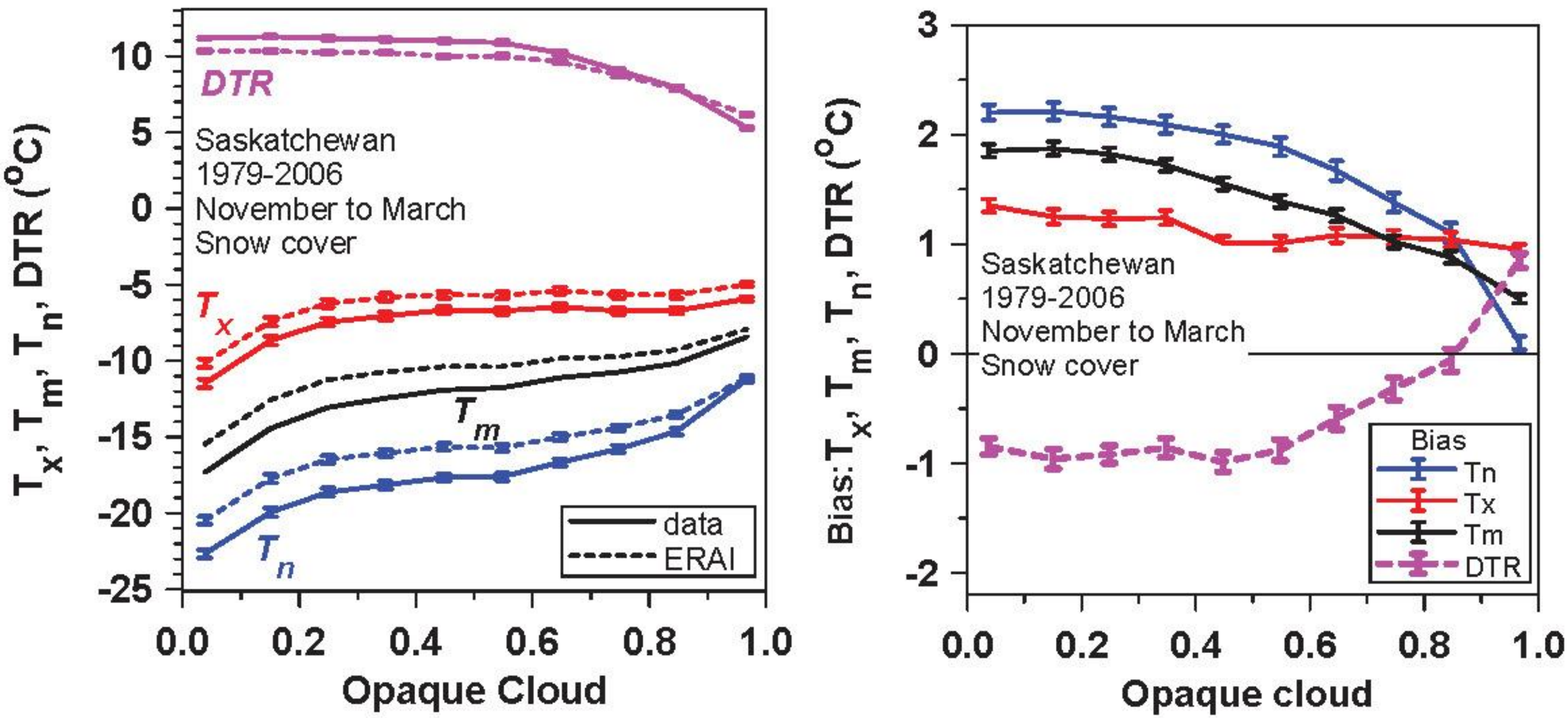
Monthly biases

- Seasonal trends large
- bias:T_n increases April to Oct
- bias:T_x min in JJ
- bias:T_m changes sign: spring to fall
- bias:DTR reaches -5^{o}C in Oct



WHY?

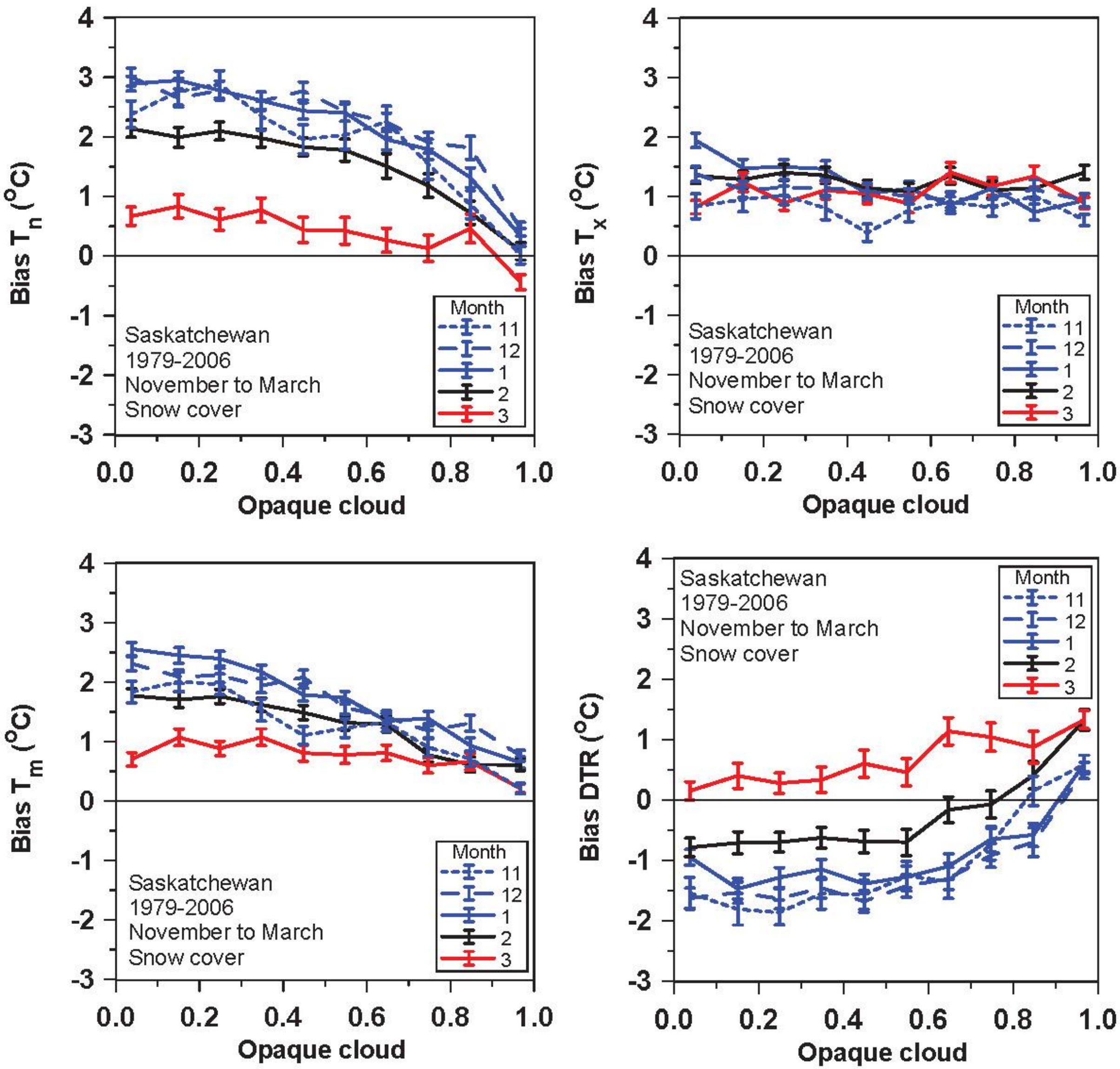
ERA-Interim Biases (cold)



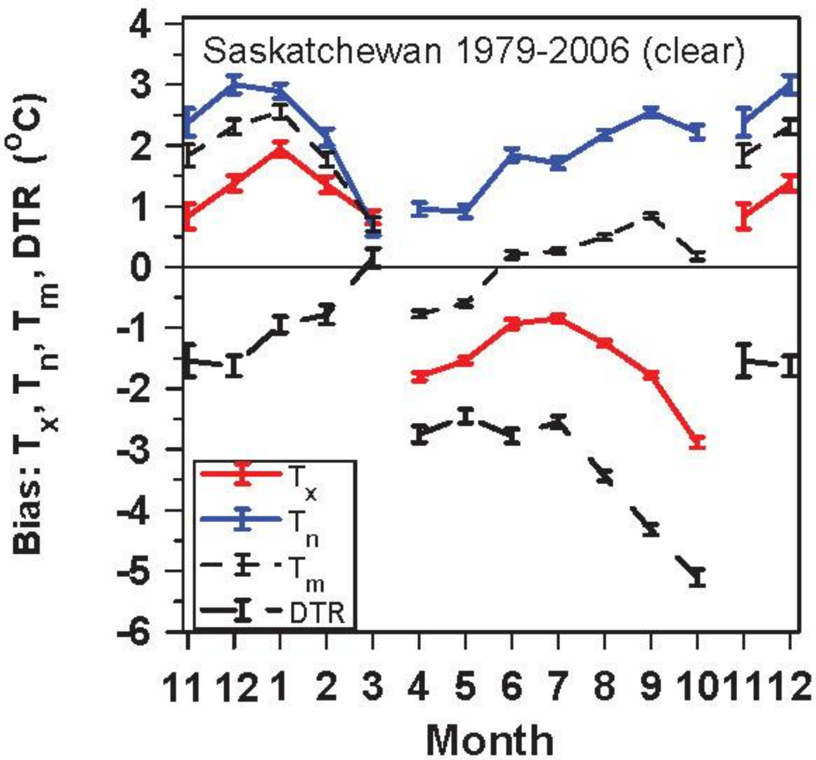
- **Cold season (snow cover)**
  - ***T_n T_m T_x all warm; DTR too small***

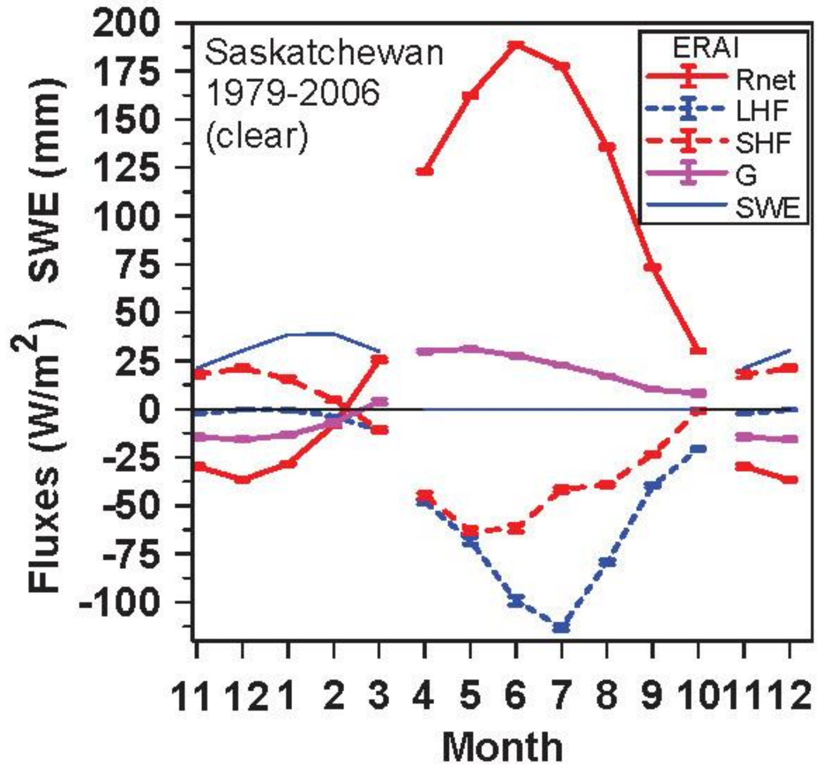
Monthly (cold)

- Monthly cloud
- bias:T_n large + drop in March
- bias:T_x flat +
- bias:DTR small reverses sign in March
- DIFFERENT from warm season
- Stable BL



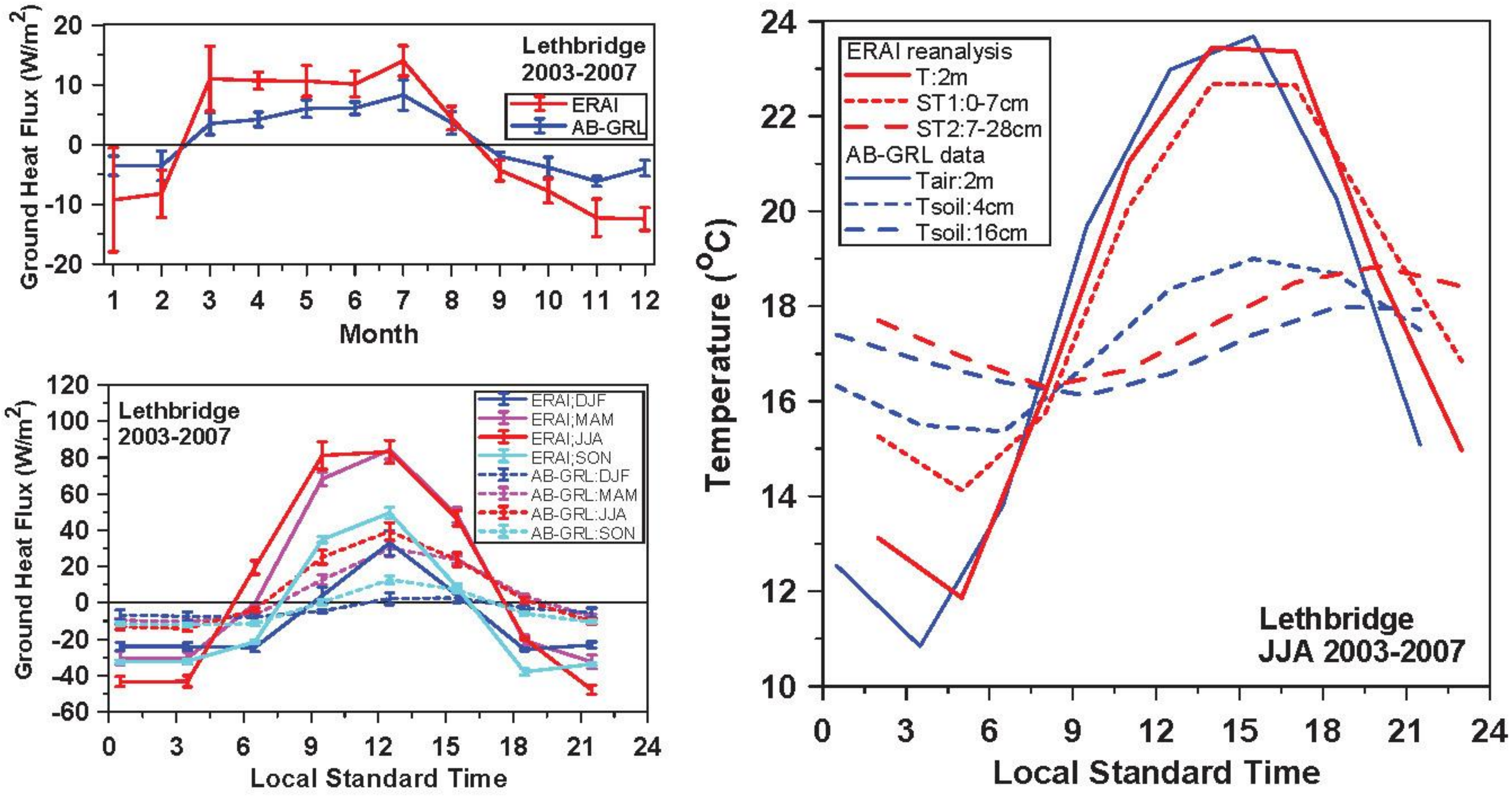
Clear-sky biases and fluxes; Reversals with snow





- **Biases largest under clear skies: not radiation error**
  - **Bias:T_x largest discontinuity: + winter peak; - spring/fall**
  - **Bias:T_n + winter max, spring min**
  - **Bias:T_m + winter, - to + in warm season**

Ground coupling too strong? Lethbridge FLUXNET



- **Diurnal and seasonal ground flux in ERA-I too large**
- **Ground temperatures too warm in summer**

Bias Issues

- Stable BL: bias:T_n positive
  - Winter bias:T_x also +
  - High bias in diurnal and seasonal G?
  - Stable BL mixing
- Unstable BL: bias:T_x negative
  - High bias in diurnal and seasonal G?
  - Lack of seasonal LAI: increases negative bias:T_x spring and fall
  - Unstable BL roughness/mixing?

ERA-Interim biases

- ***Linked to cloud radiative forcing***
- ***Seasonal shifts***
  - ***stable to unstable BLs with snow***
- ***Qualitatively linked to bias in ground fluxes and LAI and BL formulation and ??***
- ***Importance?***
  - ***Agricultural models use seasonal forecasts and reanalysis: need to remove model biases***
  - ***Model biases need fixing***
  - ***ERA5 better: probably not?***
- ***DATA, DATA, DATA essential***

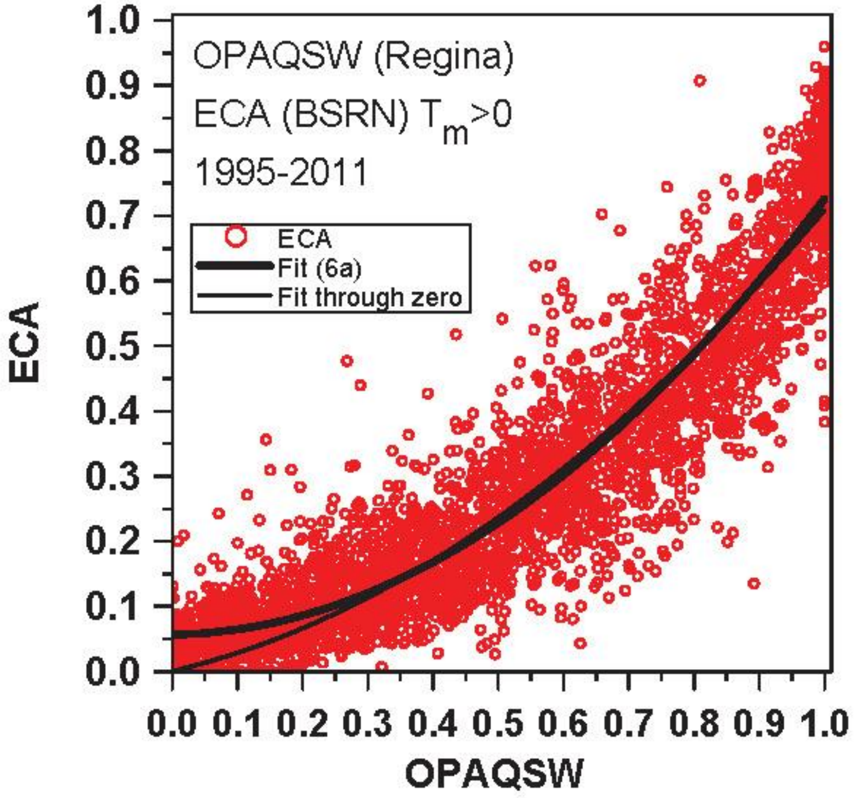
Conclusions

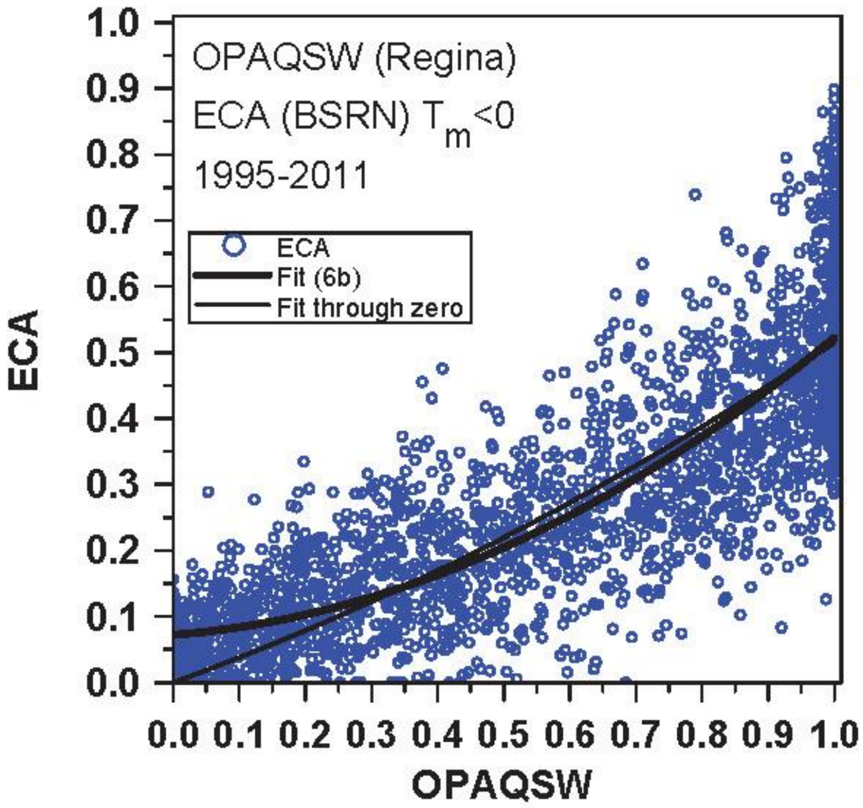
- **Comparing Canadian Prairies with their representation in the ECMWF model**
  - ***Model biases in stable and unstable BLs vary with season and cloud cover***
  - ***Snow transitions give step changes in model biases***
  - ***It is clear that the balance between ground coupling and turbulent transports for stable BLs is poorly modeled, because it is poorly known***

Suggestions

- **What observations are needed to make meaningful progress in understanding and modeling global BLs?**
- **Routine data that can be used in global data analysis**
  - **Very few routine measurements of the surface fluxes and BL structure**
  - **Satellite observations poorly sample the near-surface BL, so that the coupled BL structure is modeled using ‘historic’ parameterizations**
  - **SYNOP stations could add Doppler lidar profilers, giving profiles to 100m (useful also for wind turbines)**
  - **SYNOP stations could measure net radiation, and add a temperature observation at the top of the 10 m wind mast. This would give the (2m-10m) temperature gradient, and give observational input to the model MO fit to the surface fluxes**
  - **Workshop will suggest others!**

SW calibration





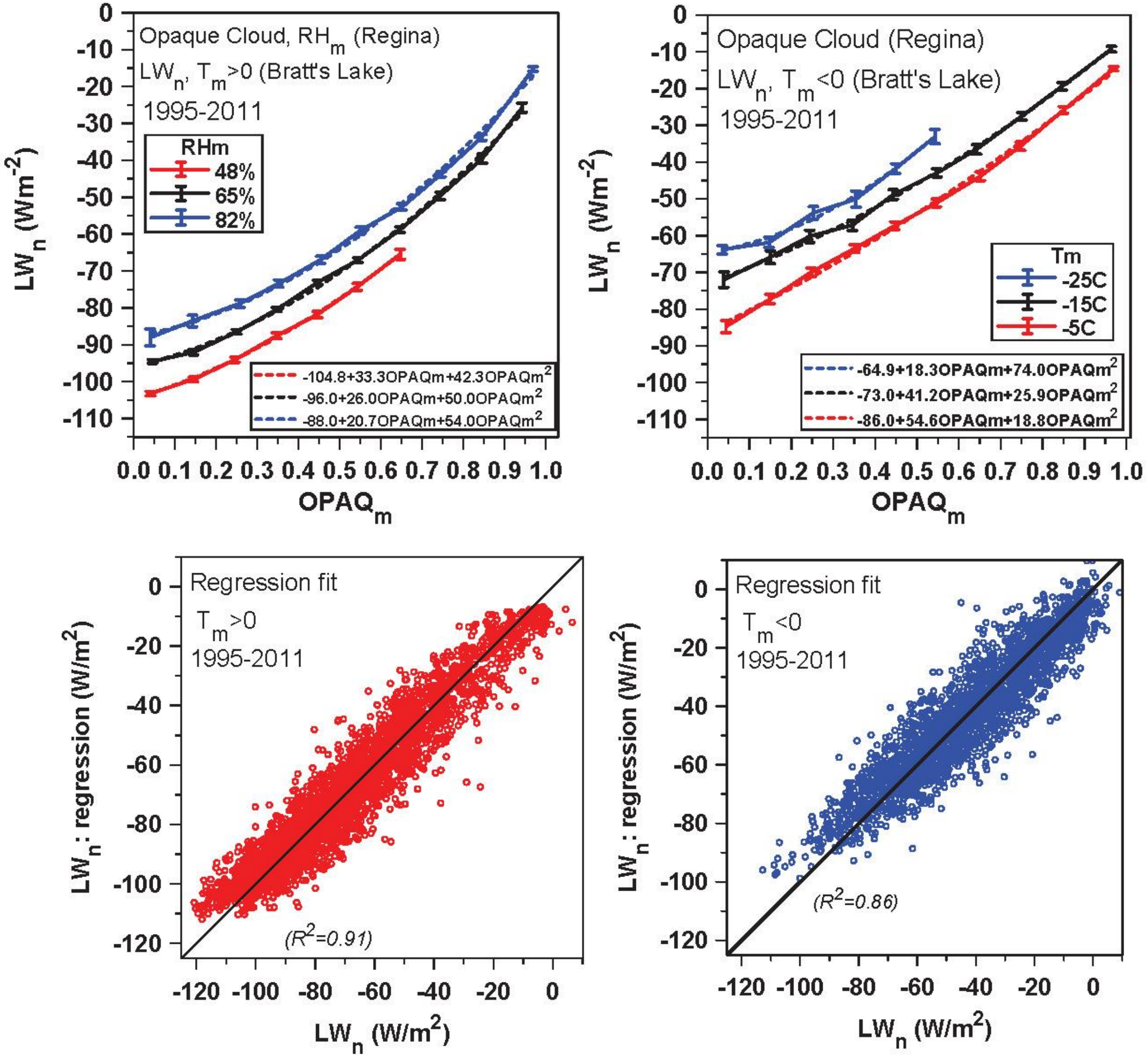
- *Contrast simple quadratic fit with fit through zero*
- *Uncertainty at low opaque cloud end*
  - *Thin cirrus not opaque*

Use BSRN data to “calibrate” daily opaque/reflective Cloud at Regina

- **Daily mean opaque cloud $OPAQ_m$**
- ***LW cools but clouds reduce cooling***
- **Net LW: LW_n**
  - *T>0: RH dependence*
  - *T<0: T, TCWV also*
- ***Regression gives LW_n to ± $8W/m^2$ for T_m>0 (R^2=0.91)***

(Betts et al. 2015)

Warm>0°C **Cold<0°C**



April: Multiple Regression on Cloud and Lagged Precipitation

1953-2010: 12 stations (620 months)

Variable R^2 =	δDTR 0.67	δT_x 0.47	δRH_n 0.65	δP_{LCLx} 0.66	
Cloud-Apr	-0.52±0.02	-0.78±0.04	0.76±0.03	-0.93±0.04	Dominant
PR-Apr	-0.06±0.02	(0.01±0.04)	0.20±0.03	-0.19±0.04	
PR-Mar	-0.12±0.02	-0.22±0.04	0.23±0.03	-0.27±0.03	
PR-Feb	-0.07±0.02	-0.12±0.04	0.16±0.03	-0.19±0.03	
PR-Jan	-0.09±0.02	-0.19±0.04	0.17±0.03	-0.21±0.03	
PR-Dec	-0.06±0.02	(-0.06±0.04)	0.16±0.03	-0.19±0.03	
PR-Nov	-0.08±0.02	-0.13±0.04	0.07±0.03	-0.11±0.03	

April remembers precip. back to freeze-up

Summer Precip Memory back to March

***JULY* 1953-2010: 12 stations (614 months)**

JULY R^2	δDTR 0.68	δRH_n 0.61	δP_{LCLx} 0.62	δQ_{Tx} 0.26
Cloud-July	**-0.56±0.03**	**0.50±0.03**	**-0.63±0.04**	(0.03±0.04)
PR-July	**-0.31±0.02**	**0.37±0.03**	**-0.45±0.04**	**0.34±0.04**
PR-June	**-0.22±0.02**	**0.34±0.03**	**-0.44±0.04**	**0.38±0.04**
PR-May	**-0.12±0.02**	**0.11±0.03**	**-0.16±0.04**	**0.16±0.04**
PR-Apr	-0.04±0.02	0.06±0.03	-0.06±0.03	**0.12±0.04**
PR-Mar		0.06±0.03	-0.07±0.03	**0.10±0.04**

June, July, Aug have precip memory back to March

Warm Season Diurnal Climatology

- **Averaging daily values (Conventional)**

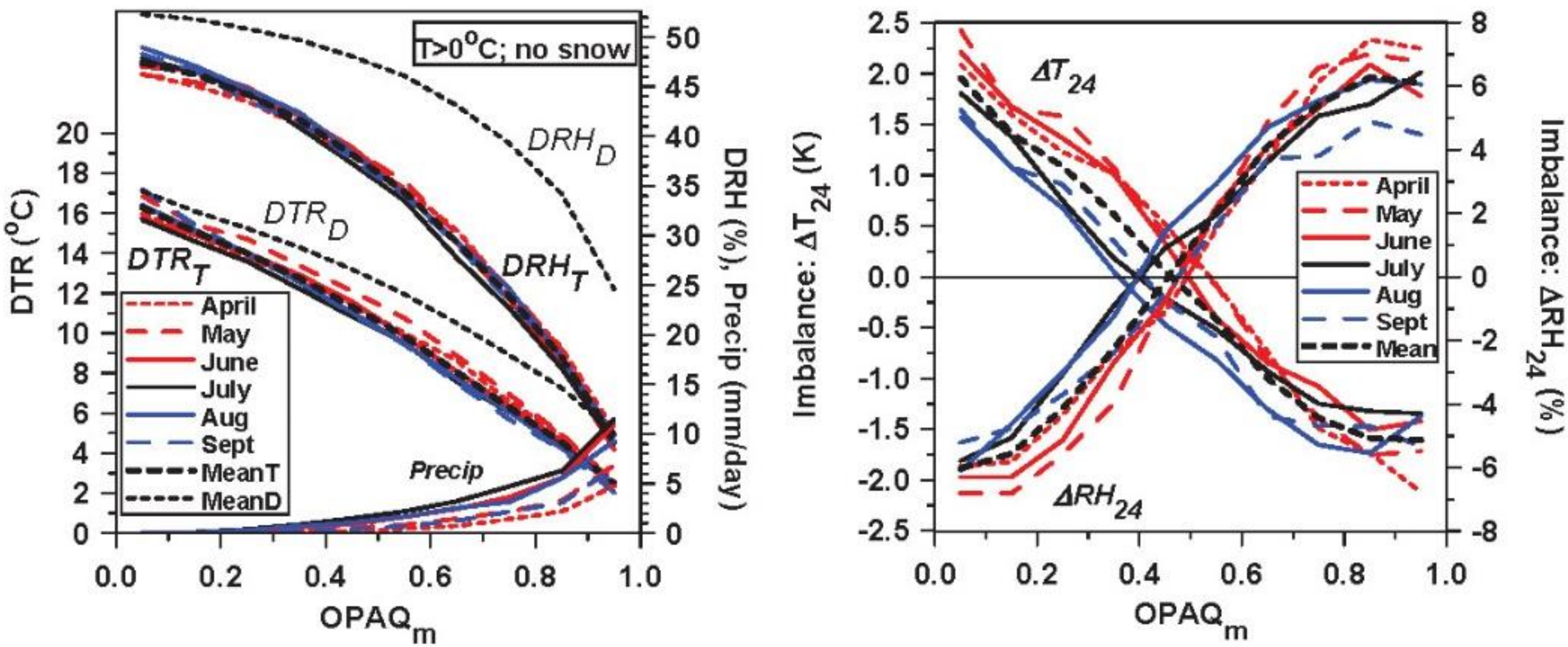
  $$DTR_D = T_{xD} - T_{nD}$$
  $$DRH_D = RH_{xD} – RH_{nD} \text{ (rarely)}$$

- **Extract mean diurnal ranges from composites *('True' radiatively-coupled diurnal ranges: damps advection)***

  $$DTR_T = T_{xT} - T_{nT}$$
  $$DRH_T = RH_{xT} – RH_{nT}$$

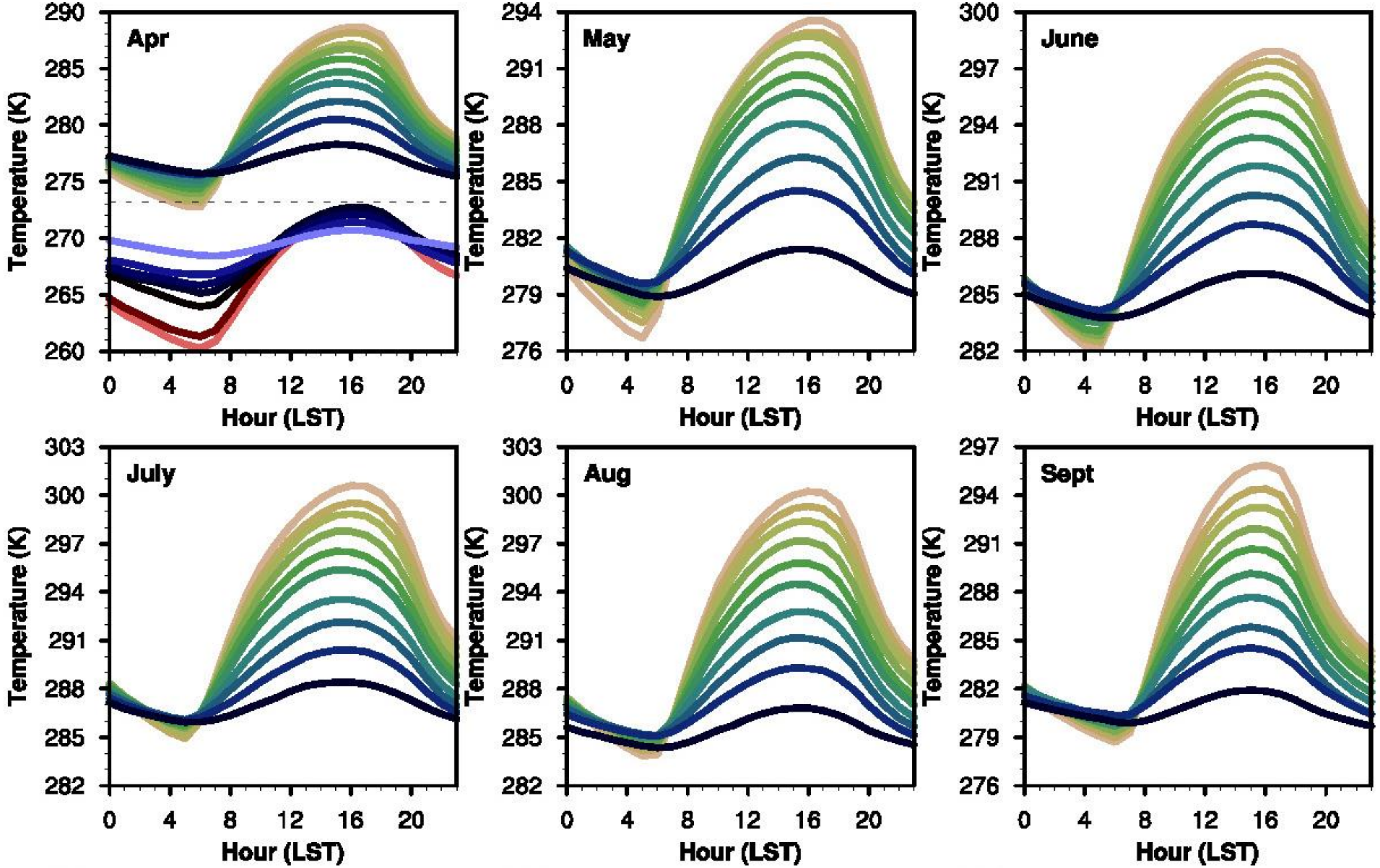
- **Q1: How are they related? $DTR_T < DTR_D$**

Diurnal Ranges & Imbalances



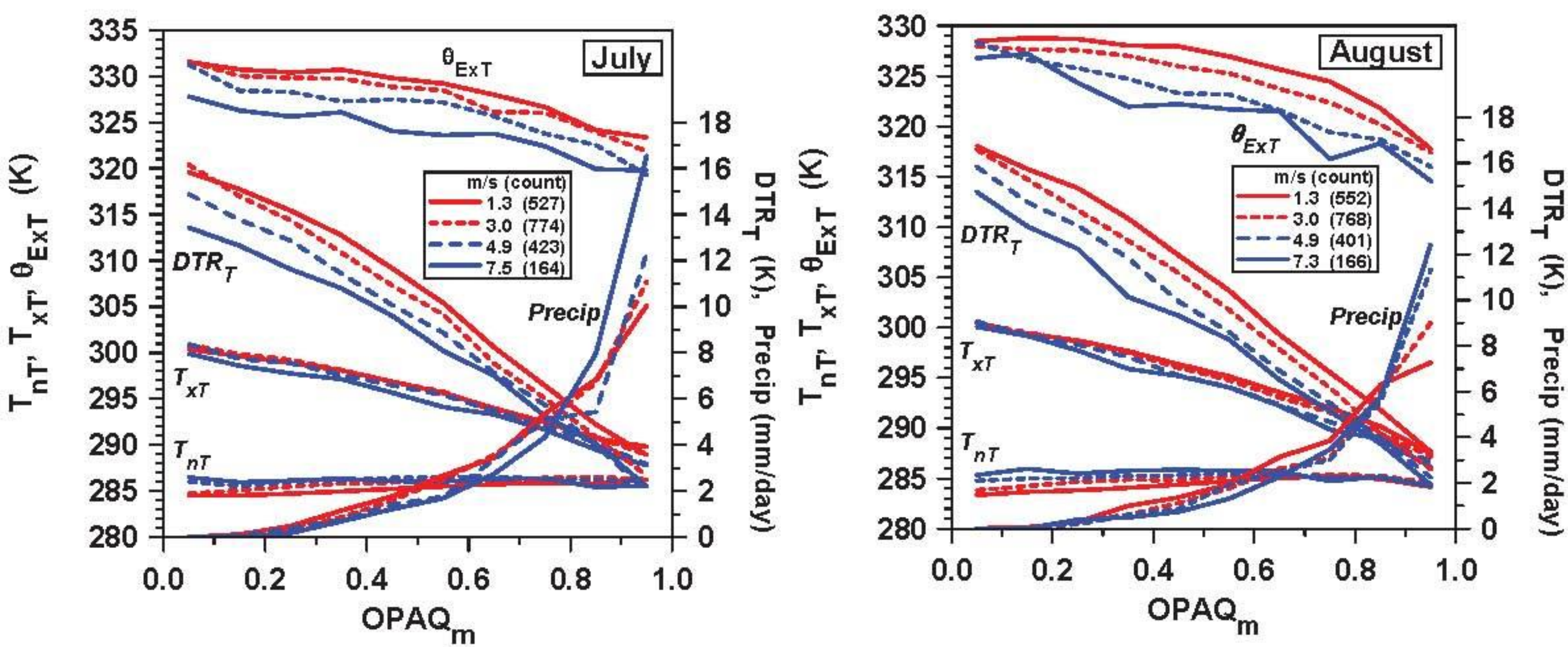
- April to Sept: <u>same coupled structure</u>
- Q1: DTR_T, DRH_T < DTR_D, DRH_D <u>always</u>
- Q2: Clear-sky: warmer (+2^{o}C), drier (-6%)

Monthly Diurnal Climatology:
Dependence on opaque cloud



Q: How much warmer is it at the end of a clear day?

Monthly Diurnal Climatology:
Wind and Cloud Dependence



Low wind: Larger T_x, cooler T_n; larger DTR_T

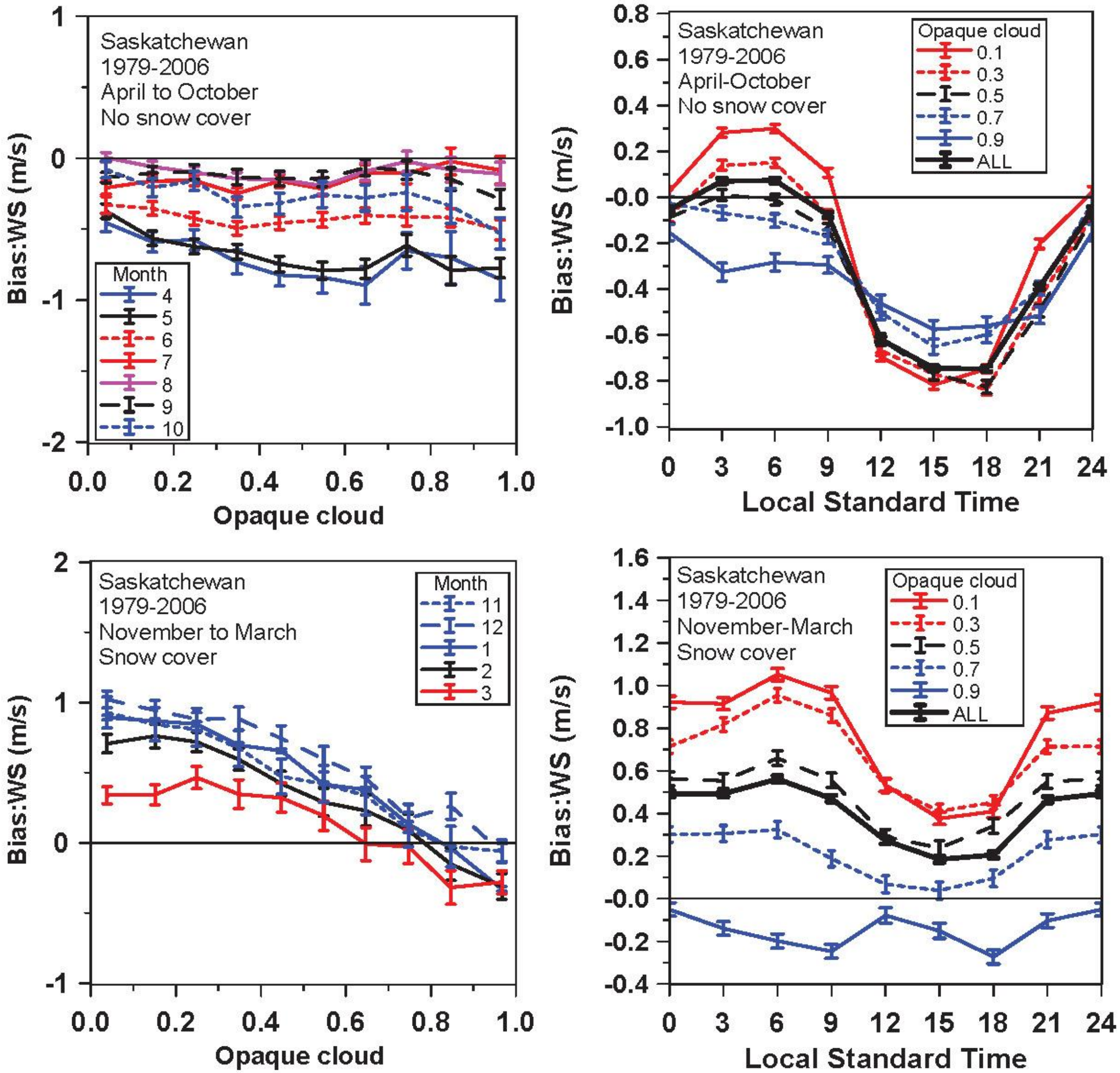
- Peaks mid-summer

- Warmer : θ_E (+4K) note flat at low cloud

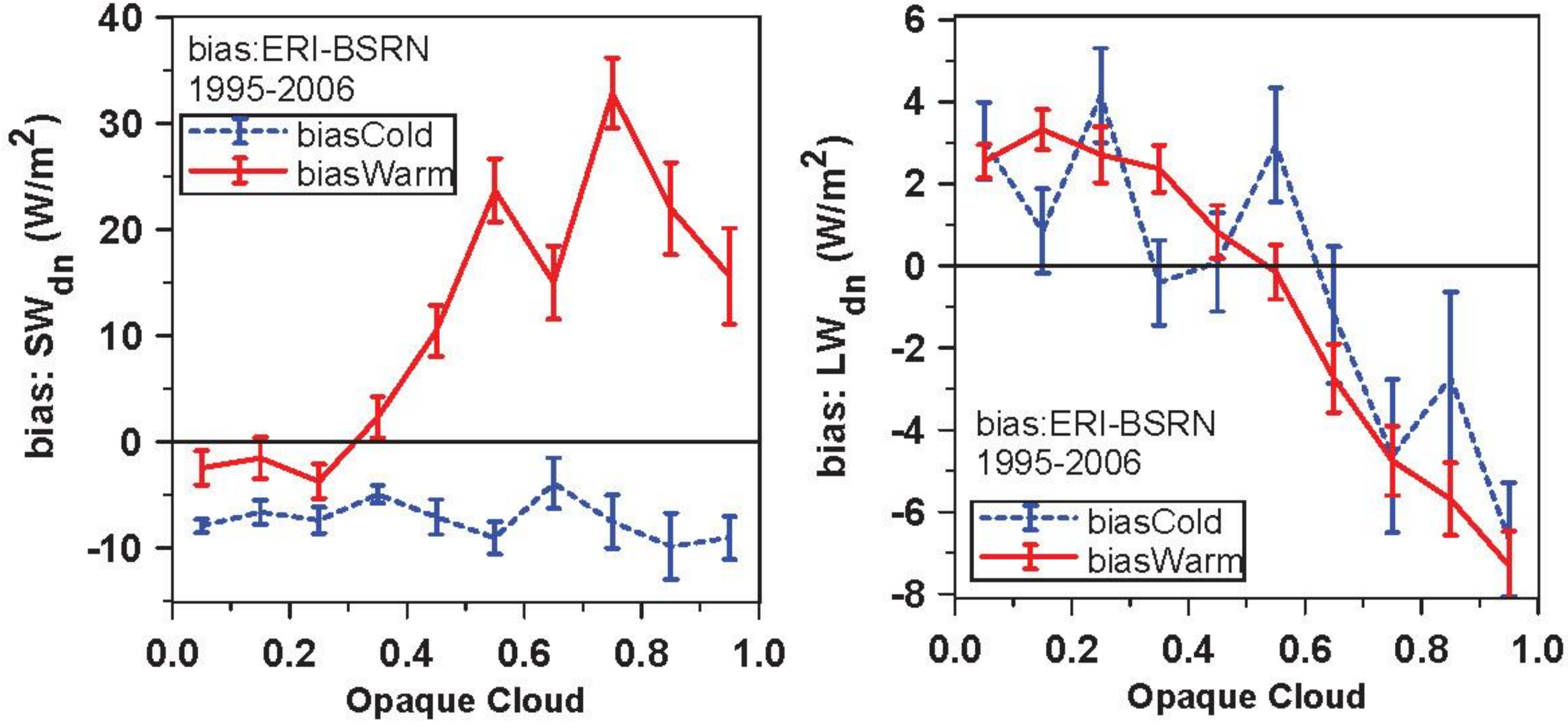
- Note coupling to Precip

Wind biases

- Negative in warm season
- Positive in cold season
- SMALL
- Diurnal structure larger under clear skies



Radiation Biases (BSRN)



- **Small under clear skies**
  - ***Bias:LW_{dn} small***
  - ***Bias: SW_{dn} too little cloud when cloudy***

Boreal forest

56% tall veg

- **Warm: smaller than Prairies**
- **Cold: bias:T_x T_m T_n similar; DTR near zero**