Seasonal analysis of near-surface biases in ERA-Interim

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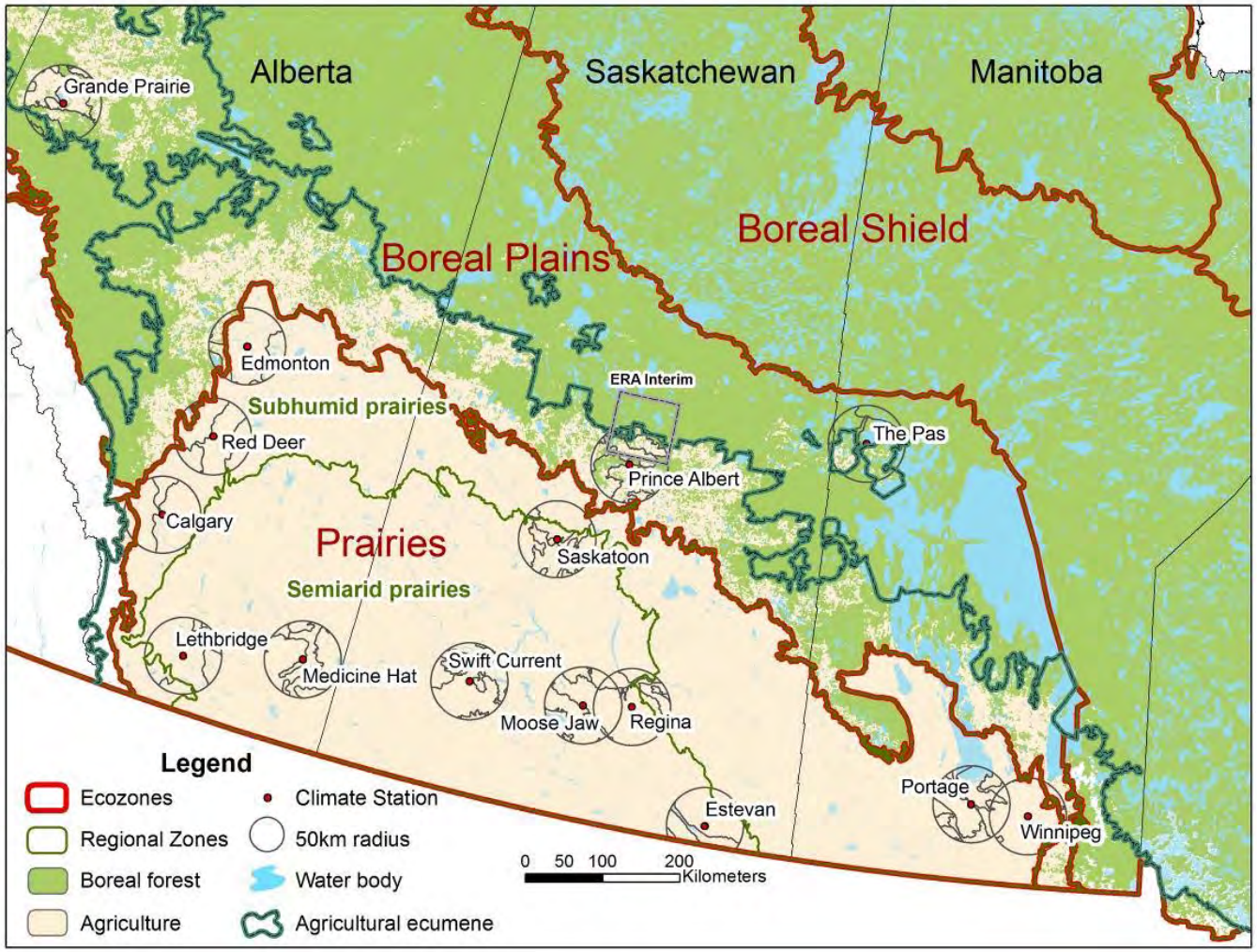
Outline

- ***Background:*** ***Remarkable 55-yr hourly Prairie data set with opaque/reflective cloud observations***
- **Northern latitude climate**
  - **Large seasonal cycle**
    - **Snow is a fast climate switch**
    - **Two separate “climates” - above and below the freezing point of water**
  - **Observational evaluation of reanalysis**
  - **By cloud and seasonal regime**

15 Prairie stations: 1953-2011



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

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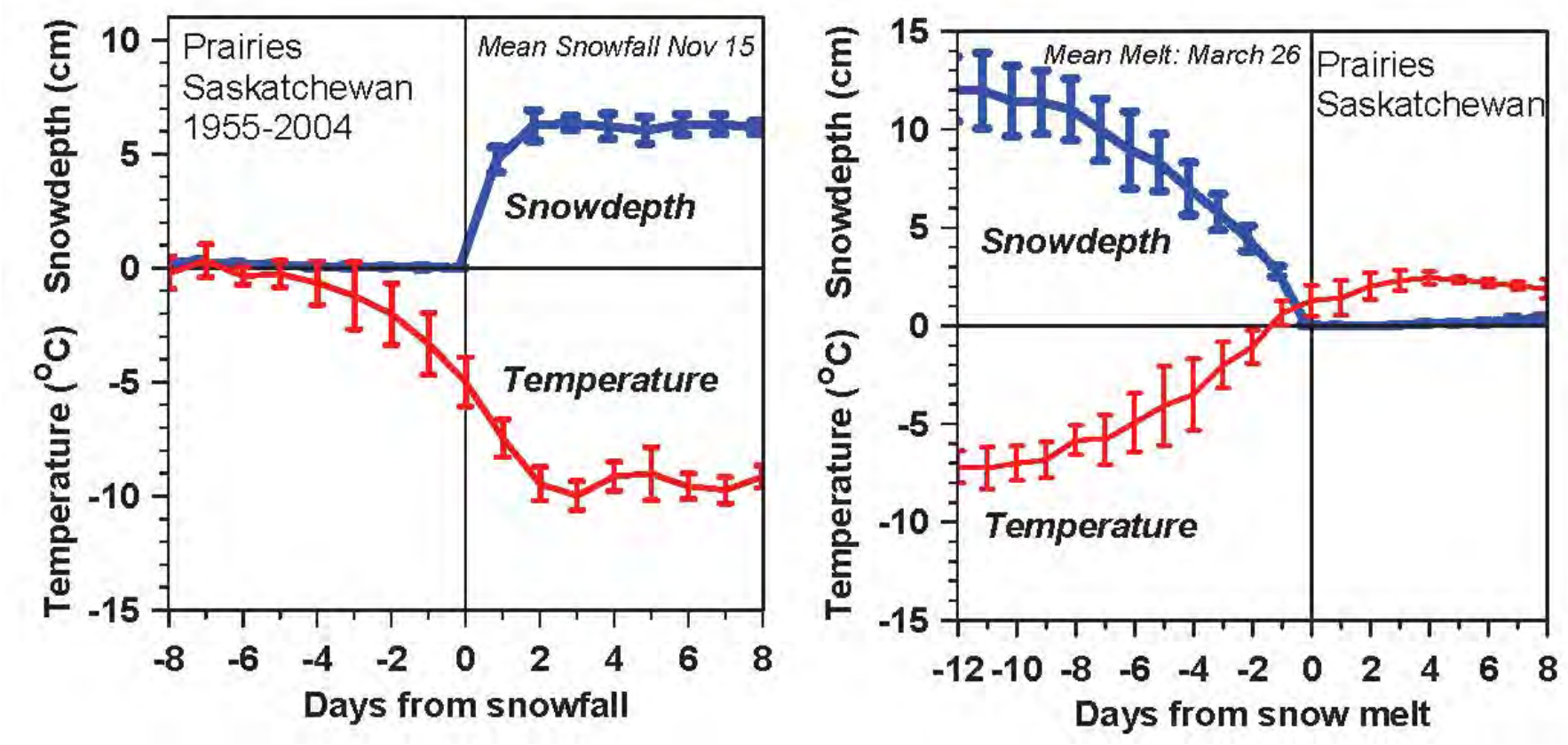
- Betts, A.K., R. Desjardins and D. Worth (2013a), Cloud radiative forcing of the diurnal cycle climate of the Canadian Prairies. *J. Geophys. Res. Atmos., 118,* 1–19, doi:10.1002/jgrd.50593
- Betts, A. K., R. Desjardins, D. Worth, and D. Cerkowniak (2013), Impact of land use change on the diurnal cycle climate of the Canadian Prairies, J. Geophys. Res. Atmos., 118, 11,996–12,011, doi:10.1002/2013JD020717.
- Betts, A.K., R. Desjardins, D. Worth, S. Wang and J. Li (2014), Coupling of winter climate transitions to snow and clouds over the Prairies. *J. Geophys. Res. Atmos*., 119, doi:10.1002/2013JD021168
- Betts, A.K., R. Desjardins, D. Worth and B. Beckage (2014), Climate coupling between temperature, humidity, precipitation and cloud cover over the Canadian Prairies. J. Geophys. Res. Atmos. 119, 13305-13326, doi:10.1002/2014JD022511
- Betts, A.K., R. Desjardins, A.C.M. Beljaars and A. Tawfik (2015). Observational study of land-surface-cloud-atmosphere coupling on daily timescales. Front. Earth Sci. 3:13. http://dx.doi.org/10.3389/feart.2015.00013
- Betts, AK and A.B. Tawfik (2016) Annual Climatology of the Diurnal Cycle on the Canadian Prairies. Front. Earth Sci. 4:1. doi: 10.3389/feart.2016.00001
- Betts, A. K., R. Desjardins and D. Worth (2016). The Impact of Clouds, Land use and Snow Cover on Climate in the Canadian Prairies. Adv. Sci. Res., 1, 1–6, doi:10.5194/asr-1-1-2016
- Betts, A.K., A.B. Tawfik and R.L. Desjardins (2017): Revisiting Hydrometeorology using cloud and climate observations. *J. Hydrometeor., 18*, 939-955.
- Betts, A. K. and A. C.M. Beljaars (2017): Analysis of near-surface biases in ERA-Interim over the Canadian Prairies. JAMES (in revision)

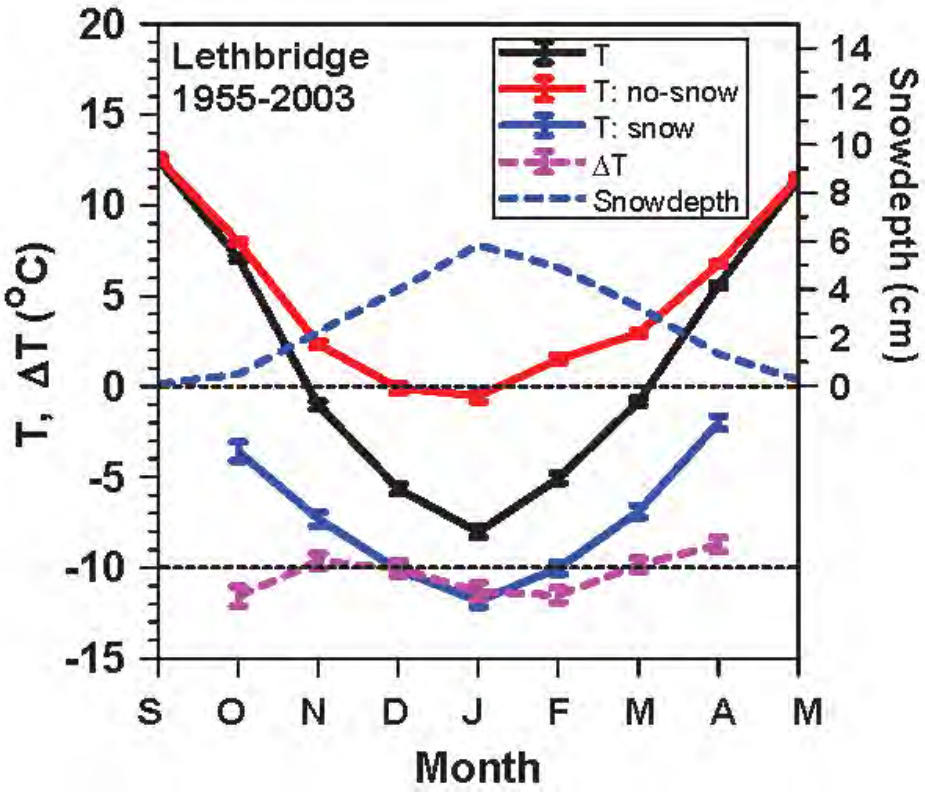
Snowfall and Snowmelt
ΔT Canadian Prairies

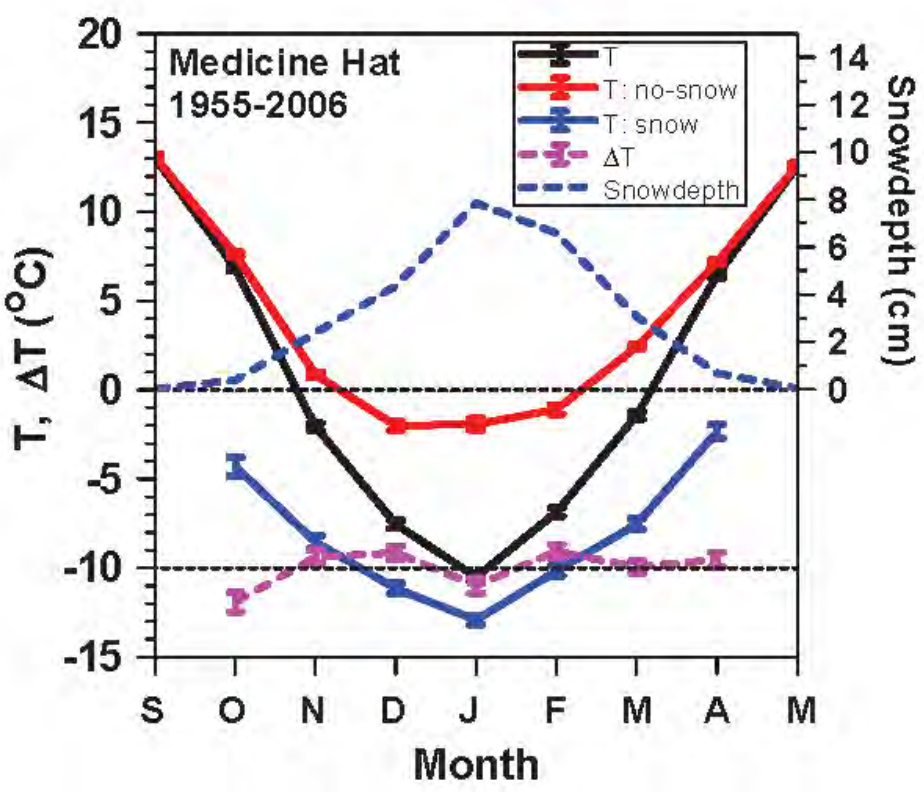


- **Temperature falls/rises 10K with first snowfall/snowmelt**
  - ***Local climate switch between warm and cold seasons***

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

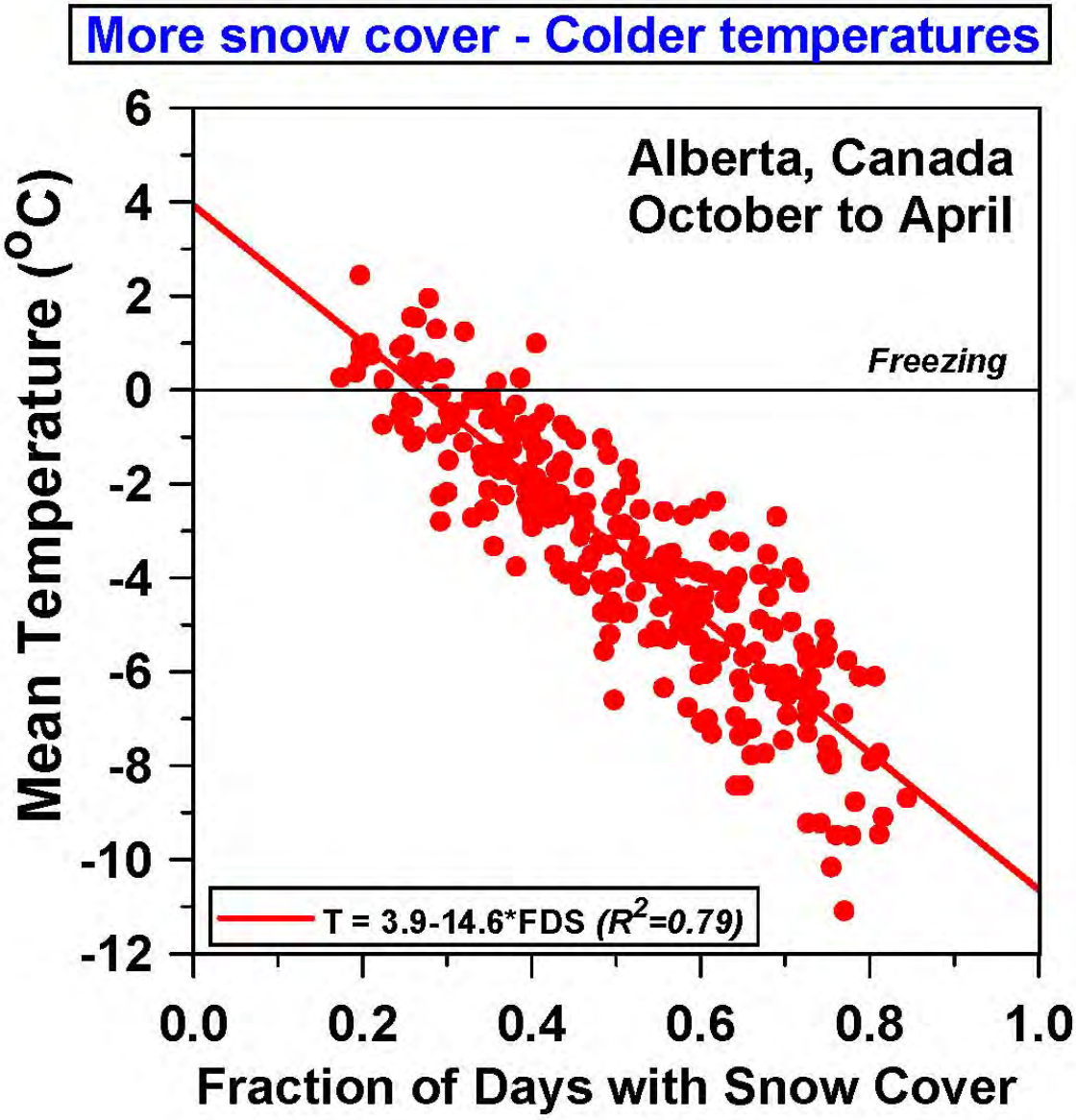
- **Alberta: 79% of variance**
- **Slope T_m - 14.7 (± 0.6) K**

10% fewer snow days

= 1.5K warmer

on Prairies

Snow: climate switch



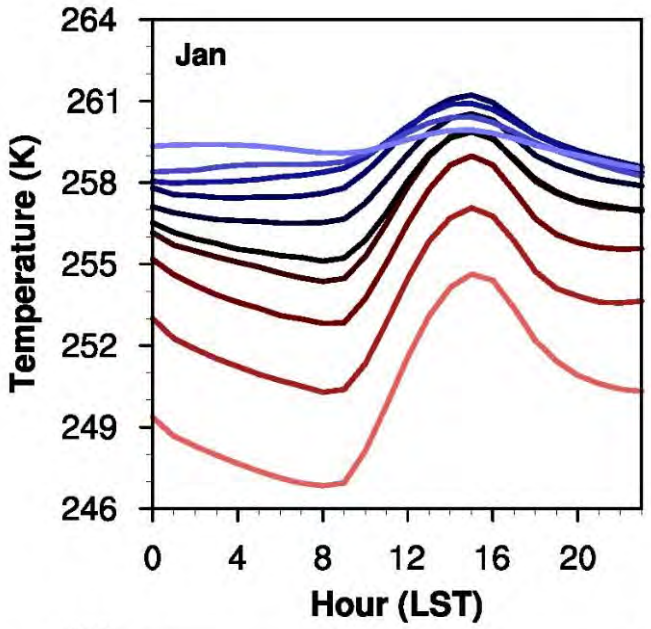
Diurnal cycle: Clouds & Snow

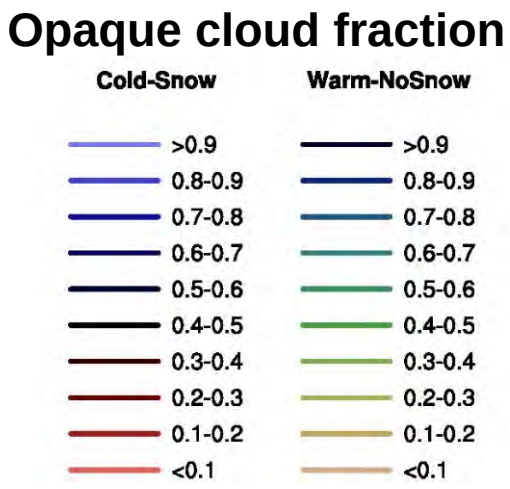
Canadian Prairies
660 station-years of data

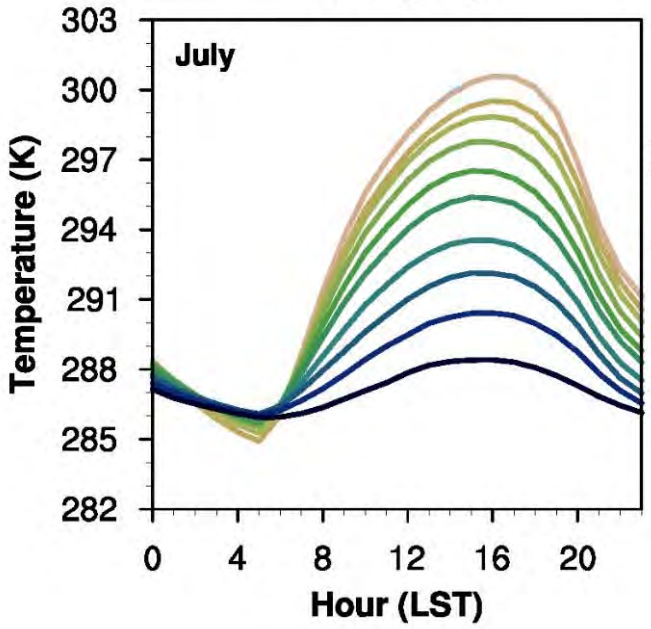
Winter climatology
- Colder when clear
- LWCF dominant with snow

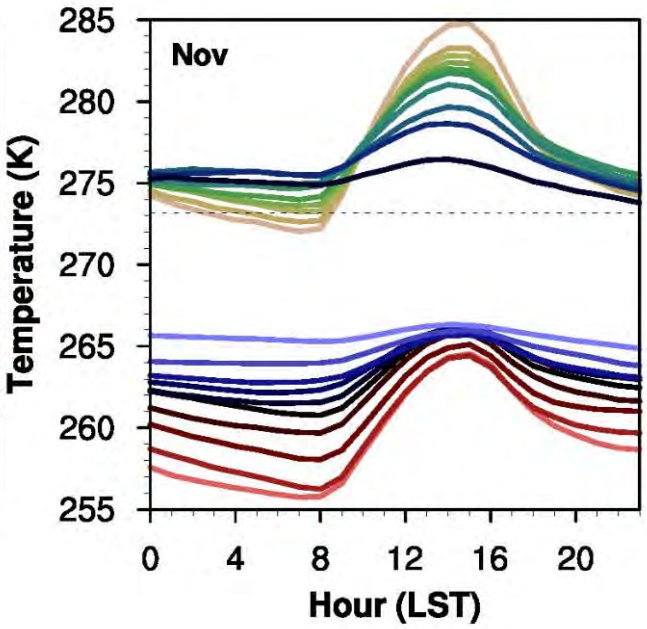
Summer climatology
- Warmer when clear
- SWCF dominant: no snow

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

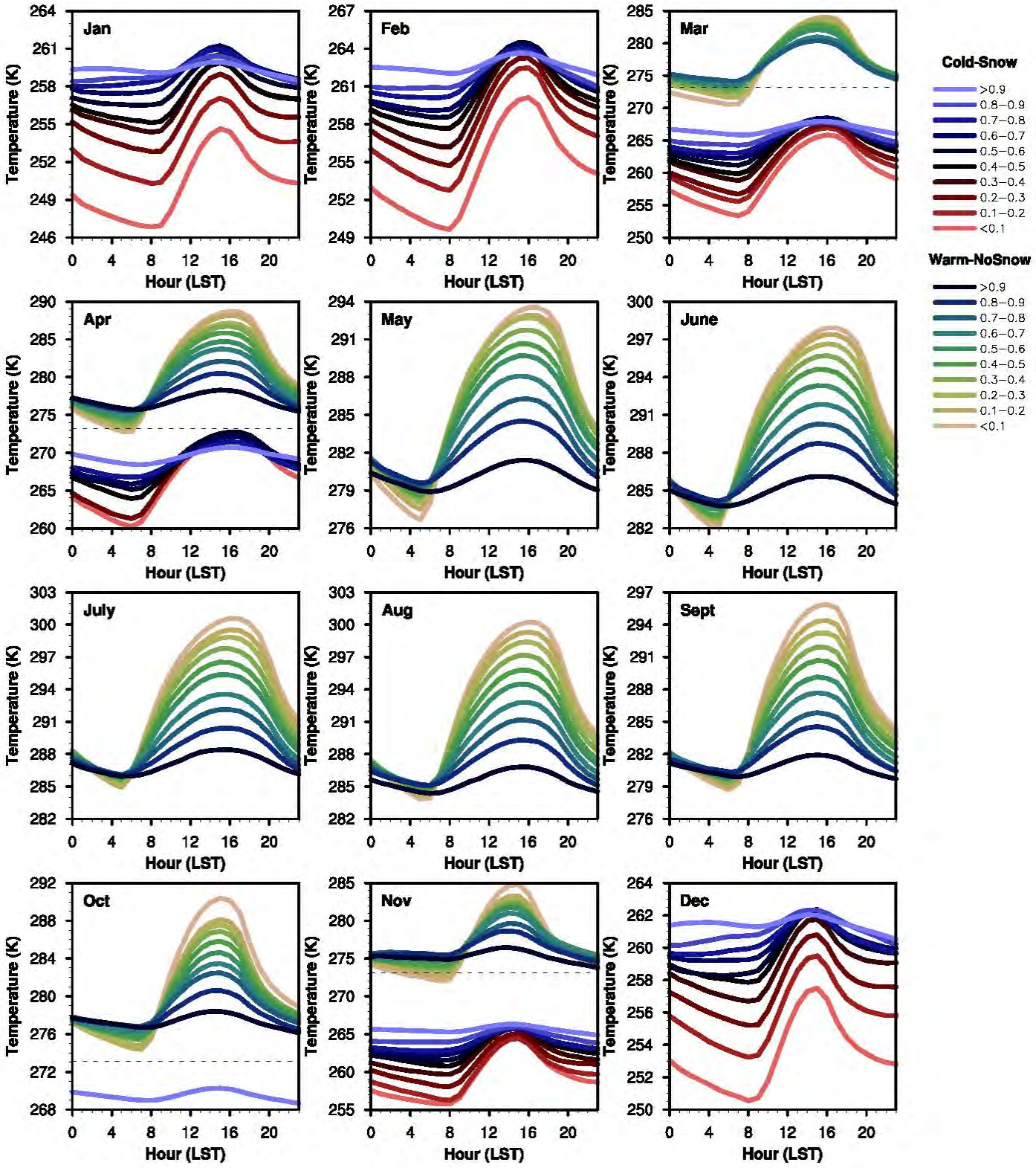








Monthly diurnal climatology (by snow and cloud)

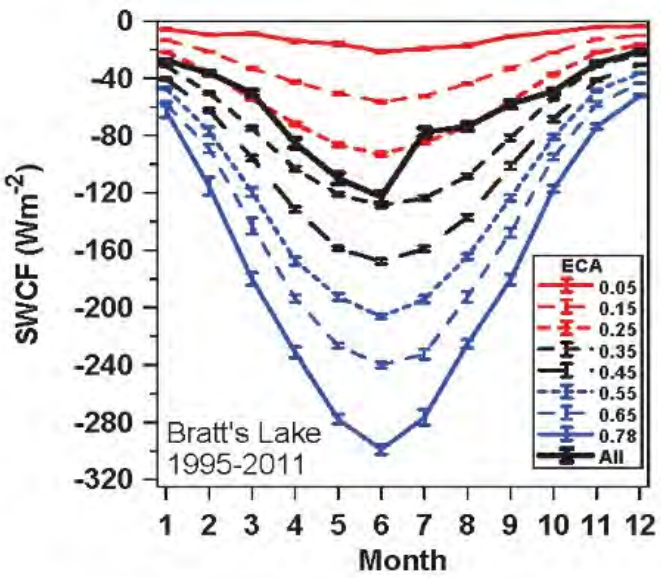


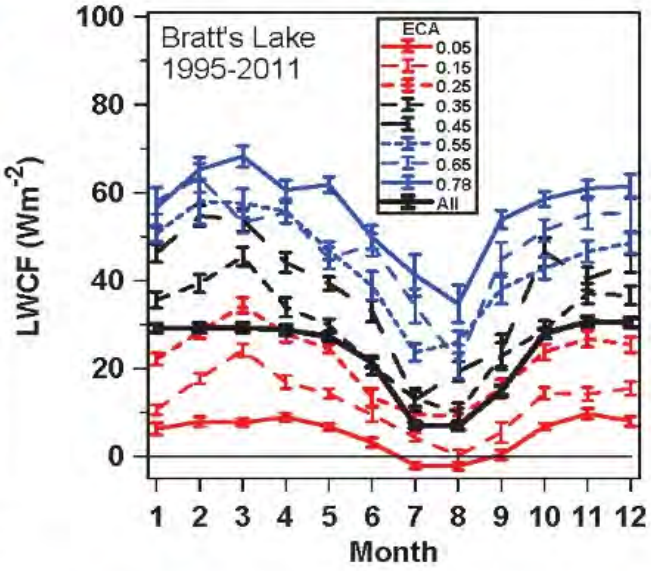
SW and LW 'Cloud Forcing'

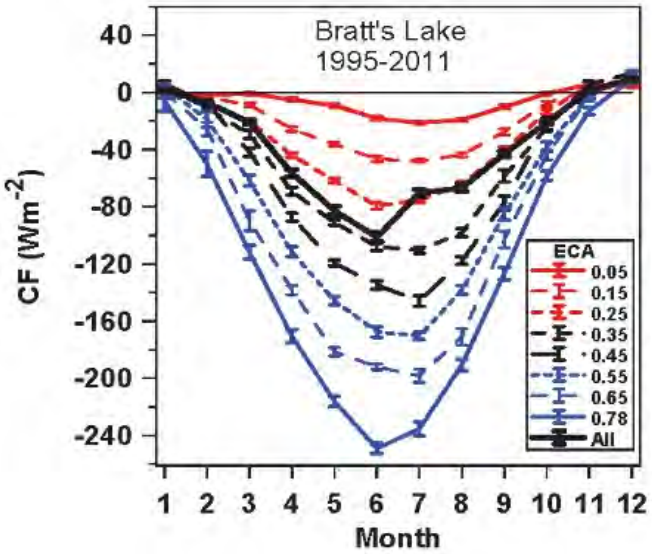
BSRN at Bratt's Lake, SK

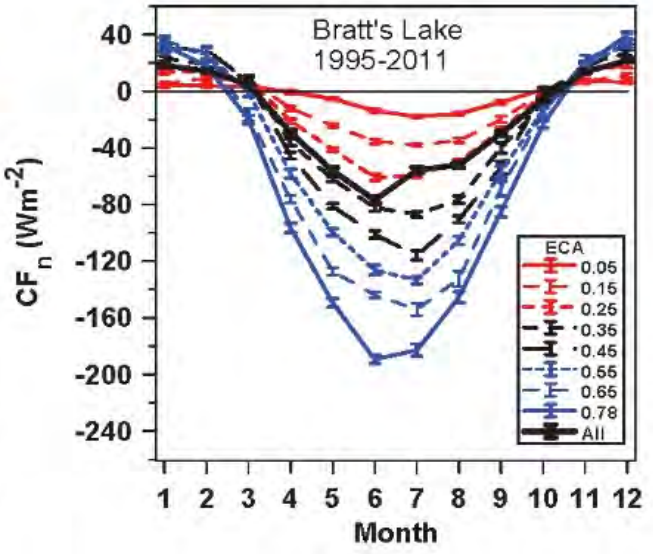
- **"Cloud Forcing"**
  - ***Change from clear-sky flux***
- **Clouds reflect SW**
  - ***SWCF***
  - ***Cool***
- ***Clouds trap LW***
  - ***LWCF***
  - ***Warms***
- ***Sum is CF***
- ***Surface albedo reduces SW_n***
  - ***Net is CF_n***
  - ***Add reflective snow, and CF_n goes +ve***
- ***Regime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

(Betts et al. 2015)







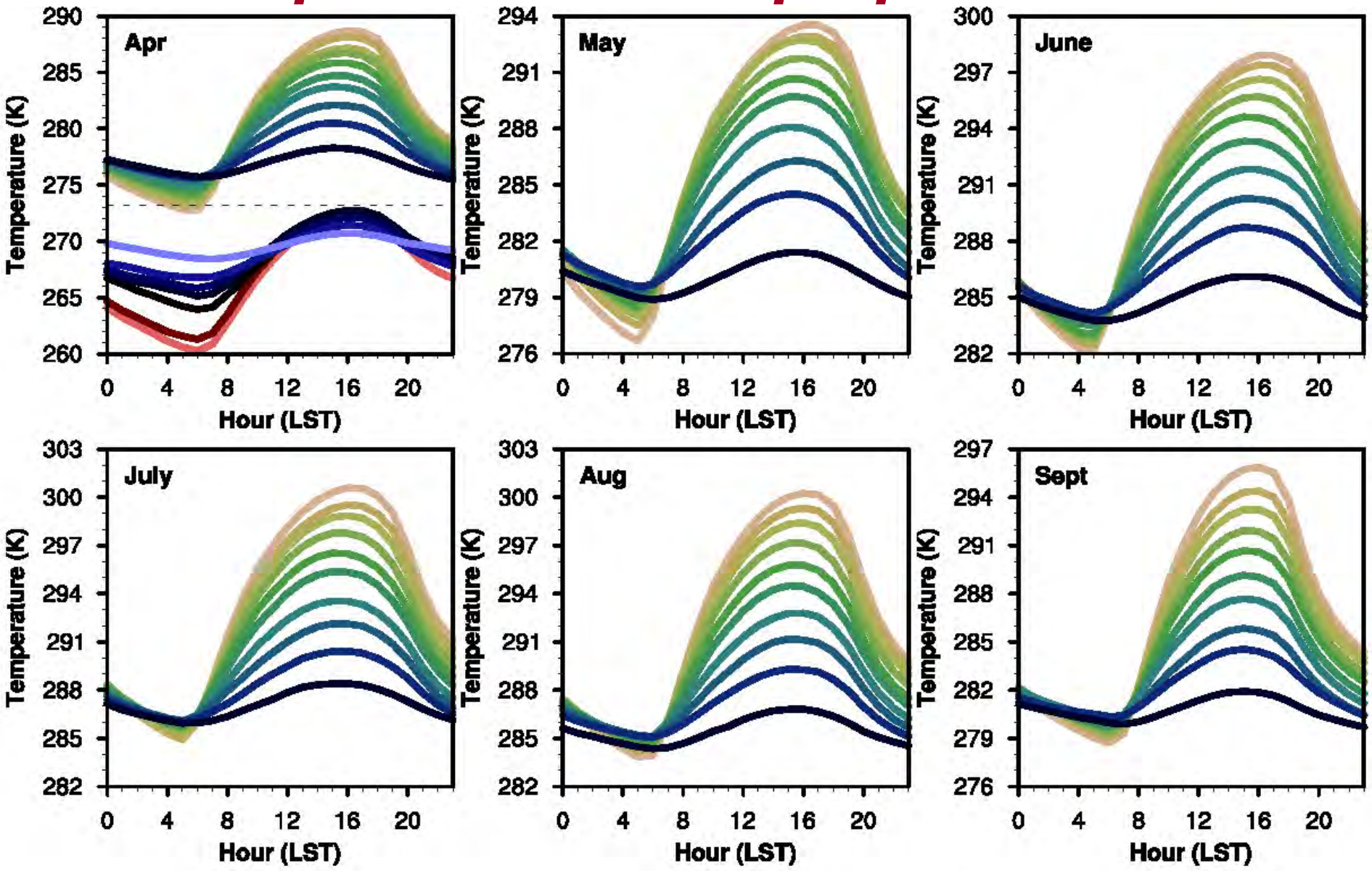


Impact of Snow

- **Distinct warm and cold season states**
- **Snow cover is the "climate switch"**
- **Prairies: ΔT = -10°C (winter albedo = 0.7)**
- **Vermont: ΔT = -6°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**
- **Don't average snow/no-snow climates**

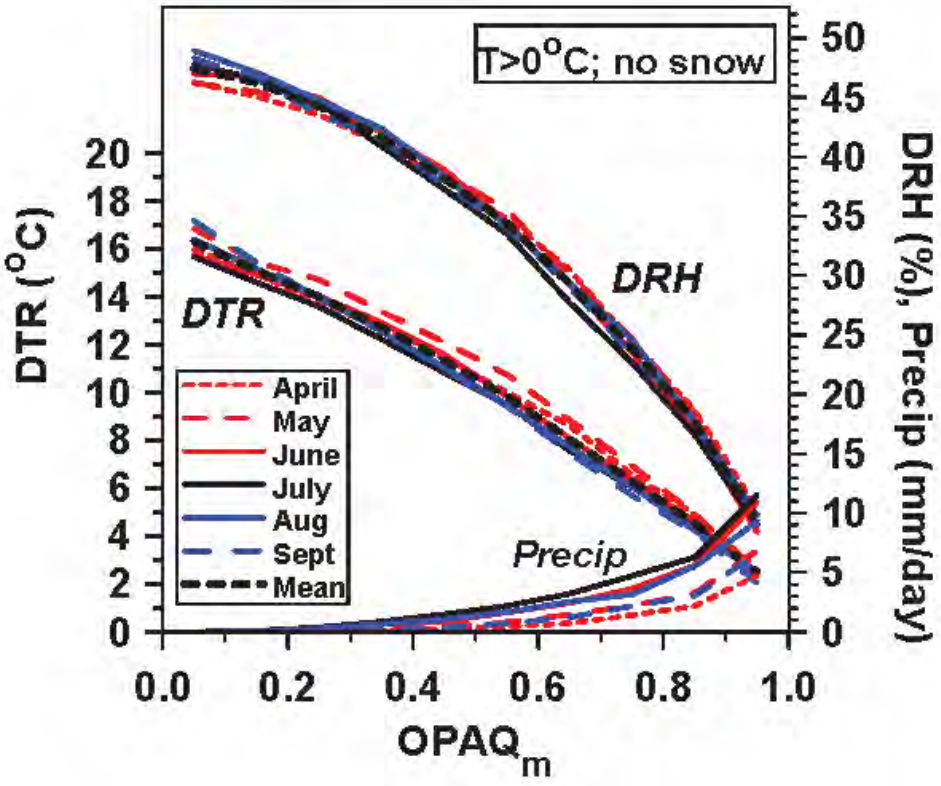
Monthly Diurnal Climatology:

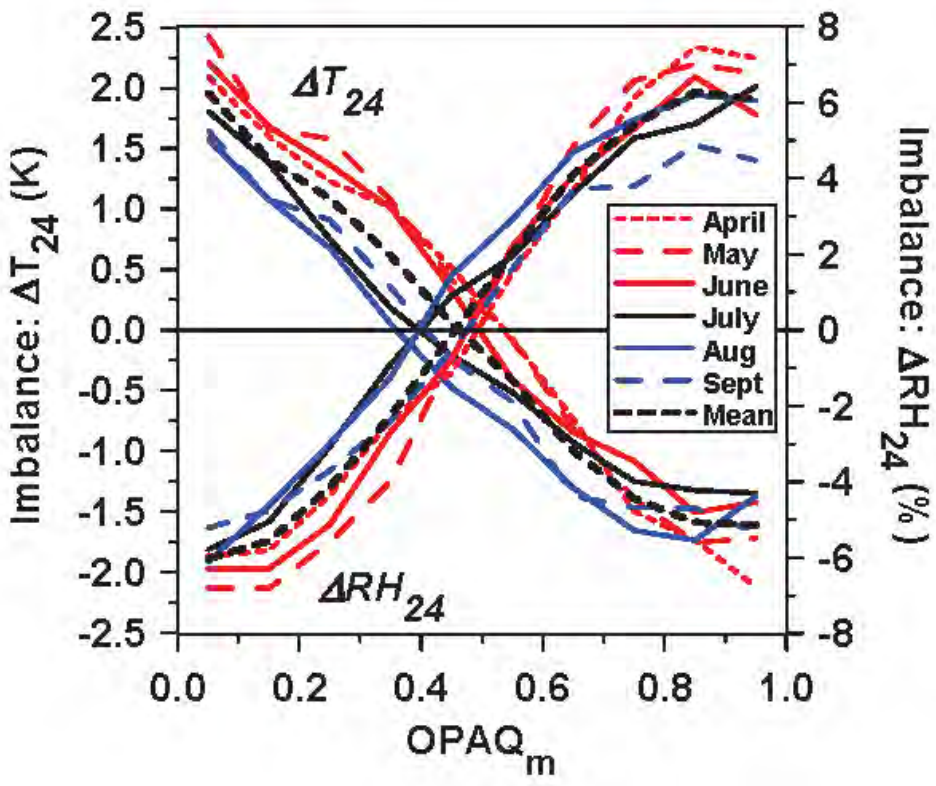
Dependence on opaque cloud



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

Diurnal Ranges & Imbalances





- **April to Sept: *same coupled structure***
- **Clear-sky: warmer (+2ºC), drier (-6%)**

(Betts and Tawfik 2016)

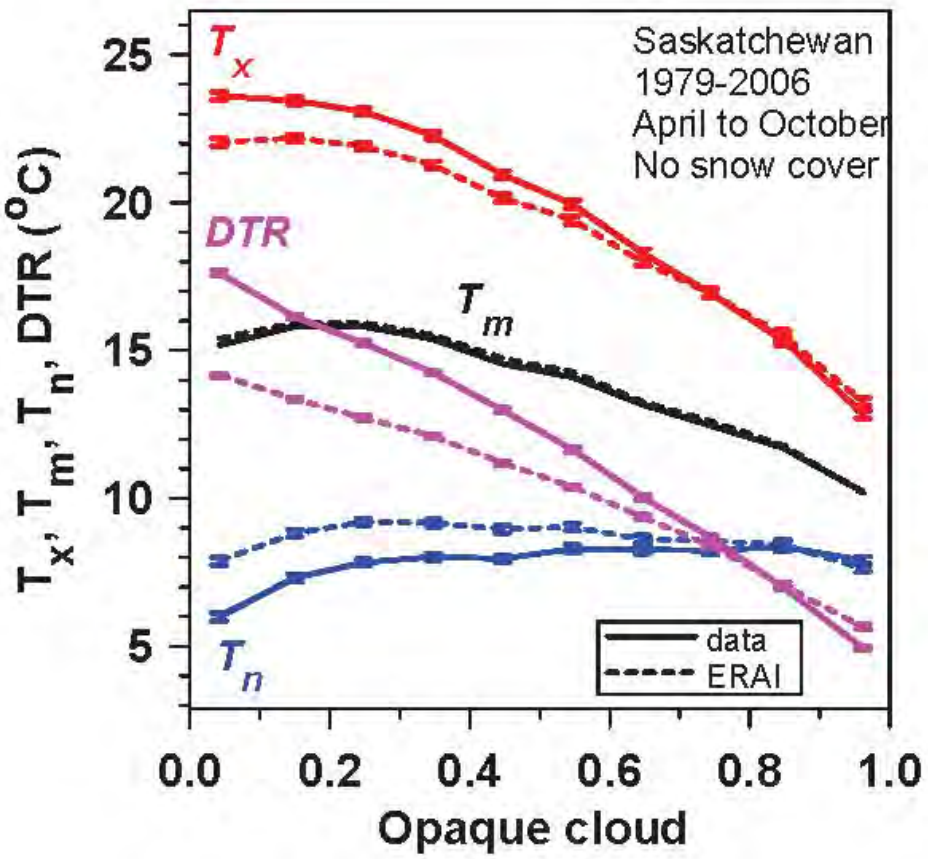
ERA-Interim 2-m Temperature Biases

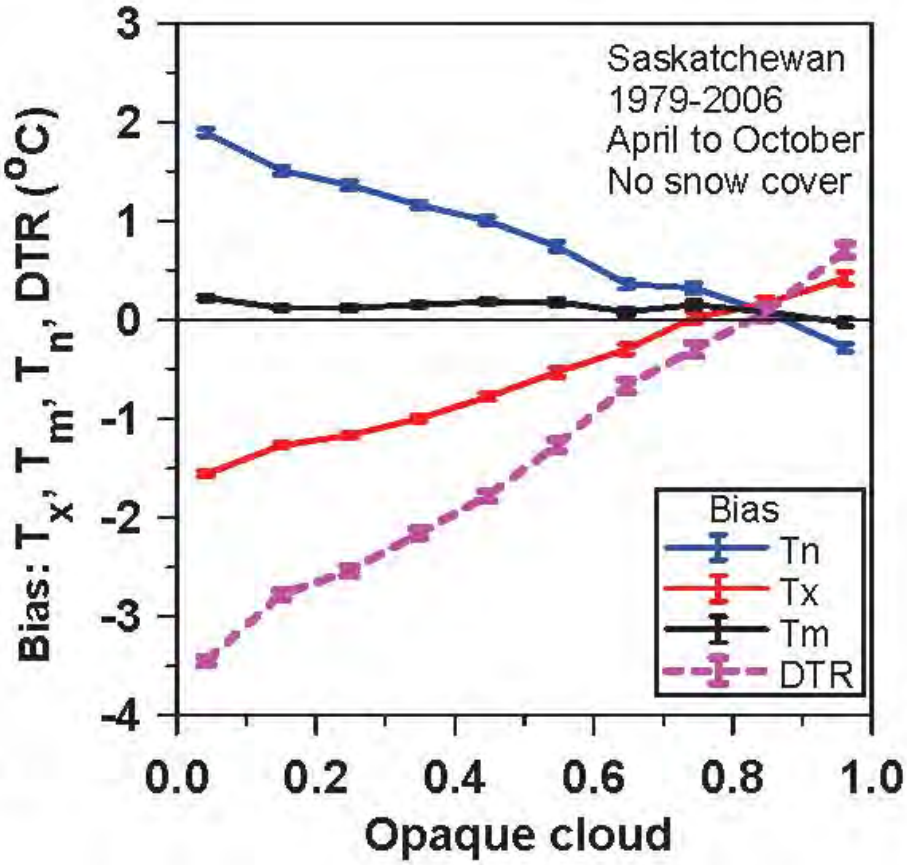
- **Referenced to data hourly data**
  - **Bias:T_x = T_x:ERAI –T_x:2m**
  - **Bias:T_n = T_n:ERAI –T_n:2m**
  - **Bias:T_m = T_m:ERAI –T_m:2m**
  - **Bias:DTR = DTR:ERAI –DTR:2m**
- **Stratified by Opaque cloud (data)**
- **Partitioned**
  - **Cold season with snow (MDJFM)**
  - **Warm season (no snow)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

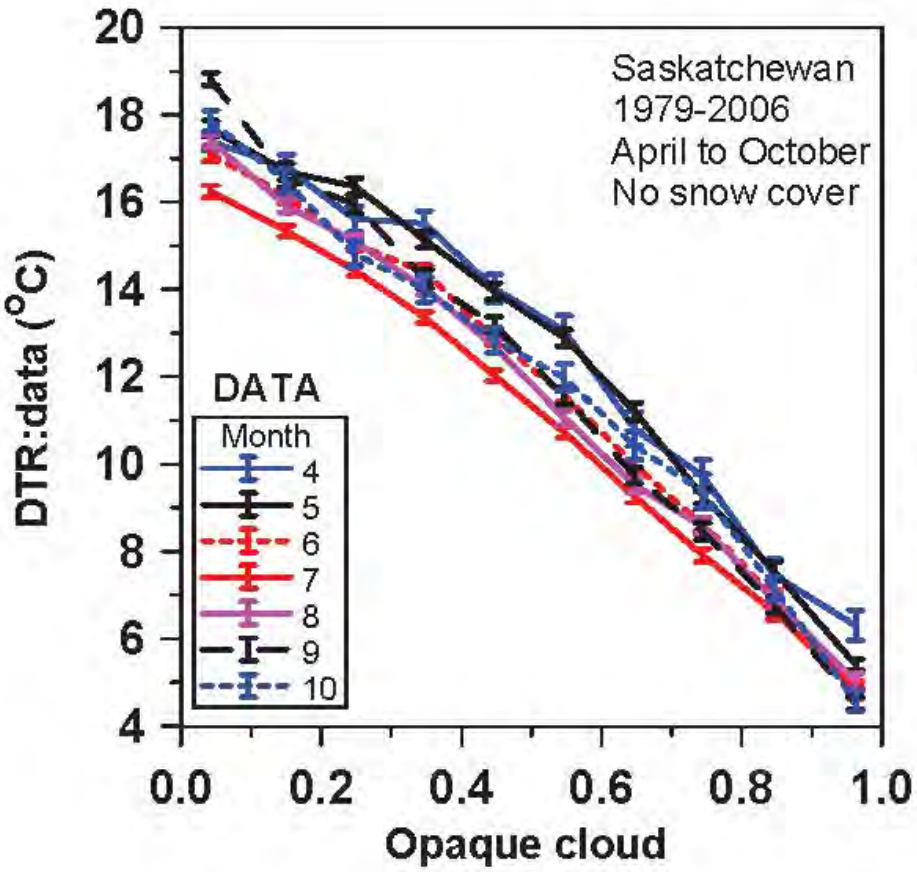
ERA-Interim Biases

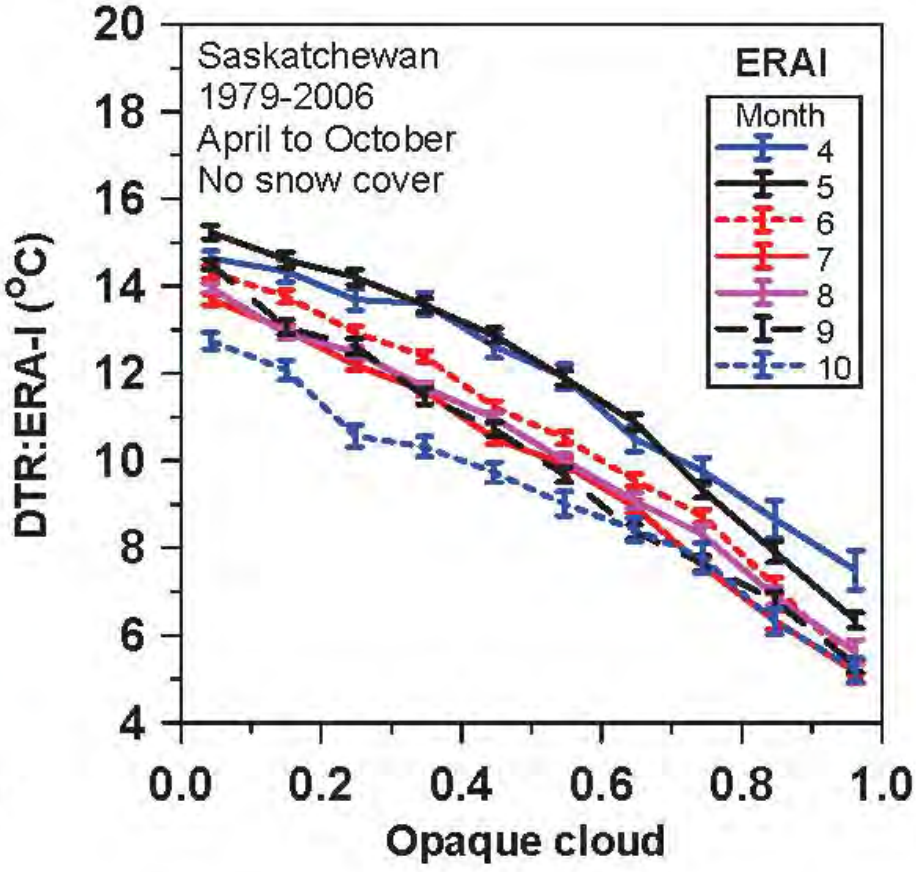




- **Warm season: linear in opaque cloud**
  - ***T_x cold, T_n warm; DTR too small***

Compare monthly DTR



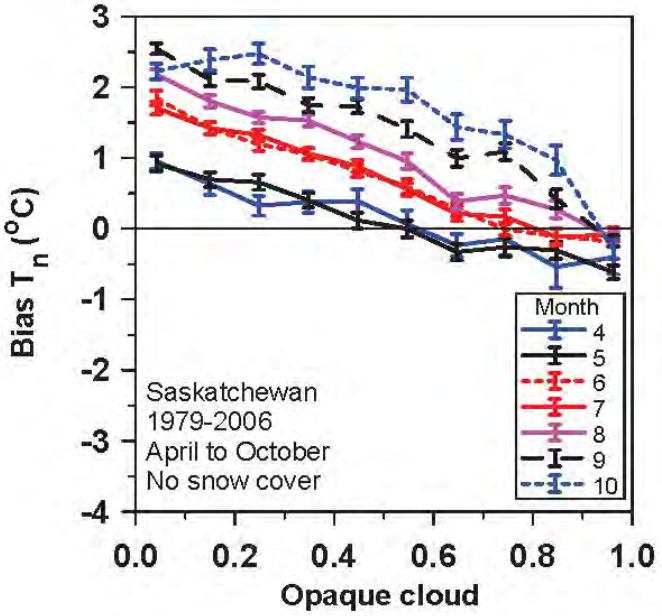


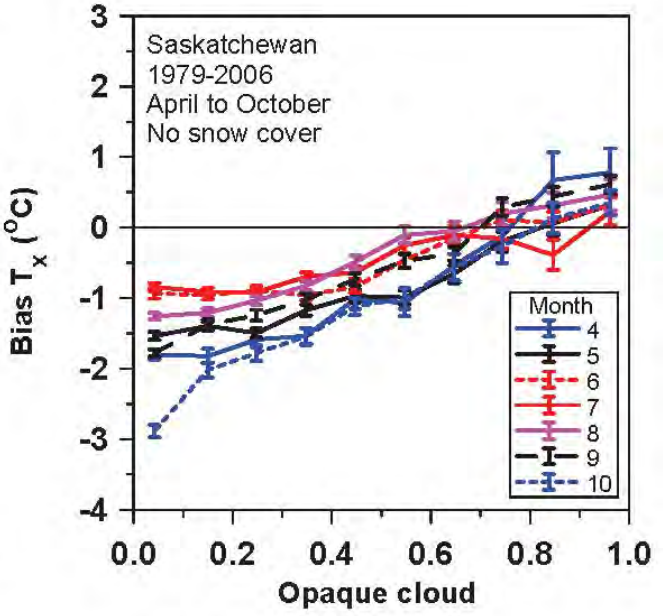
- **DTR: ERAI wider spread, different seasonal structure**

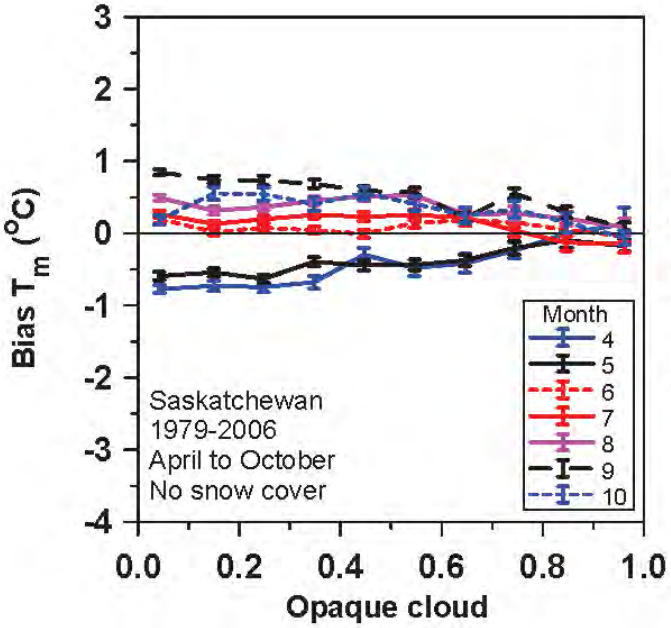
Monthly biases

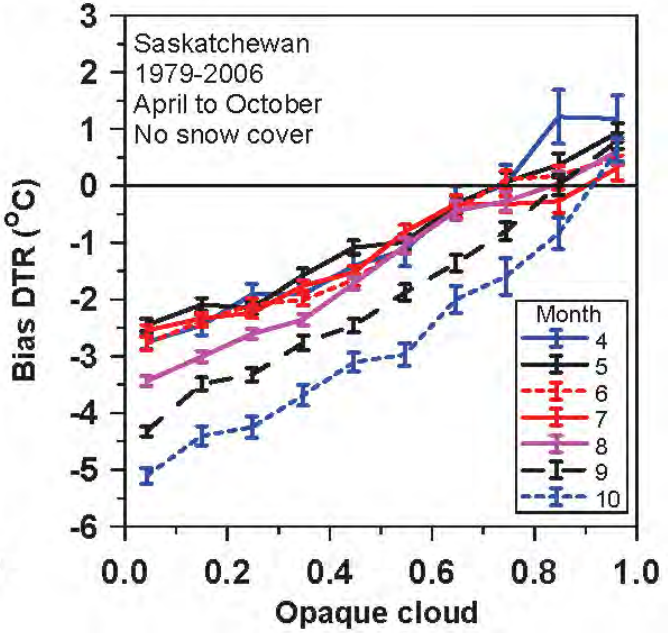
- Seasonal trends large
- bias:T_n increases April to Oct
- bias:T_x min in JJ
- bias:T_m changes sign: spring to fall
- bias:DTR reaches -5°C in Oct

WHY?

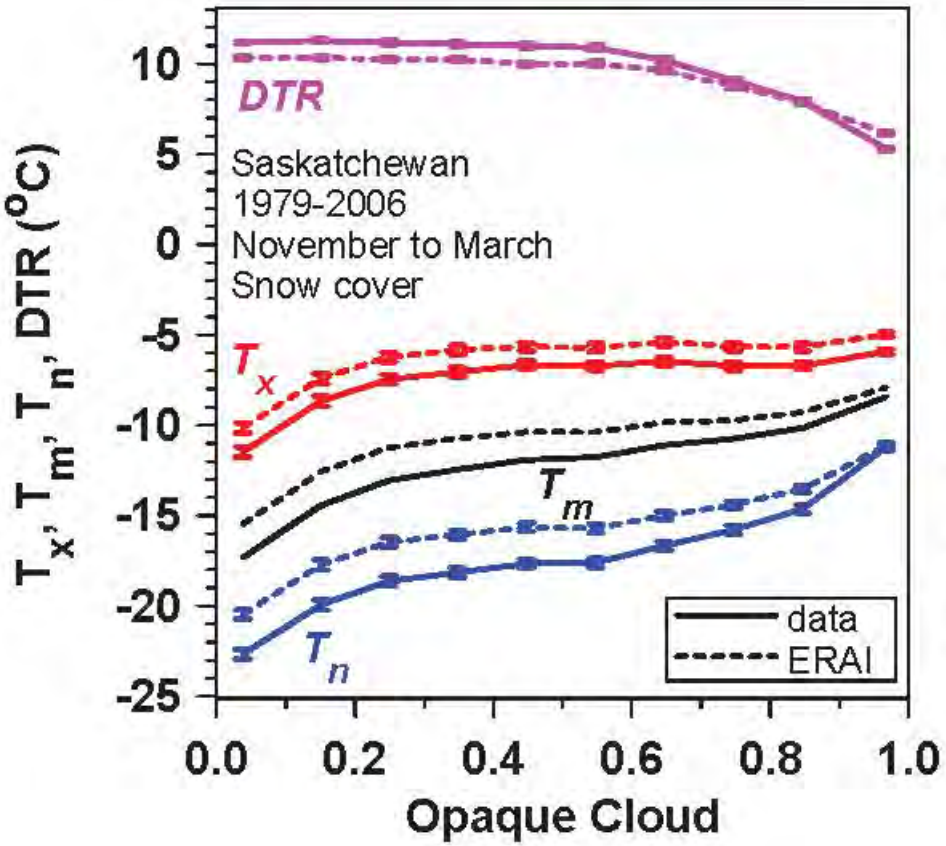


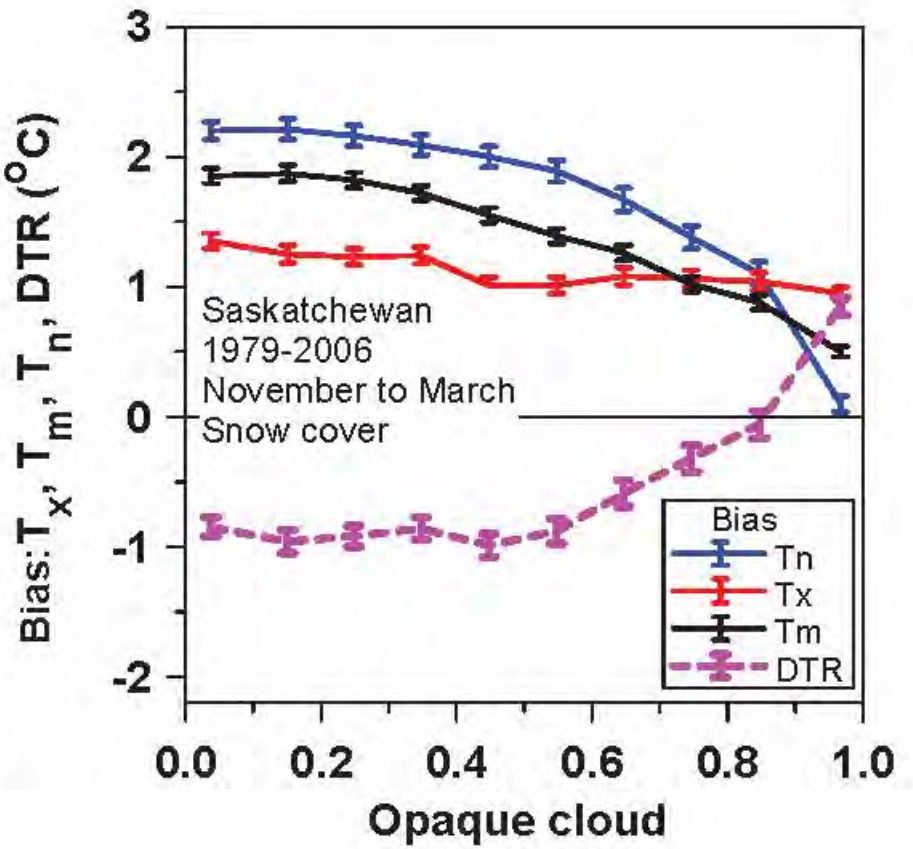






ERA-Interim Biases (cold)

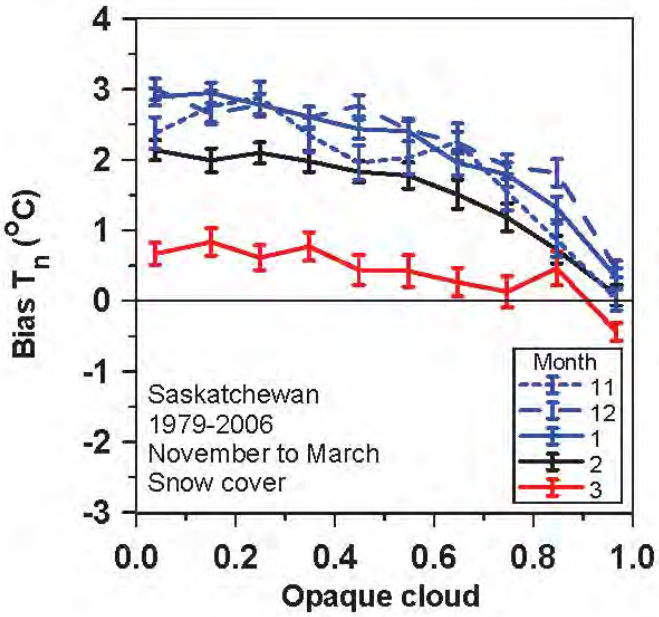


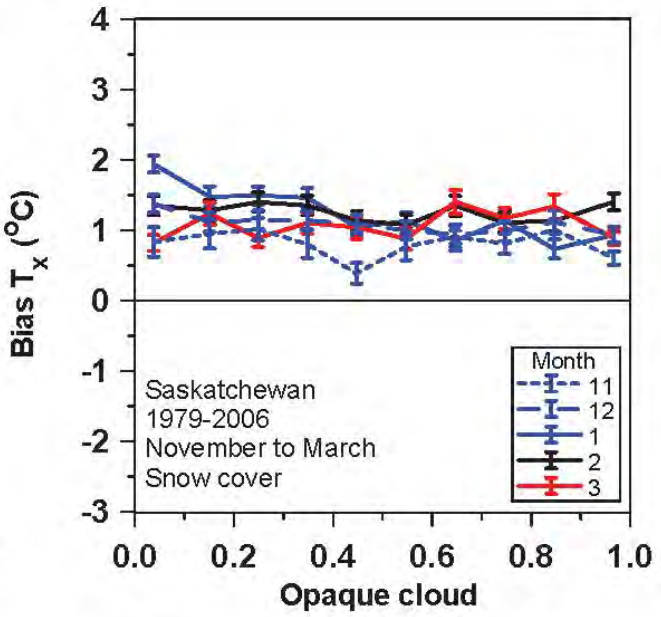


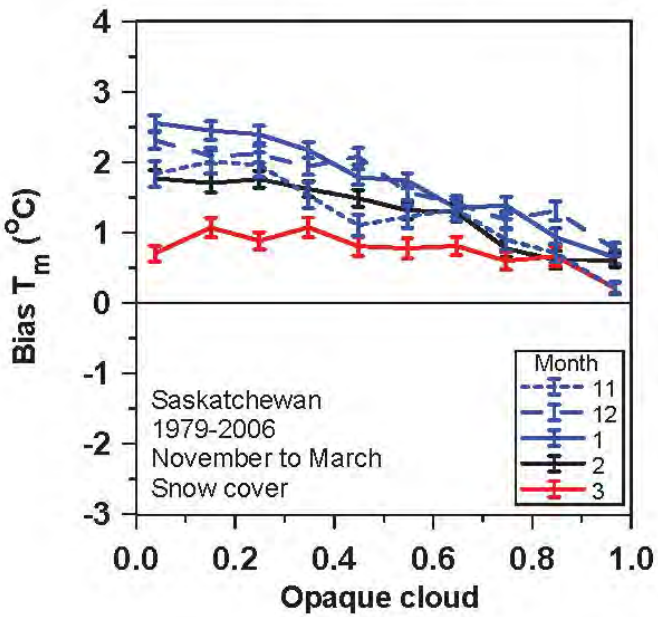
- **Cold season (snow cover)**
  - ***T_n T_m T_x all warm; DTR too small***

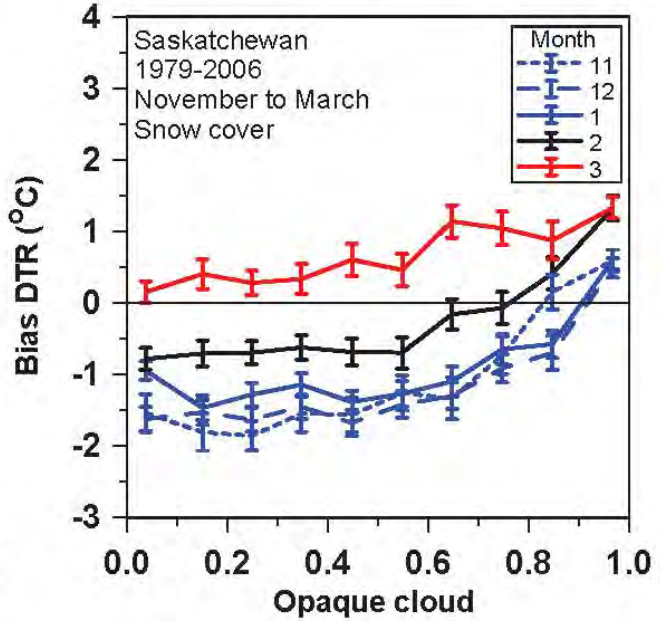
Monthly (cold)

- 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



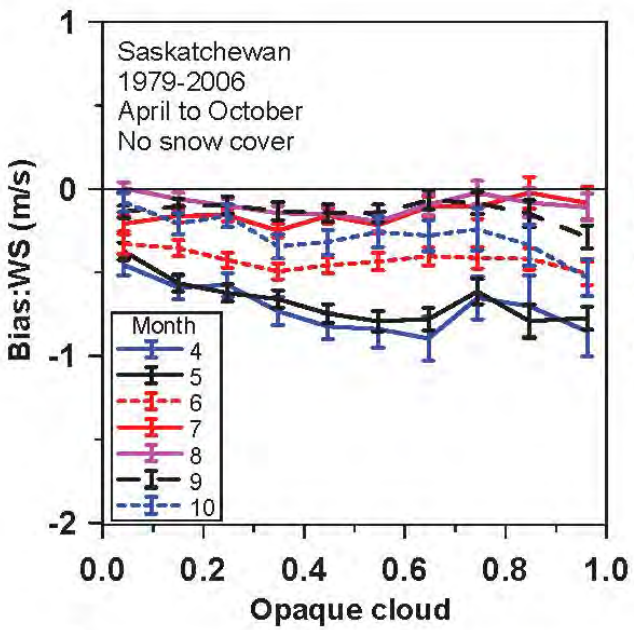


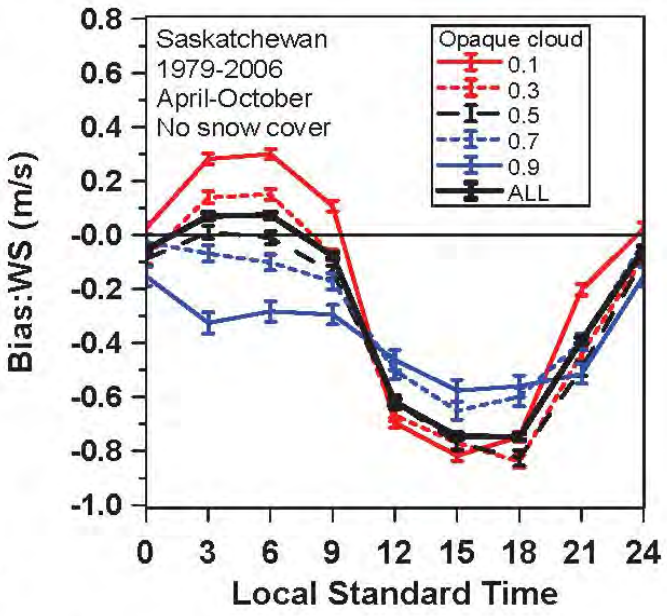


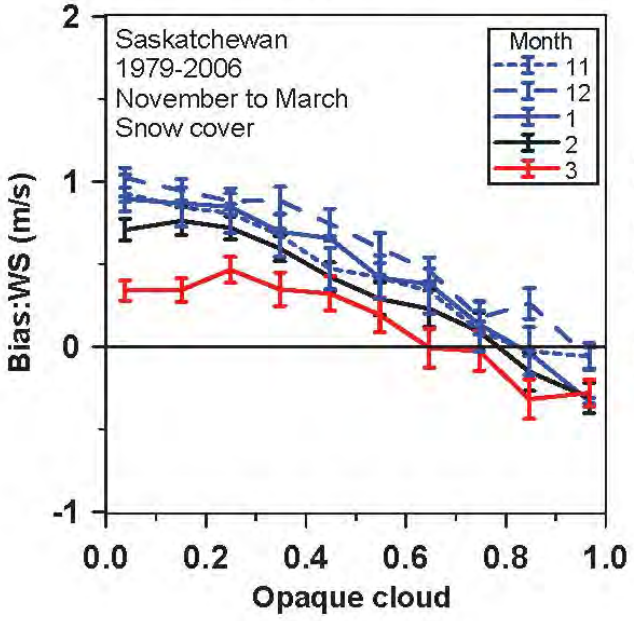


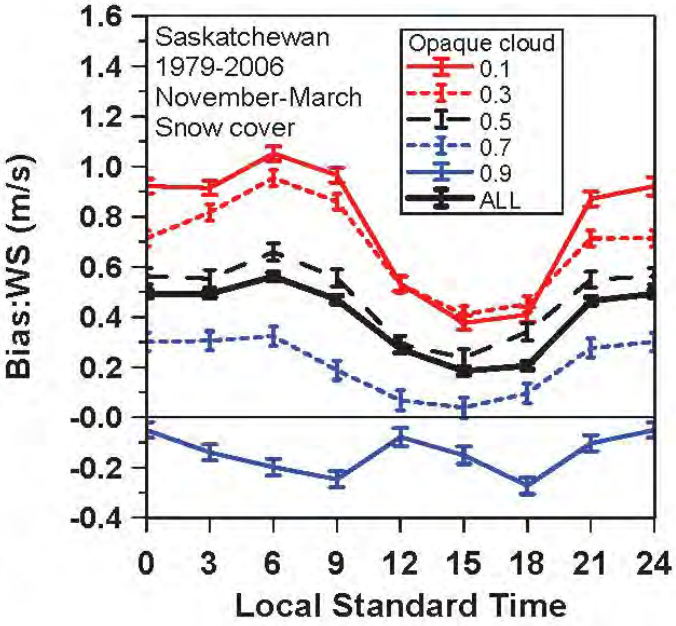
Wind biases

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

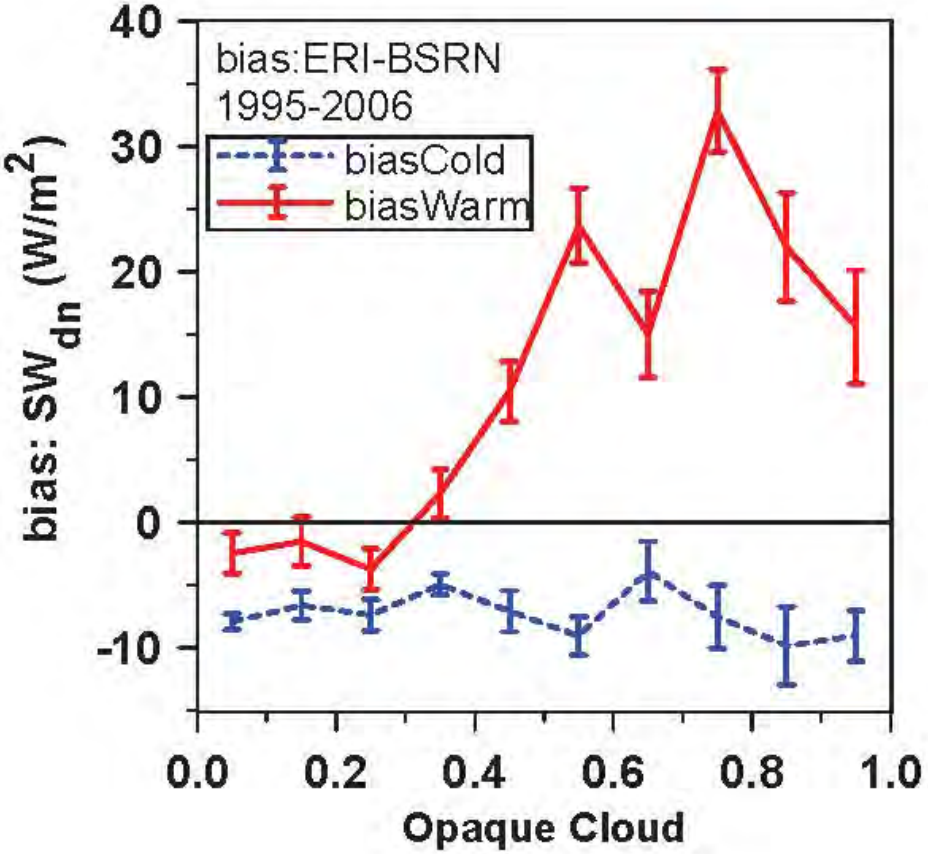


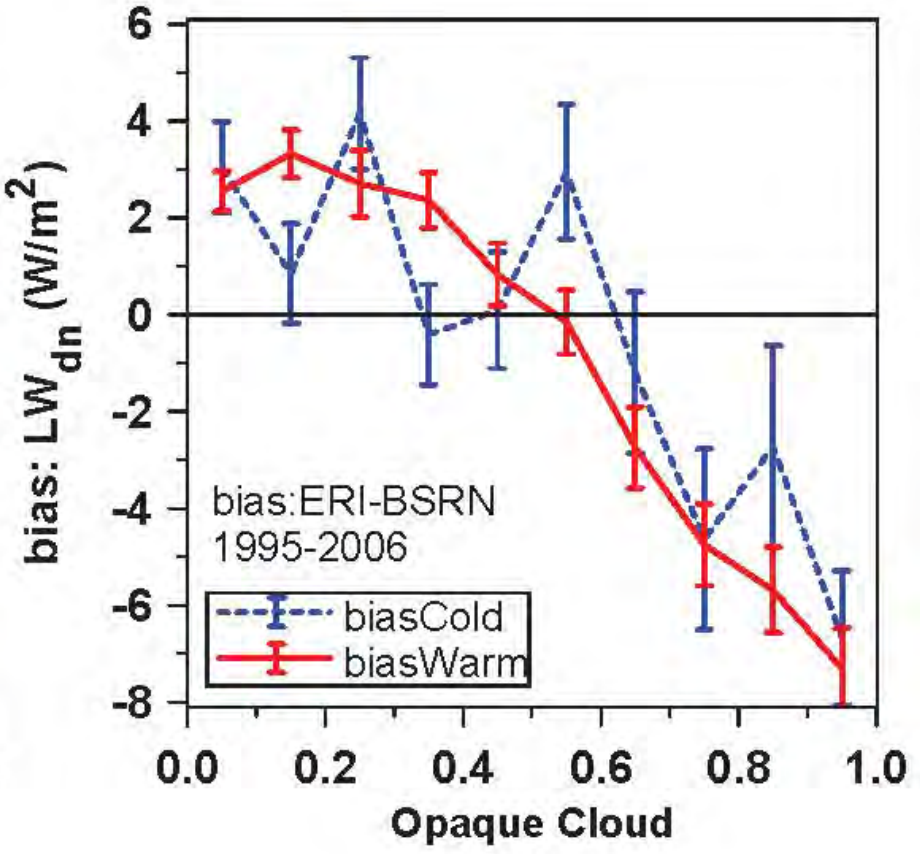






Radiation Biases (BSRN)



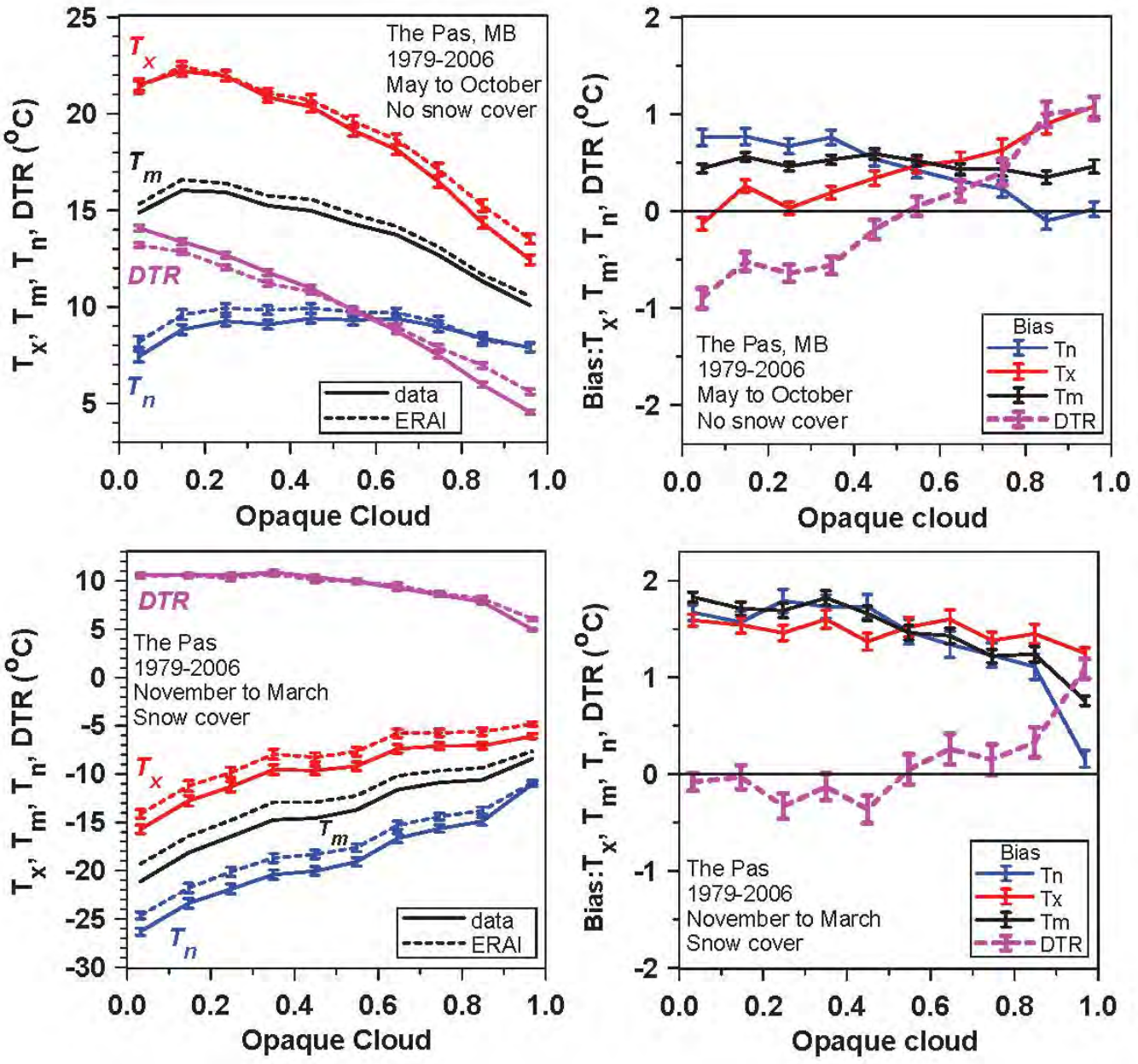


- **Small under clear skies**
  - ***Bias:LW$_{dn}$ small***
  - ***Bias: SW$_{dn}$ too little cloud when cloudy***

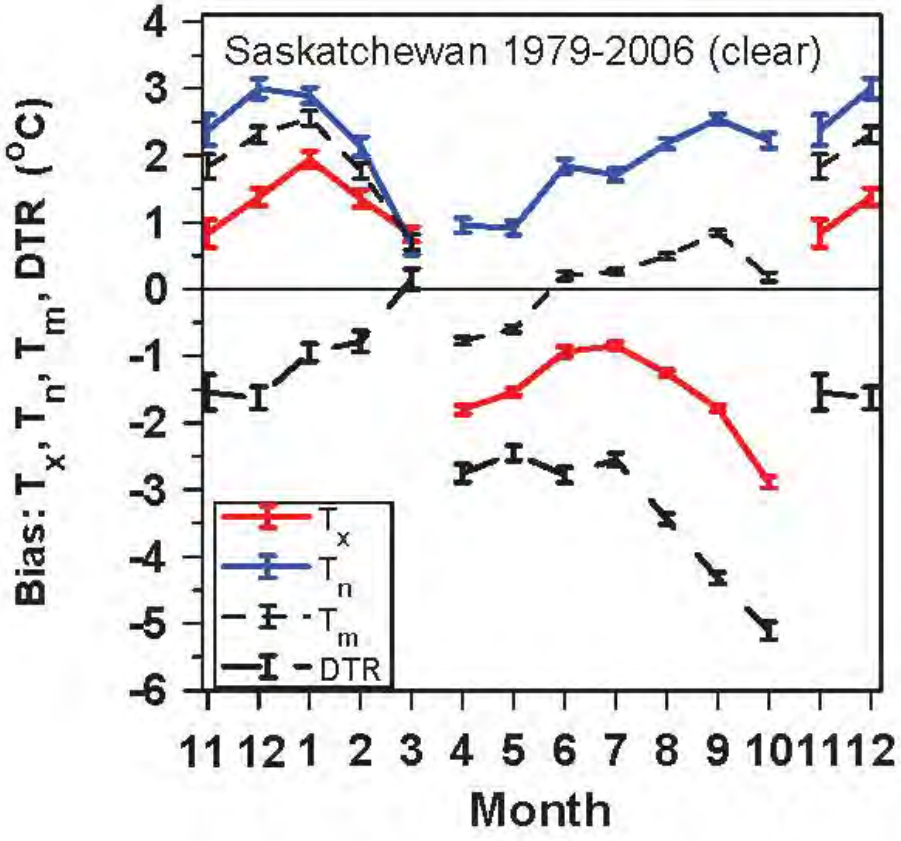
Boreal forest

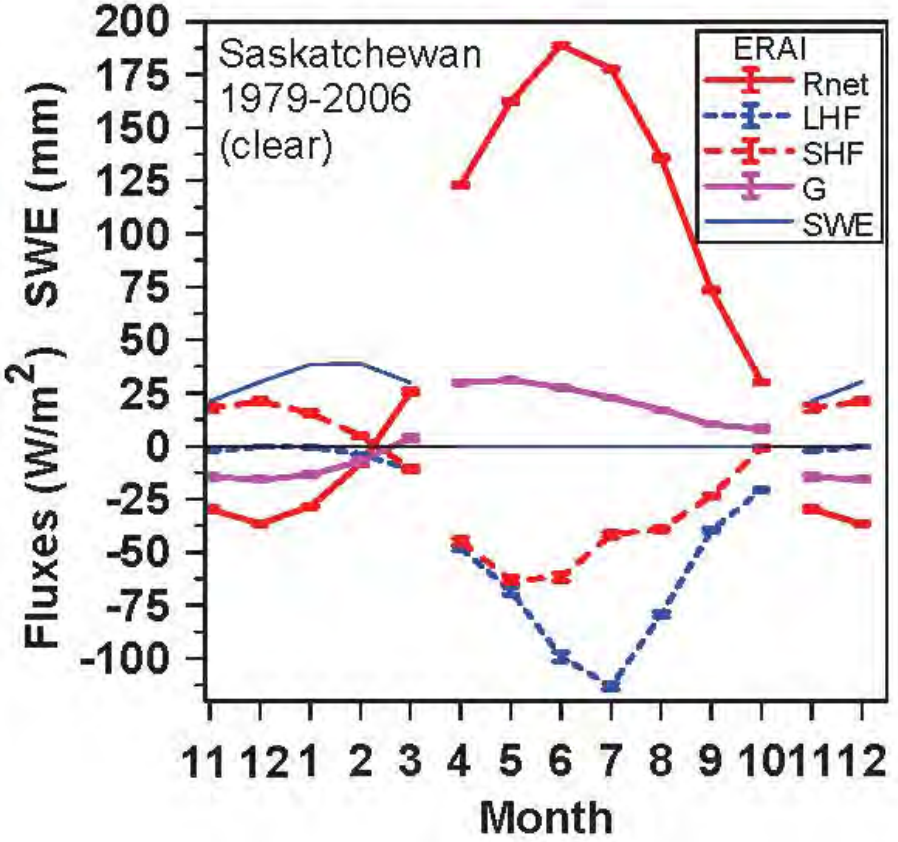
56% tall veg

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



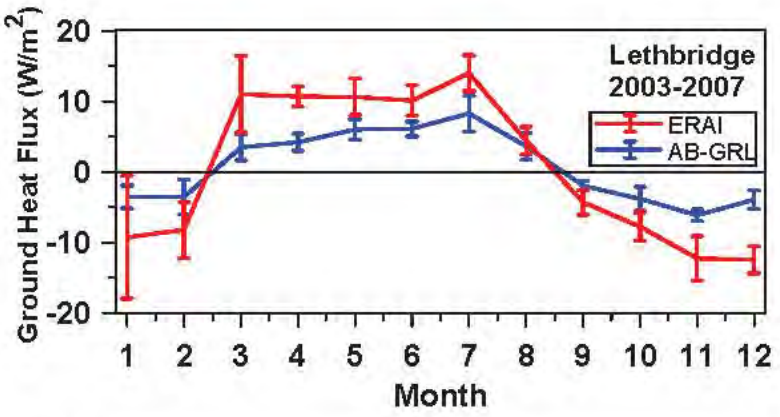
Clear-sky biases and fluxes; Reversals with snow

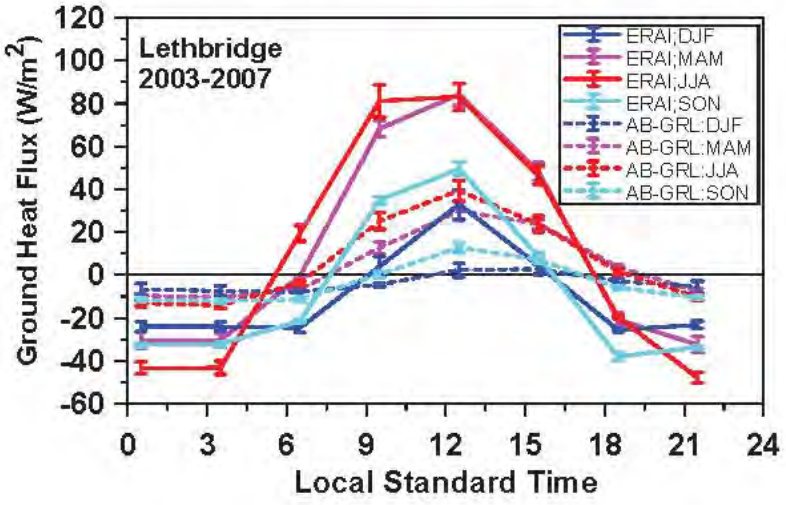


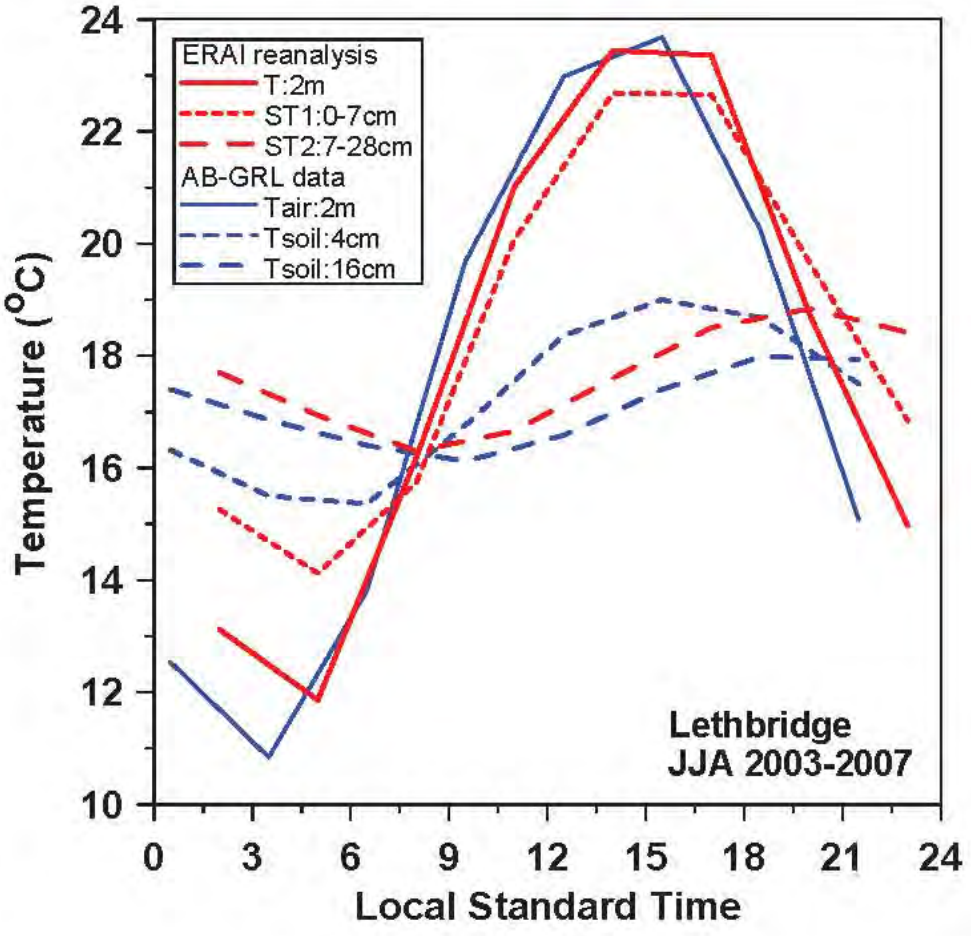


- **Biases largest under clear skies: not radiation error**
  - **Bias:T_x largest discontinuity: + winter peak; - spring/fall**
  - **Bias:T_n + winter max, spring min**
  - **Bias:T_m + winter, - to + in warm season**

Ground coupling too strong? Lethbridge FLUXNET







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

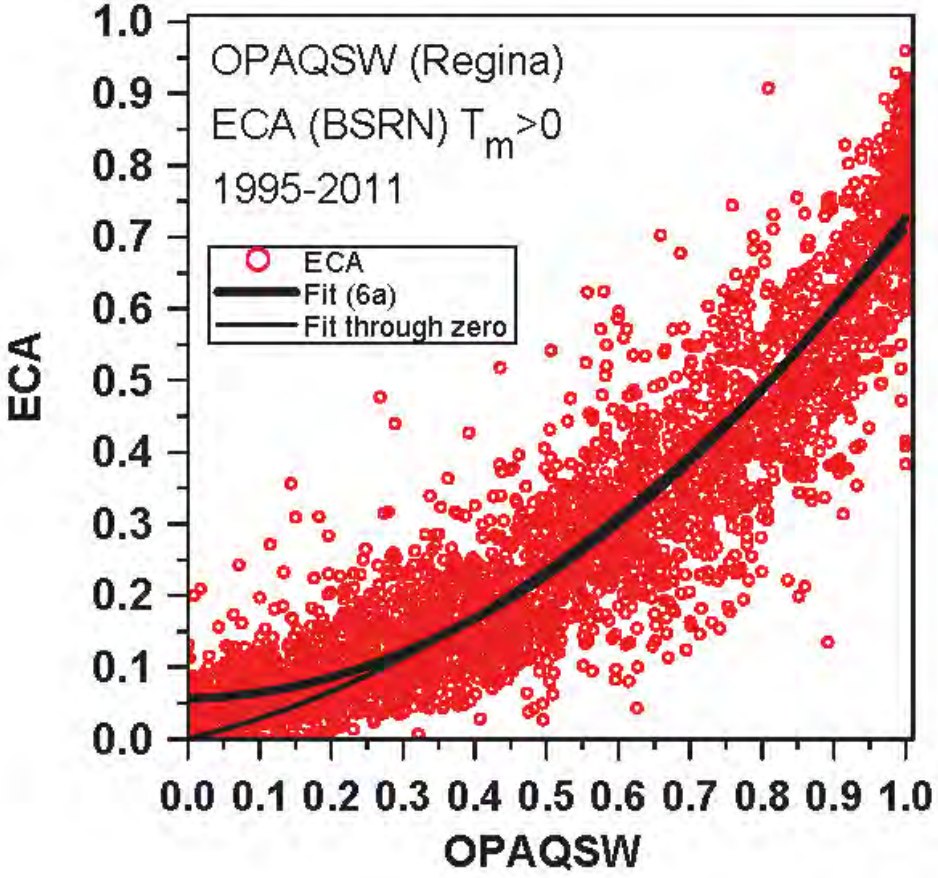
Biases Issues

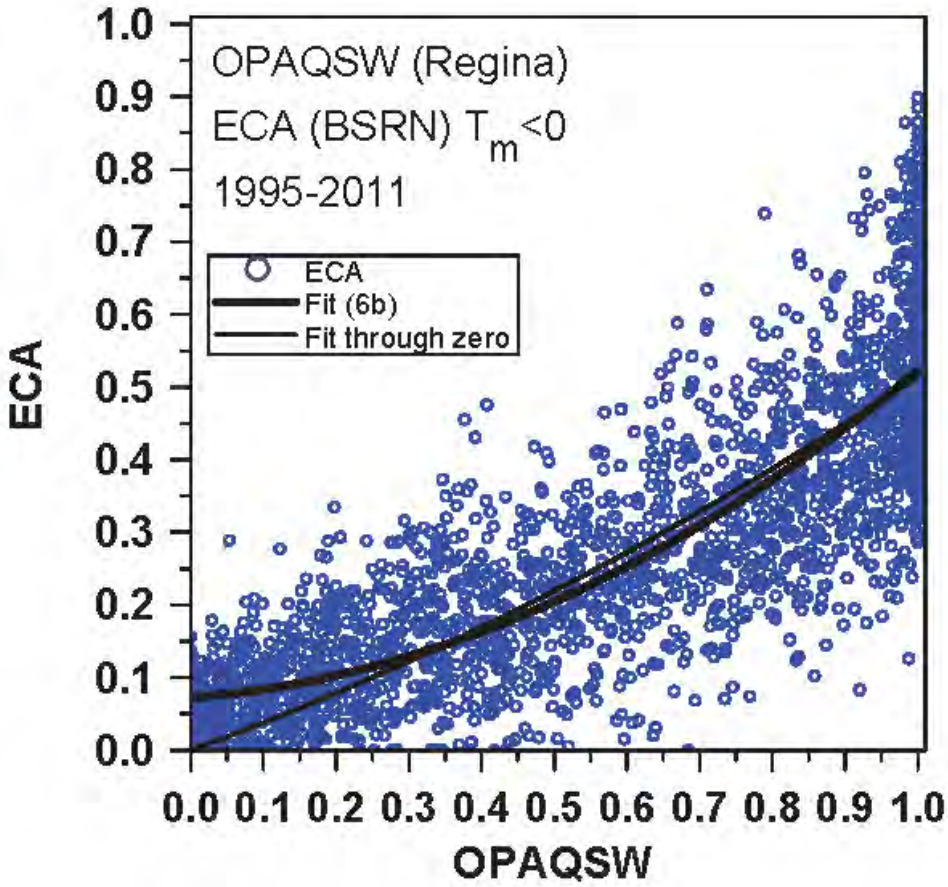
- **Stable BL: bias:T_n positive**
  - **Winter bias:T_x also +**
  - **High bias in diurnal and seasonal G?**
  - **Stable BL mixing**
- **Unstable BL: bias:T_x negative**
  - **High bias in diurnal and seasonal G?**
  - **Lack of seasonal LAI: negative bias:T_x spring and fall**
  - **Unstable BL roughness/mixing?**

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?***
- ***DATA, DATA, DATA essential***

SW calibration



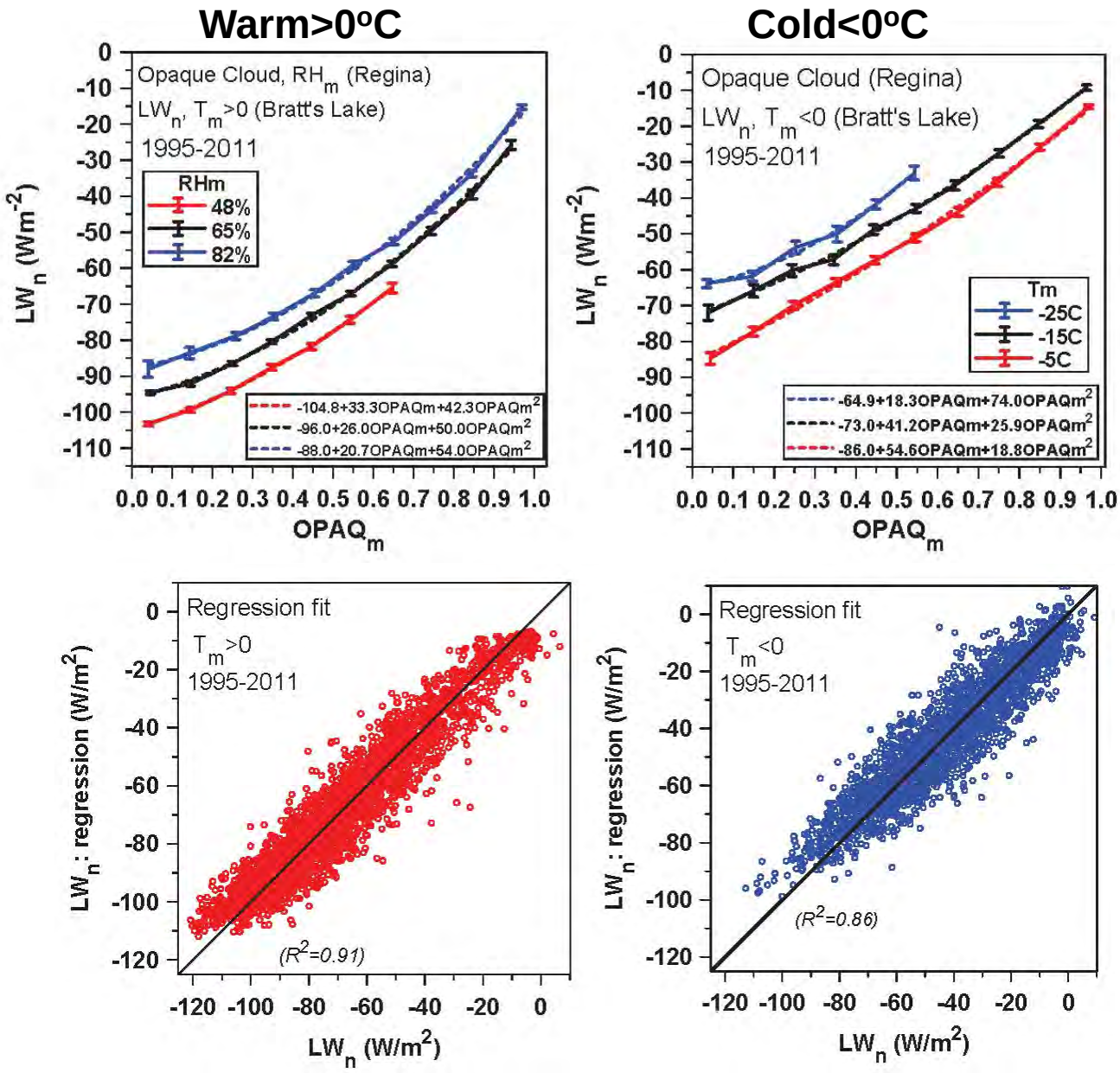


- ***Contrast simple quadratic fit with fit through zero***
- ***Uncertainty at low opaque cloud end***
  - ***Thin cirrus not opaque***

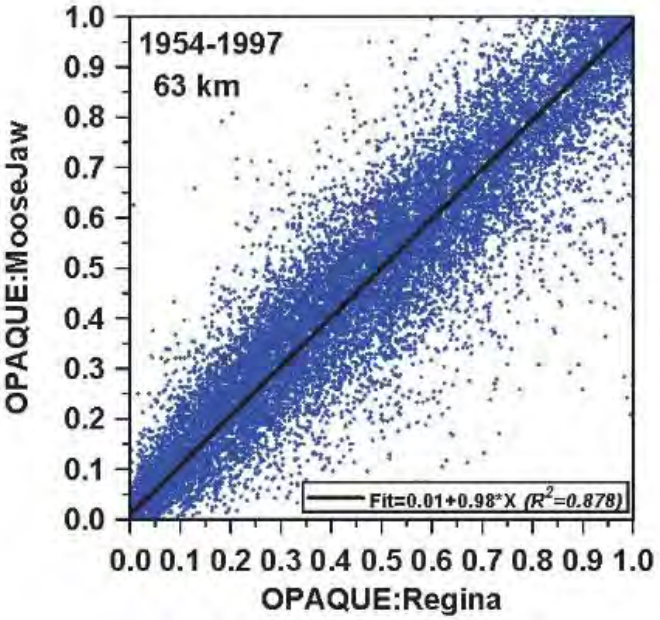
Use BSRN data to "calibrate" daily opaque/reflective Cloud at Regina

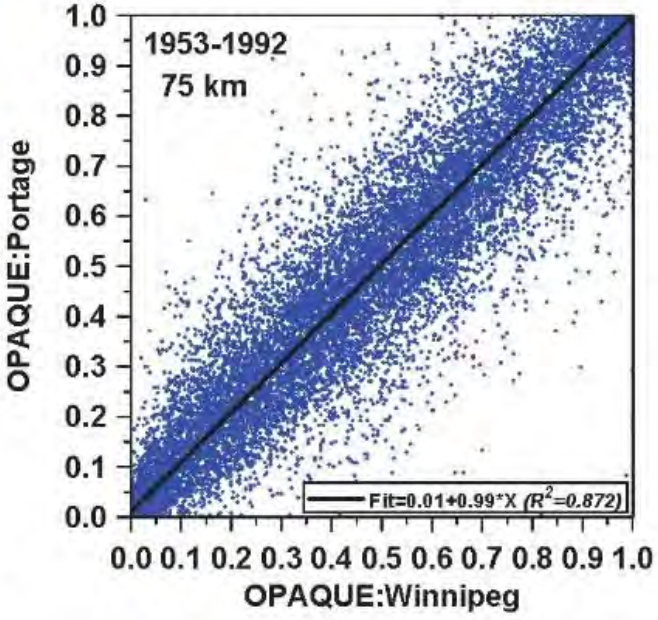
- **Daily mean opaque cloud $OPAQ_m$**
- ***LW cools but clouds reduce cooling***
- **Net LW: LW_n**
  - ***T>0: RH dependence***
  - ***T<0: T, TCWV also***
- ***Regression gives LW_n to ± 8W/m² for T_m>0 (R^2=0.91)***

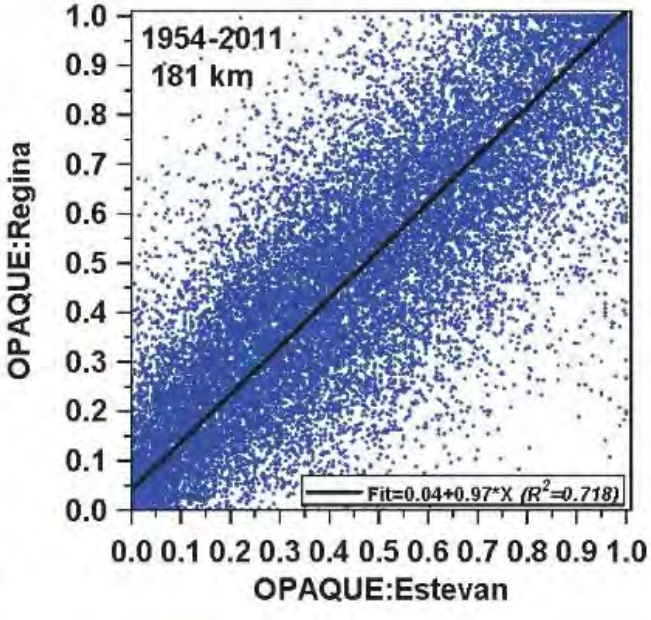
(Betts et al. 2015)



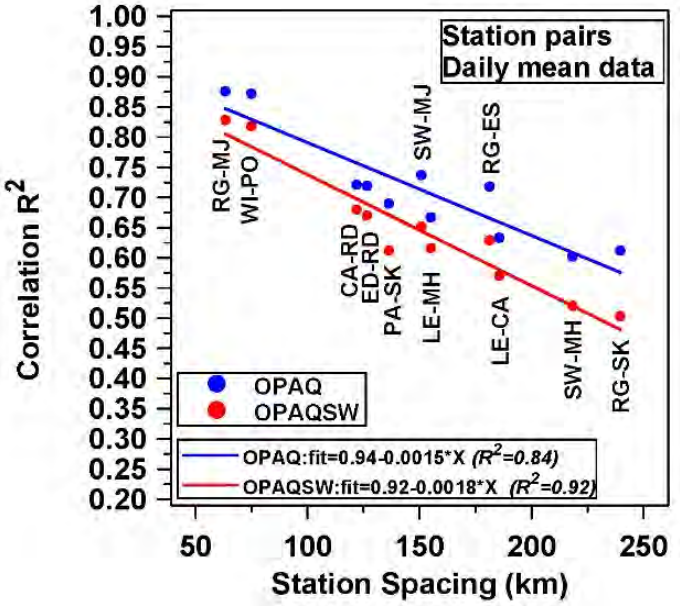
Opaque Cloud (Observers)





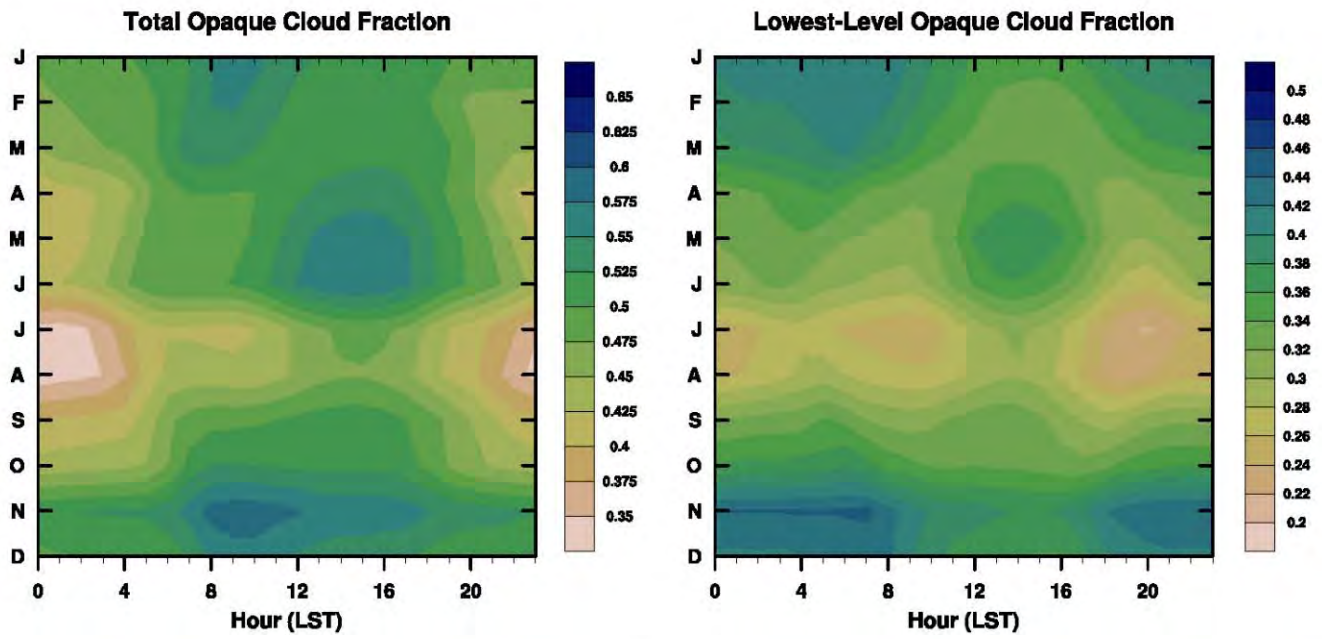


- **Daily means unbiased**
- **Correlation falls with distance**
- **Good data!**

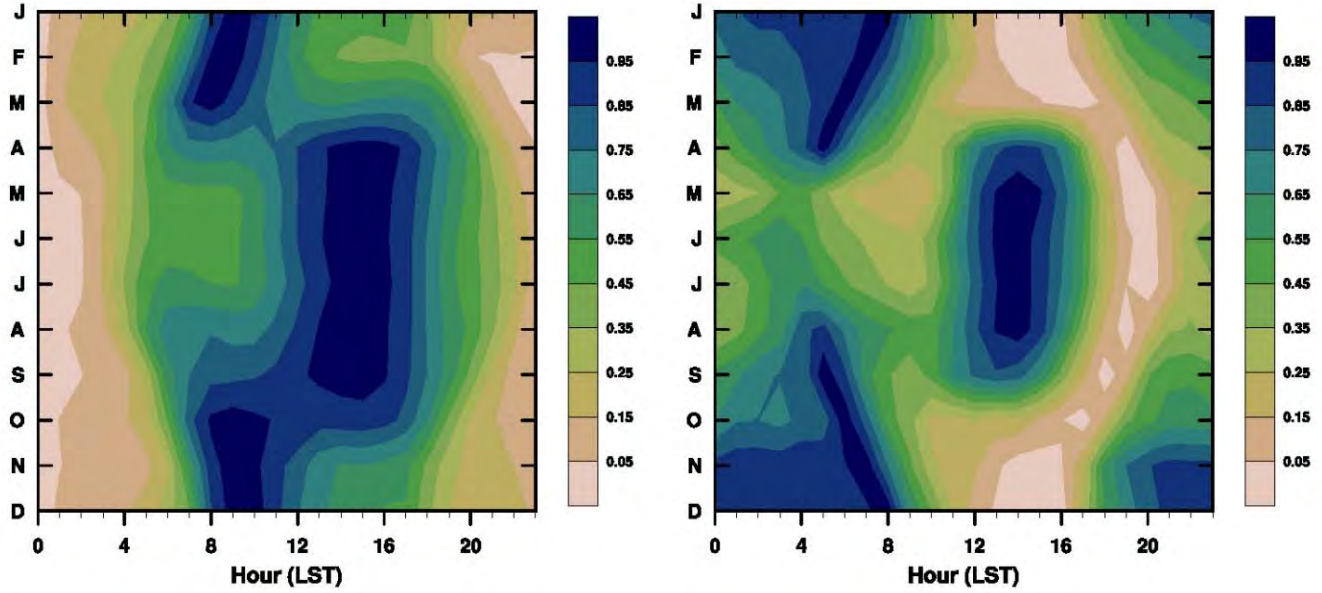


Annual/Diurnal Opaque Cloud

- **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**