Landscape Coupling Between Climate, Clouds, Precipitation, Snow and Crops

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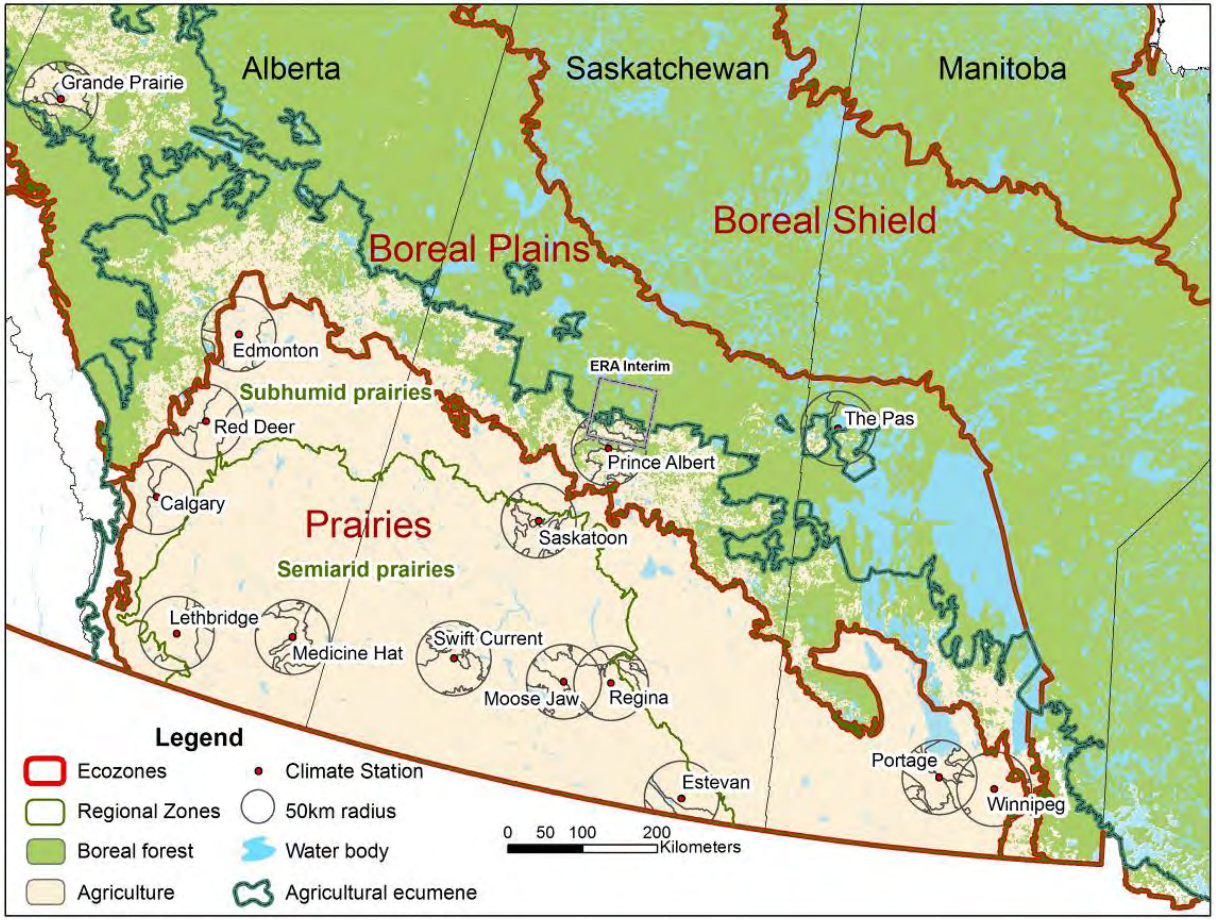
14 Prairie stations: 1953-2011



- *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)

References

- **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 (2013b), 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 (2014a), 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 (2014b), Climate coupling between temperature, humidity, precipitation and cloud cover over the Canadian Prairies. *J. Geophys. Res. Atmos*., 119, doi:10.1002/2014JD022511**

- **http://alanbetts.com**

Methods: Analyze Coupled System

- *Seasonal diurnal climate by station/region*
- 220,000 days, excellent data (600 station-years)
- Impact of reflective/opaque cloud on diurnal cycle in summer and winter
  - Calibrate “cloud radiative forcing”
- Change of seasonal climate with cropping
  - ‘Summerfallow’ to annual crops on 5MHa in 30 yrs
- Impact of snow transitions
  - First snow in fall; spring melt of snowpack
  - Winter climate and % days snow cover

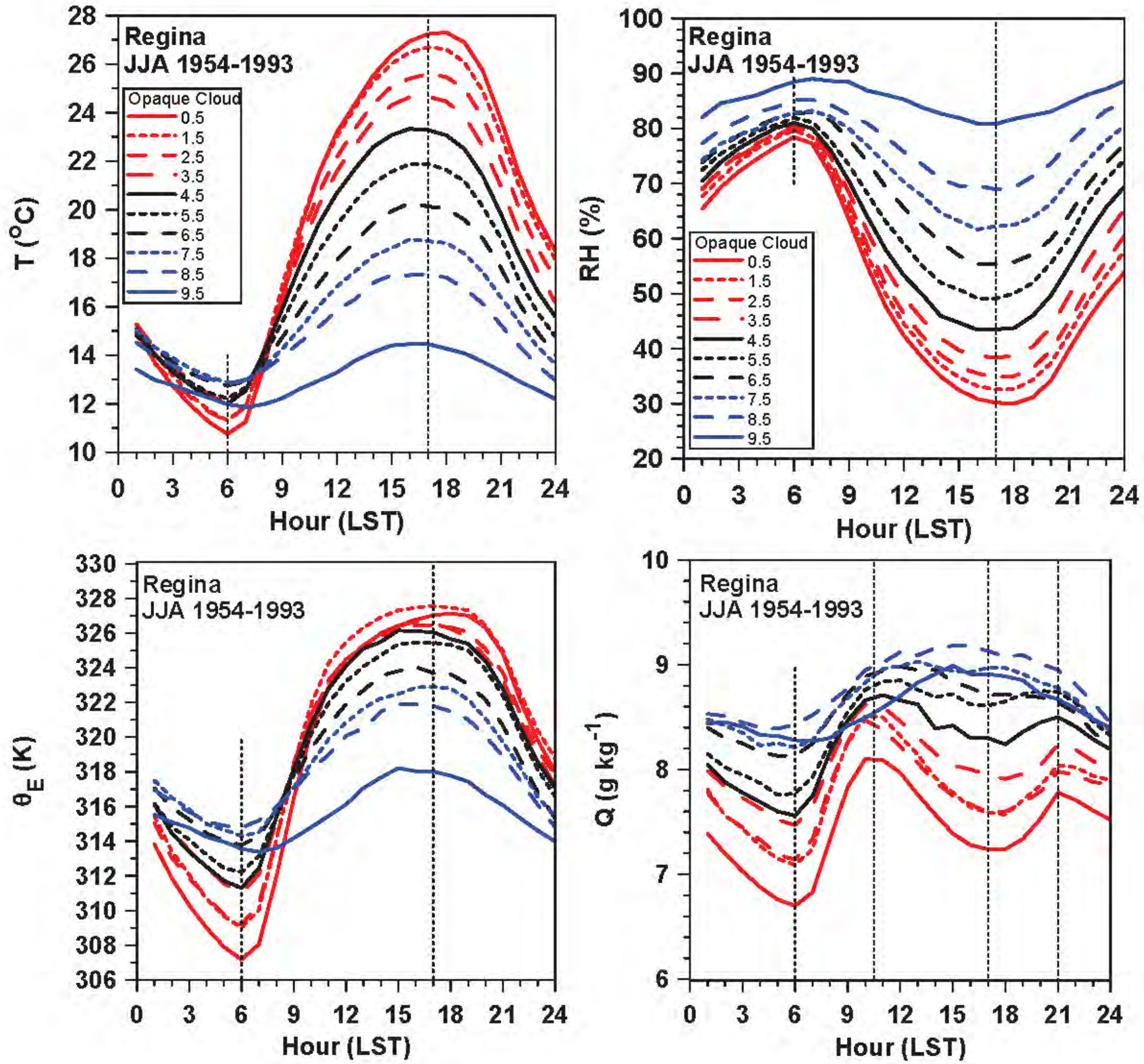
Clouds and Diurnal Climate

- Reduce hourly data to
  - daily means: T_{mean} , RH_{mean} etc
  - data at T_{max} and T_{min}
- *Diurnal cycle climate*
  - $DTR = T_{max} - T_{min}$
  - $\Delta RH = RH_{tn} - RH_{tx}$
- *Almost no missing hourly data*

  (until recent cutbacks)

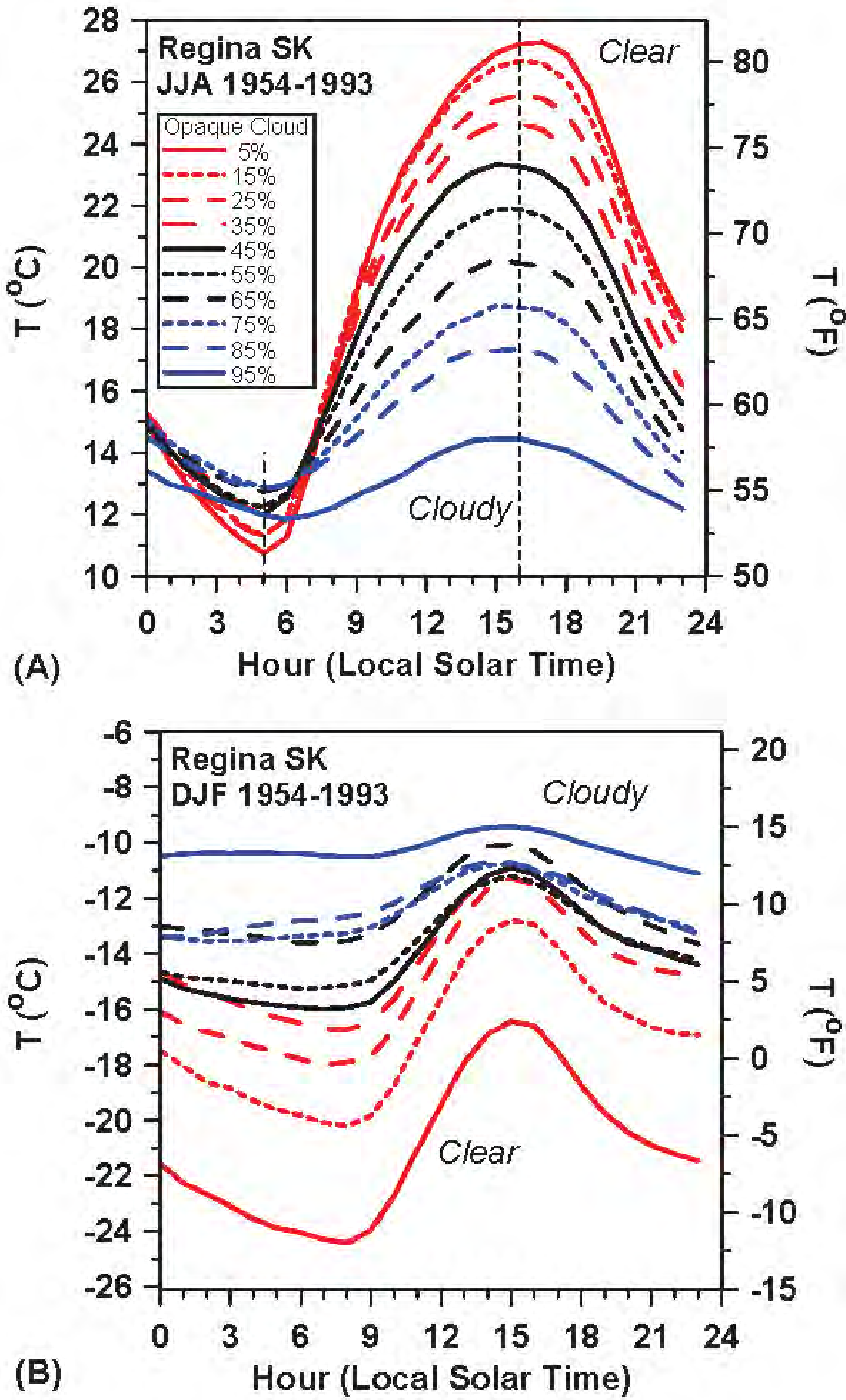
Clouds to Summer Diurnal Cycle

- ***40-yr climate***
- **T and RH are inverse**
- **Q has double maximum for BL transitions**
- **θ_E flatter**
- ***Overcast (rain) only outlier***



Cloud Impacts

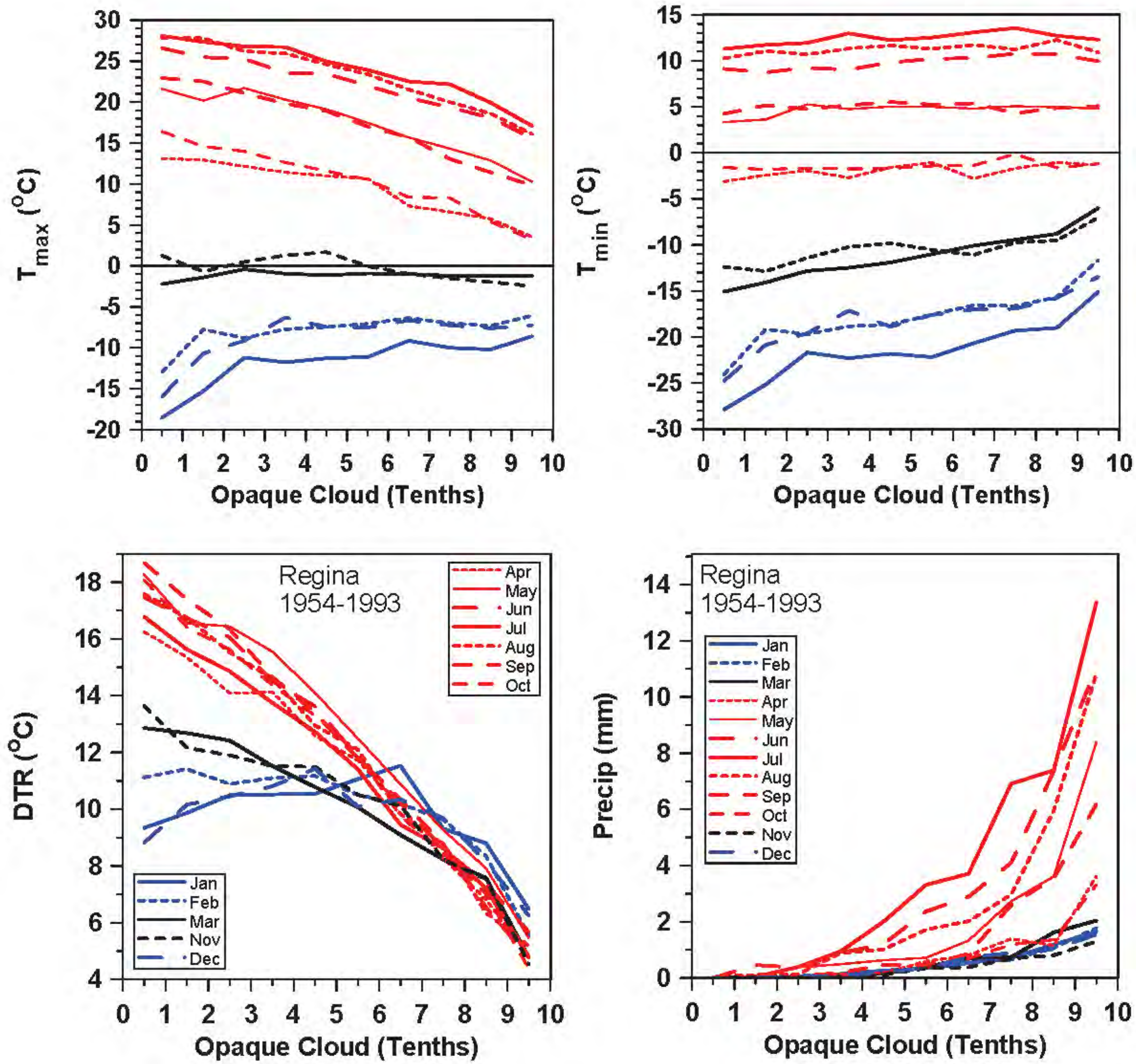
- **Summer:** Clouds reflect sunlight
  - no cloud, hot days; only slightly cooler at night
- **Winter:** Clouds are greenhouse
  - snow reflects low sun
  - clear & dry sky, cold days, very cold nights
- ***Fast transition with snow in 5 days***



Betts et al. 2013

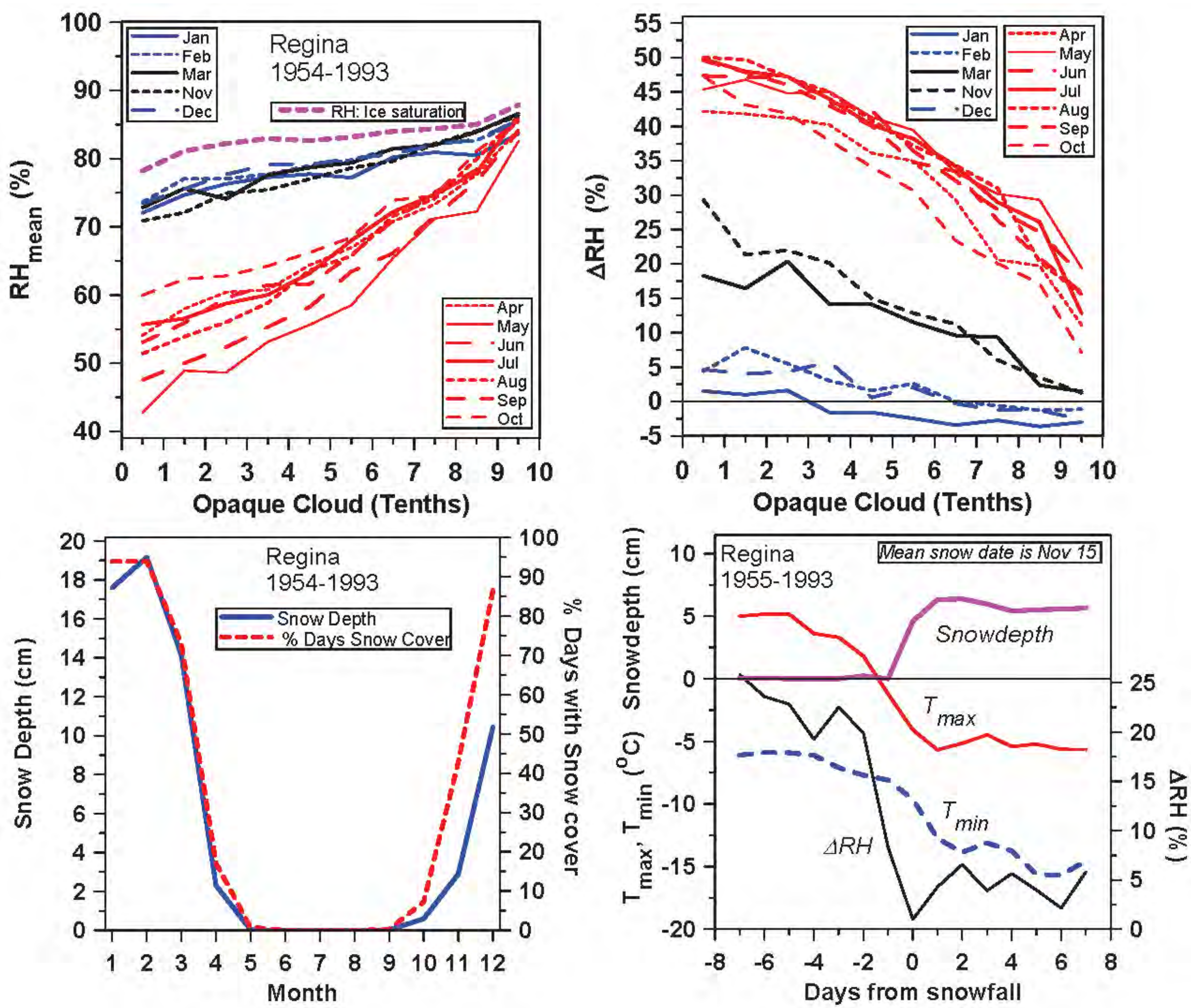
Annual Cycle: T_{max}, T_{min}, DTR, Precip

- **Warm state: April – Oct**
- **Cold state: Dec – Feb**
- **Transitions: Nov, Mar**
  $T_{max} \approx 0^oC$
- ***Actually occur in <5 days***

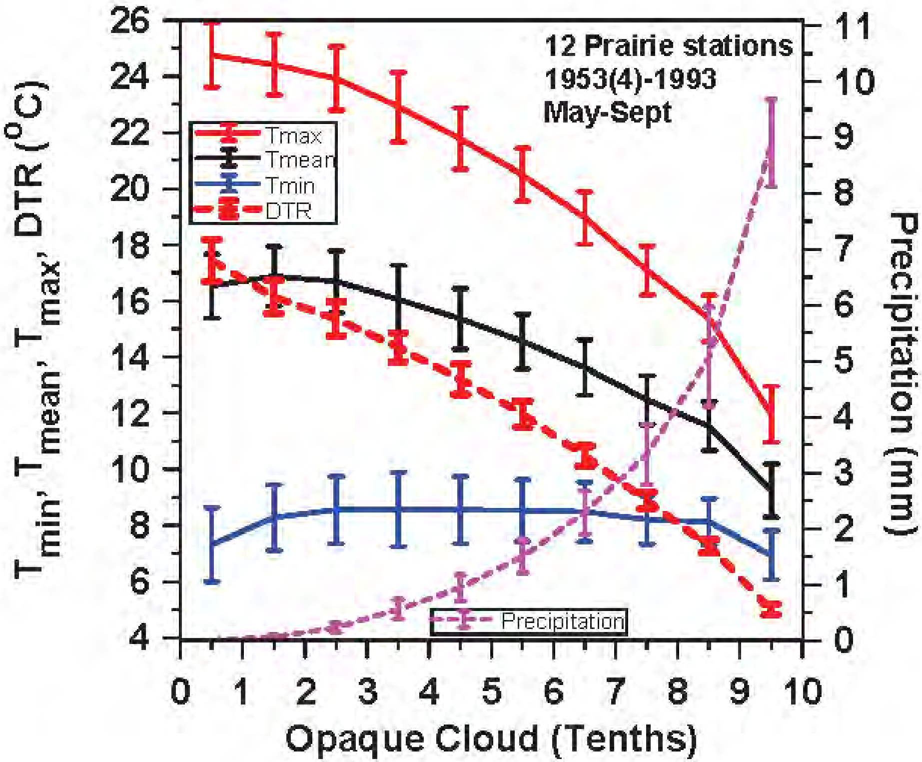


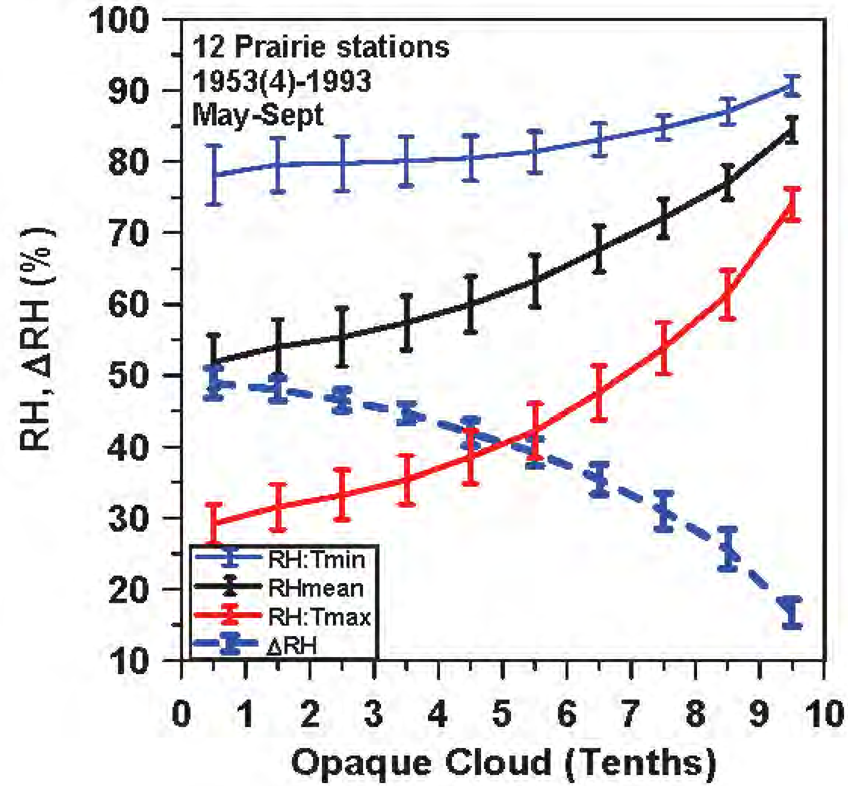
Annual Cycle: RH and ΔRH

- **Warm state: April – Oct**
- **Cold state: Dec – Feb**
- **Transitions: Nov, Mar**
  $T_{max} \approx 0^{o}C$
- **Transition**
  - *in <5 days with snow*



Prairie Warm Season Climate





- **12 stations:** ***Uniform climatology***
- **<u>Tiny variability</u> in DTR and ΔRH**

Surface Radiation Budget

- $R_{net} = SW_{net} + LW_{net}$
  $= (SW_{dn} - SW_{up}) + (LW_{dn} - LW_{up})$

Define Effective Cloud Albedo (reflection)

- $ECA = (SW_{dn}(clear) - SW_{dn}) / SW_{dn}(clear)$

  Clear sky

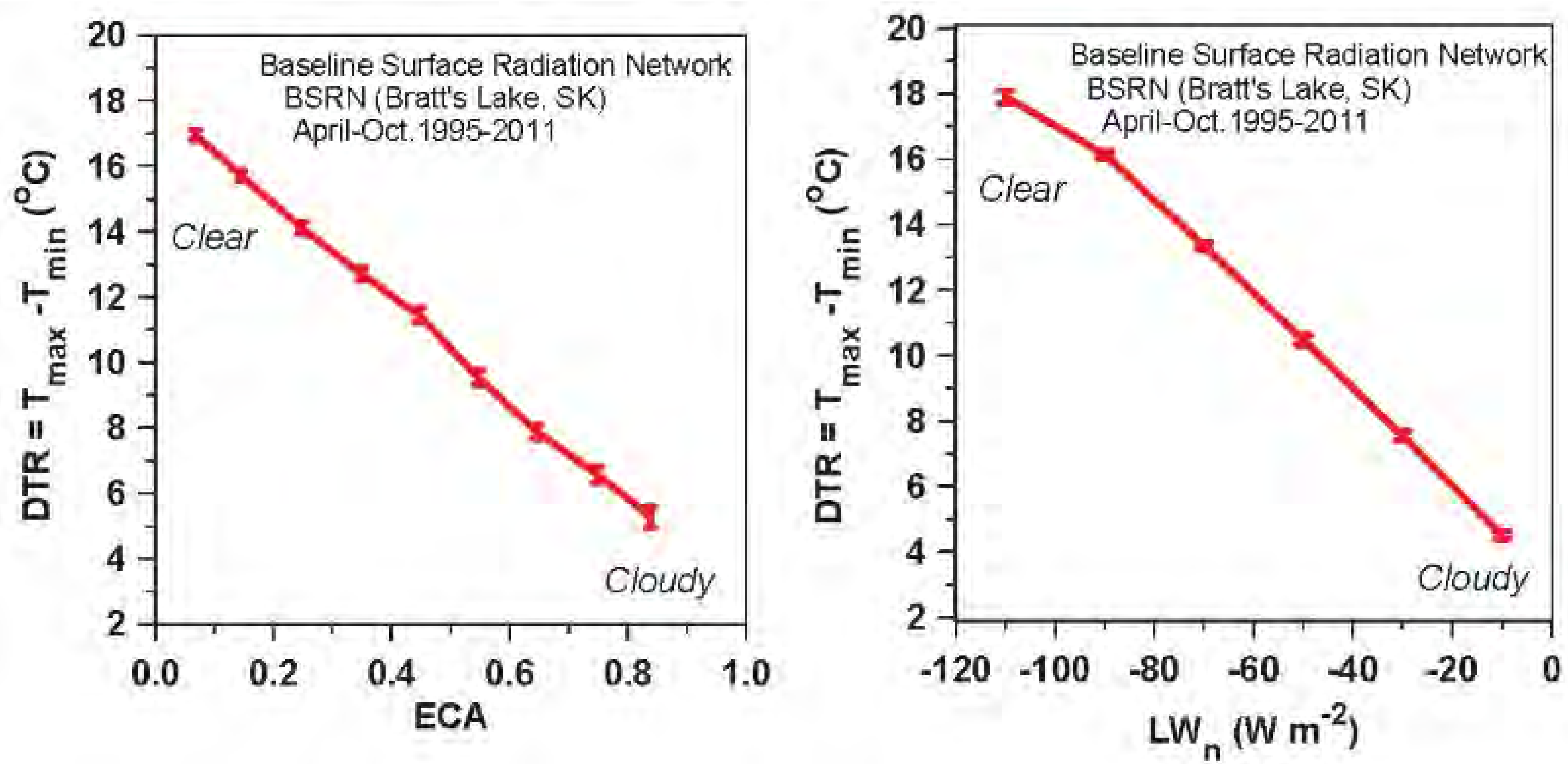
- $SW_{net} = (1 - \alpha_s)(1 - ECA)\ SW_{dn}(clear)$

  Reflected by surface, clouds

  MODIS Calibrate Opaque Cloud data

Diurnal Temperature Range

Warms in daytime and cools at night



- **Daytime warming related to clouds: ECA**
- **Night-time cooling related to clouds: LW_{net}**

Warm and Cold Seasons

- Unstable BL: SWCF
- Clouds at LCL
- reflecting sunlight

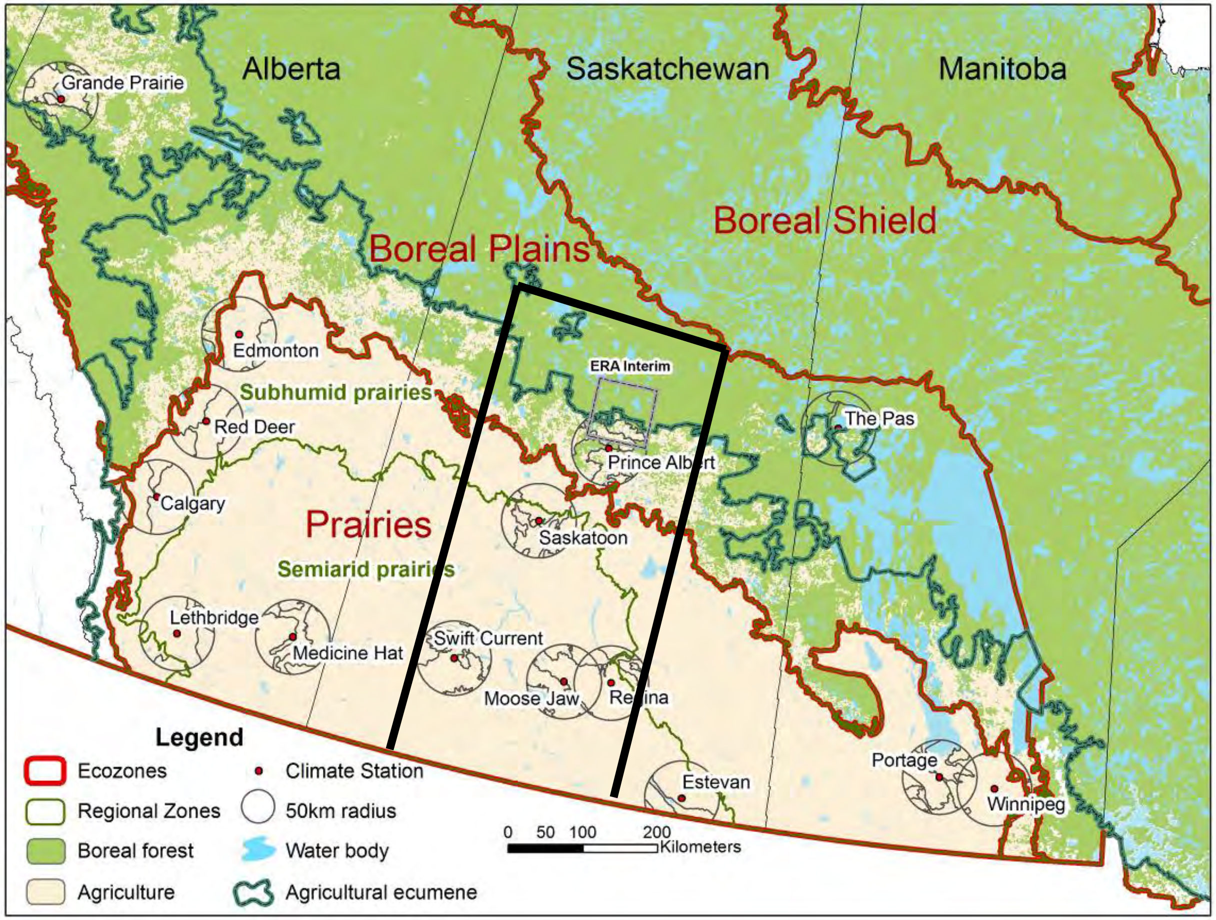
- Stable BL: LWCF
- Snow reflecting sunlight

Impact of Snow on Climate

"*Winter transitions*"

- Composite about snow date
  - First lying snow in fall
  - Final snow-pack melt in spring
- Gives mean climate transition with snow
  - 13 stations with 40-50 years of data
- *Snow cover and winter climate*
- Snow cover cools surface 10-14K
  - Snow cover is a fast "*climate switch*"
  - Shift to 'LW cloud forcing' from 'SW cloud forcing'
    - Shift to 'Cold when clear' from 'Warm when clear'

14 Prairie stations: 1953-2011

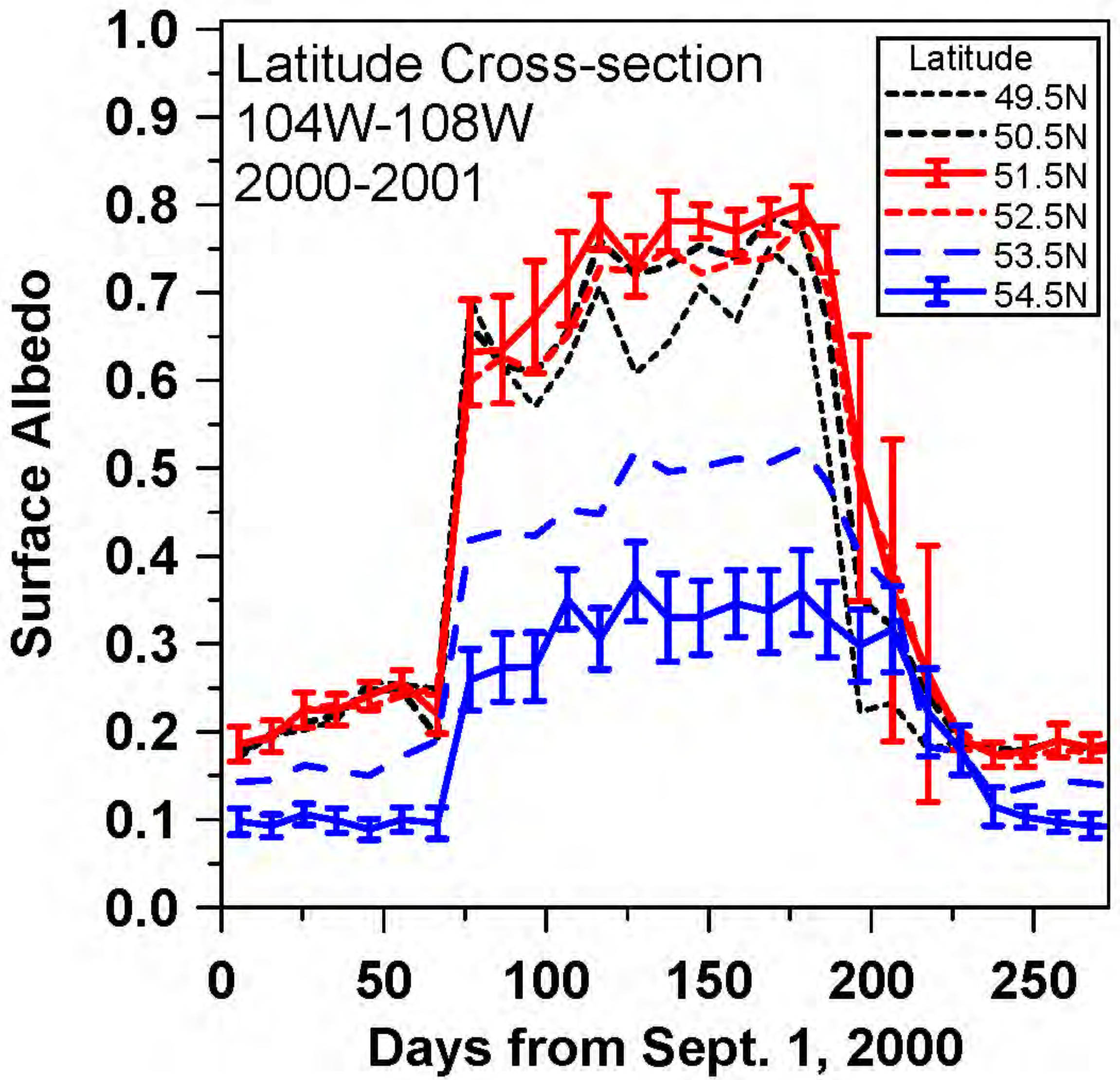


- **Hourly p, T, RH, WS, WD, Opaque Cloud by level, (SW_{dn}, LW_{dn})**
- **Daily precipitation and snowdepth**
- **Ecodistrict crop data since 1955**
- **Albedo data (MODIS/CCRS: 250m, after 2000)**

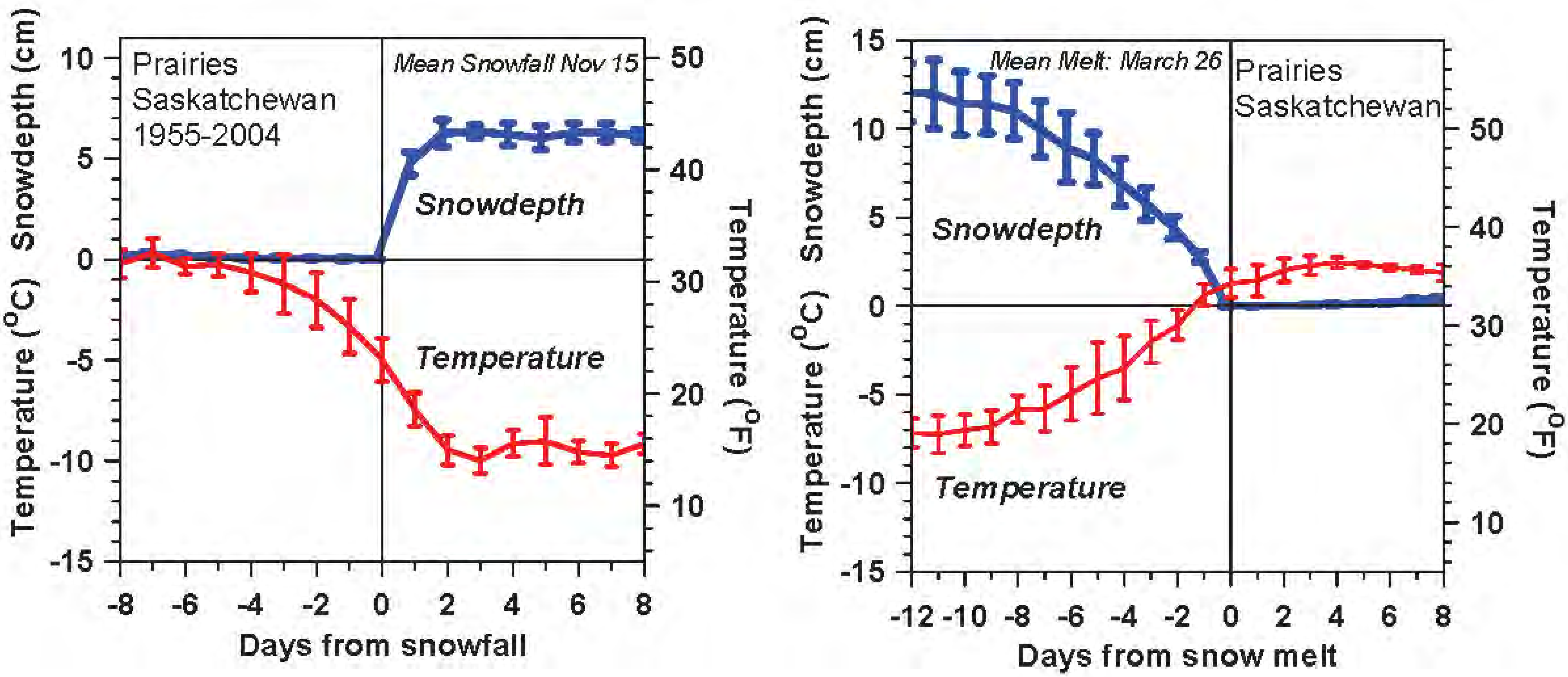
N-S Albedo through Winter

- **Prairies (SK)**
  α_s: 0.2 to 0.73
- **Boreal forest**
  α_s: 0.1 to 0.35

- ***MODIS: 10day, 250m, avg. to 50x50km to latitude bands***
  - *CCRS product*



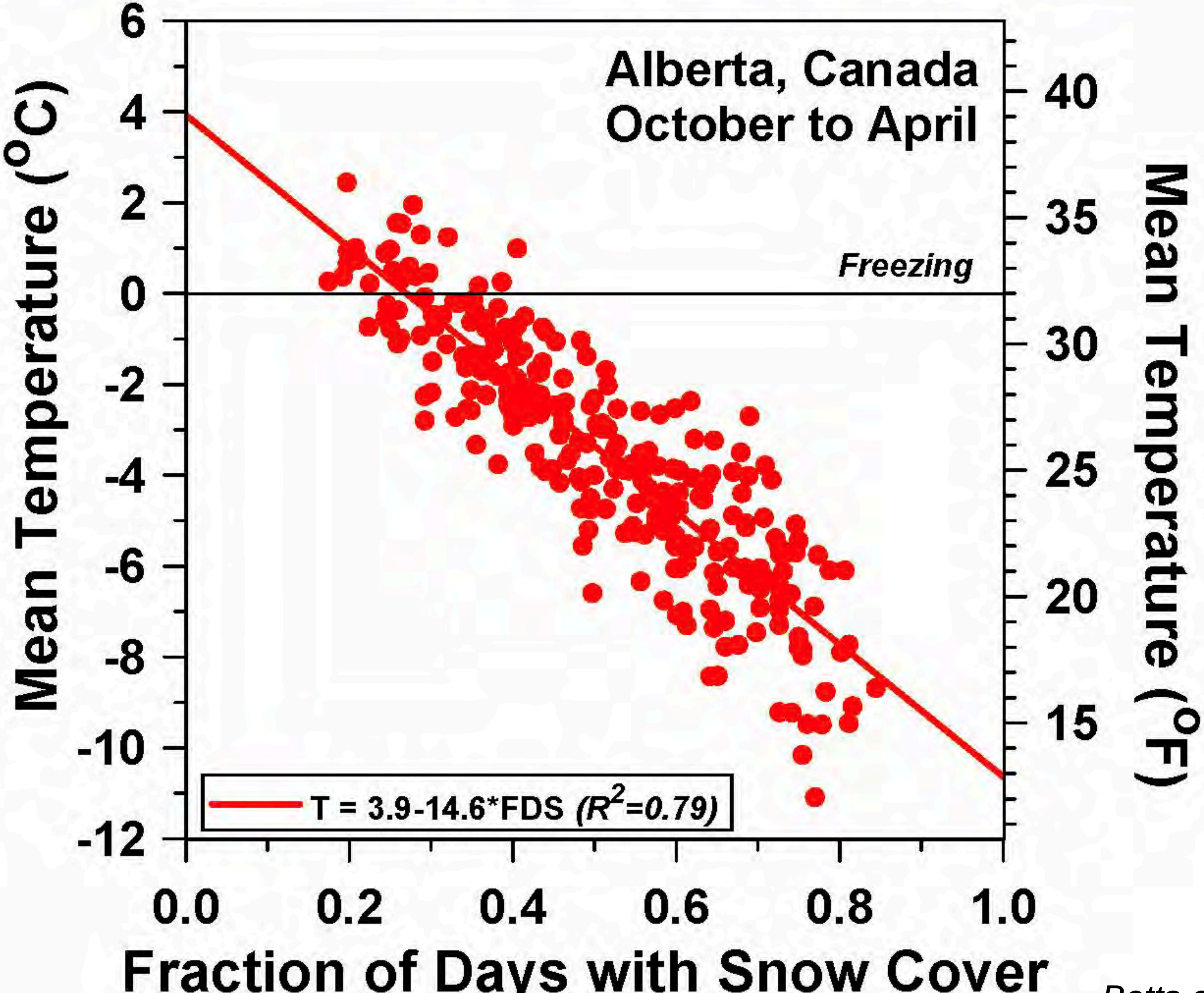
Snowfall and Snowmelt



- **Temperature falls 10C (18F) with first snowfall**
- **Similar change with snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – changes 'local climate'***

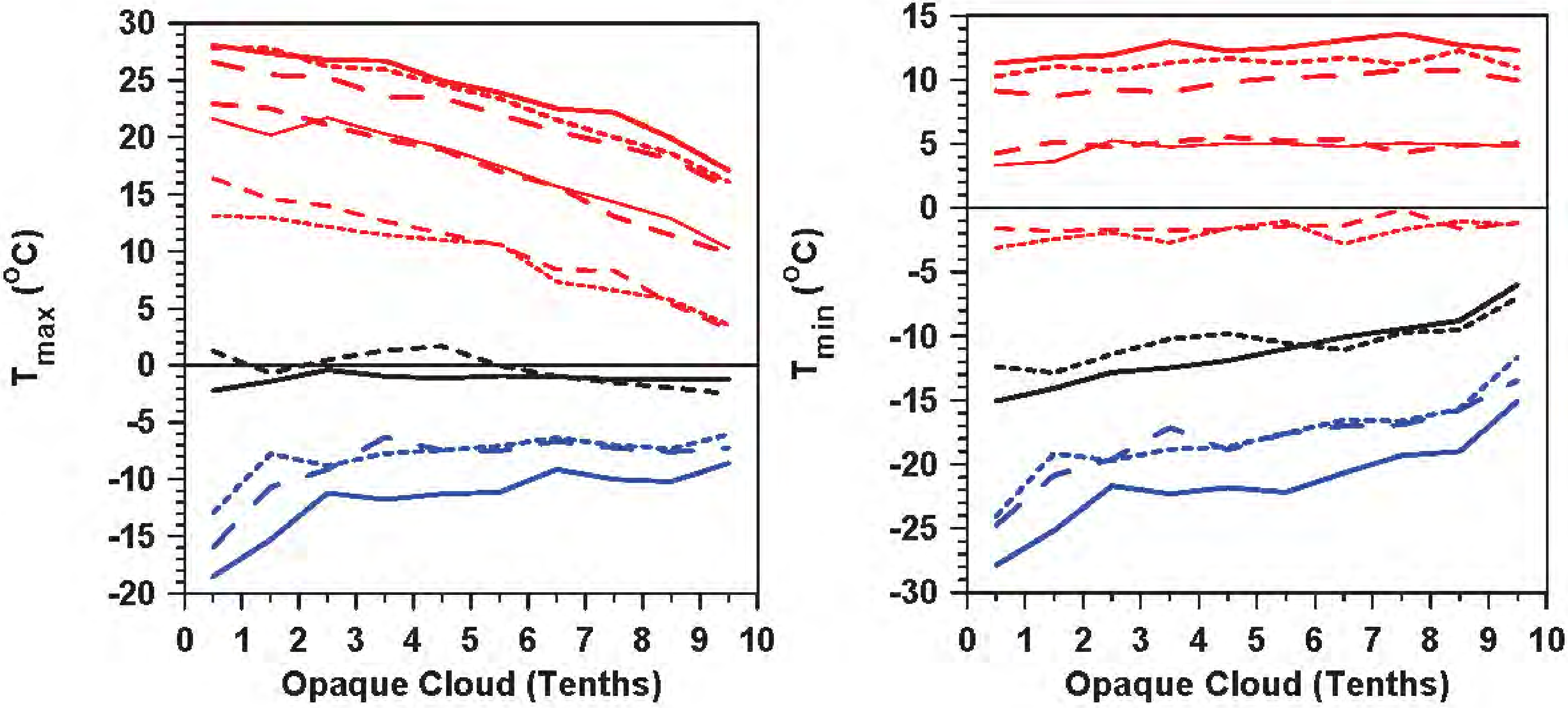
Betts et al. 2014

More snow cover - Colder temperatures



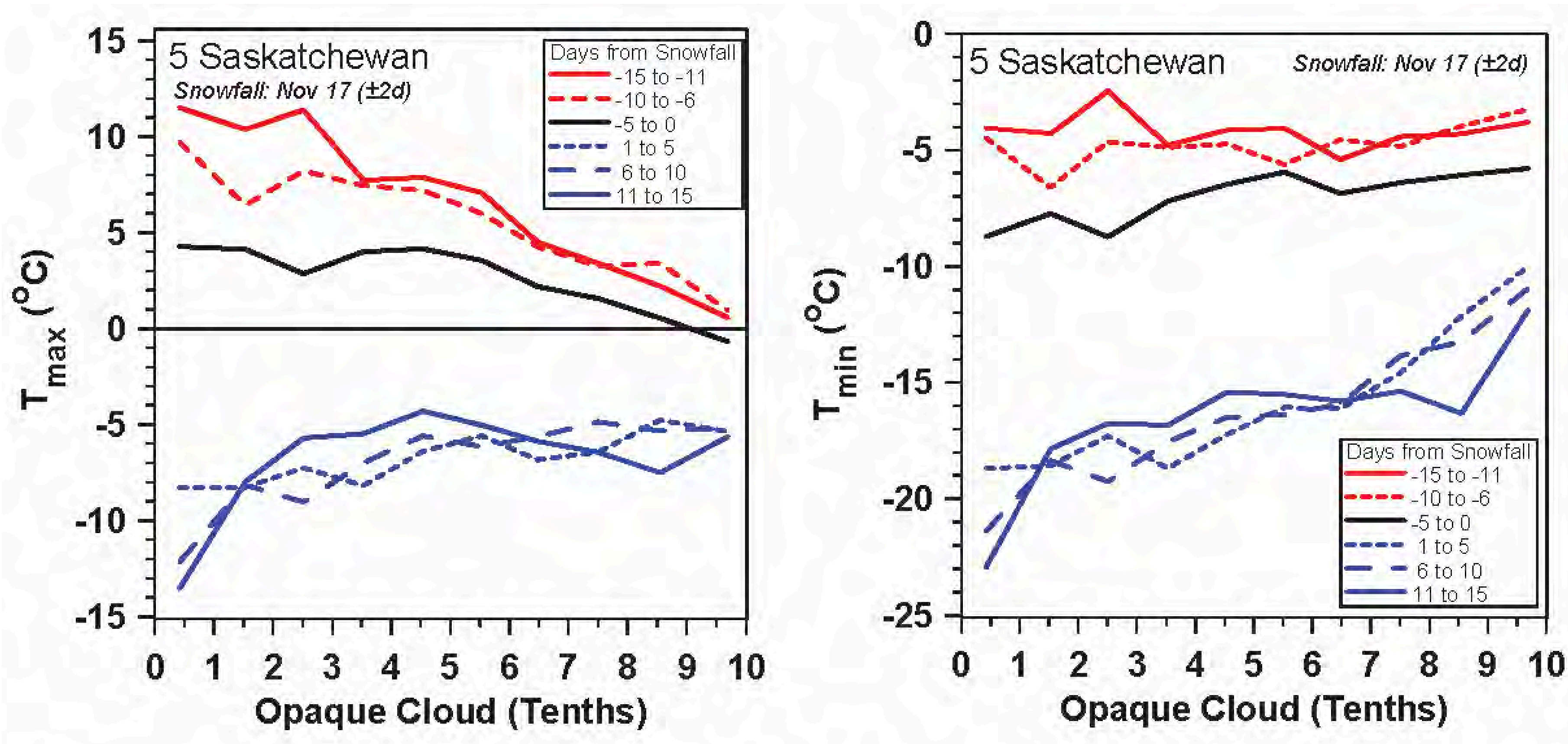
Betts et al. 2014

Recall: Annual Cycle: T_{max},T_{min}



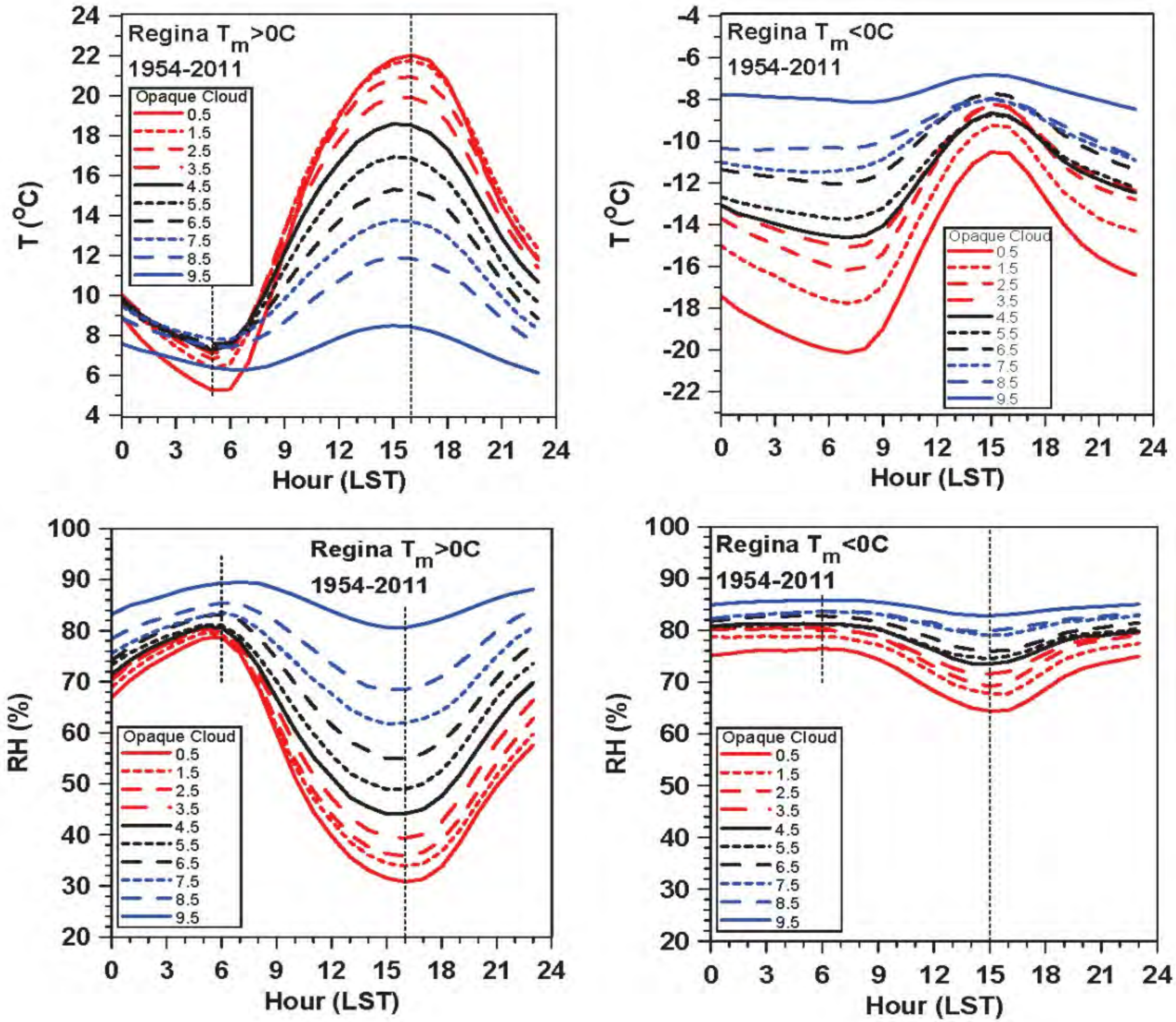
- Warm state: April – Oct
- Transitions: Nov, Mar when $T_{max} \approx 0^oC$
- Cold state: Dec – Feb

Snowfall is a 'Climate Switch'



- **5-day means: *red: no snow; blue: snow* (6000 days)**
- **With snow: T_{max}, T_{min} plunge**
- **Cloud coupling shifts in 5 days**
- **From 'Warm when clear' to 'Cold when clear'**

T>0^{o}C T<0^{o}C



Regina Tm>0C
1954-2011
Opaque Cloud
0.5
1.5
2.5
3.5
4.5
5.5
6.5
7.5
8.5
9.5
T (°C)
Hour (LST)
Regina Tm<0C
1954-2011
RH (%)

Surface Radiation Balance

- **Across snow transition**
  - **Surface albedo α_s increases: 0.2 to 0.73**
  - **LW_{dn} decreases**
  - **Opaque cloud increases**

- **SW_{net} falls 34 W/m^2**
- **LW_{dn} falls 15 W/m^2**
- **Total 49 W/m^2**

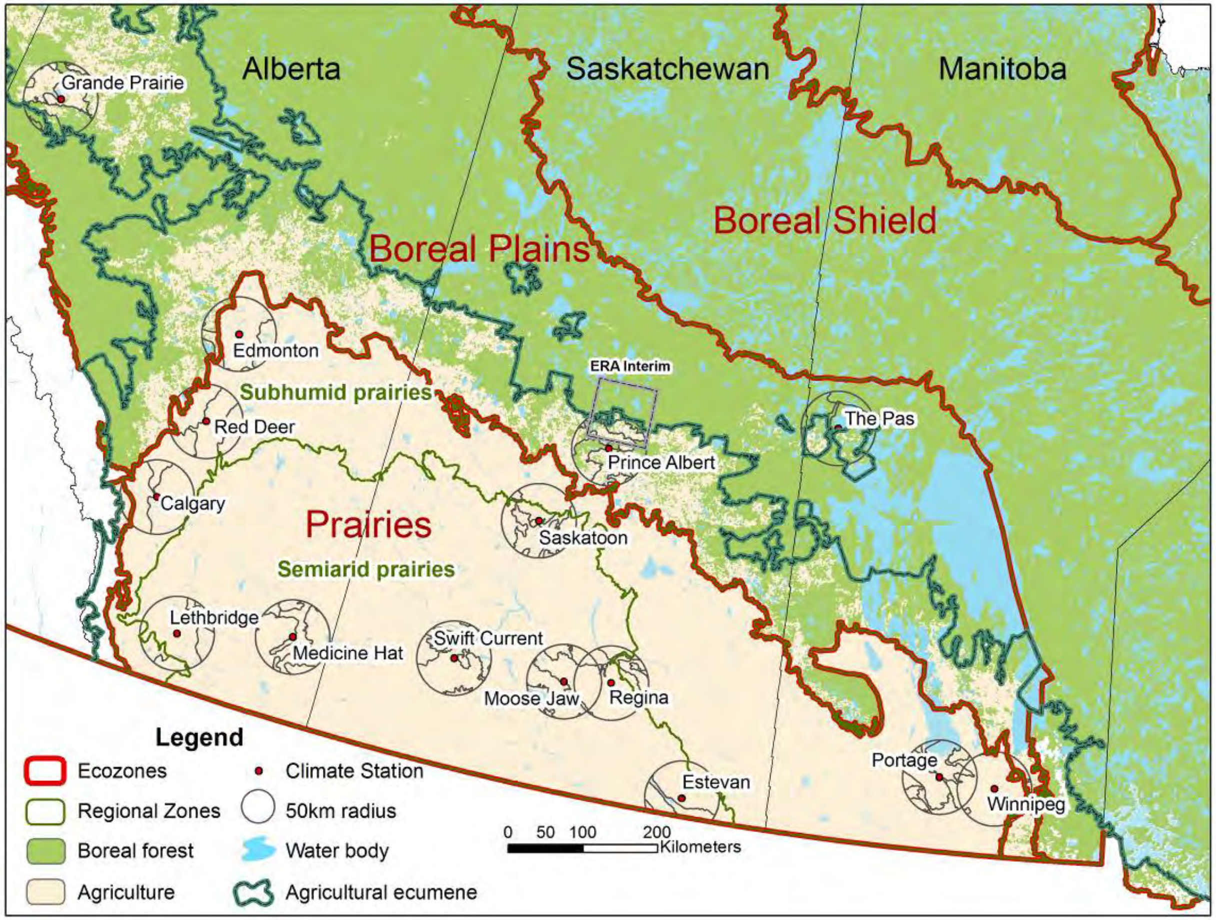
- **Surface skin T falls: $\Delta T = -11K$ to balance**

  (Stefan-Boltzman law: $\Delta(LW) = \Delta(\sigma T^4) = 4\sigma T^3 \Delta T$)

Annual crops and seasonal diurnal cycle

- Ecodistrict crop data since 1955
  - Ecodistricts mapped to soils
  - Typical scale: 2000 km^2 (500-7000)
- Ecozones
  - boreal plains ecozone
  - semiarid/subhumid prairie regional zones
- Shift from 'Summerfallow' (no crops) to annual cropping on 5 MHa (11 M acres)
  - *Large increase in transpiration: Jun-Jul*

13 Prairie stations: 1953-2011



- Hourly p, T, RH, WS, WD, Opaque Cloud by level, (SW_{dn}, LW_{dn})
- Daily precipitation and snowdepth
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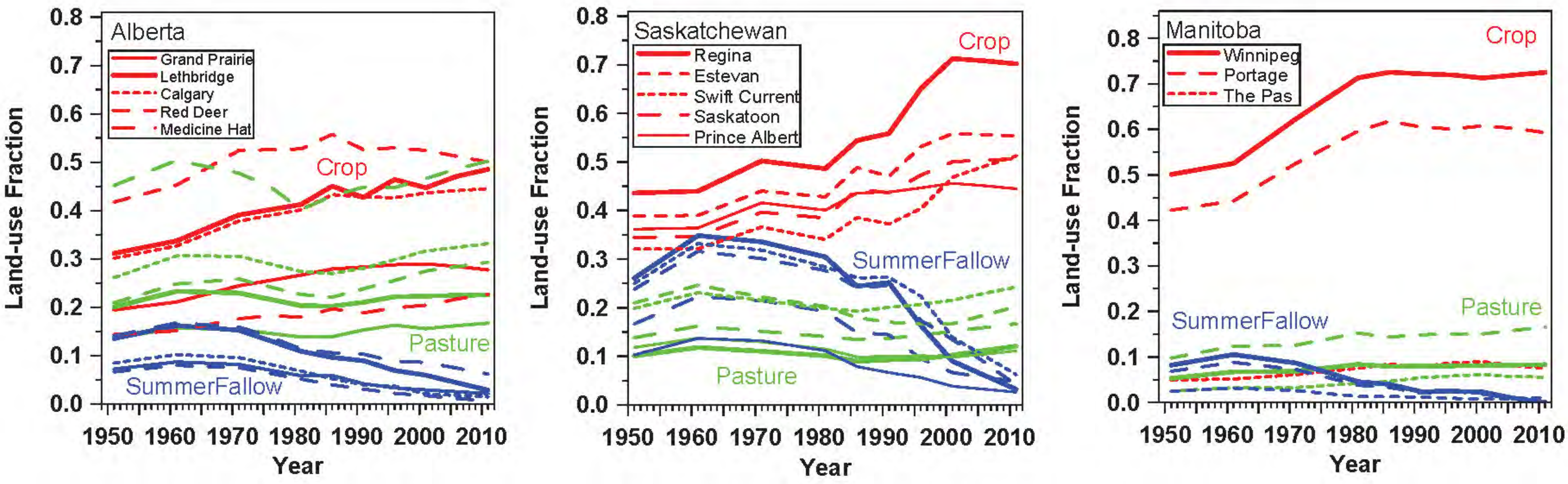
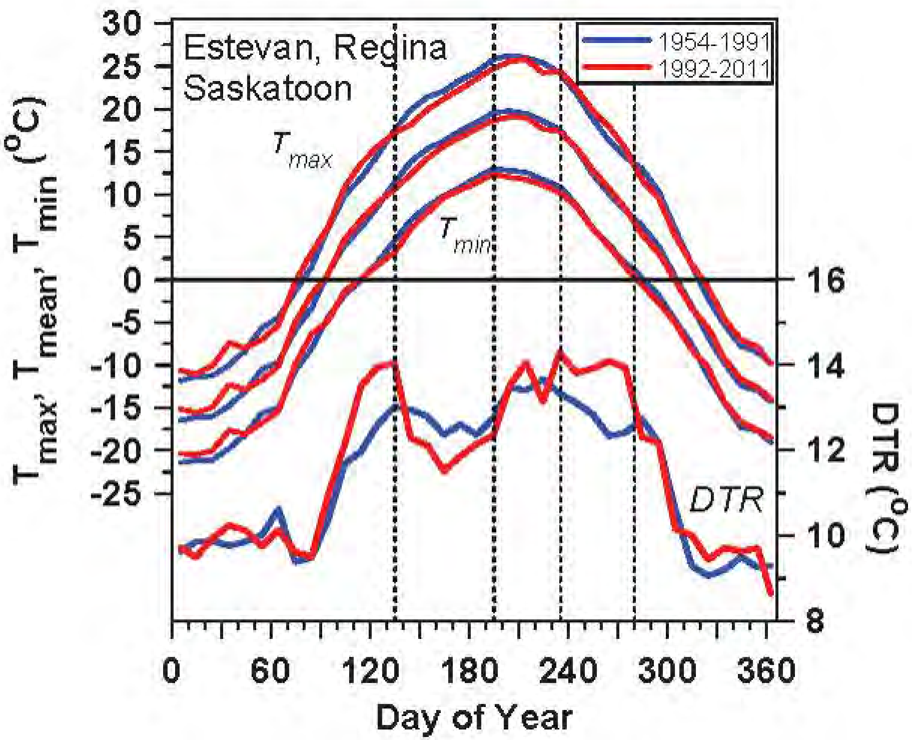
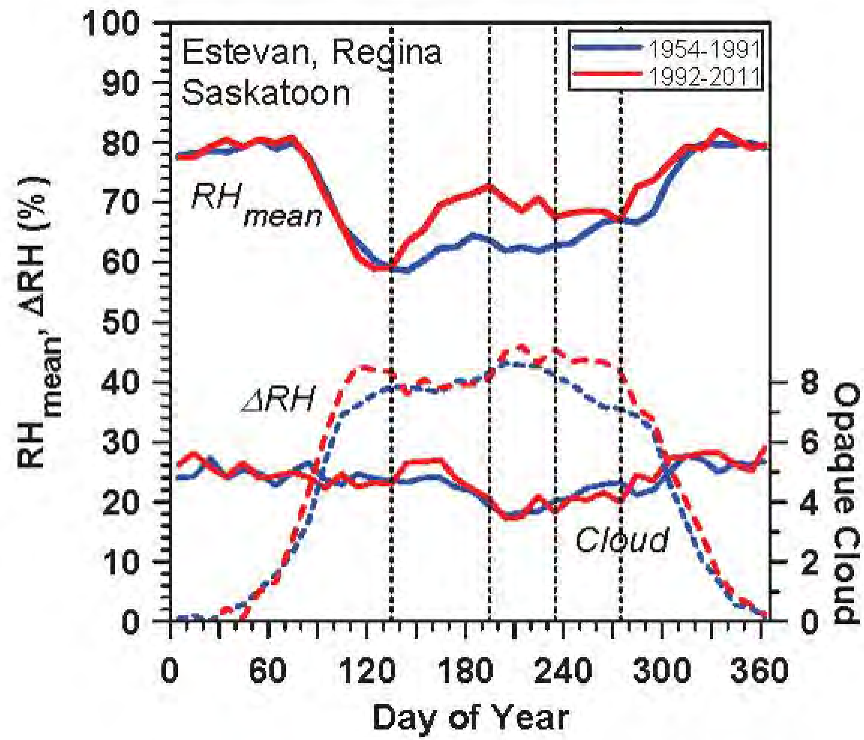
Change in Cropping



- **Ecodistrict mean for 50-km around station**
- **Saskatchewan: 25% drop in 'SummerFallow'**
- ***Split at 1991- has summer climate changed?***

Three Station Mean in SK



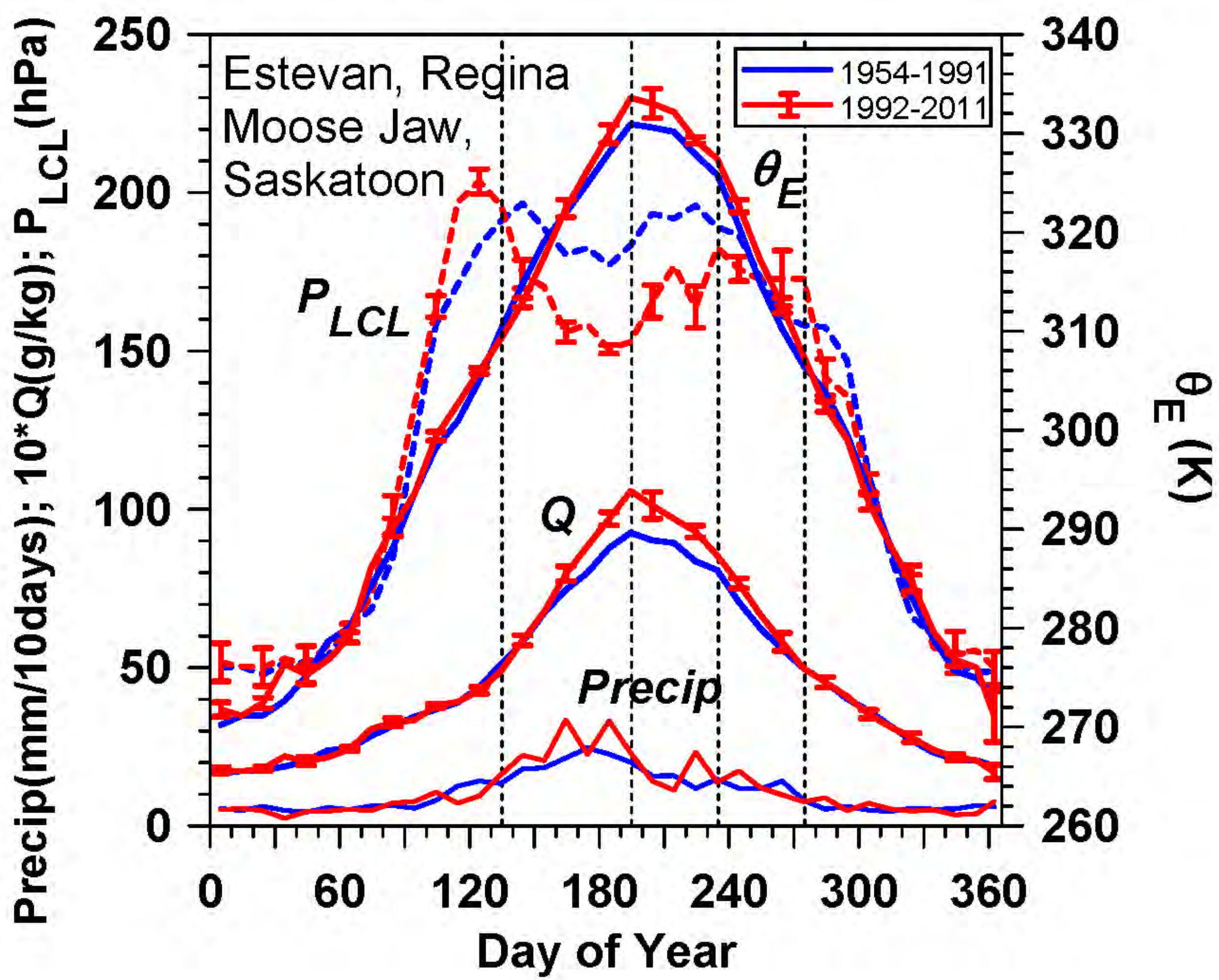


- **Winter climate warmer but growing season**
  - **T_{max} cooler; RH moister**
  - **DTR and ΔRH seasonal structure changes**

Impact on Convective Instability

Growing season

- **Lower LCL**
- **Higher θ_E**
- **More Precip**

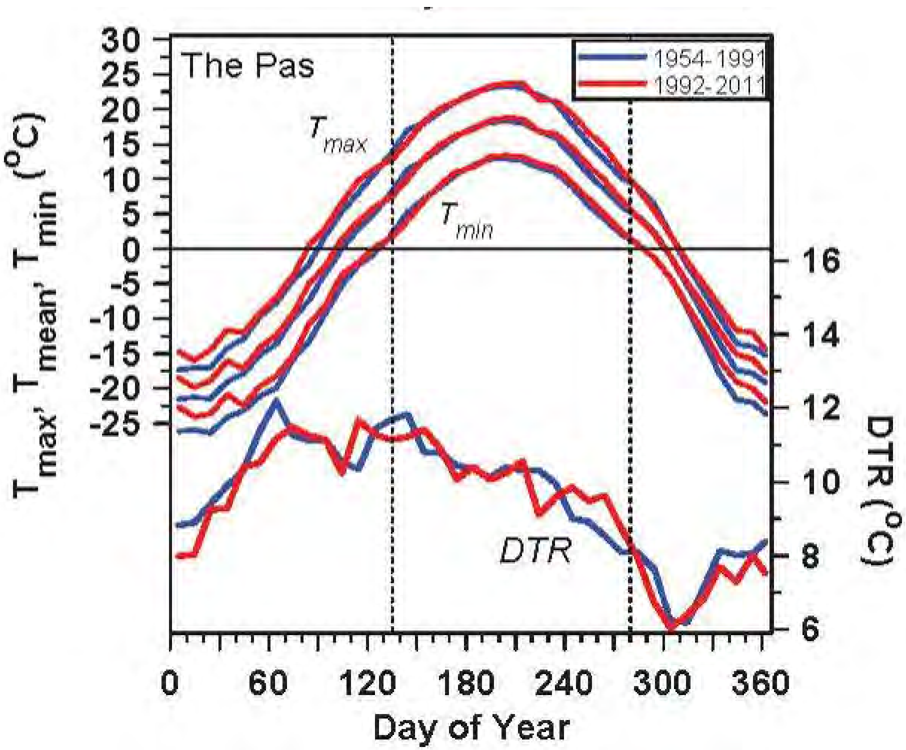


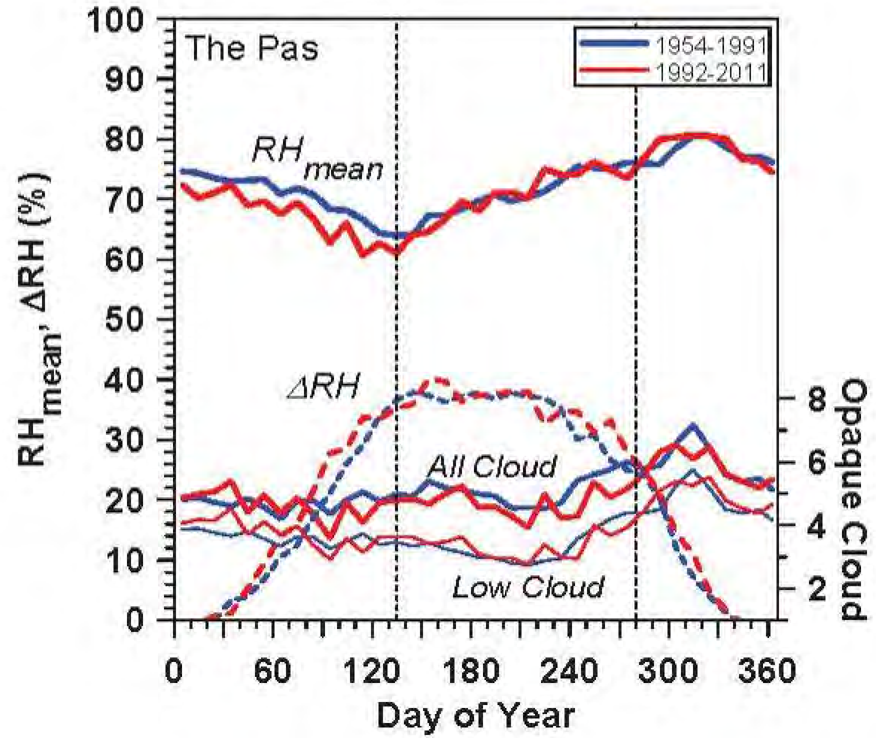
Summary

- *High quality dataset with <u>Opaque cloud</u>*
- **Understand cloud coupling to climate**
- **Distinct warm and cold season states**
  - **Sharp transitions with snow cover: α_s = 0.7**
  - **Snow cover is a <u>"climate switch"</u>**
    - **From 'Warm when clear', convective boundary layer**
    - **To 'Cold when clear', with stable boundary layer**
- **Increased transpiration changed climate**
  - **Cools and moistens summer climate**
  - **Lowers cloud-base and increases θ_E**
  - **(While winter climate has warmed)**

Papers at <u>http://alanbetts.com</u>

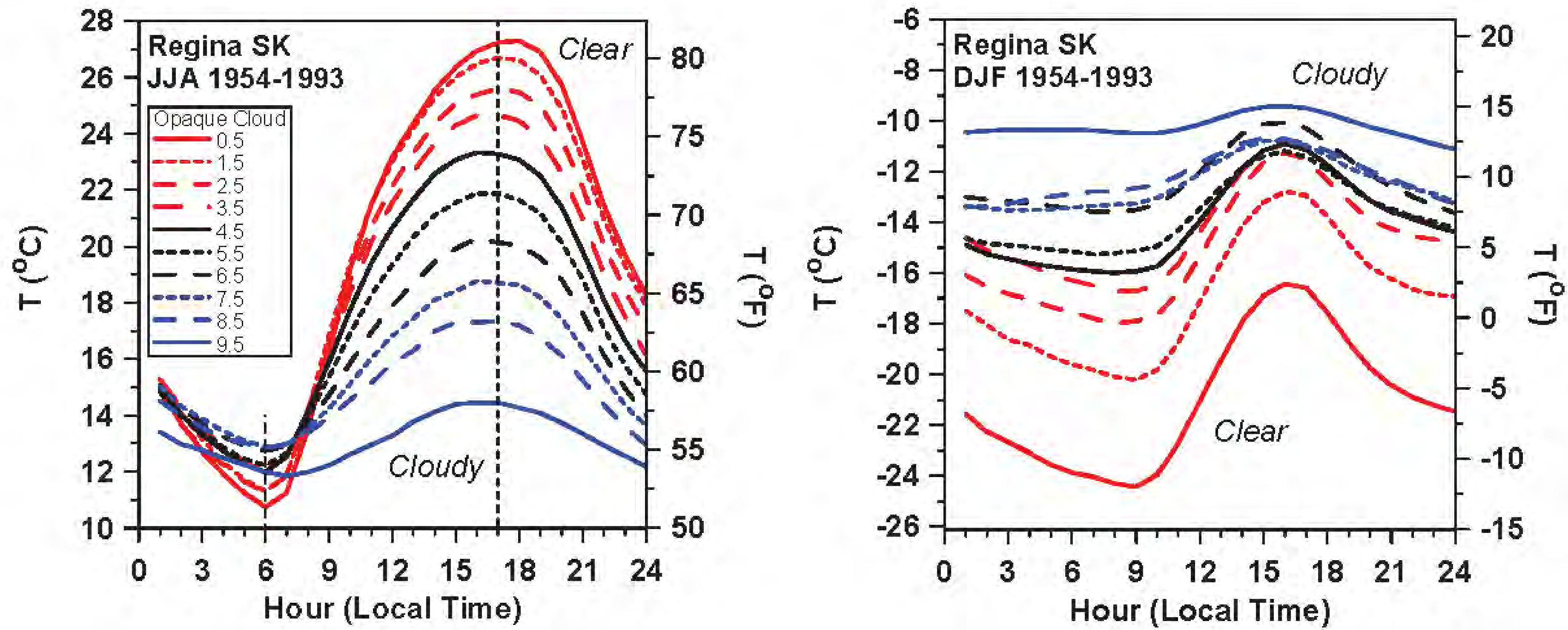
Contrast Boreal Forest





- **No RH, DTR signal**

Clouds: Summer & Winter Climate
Opposite Impact



- **Summer: Clouds reflect sunlight (soil absorbs sun)**
  - **no cloud, hot days; only slightly cooler at night**
  - **Convective boundary layer in daytime**
- **Winter: Clouds are greenhouse (snow reflects sun)**
  - **clear & dry sky, cold days and very cold nights**
  - **Stable boundary layer**

Betts et al. 2013a