Coupling Climate to Clouds, Precipitation and Snow

Alan K. Betts

akbetts@aol.com

http://alanbetts.com

Co-authors:

Ray Desjardins, Devon Worth

Agriculture and Agri-Food Canada

Shusen Wang and Junhua Li

Natural Resources Canada

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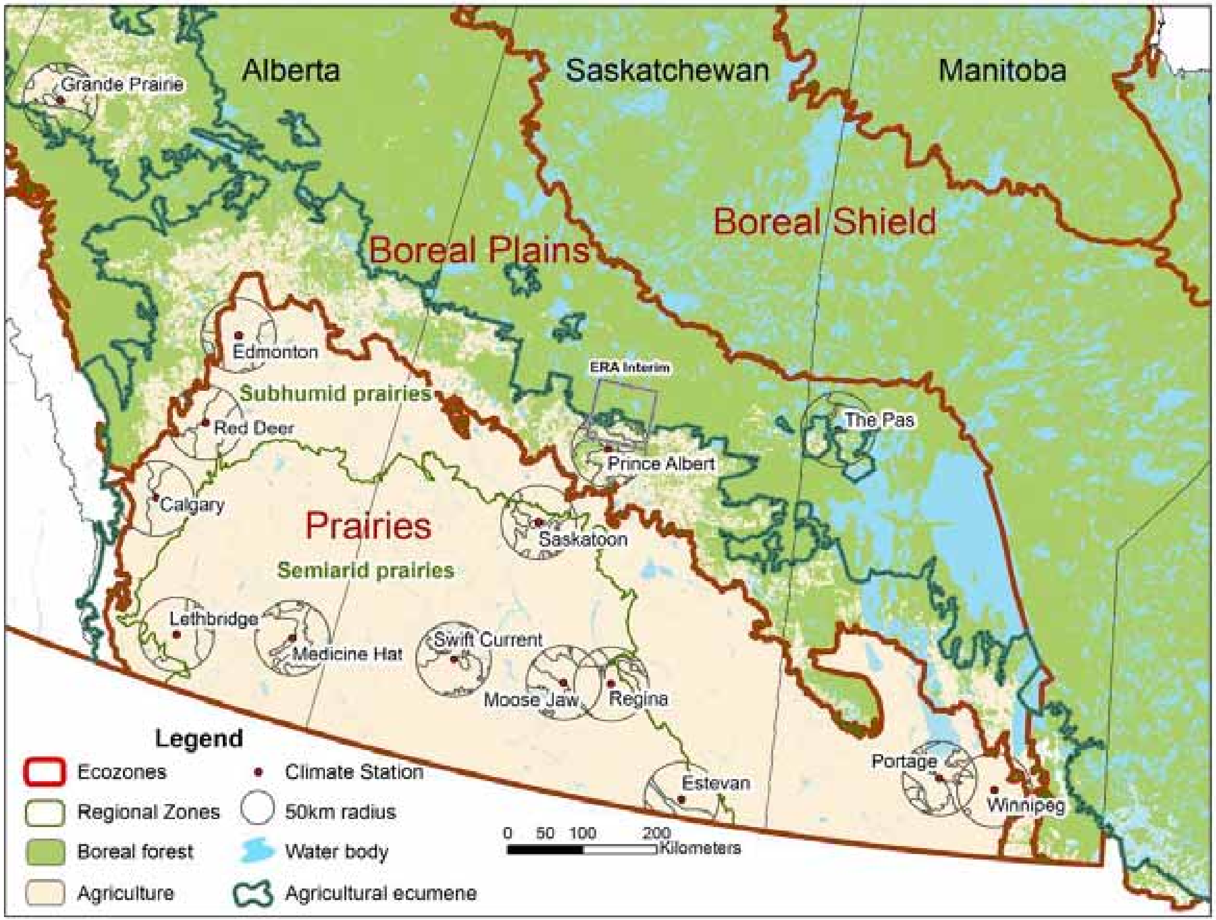
14 Prairie stations: 1953-2011



- *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)

Prairie Station Locations

Station Name	Station ID	Province	Latitude	Longitude	Elevation (m)
Red Deer*	3025480	Alberta	52.18	-113.62	905
Calgary*	3031093	Alberta	51.11	-114.02	1084
Lethbridge†	3033880	Alberta	49.63	-112.80	929
Medicine Hat	3034480	Alberta	50.02	-110.72	717
Grande Prairie*	3072920	Alberta	55.18	-118.89	669
Regina*	4016560	Saskatchewan	50.43	-104.67	578
Moose Jaw	4015320	Saskatchewan	50.33	-105.55	577
Estevan*	4012400	Saskatchewan	49.22	-102.97	581
Swift Current†	4028040	Saskatchewan	50.3	-107.68	817
Prince Albert*	4056240	Saskatchewan	53.22	-105.67	428
Saskatoon*	4057120	Saskatchewan	52.17	-106.72	504
Portage-Southport	5012320	Manitoba	49.9	-98.27	270
Winnipeg*†	5023222	Manitoba	49.82	-97.23	239
The Pas*†	5052880	Manitoba	53.97	-101.1	270

Outline

- **Clouds and Diurnal Cycle over seasons**
  - ***Betts et al (2013a)***
- **Winter snow transitions and climate**
  - ***Betts et al (2014a)***

- ***Betts et al (2013b)*** **Annual crops and seasonal diurnal cycle**

- ***[Betts et al. 2014b: Coupling of temperature and humidity to precipitation and cloud cover in the growing season]***

Papers at http://alanbetts.com

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, 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.**

Methods: Analyze Coupled System

- ***Seasonal/diurnal climate by station/region***
- **220,000 days of excellent data (600 years)**

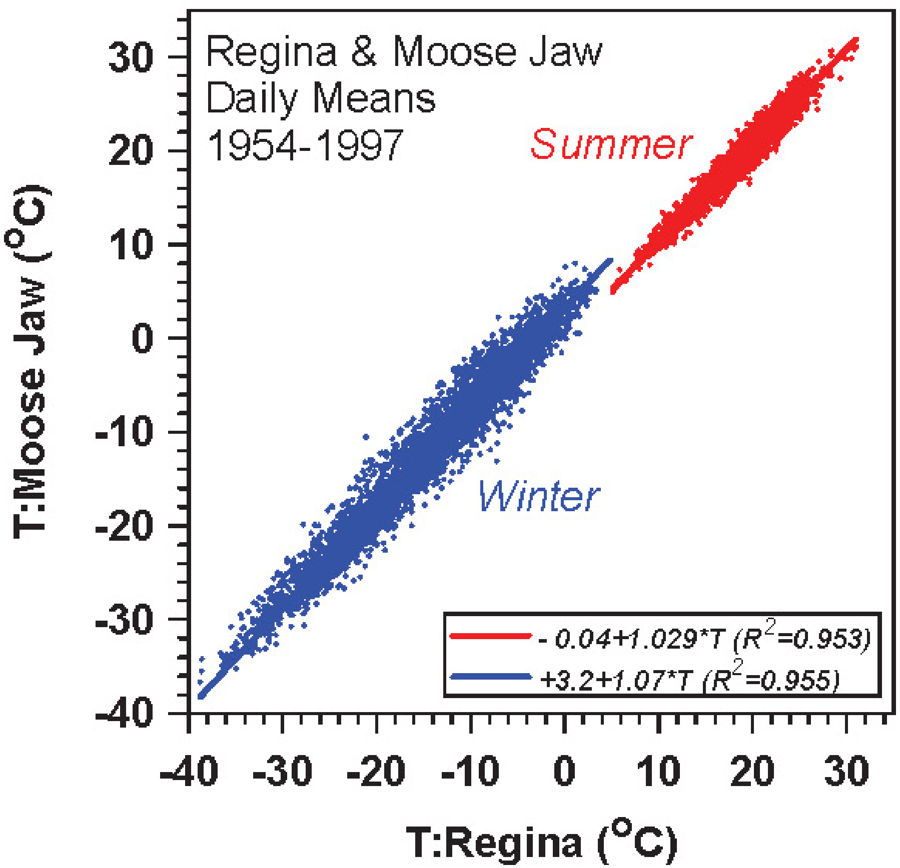
- **Composite by daily mean opaque cloud**
  - **Calibrate SWCF, LWCF against radiation data**

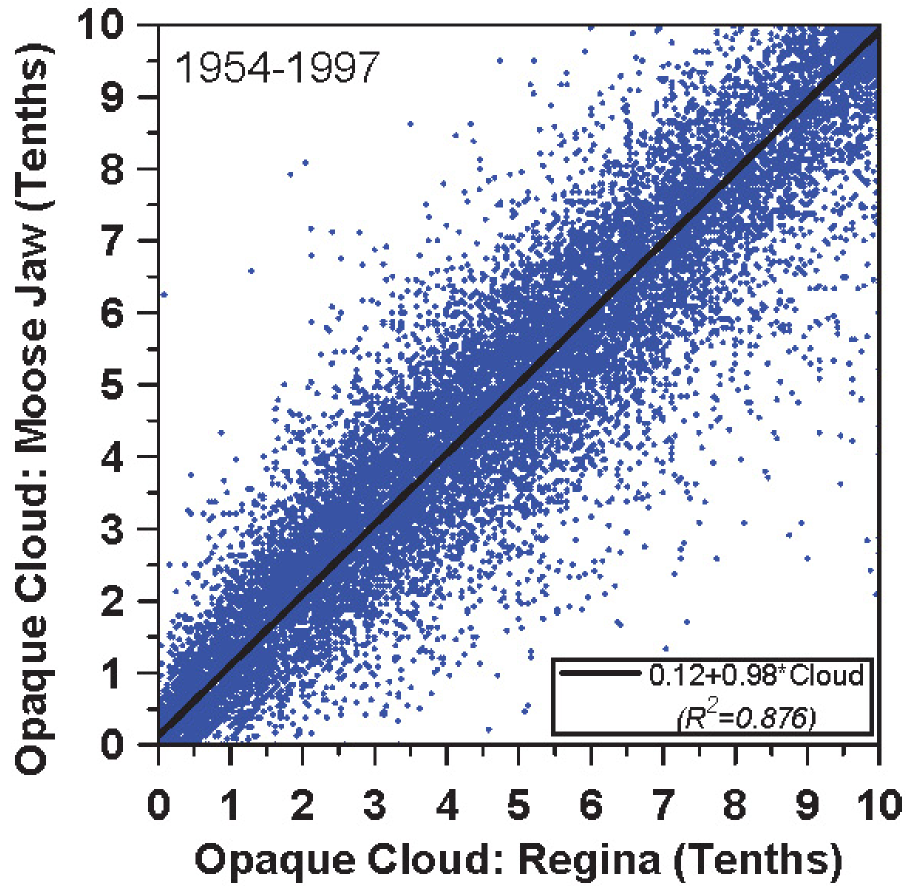
- **Composite across snow transitions**
  - **First snow in fall; spring melt of snowpack**
  - **Winter climate and % days snow cover**

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}** ***(T_x-T_n)***
  - **ΔRH = RH:T_x – RH:T_n**
- ***Almost no missing hourly data (until recent government cutbacks!)***

Compare Neighbors: 64 km



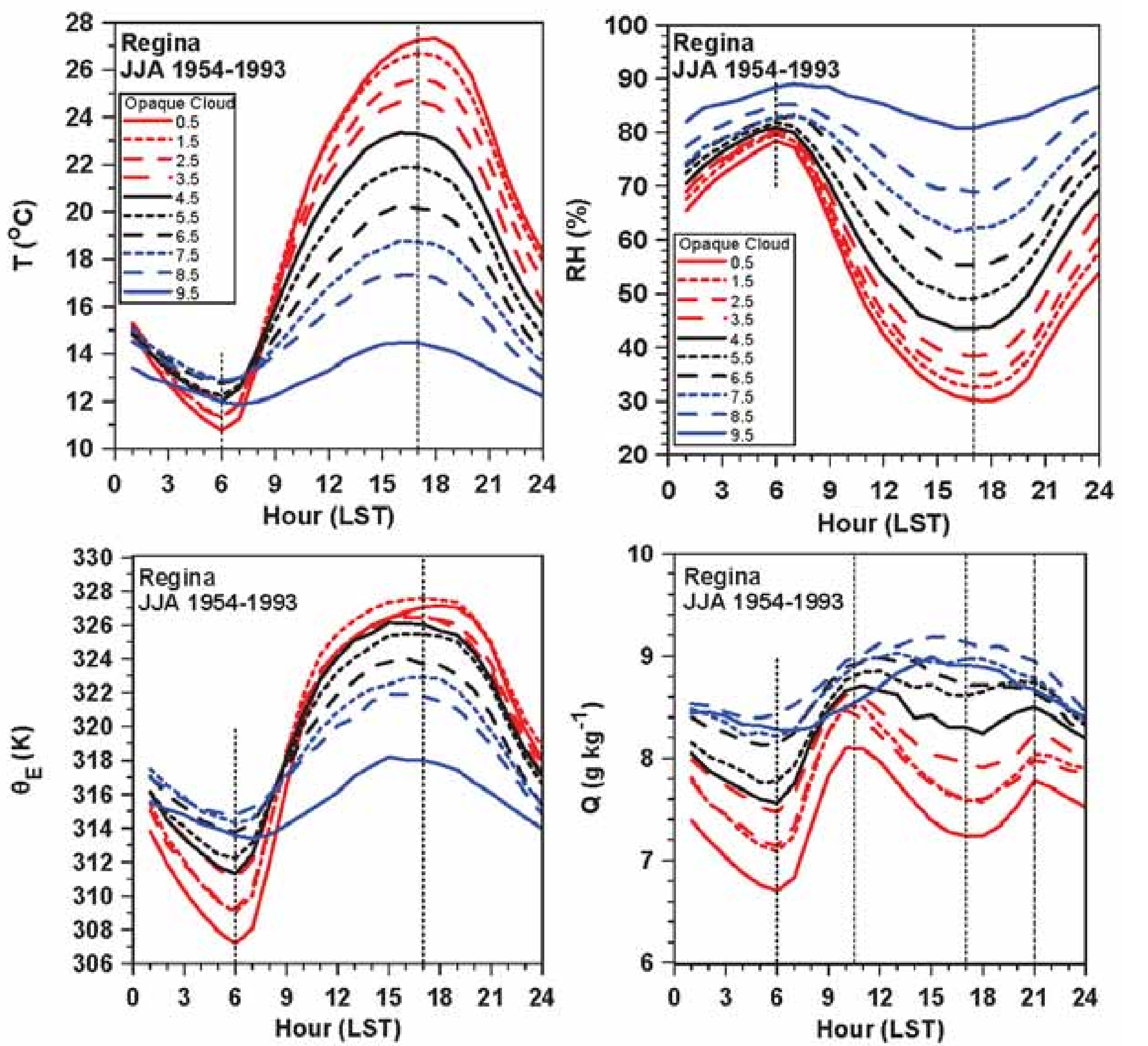


T: (R^2=0.95)

Opaque Cloud: 1 to 1
(R^2=0.88)

Clouds to Summer Diurnal Cycle

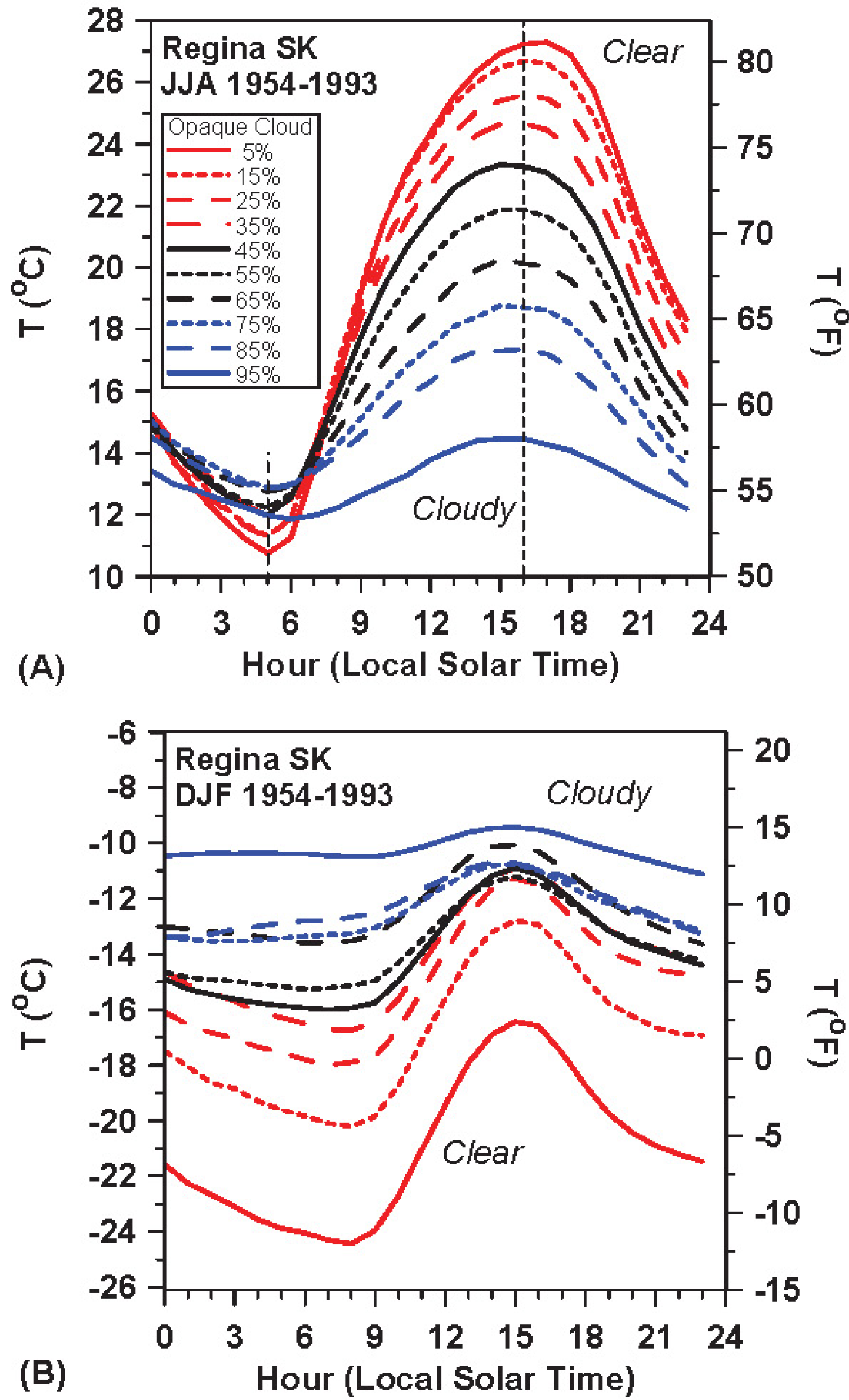
- ***40-yr climate***
- **T and RH are inverse**
- **Q has double maximum for BL transitions**
- **θ_E flatter**
- ***Overcast (rain) only outlier***



Cloud Impacts

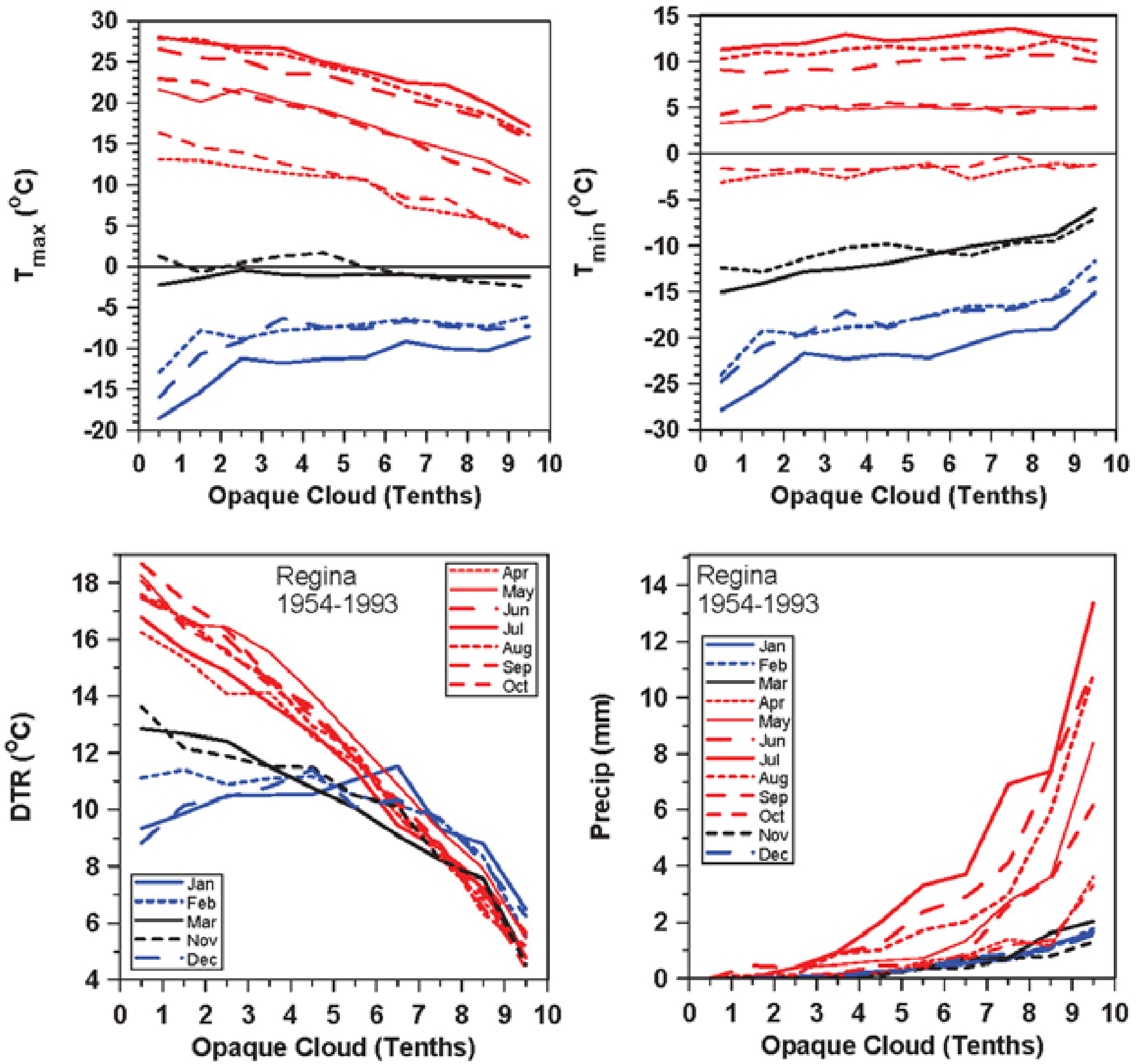
- **Summer: Clouds reflect sunlight**
  - no cloud, hot days; only slightly cooler at night
- **Winter: Clouds are greenhouse**
  - snow reflects low sun
  - clear & dry sky, cold days, very cold nights
- ***Fast transition with snow in 5 days***

Betts et al. 2013



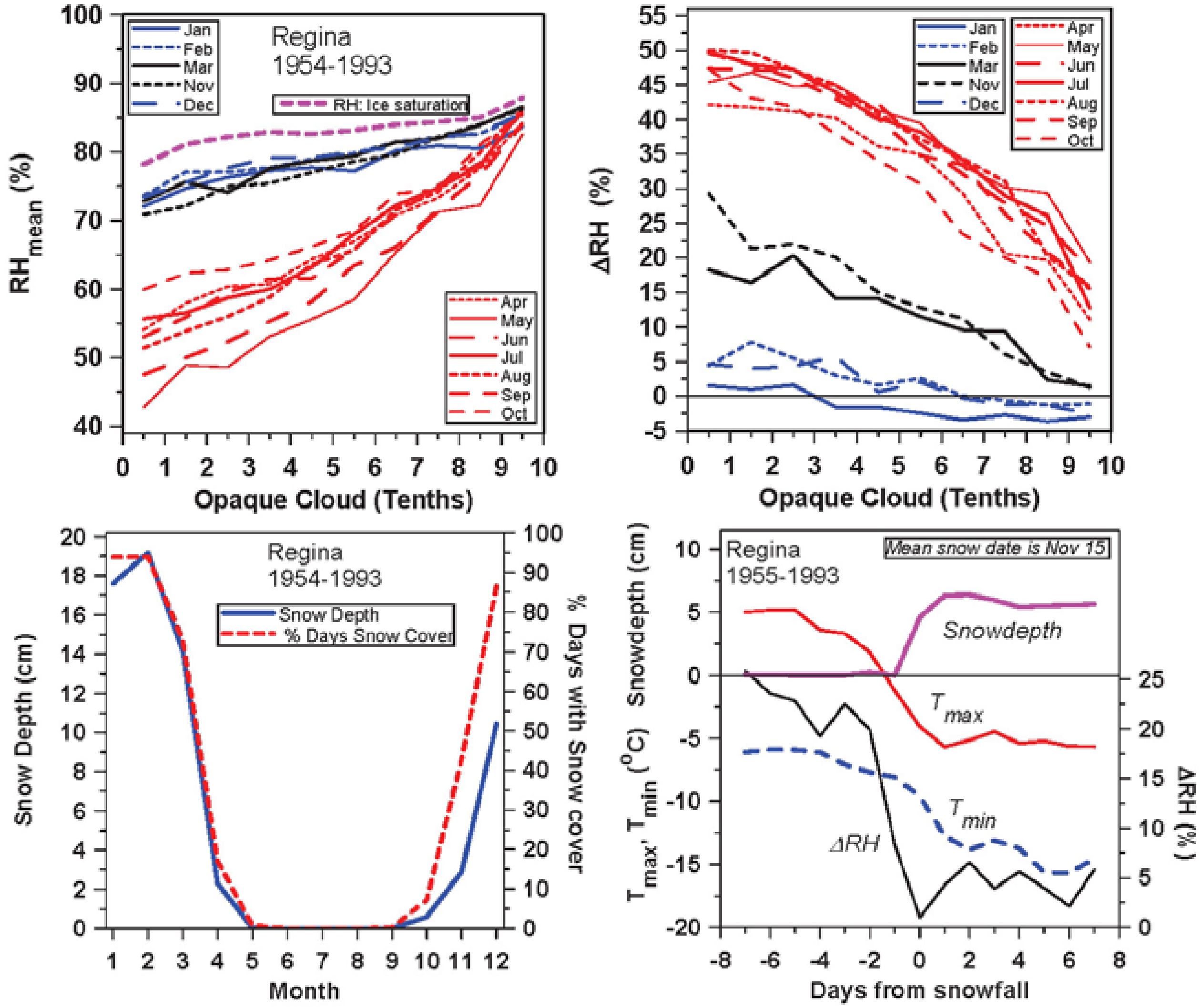
Annual Cycle: T_{max}, T_{min}, DTR, Precip

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

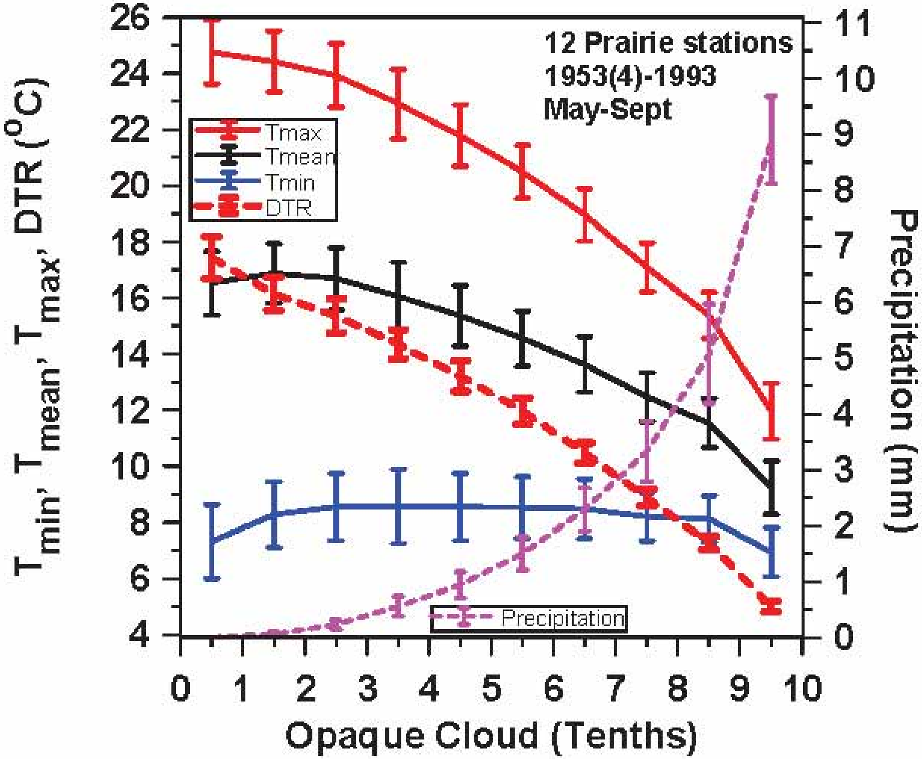


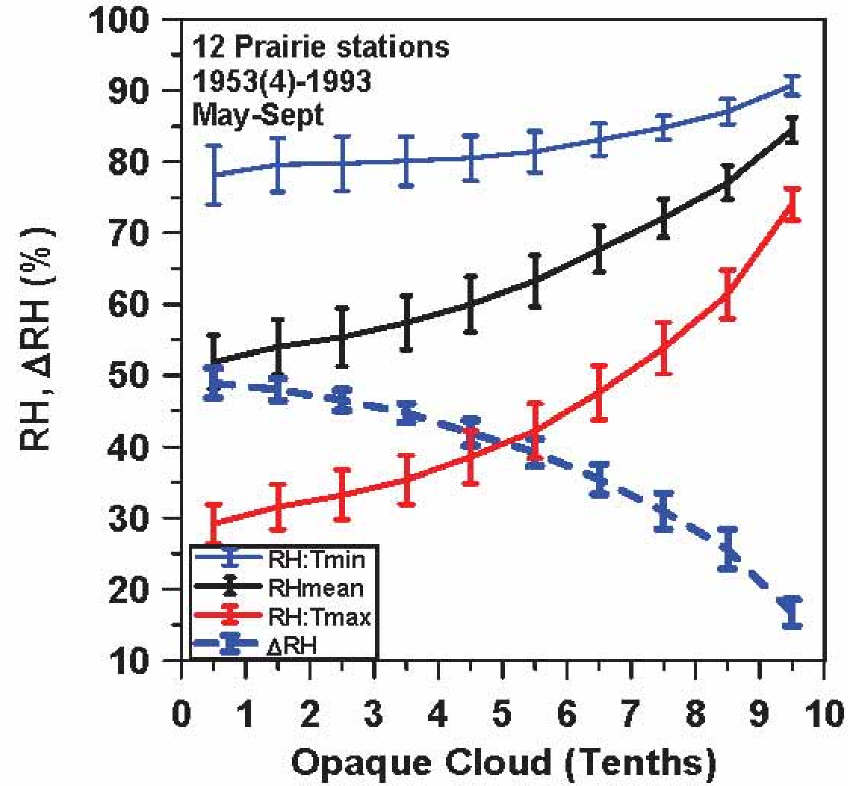
Annual Cycle: RH and ΔRH

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



Prairie Warm Season Climate

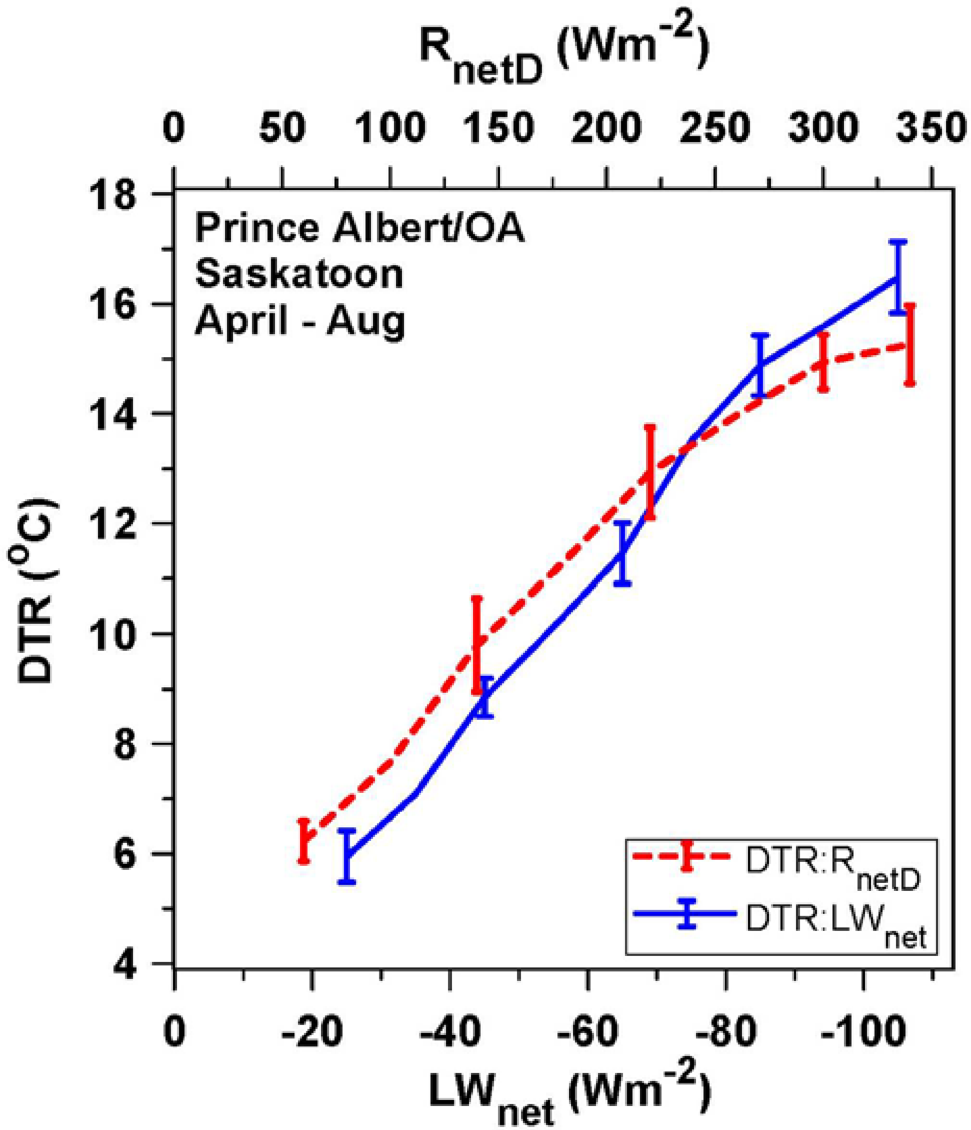




- **12 stations:** ***Uniform climatology***
- **<u>Tiny variability</u> in DTR and ΔRH**

Diurnal Temperature Range

- ***Warms in daytime and cools at night***
- **Daytime Driver: R_{netD}**
- **Nighttime driver: LW_{net}**



(Betts JGR 2006)

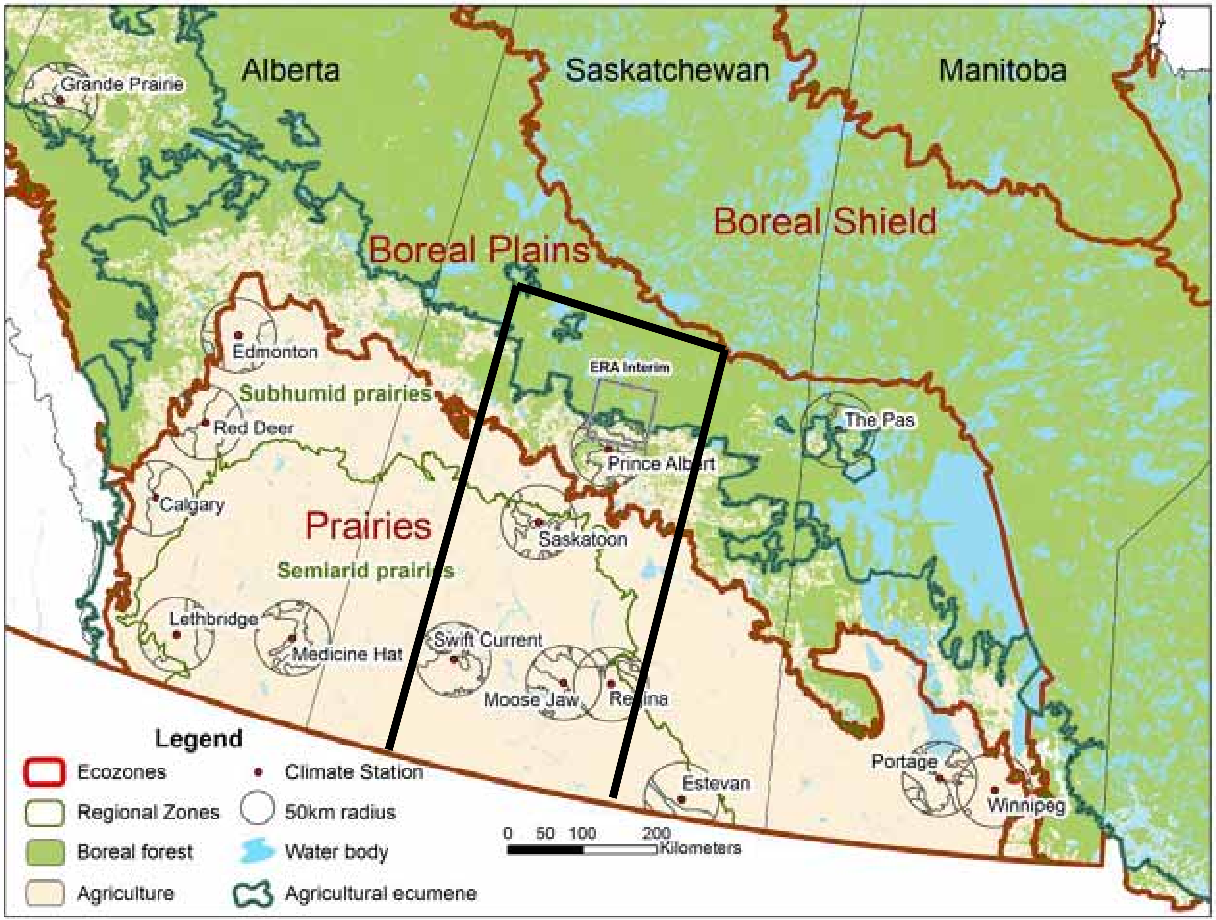
Impact of Snow on Climate

"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

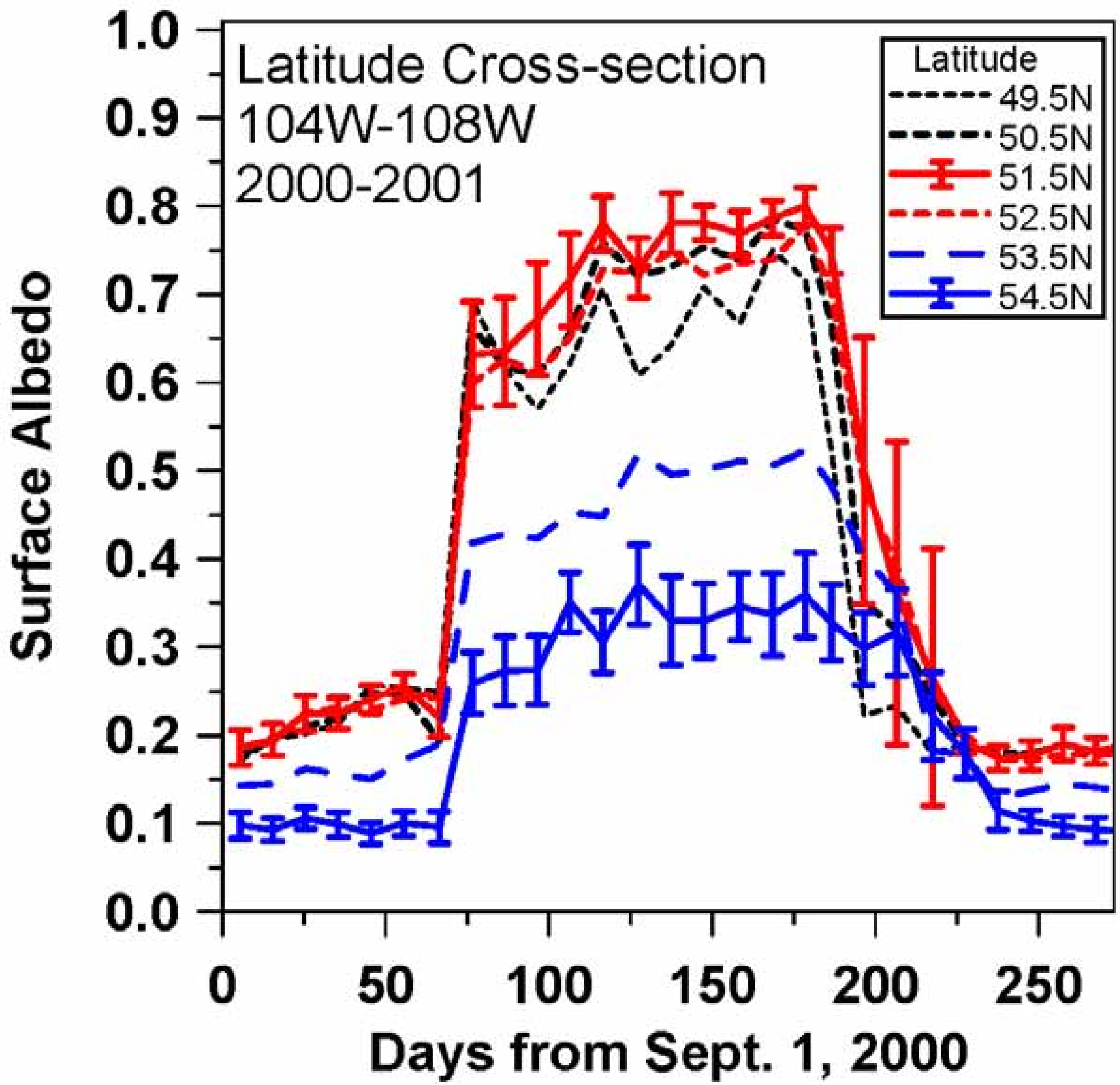


- **Hourly p, T, RH, WS, WD, Opaque Cloud by level, (SW_{dn}, LW_{dn})**
- **Daily precipitation and snowdepth**
- **Albedo data (MODIS/CCRS: 250m, after 2000)**

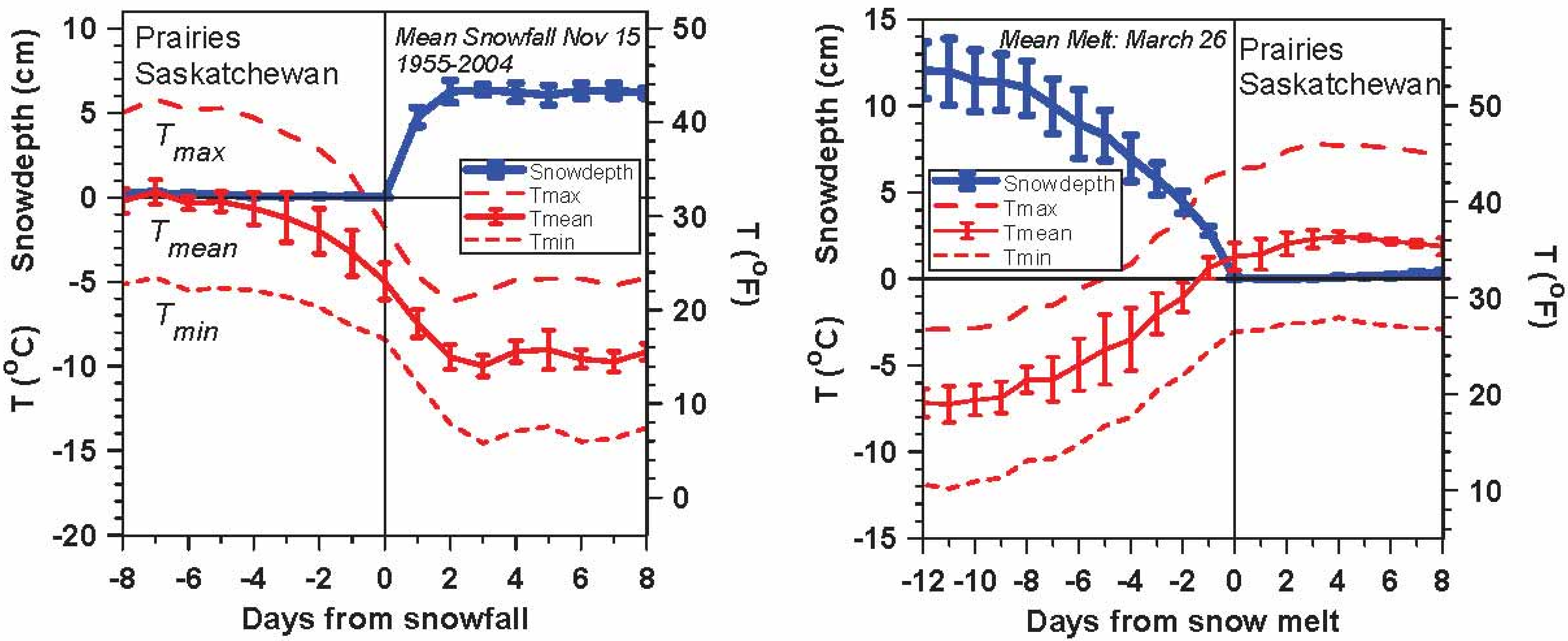
N-S Albedo through Winter

- **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*



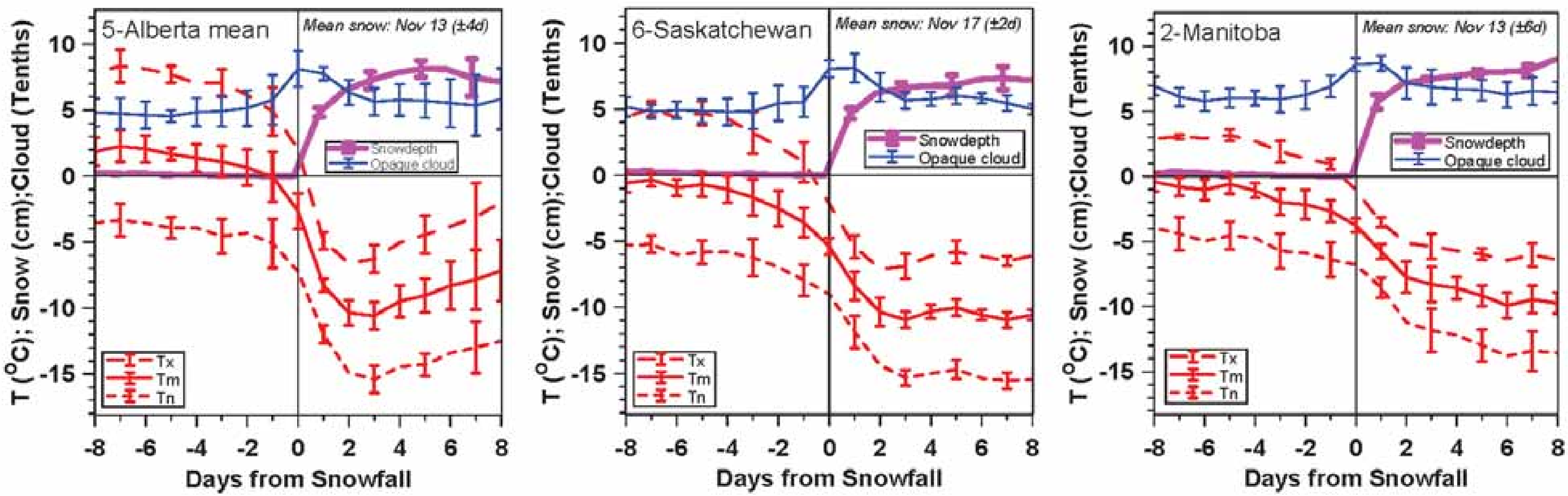
Snowfall and Snowmelt
Winter and Spring transitions



- **Temperature falls/rises about 10K with first snowfall/snowmelt**
- ***Snow reflects sunlight; reduces evaporation and water vapor greenhouse – loss of snow warms 'local climate'***
  - ***Same feedbacks that are speeding Arctic ice melt in summer***
  - ***Local climate switch between warm and cold seasons***

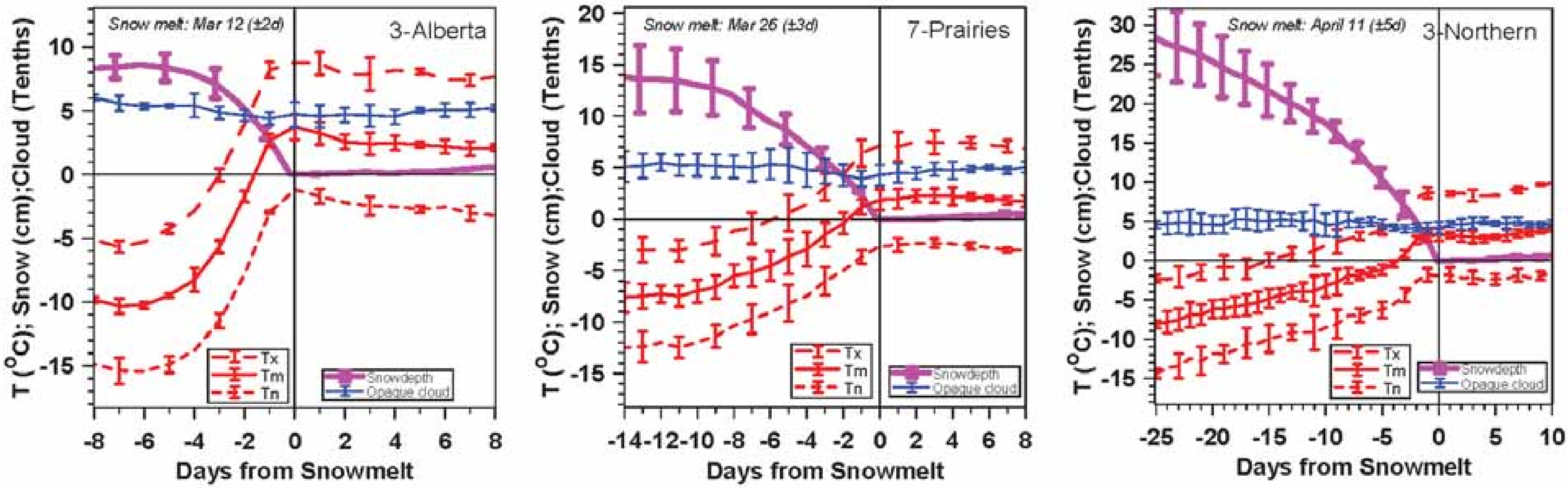
Betts et al. 2014

Fall Snow Transition Climatology



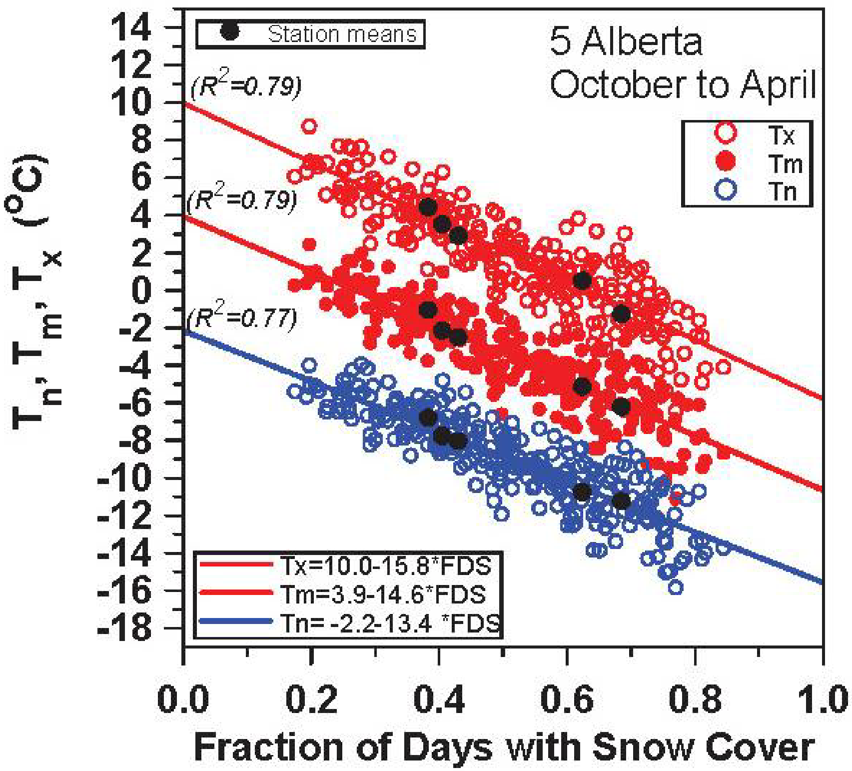
- T_x, T_m, T_n fall about 10K
- **Cloud peaks with snow; increases ≈10%**
- Snow date: Nov 15 ± 3 days

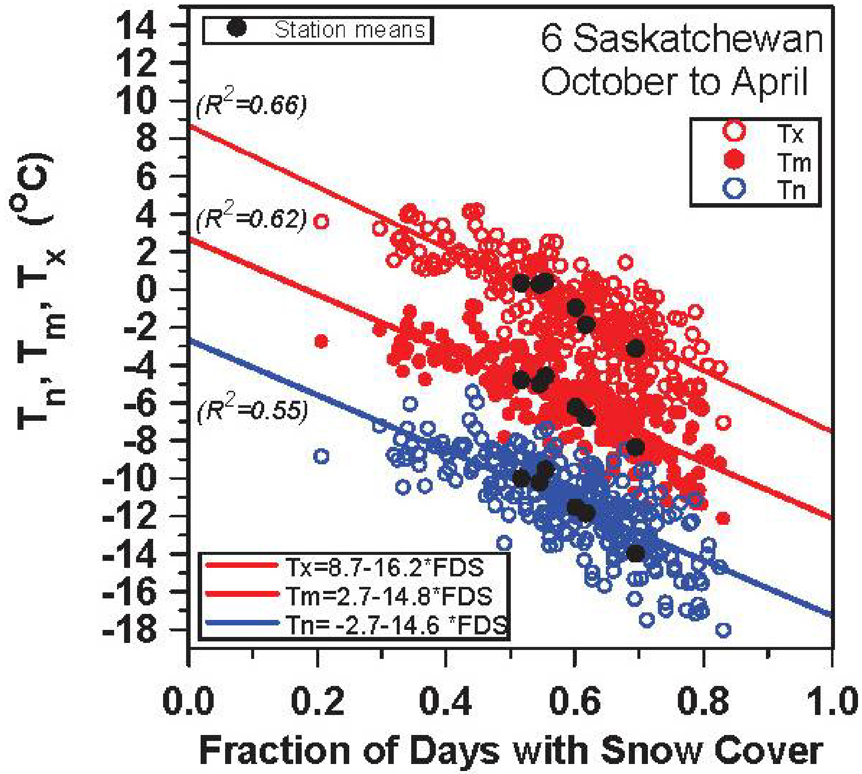
Snow-melt Transition Climatology



- **SW Alberta: T increase about 11K**
- **Saskatchewan: T increase about 10K**
- **3 northern stations: increase 10K, slower**
- **Melt date: March 12–April 11**

Snow Cover: Winter Climatology





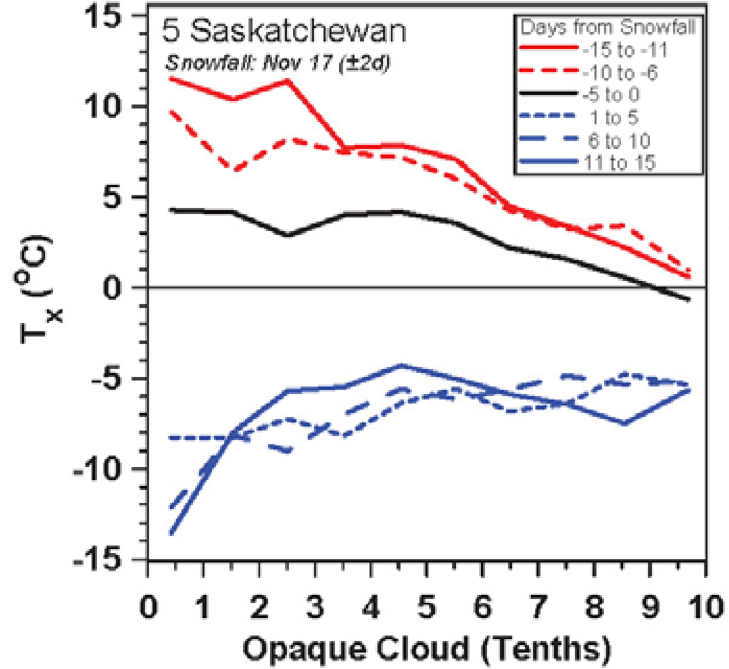
- **Alberta: 79% of variance**
- **Slopes**
  - **T_x -16.0(± 0.6) K**
  - **T_m -14.7 (± 0.6) K**
  - **T_n -14.0 (± 0.7) K**

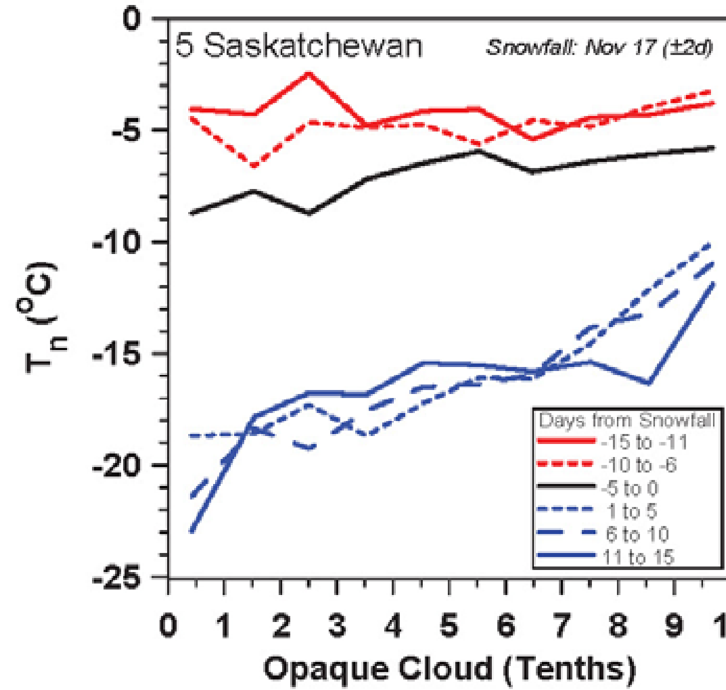
10% fewer snow days

= 1.5K warmer

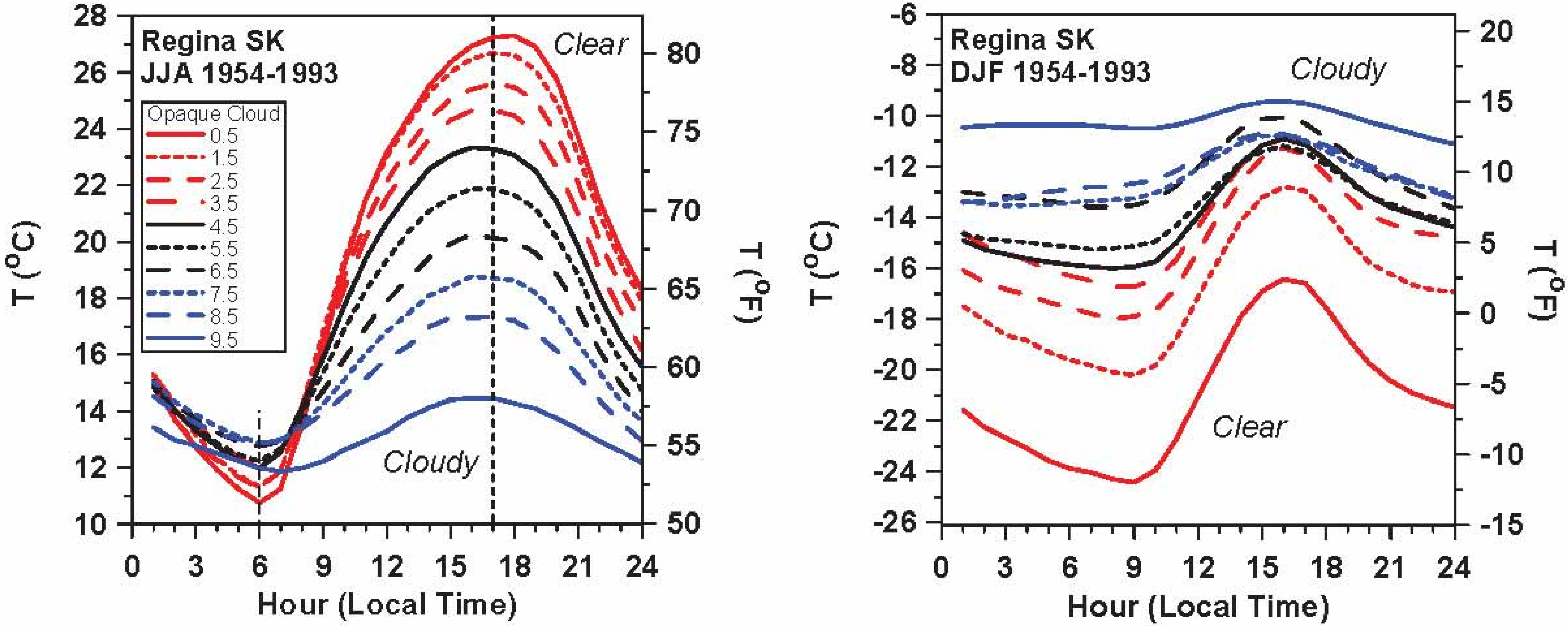
Coupling to Cloud Cover Across Snowfall

- **Mid-November**
- **5-day means (6000 days)**
  - ***red: no snow***
  - ***blue: snow***
- **With snow**
  - **T_x, T_n plunge**
- **Cloud coupling shifts in 5 days**
  - **from 'Warm when clear' to 'Cold when clear**
  - **"SWCF to LWCF"**





Clouds: Summer & Winter Climate
Opposite Impact

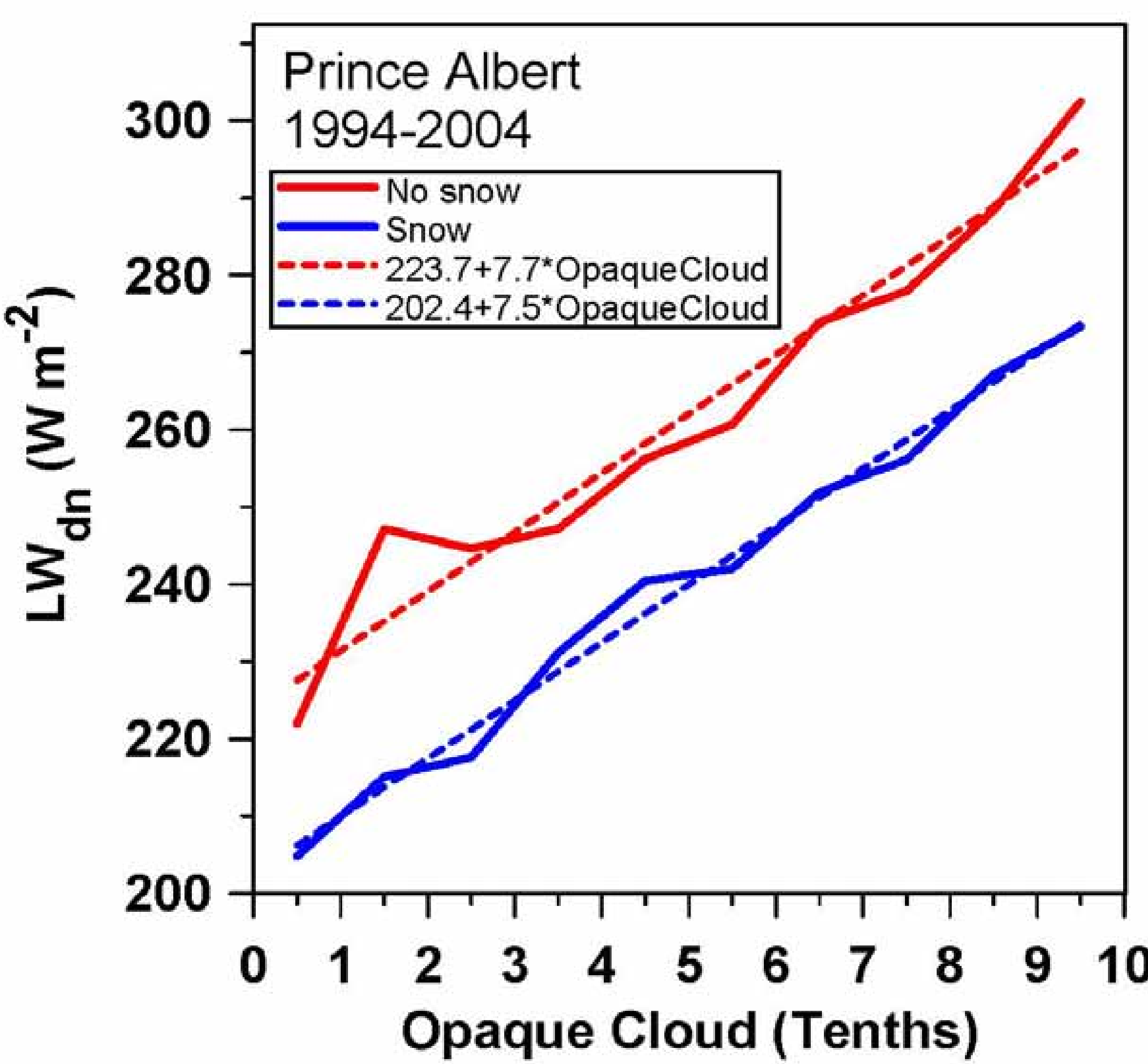


- **Summer: Clouds reflect sunlight (soil absorbs sun)**
  - **no cloud, hot days; only slightly cooler at night**
  - **Convective boundary layer in daytime**
- **Winter: Clouds are greenhouse (snow reflects sun)**
  - **clear & dry sky, cold days and very cold nights**
  - **Stable boundary layer**

Betts et al. 2013a

Role of LW_{dn} in Surface Radiation

- **Snow reduces vapor flux**
- **Atmosphere cooler and drier**
  - **Less water vapor greenhouse**
  - **$-22\ W/m^2$**
- ***Offset by 10% cloud increase with snow***



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: $\Delta LW = \Delta(\sigma T^4) = 4\sigma T^3 \Delta T$)

Summary

- ***High quality dataset with Opaque cloud***
- **Understand cloud coupling to climate**
- **Distinct warm and cold season states**
  - **Sharp transitions with snow cover: $\alpha_s = 0.7$**
  - **Snow cover is a “climate switch”**
    - **From ‘Warm when clear’ - convective BL**
    - **To ‘Cold when clear’ - stable BL**

Papers at http://alanbetts.com

Transformative Concepts

- Snow as climate switch

- Opaque/reflective cloud → R_n
- Separation of land-surface coupling
  - RH to precipitation and soil moisture
  - T to opaque cloud and R_n

Surface Radiation Budget

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

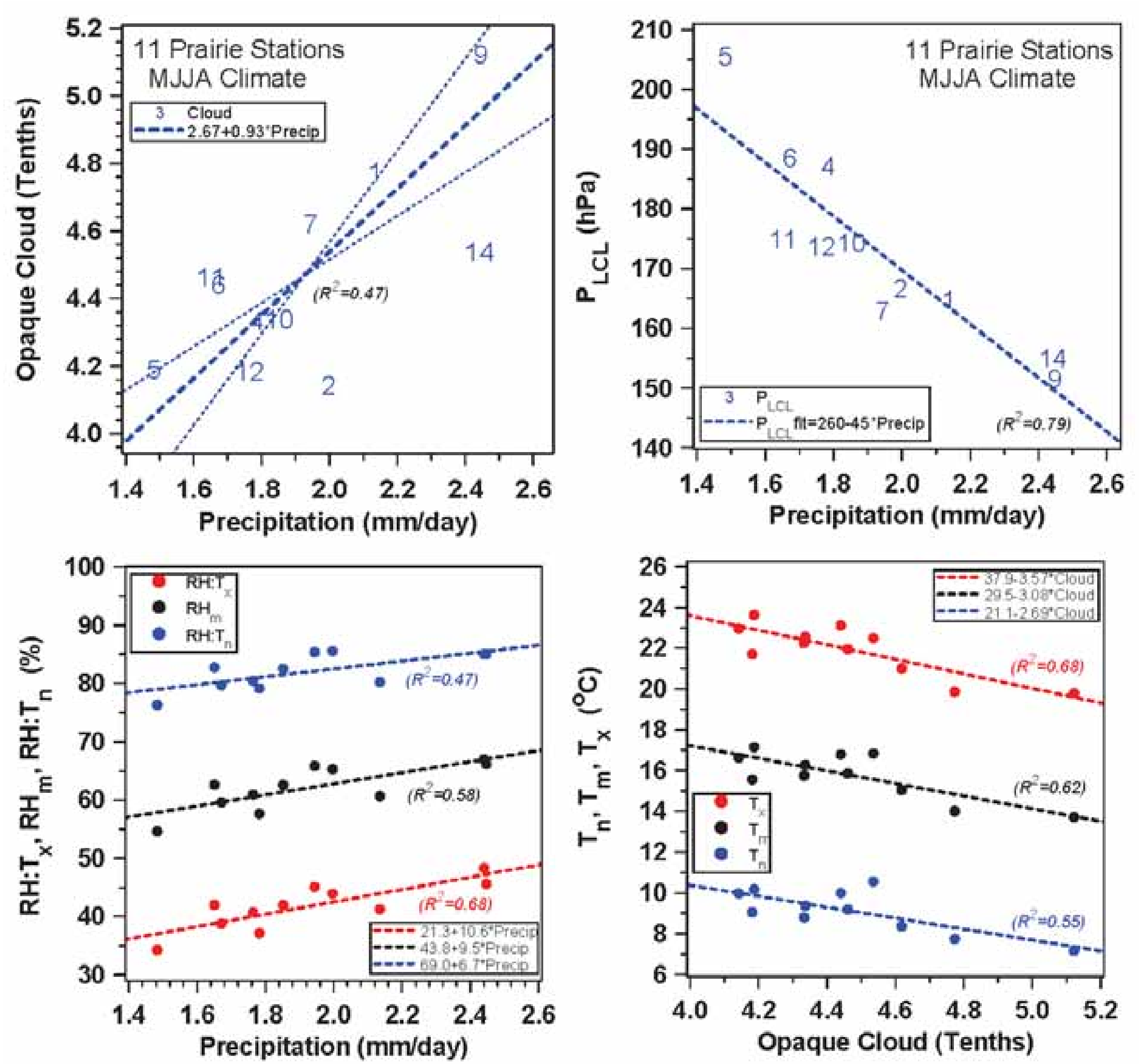
Define Effective Cloud Albedo (reflection)

- $ECA = (SW_{dn}(clear) - SW_{dn}) / SW_{dn}(clear)$
  Clear sky
- $SW_{net} = (1 - \alpha_s)(1 - ECA)\ SW_{dn}(clear)$
  Reflected by surface, clouds

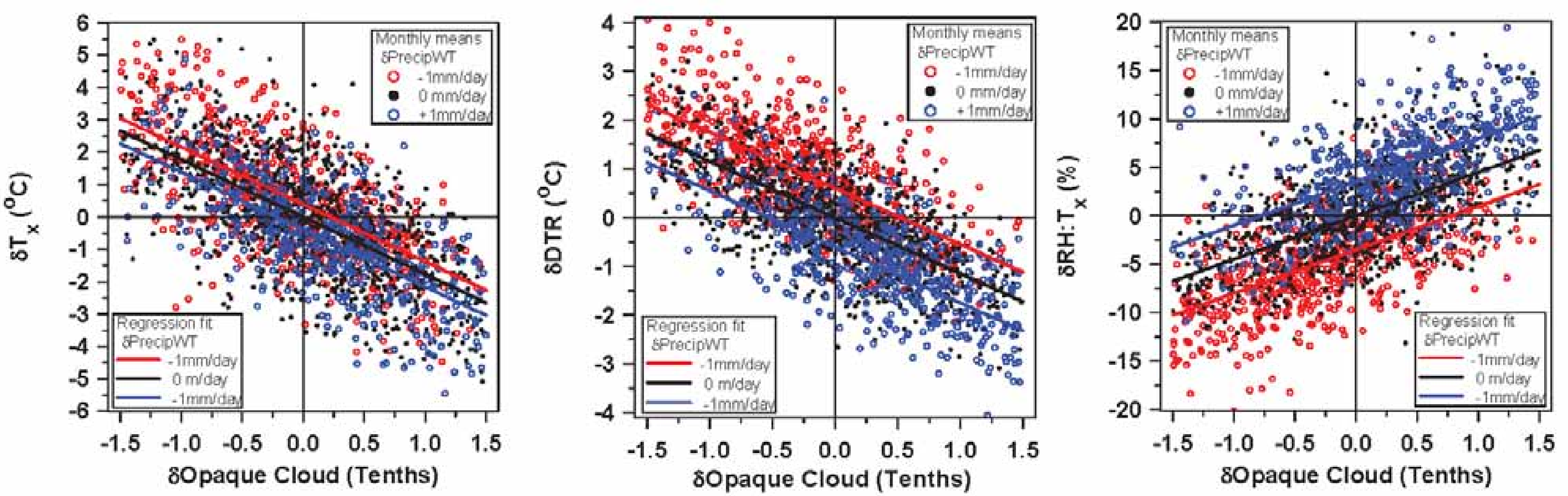
  MODIS *Calibrate Opaque Cloud data*

11 stations: 55-yr MJJA climate

- **Precip to**
  - Cloud (0.47)
  - LCL (0.79)
  - RH:T_x (0.68)
- **Cloud to**
  - T_x (0.68)
- ***Month: blend***
- ***Daily: cloud***



Monthly anomalies (MJJA: 2346 months)



- **Less cloudy and less rain (this month and last)**
  - **δT_x warmer (cloud mostly) ($R^2 = 0.55$)**
  - **δDTR larger (both) ($R^2 = 0.72$)**
  - **δRH drier (both) ($R^2 = 0.66$)**