Understanding Land-atmosphere Coupling in the Warm Season

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AGU Session A11N, 8:00am

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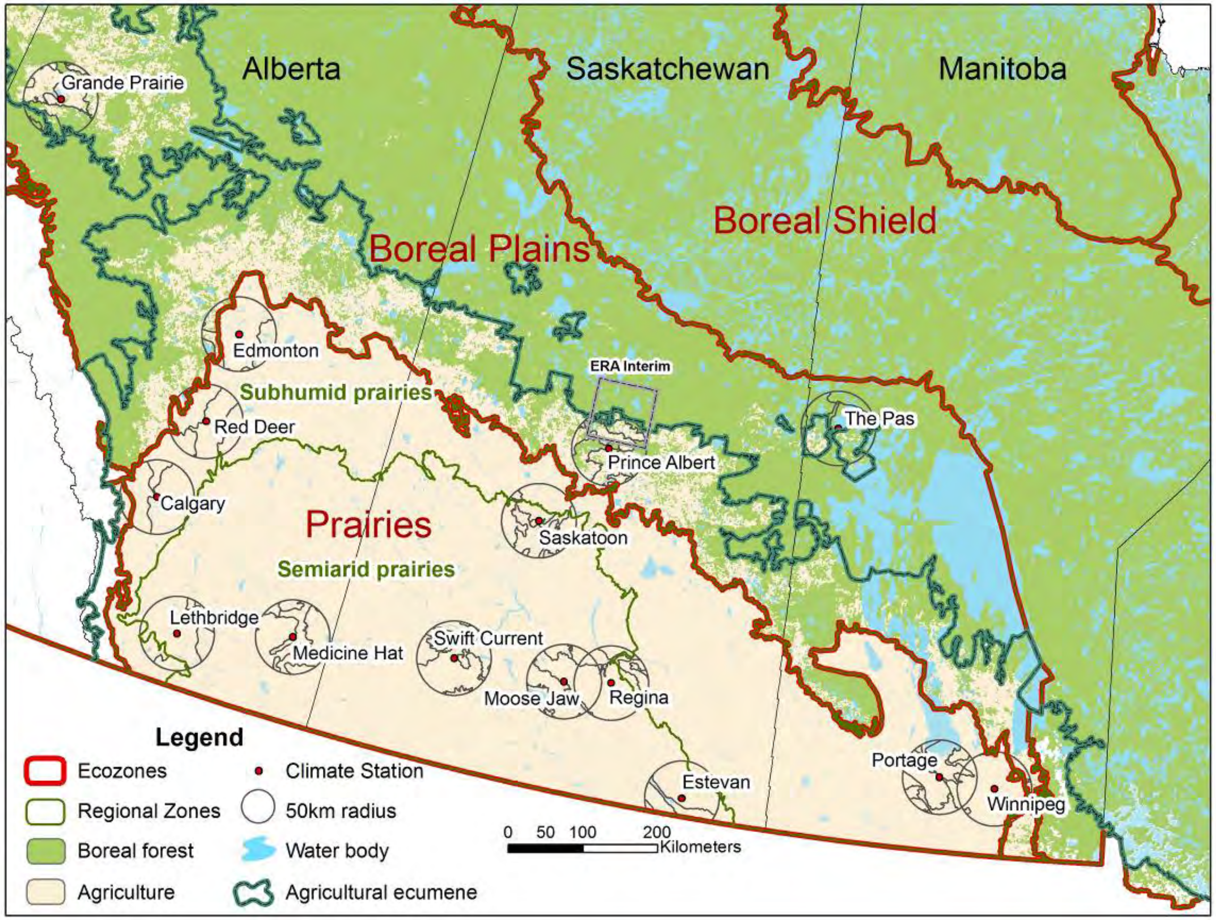
14 Prairie stations: 1953-2011



- *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 (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, doi:10.1002/2014JD022511**
- Betts, A.K., R. Desjardins A.C.M. Beljaars and A.Tawfik, (2015): Land-surface-atmosphere coupling on daily timescales. *Frontiers in Earth Science, (*In Preparation).

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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”
- Climate coupling between Precip, cloud, T and RH
  - monthly to seasonal
- Diurnal coupling in summer
  - RH, wind, day/night cloud asymmetry, precip anomalies

Diurnal Climate

- **Reduce hourly data to**
  - **daily means: T_m , RH_m, $OPAQ_m$ etc**
  - **data at max/min: T_x and T_n**
- ***Diurnal cycle climate***
  - **$DTR = T_x - T_n$**
  - **$\Delta RH = RH_{tn} - RH_{tx}$**

- ***Almost no missing hourly data***

  (until recent government cutbacks)

Surface Radiation Budget

- R_{net} = SW_{net} + LW_{net}

Define Effective Cloud Albedo (reflection)

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

  Clear sky

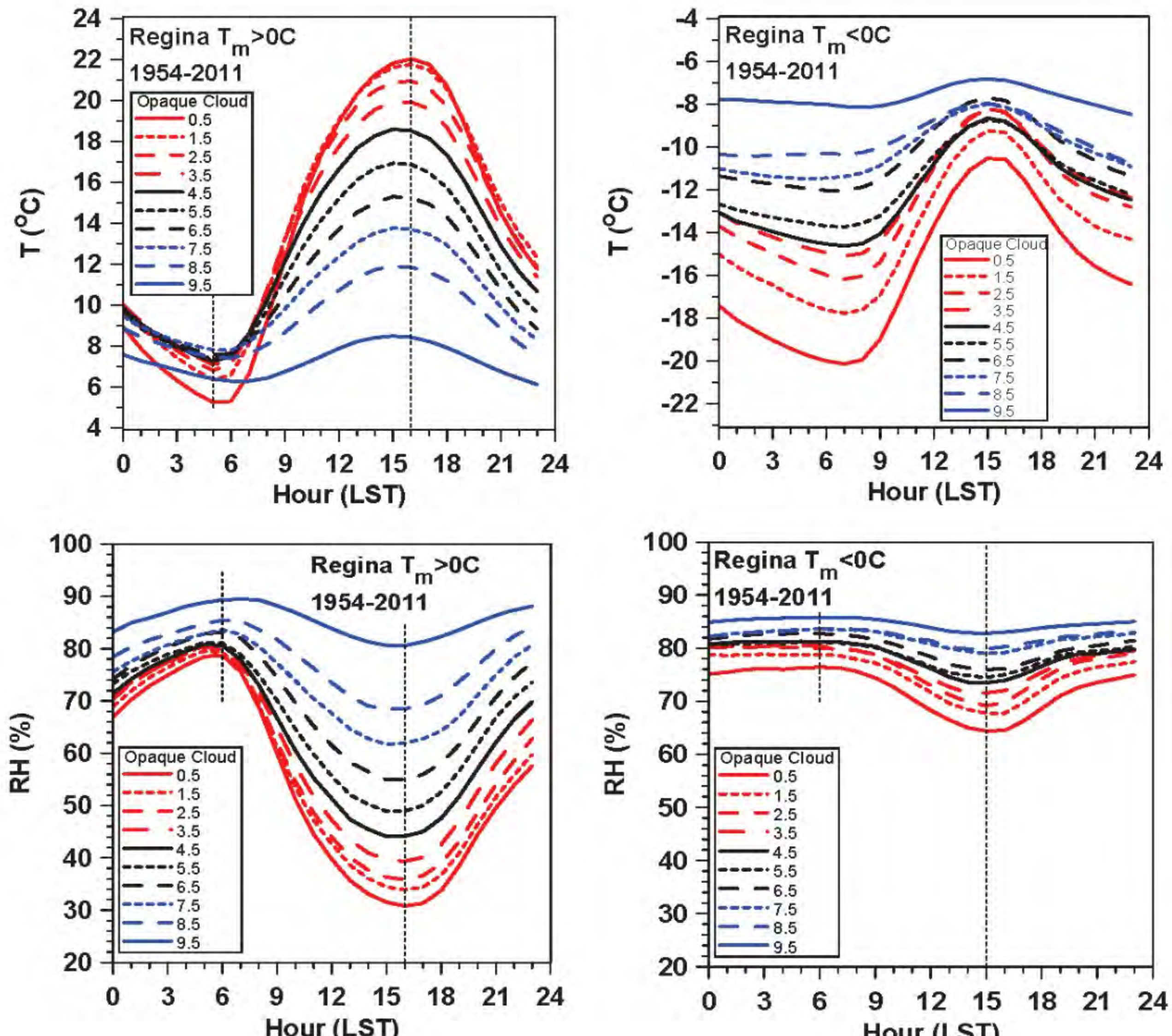
- $SW_{net} = (1 - \alpha_s)(1 - ECA)$ SW_{dn}(clear)

  Reflected by surface, clouds

  MODIS *Calibrate Opaque Cloud data with BSRN*

Prairie has 2 climates

T>0°C T<0°C

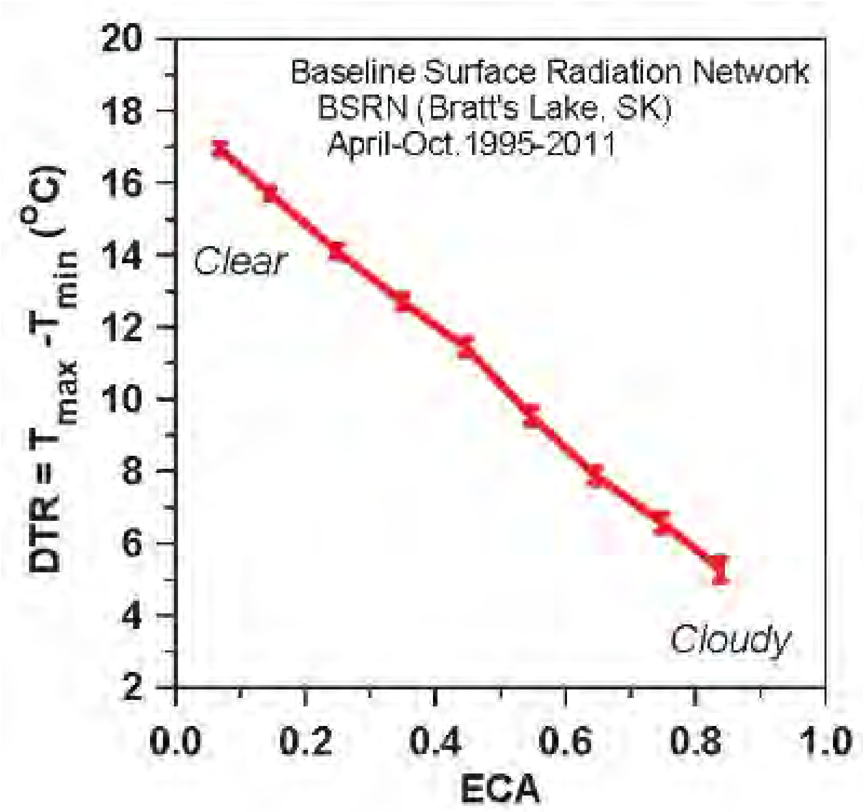


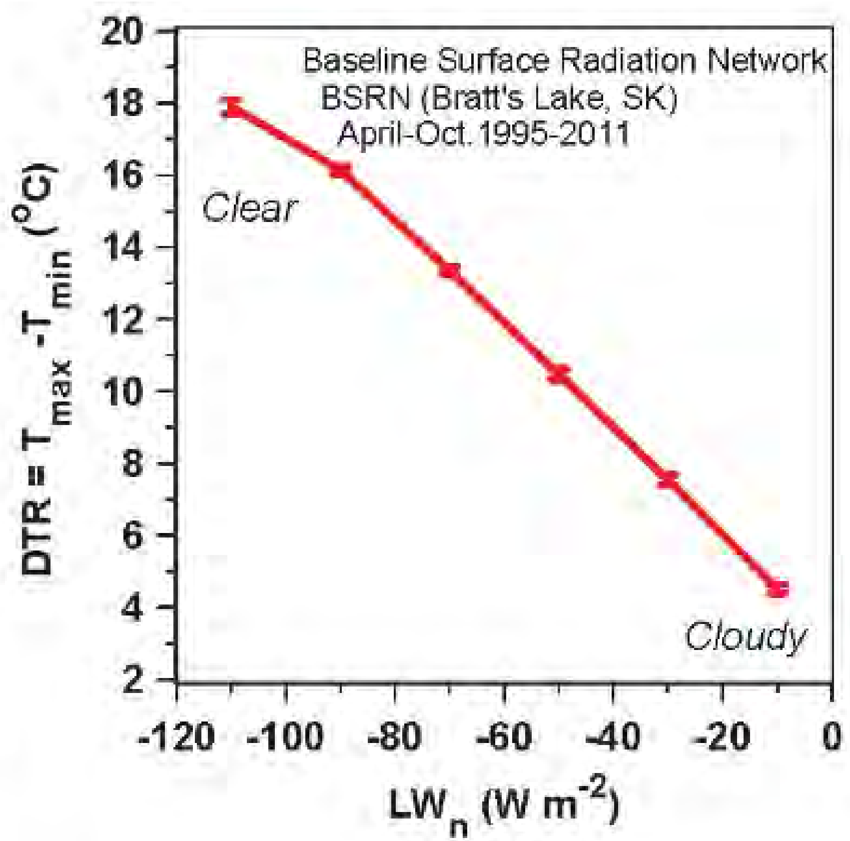
Warm Season Climate: T>0°C No snow: April - October

- ***Hydrometeorology***
  - ***with Precipitation and Radiation***
  - ***Diurnal cycle of T and RH***

Diurnal Temperature Range

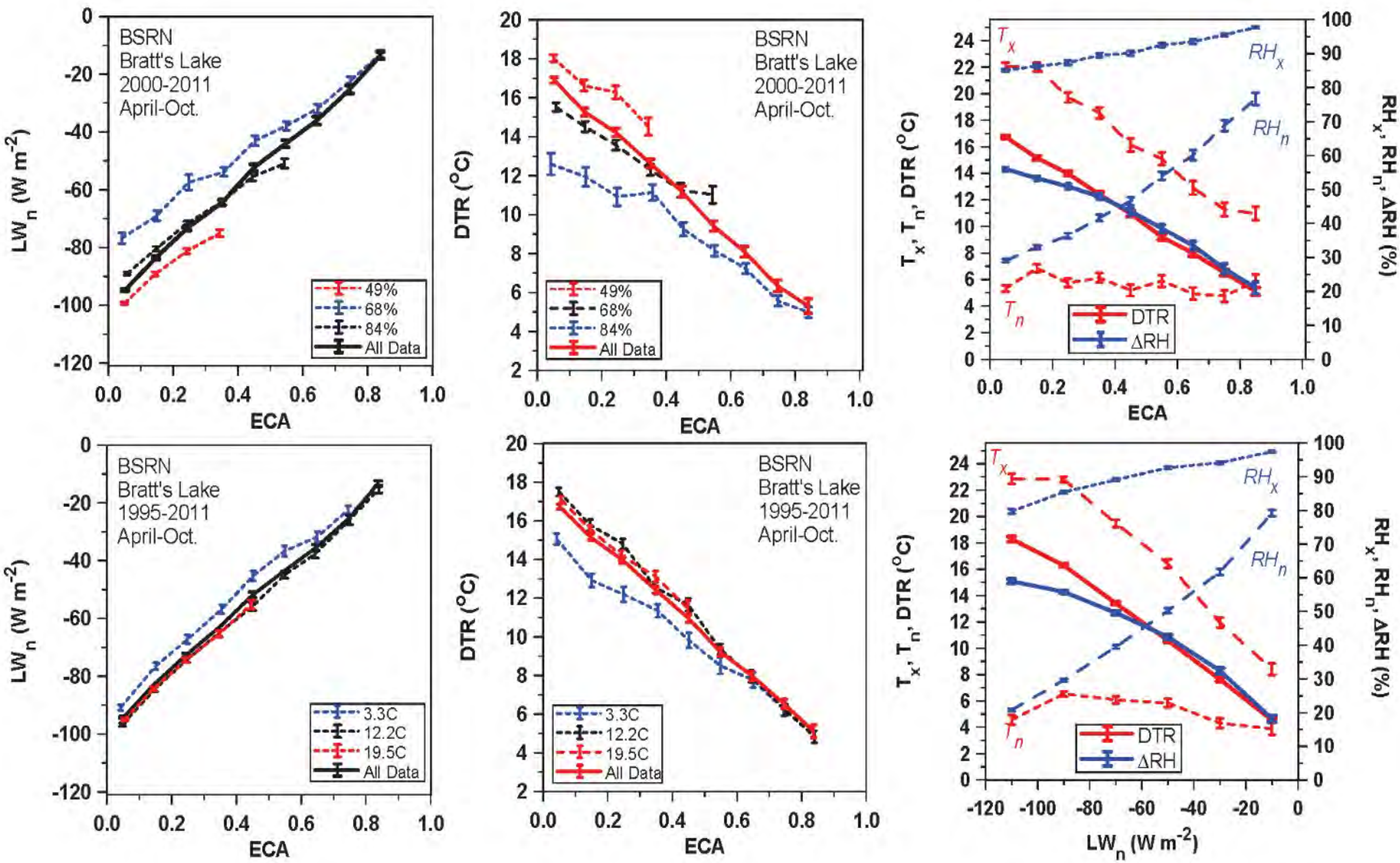
Warms in daytime and cools at night



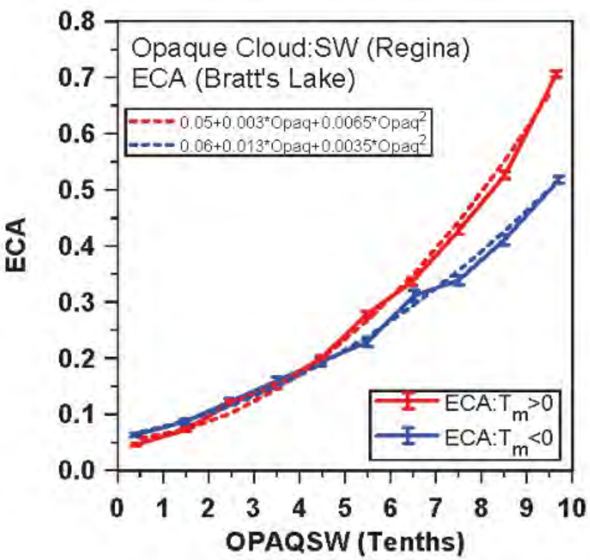


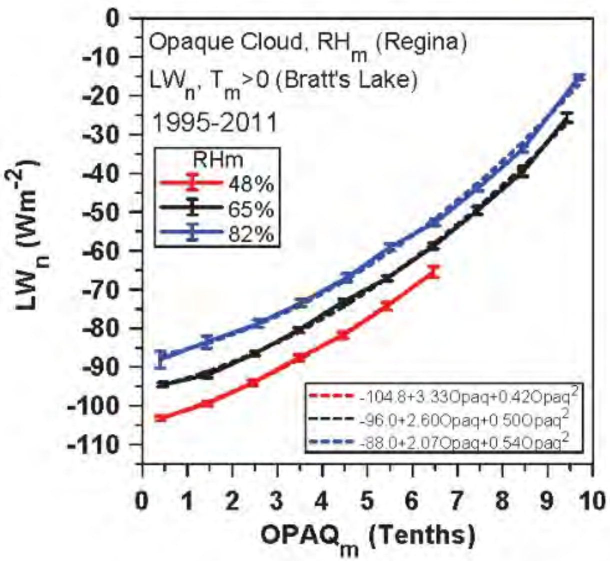
- **Daytime warming related to clouds: ECA**
- **Night-time cooling related to clouds: LW_{net}**

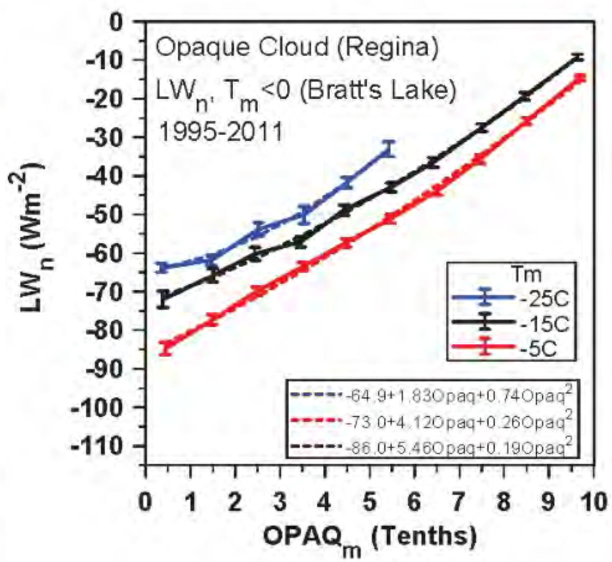
BSRN: ECA, LW_n, DTR and ΔRH coupled



Calibrate Opaque Cloud to BSRN ECA and LW_n







$T_m > 0^oC$

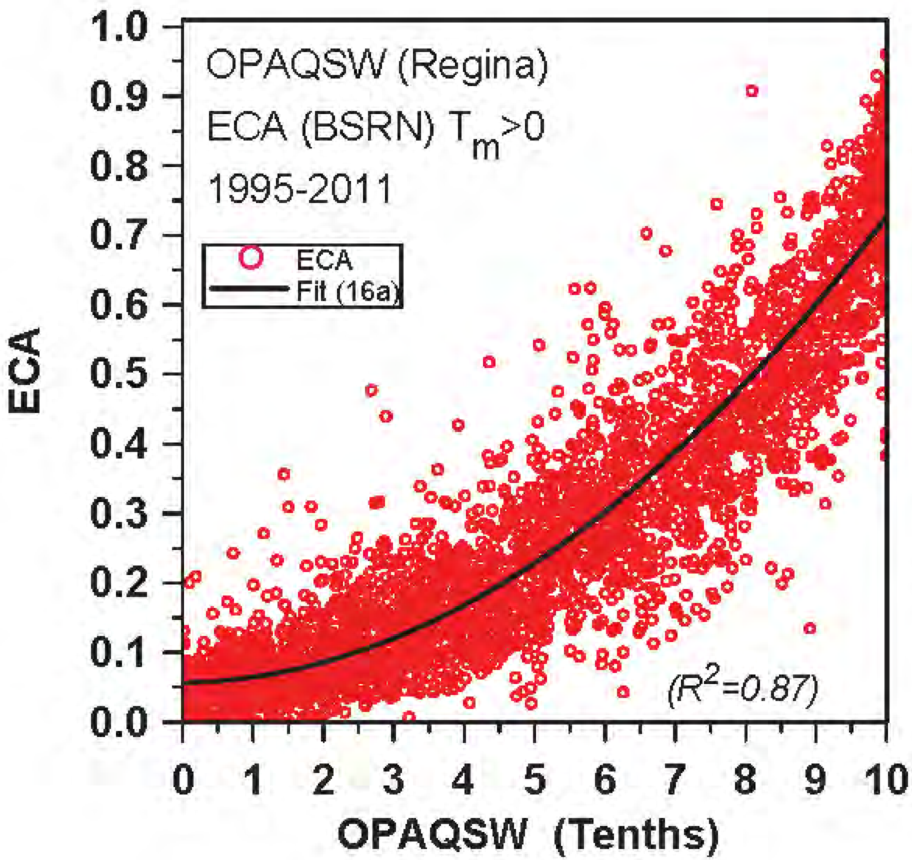
$ECA = 0.06(\pm 0.08) + 0.002(\pm 0.002)\ OPAQSW + 0.0065(\pm 0.0002)\ OPAQSW^2$ ***(R^2=0.87)***

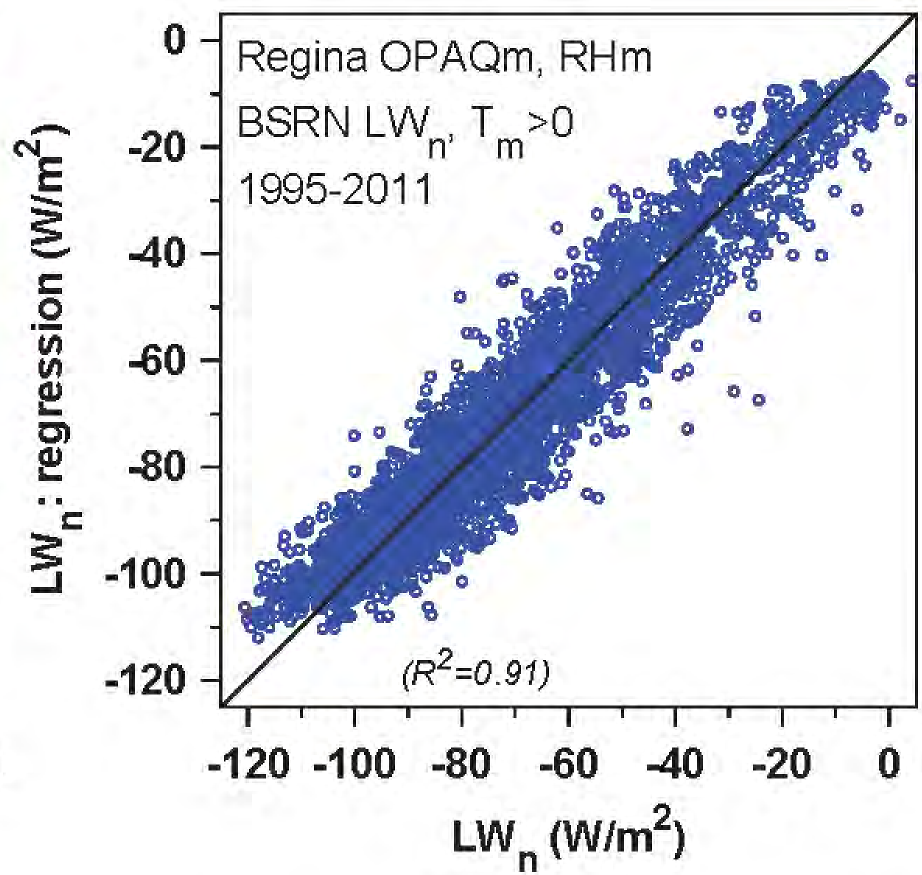
$LW_n = -129(\pm 8) + 2.8(\pm 0.2)\ OPAQ_m + 0.45(\pm 0.02)\ OPAQ_m{}^2 + 0.49(\pm 0.01) RH_m$ ***(R^2=0.91)***

$T_m < 0^oC$

$LW_n = -89(\pm 10) + 4.6(\pm 0.3)\ OPAQ_m + 0.26(\pm 0.03)\ OPAQ_m^2 + 0.86(\pm 0.03) T_m$ ***(R^2=0.82)***

Regression fits to Opaque Cloud





Daily data: warm season, T_m >0 (to ±0.08)

Opaque cloud gives ECA, $LW_n \longrightarrow R_n$

Monthly, Seasonal, 50-yr Climate

- **Observables**
- **Opaque/reflective cloud** → R_n
- **Precipitation+Drydown** → **Evaporation**

- **50-yr timescale see separation**

  RH to precipitation and soil moisture

  T to opaque cloud and R_n

- ***Monthly, seasonal timescale blended***

- *Betts, A.K., R. Desjardins, D. Worth and B. Beckage (2014), Climate coupling between temperature, humidity, precipitation and cloud cover over the Canadian Prairies. JGR, 119, doi:10.1002/2014JD022511.*

Monthly timescale: Regression

δDTR = K + A* δPrecip(Mo-2) + B * δPrecip(Mo-1) + C * δPrecip + D * δOpaqueCloud
(Month-2) (Month-1) (Month) (Month)

δDTR anomalies

	K	A	B	C	D	R^2 All	R^2 Precip	R^2 Cloud
May	**0±0.8**		**-0.37±0.05**	**-0.37±0.04**	**-1.10±0.05**	**0.73**	**0.41**	**0.66**
Jun	**0±0.7**		**-0.30±0.03**	**-0.32±0.02**	**-0.97±0.04**	**0.69**	**0.42**	**0.52**
July	**0±0.7**	**-0.20±0.03**	**-0.25±0.02**	**-0.33±0.03**	**-1.10±0.05**	**0.67**	**0.42**	**0.48**
Aug	**0±0.7**	**-0.07±0.02**	**-0.21±0.03**	**-0.40±0.03**	**-1.24±0.04**	**0.79**	**0.46**	**0.71**
Sept	**0±0.8**		**-0.22±0.03**	**-0.49±0.04**	**-1.27±0.04**	**0.82**	**0.43**	**0.75**
Oct	**0±0.8**		**-0.27±0.03**	**-0.70±0.07**	**-1.33±0.04**	**0.77**	**0.37**	**0.70**

Monthly timescale: Regression

δRH_{tx} = K + A* δPrecip(Mo-2) + B * δPrecip(Mo-1) + C * δPrecip + D * δOpaqueCloud
(Month-2) (Month-1) (Month) (Month)

Afternoon δRH_{tx} anomalies

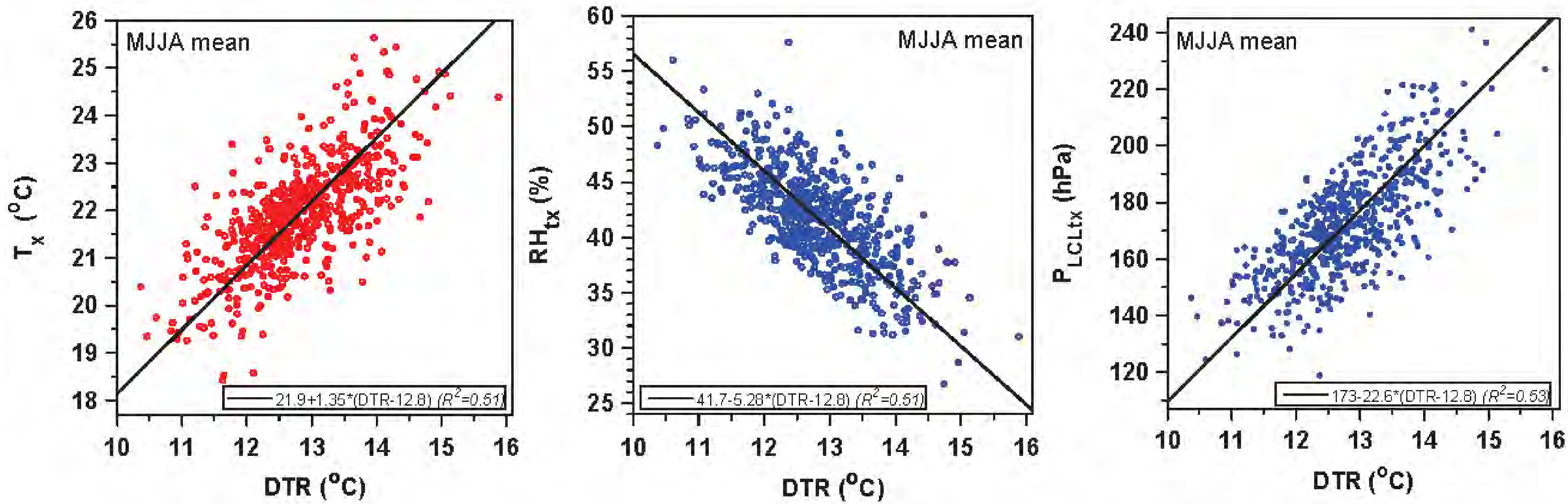
Month	K	A *(Mo-2)*	B*(Mo-1)*	C*(Mo)*	D	R^2 All	R^2 Precip	R^2 Cloud
May	0±3.6	1.30±0.38	1.47±0.22	2.07±0.17	4.75±0.20	0.72	0.46	0.62
Jun	0±3.6	0.69±0.23	1.26±0.15	1.96±0.12	4.36±0.22	0.68	0.47	0.48
July	0±4.1	0.84±0.18	1.71±0.12	1.81±0.17	4.40±0.30	0.59	0.43	0.33
Aug	0±3.6	0.66±0.11	1.23±0.13	2.42±0.16	4.08±0.20	0.73	0.53	0.56
Sept	0±3.5		1.40±0.13	2.10±0.18	4.35±0.16	0.75	0.45	0.63
Oct	0±4.3		1.28±0.19	5.02±0.39	4.58±0.23	0.67	0.44	0.53

MJJA Growing Season

$\delta Y_\sigma = K_\sigma + B_\sigma * \delta Precip(AMJJA)_\sigma + C_\sigma * \delta OpaqueCloud_\sigma$

Variable: δY_σ	K_σ	B_σ	C_σ	R^2_σ	$\sigma(\delta Y)$
$\delta T_{x\sigma}$	0±0.7	**-0.33±0.03**	**-0.52±0.03**	**0.52**	**1.11**
$\delta T_{m\sigma}$	0±0.8	-0.21±0.05	-0.50±0.07	0.38	**0.88**
δDTR_σ	0±0.6	**-0.55±0.03**	**-0.39±0.03**	**0.62**	**0.83**
$\delta RH_{tx\sigma}$	0±0.6	**0.56±0.03**	**0.35±0.03**	**0.60**	**4.35**
$\delta RH_{m\sigma}$	0±0.7	0.51±0.03	0.33±0.03	0.50	**4.61**
$\delta P_{LCLtx\sigma}$	0±0.6	**-0.56±0.03**	**-0.37±0.03**	0.61	**18.6**
$\delta Q_{tx\sigma}$	0±0.9	0.50±0.04	0.03±0.04	0.26	**0.58**
$\delta \theta_{Etx\sigma}$	**0±1.0**	**0.22±0.04**	**-0.31±0.04**	**0.09**	**1.95**

Diurnal coupling: MJJA mean

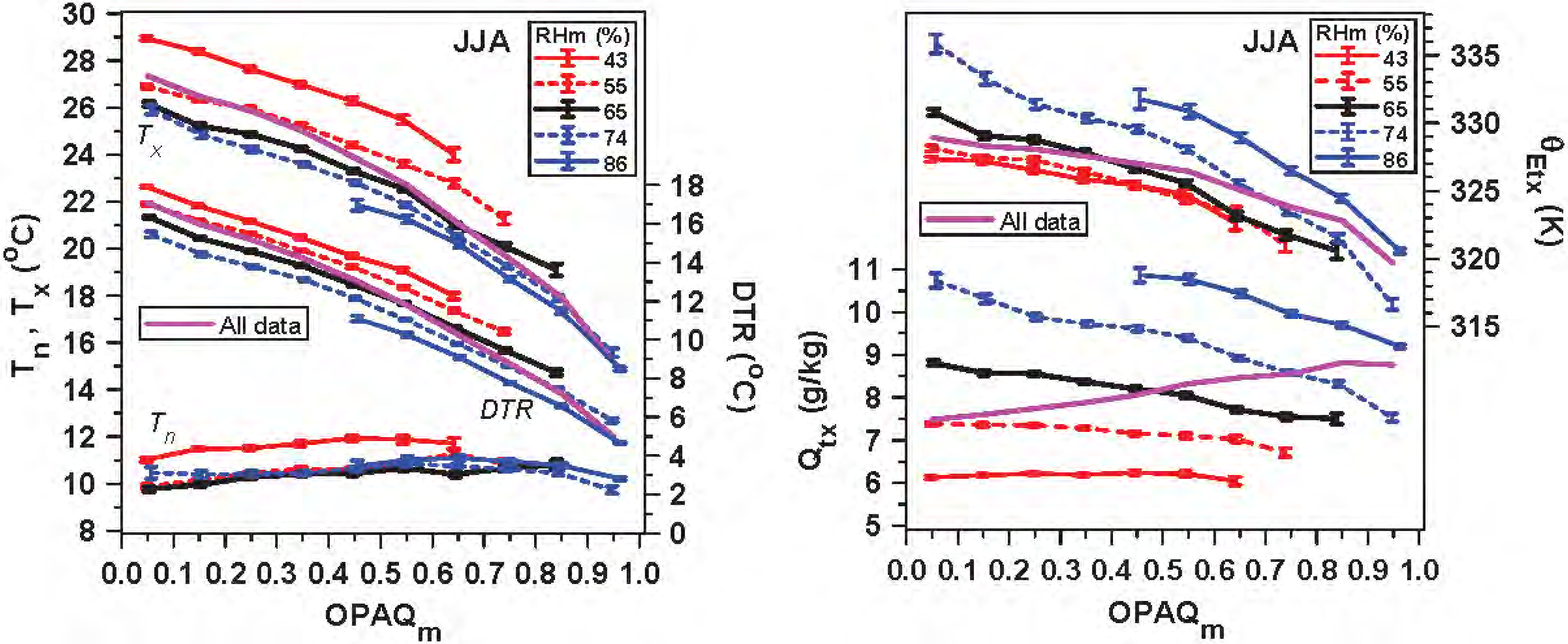


- **Internal coupling well-defined**
  - **Slopes less than 50-yr climate**

Land-surface-atmosphere coupling: daily timescales

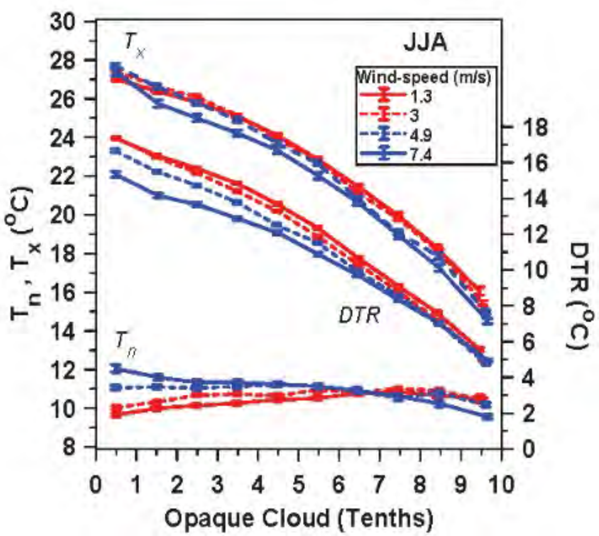
- 11 stations: 54000 days in JJA
  - Calibrate cloud to BSRN ECA, LW_{dn}
  - Cloud, ECA, LW_n $\longrightarrow$ DTR and ΔRH
  - *Fully coupled L-A system*
- Stratify: *opaque cloud and*
  - RH
  - Wind
  - Day-Night cloud asymmetry
  - Precipitation anomalies

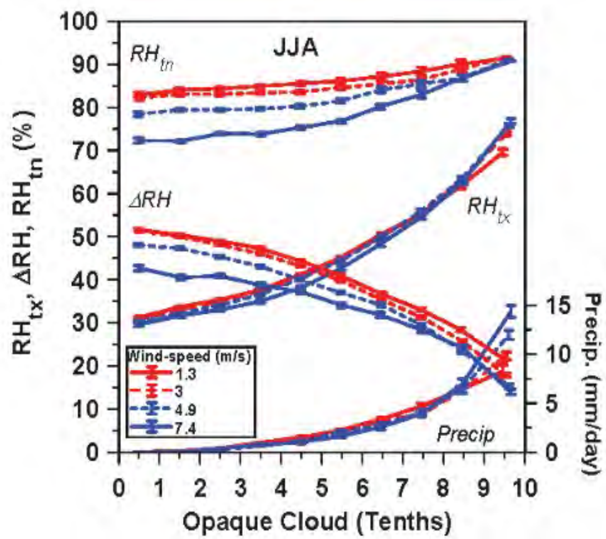
Partition: Cloud + RH

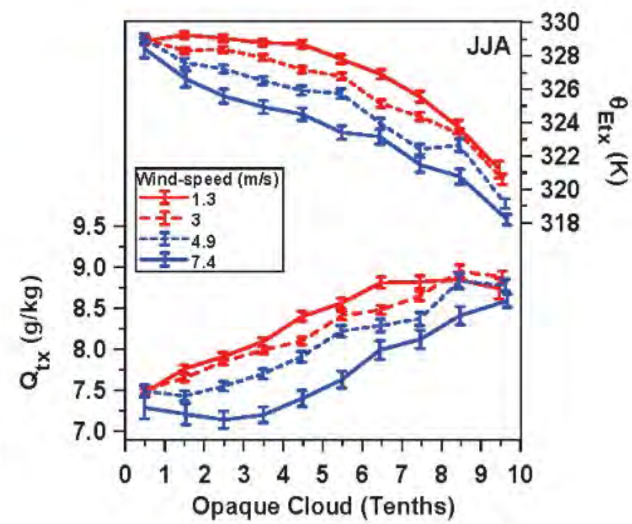


- Low RH: warmer T_x and DTR (low precip.)
- High RH: higher afternoon θ_{Etx}

Partition: Cloud + Windspeed

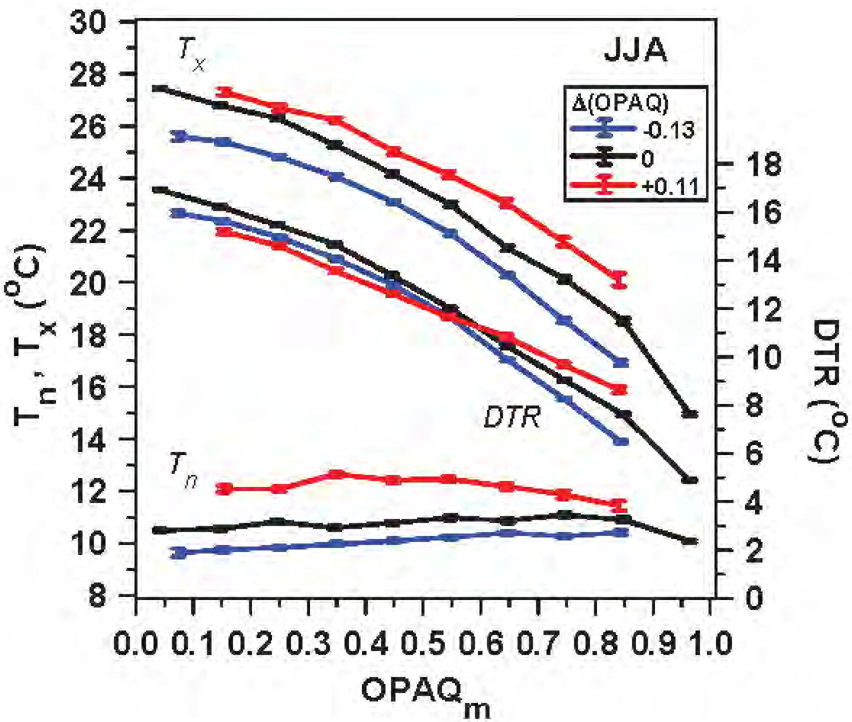


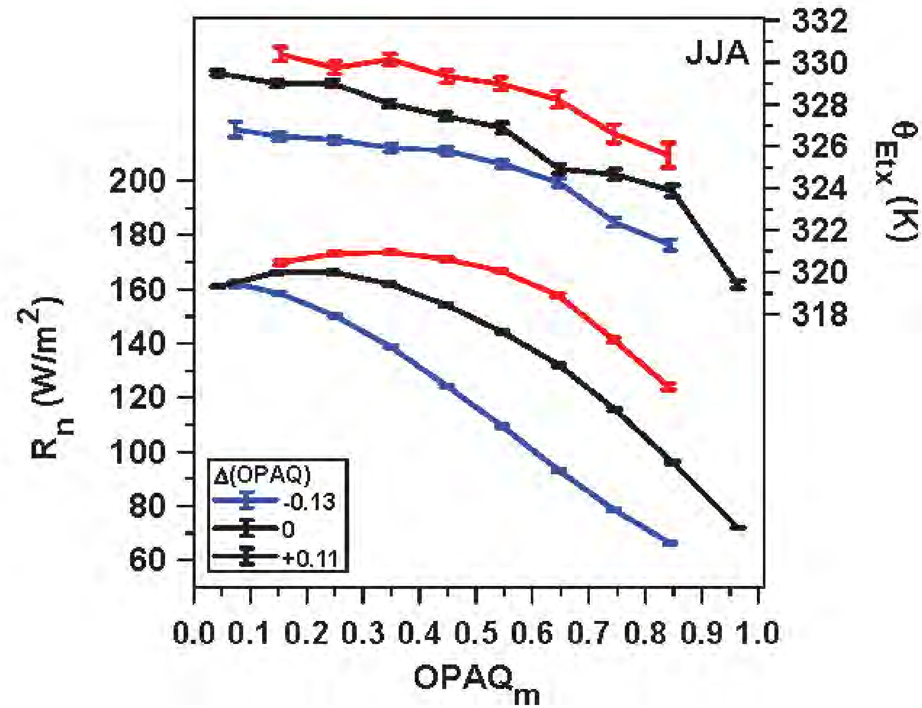




- Low wind: lower T_n, higher DTR, RH_{tn}
  - Clear-sky radiative cooling
- Low wind: higher afternoon Q_{tx}, θ_{Etx}
  - Stronger superadiabatic layer?

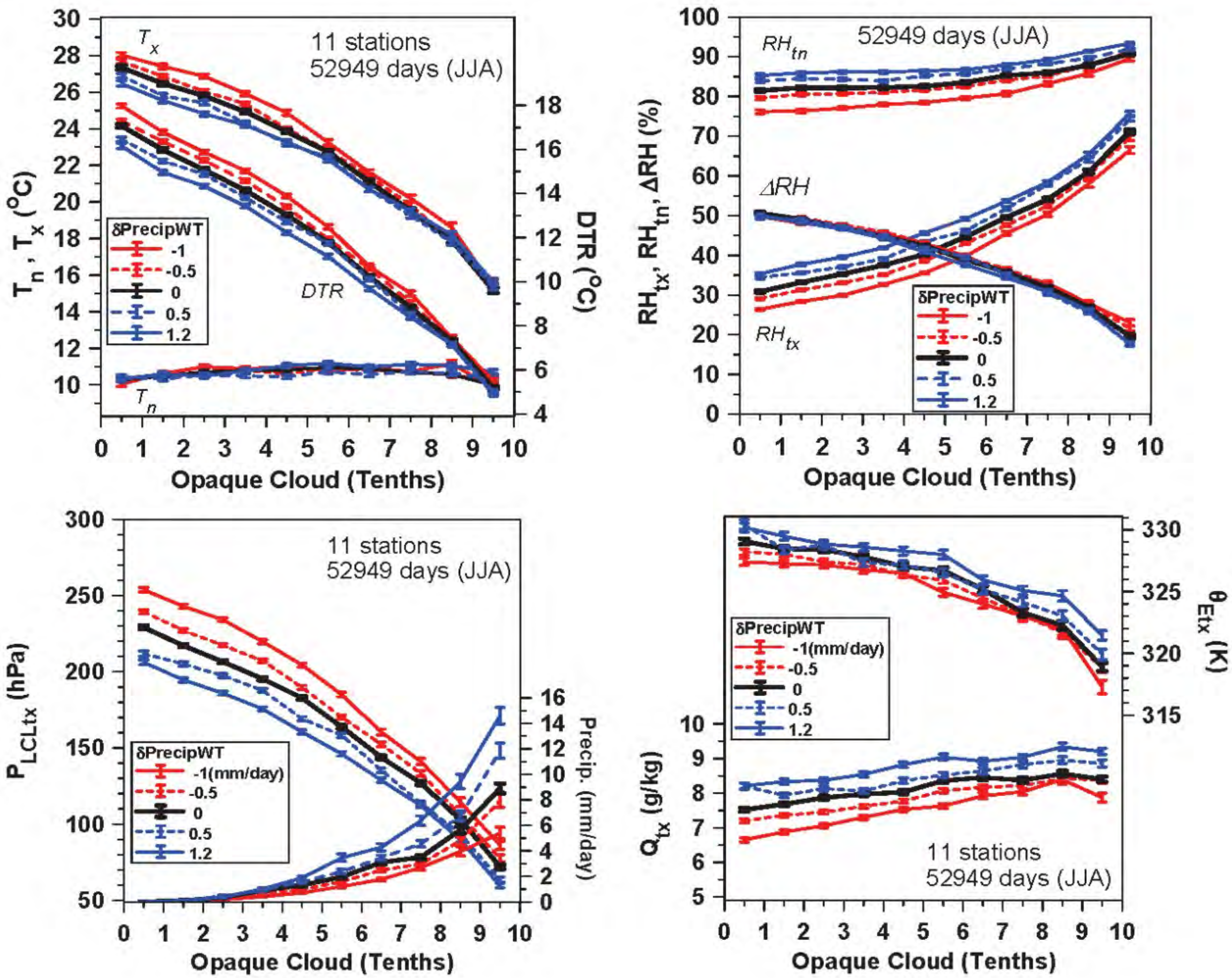
Day-Night Cloud Asymmetry



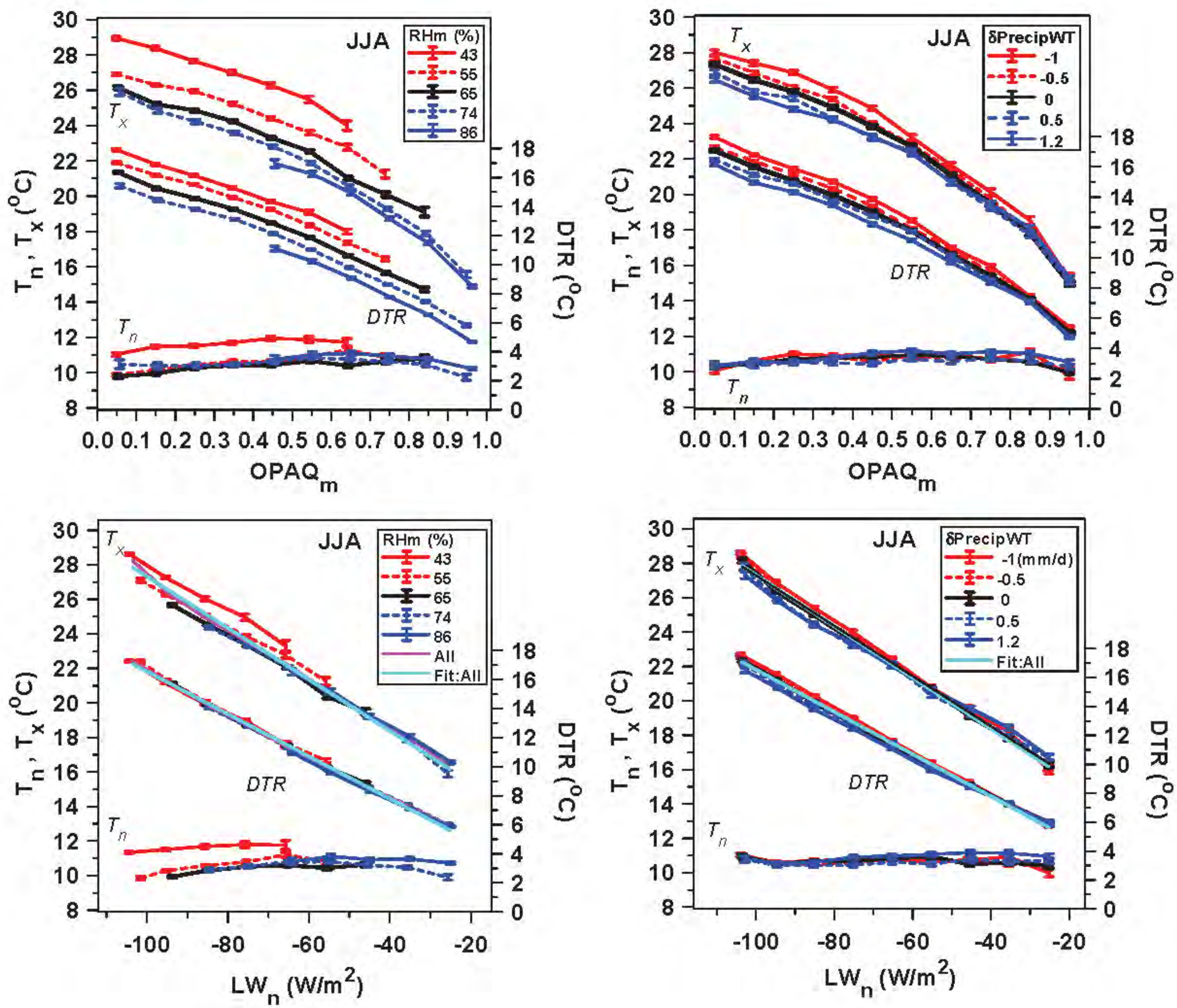


- **ΔOPAQ = (OPAQ$_m$ - OPAQSW) > 0**
  - **Less daytime cloud ⟶ Larger R_n**
  - **T_x, T_n shift up**
  - **Higher afternoon θ_{Etx}**
  - **(Higher precip)**

Cloud + δPrecipWT
(Monthly Precip Anomalies)



Remap: $OPAQ_m$ to LW_n



Land-surface-atmosphere coupling: daily timescales

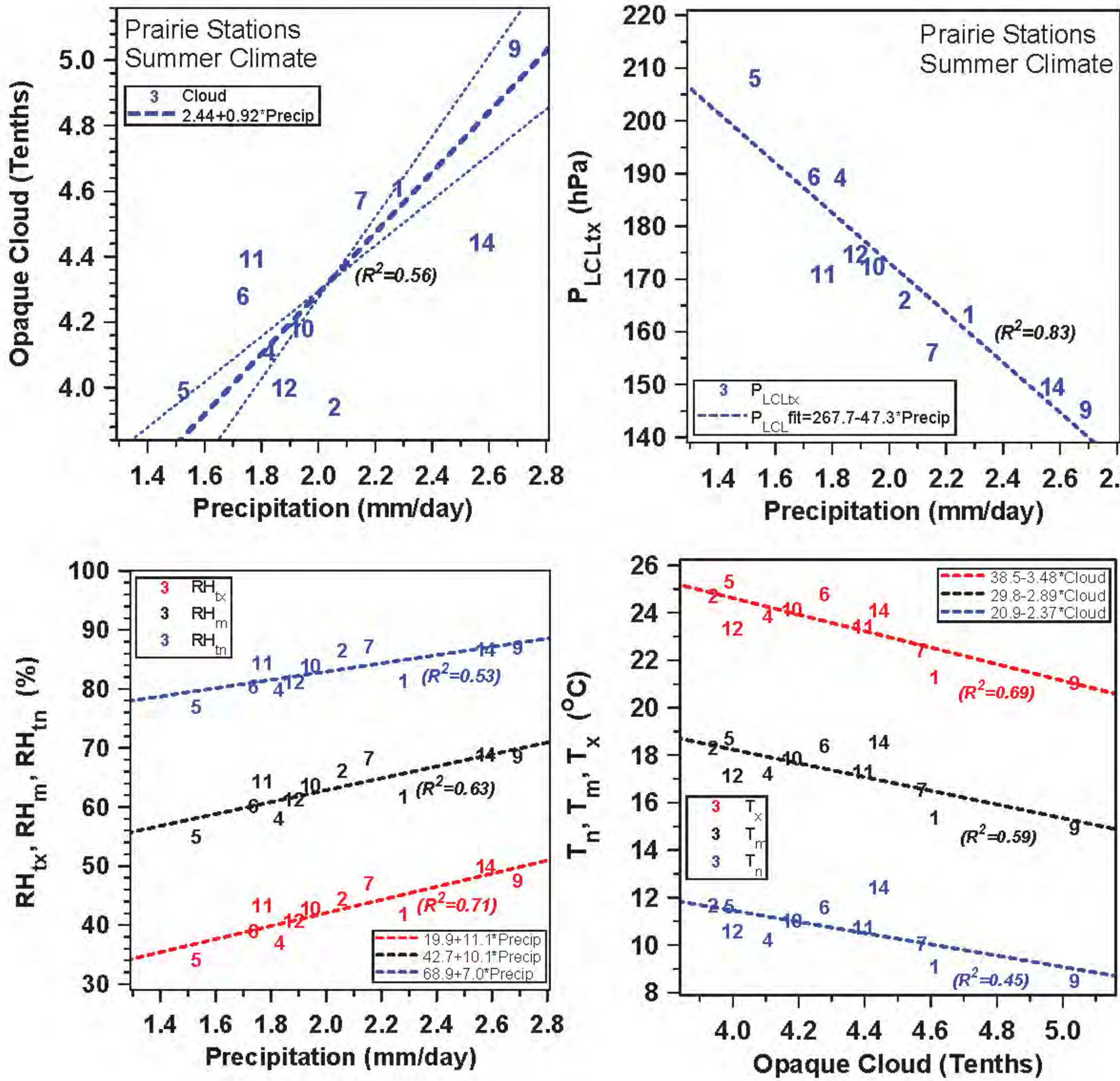
- **11 stations: 54000 days in JJA**
- ***Fully coupled system***
- **Diurnal cycle driven by $OPAQ_m$**
  - ***RH, wind, day-night cloud asymmetry, monthly precip anomalies***
  - ***Tight linear DTR-LW_n coupling***
- ***Work in progress***
  - ***Full annual cycle of diurnal cycle***

Conclusions

- Hydrometeorology requires
  - Precipitation and cloud/radiation
    - Cloud dominates on daily timescale
    - Both matter: monthly to seasonal
  - Temperature and RH
    - Giving LCL and θ_E: feedback to Precip
- Canadian Prairie data
  - Describe fully coupled L-A system
  - Invaluable for model evaluation

11 stations: 53-yr JJA climate

- **Precip to (R^2)**
  - Cloud (0.56)
  - P_{LCLtx} (0.83)
  - RH_{tx} (0.71)
- **Cloud to**
  - T_x (0.69)
- **Separation**
- ***Month: blend***
- ***Daily: cloud***



How good is the regression fit?

- **September**

  T_x ±1.4°C

  DTR ±0.8°C

  RH_{tx} ±3.5%

  P_{LCLtx} ±13hPa

- **Some extremes underestimated**

(586 station-yrs)