Using cloud and climate data to understand warm season hydrometeorology from diurnal to monthly timescales

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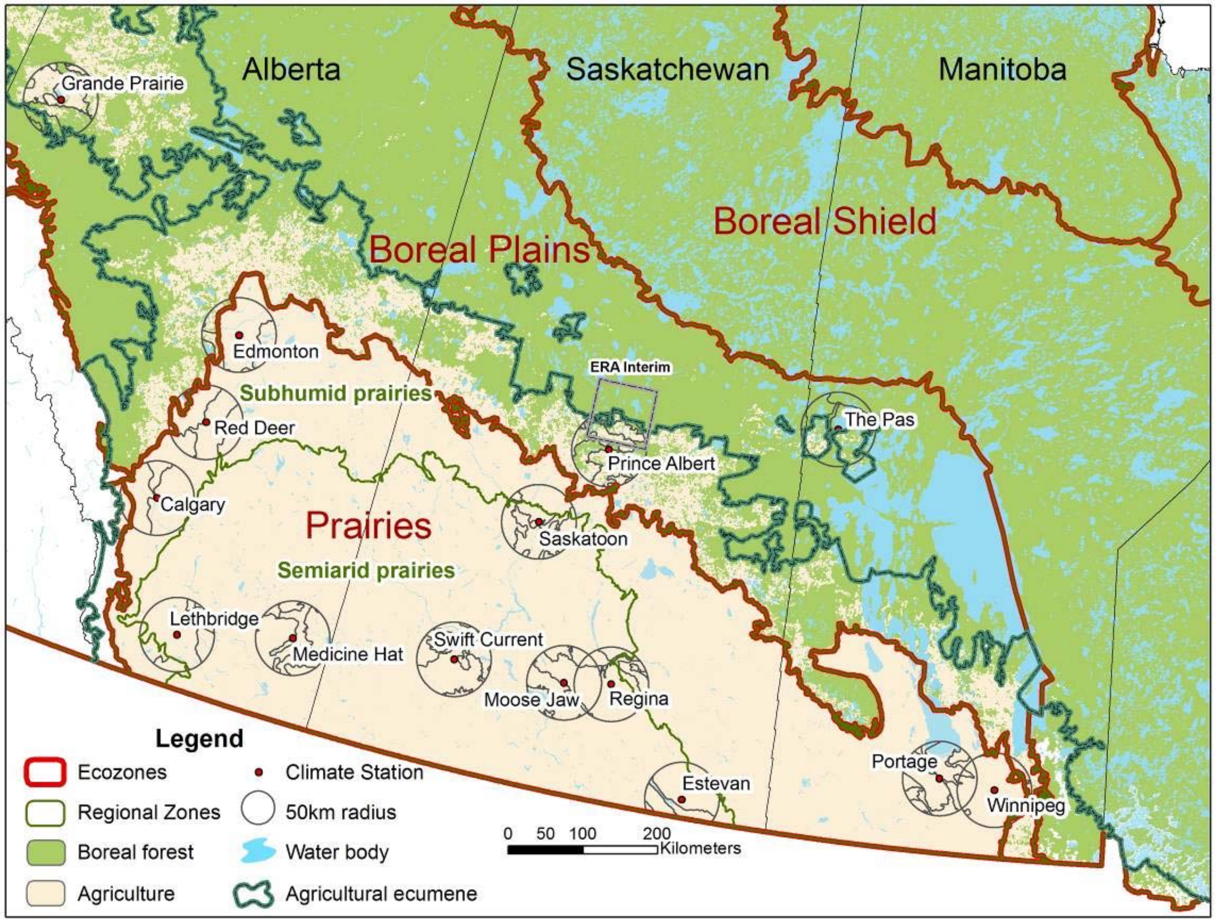
15 Prairie stations: 1953-2011



- *Hourly* p, T, RH, WS, WD, Opaque Cloud
  - Calibrated to BSRN SW_{dn}, LW_{dn}
- *Daily* precipitation and snowdepth

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
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- 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). 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., A. Tawfik and R. Desjardins (2016), Revisiting hydrometeorology using cloud and climate observations. *J. Hydromet. (in revision)*

- ***Past Work***
  - ***Cloud-climate coupling***
  - ***Distinct warm and cold season climates***
  - ***Snow cover is a "climate switch"***
  - ***Intensive cropping has cooled climate***

- **<u>This talk</u>**
- **Warm Season (April-Sept with no snow)**
  - ***Diurnal imbalance depends on cloud***
  - ***Precipitation Memory in summer back to March***

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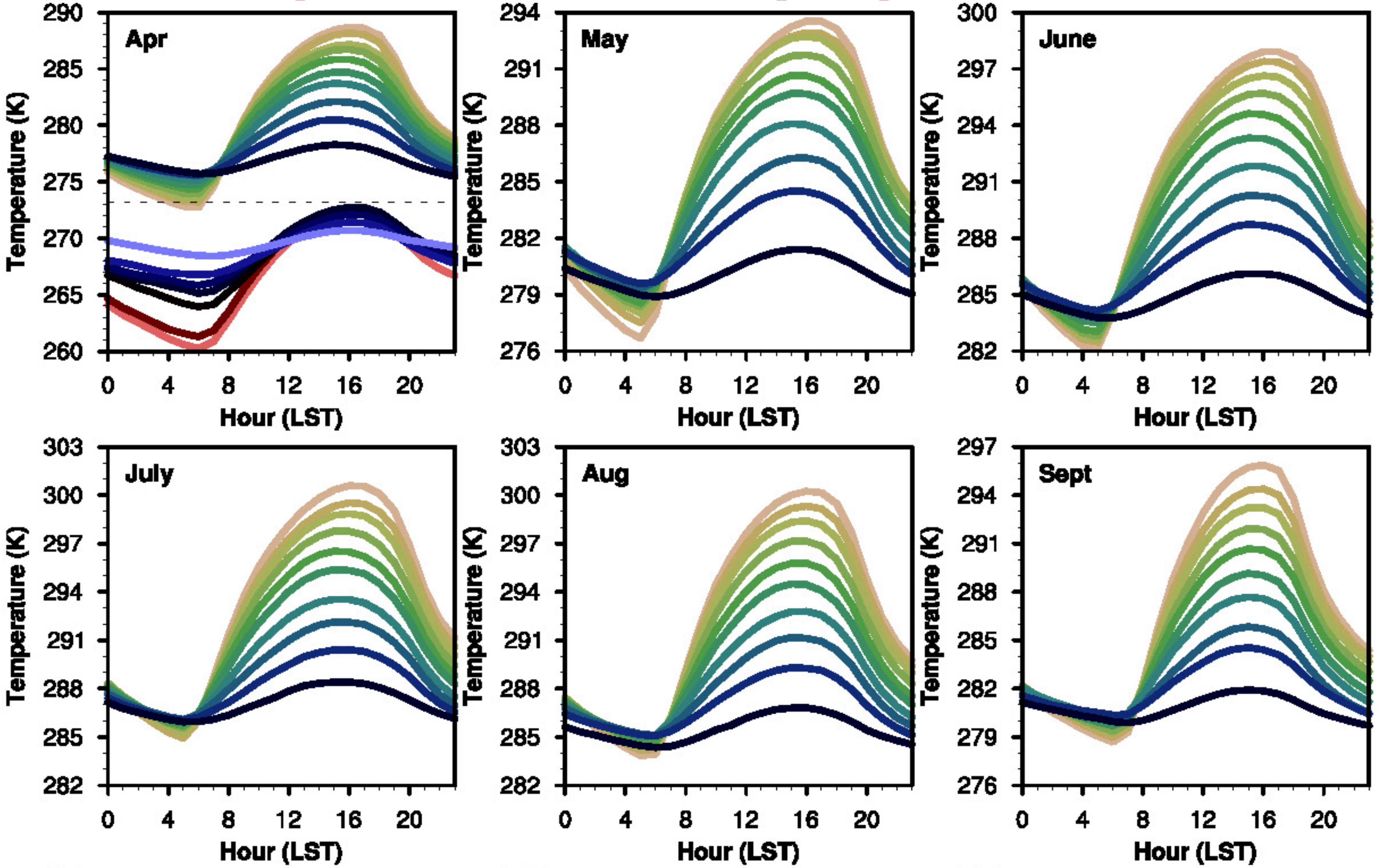
Warm Season Climate: T>0°C
(April – October with no snow)

- *Hydrometeorology*
  - *with Precipitation and Radiation*
  - *Diurnal cycle of T and RH*
  - *Cannot do climate with just T & Precip !*

- ***Daily timescale is radiation driven***
  - *Night LW_n; day SW_n (and EF)*
- ***Monthly timescale: Fully coupled***

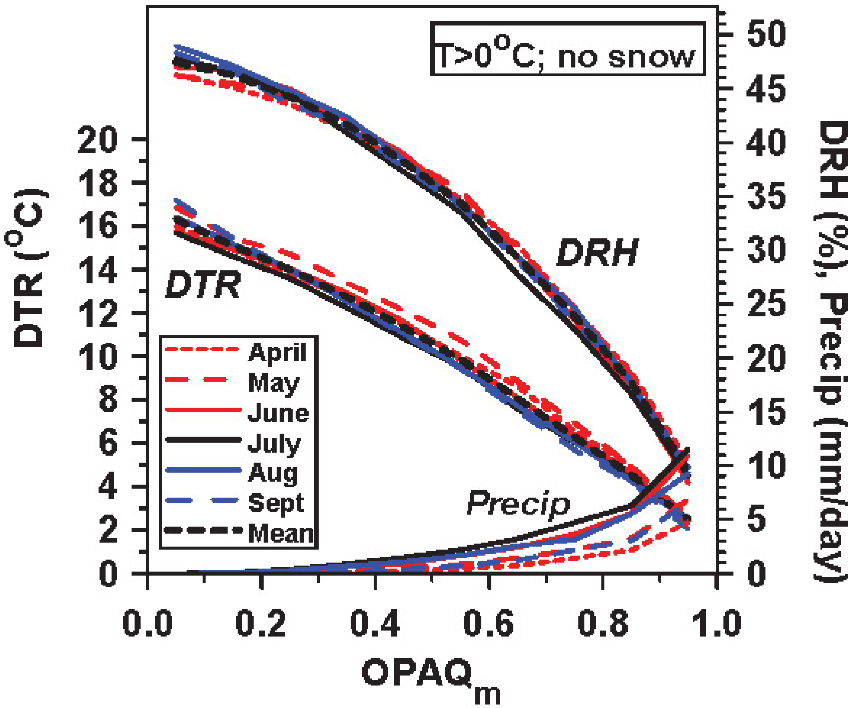
Betts et al. 2016;
Betts and Tawfik 2016)

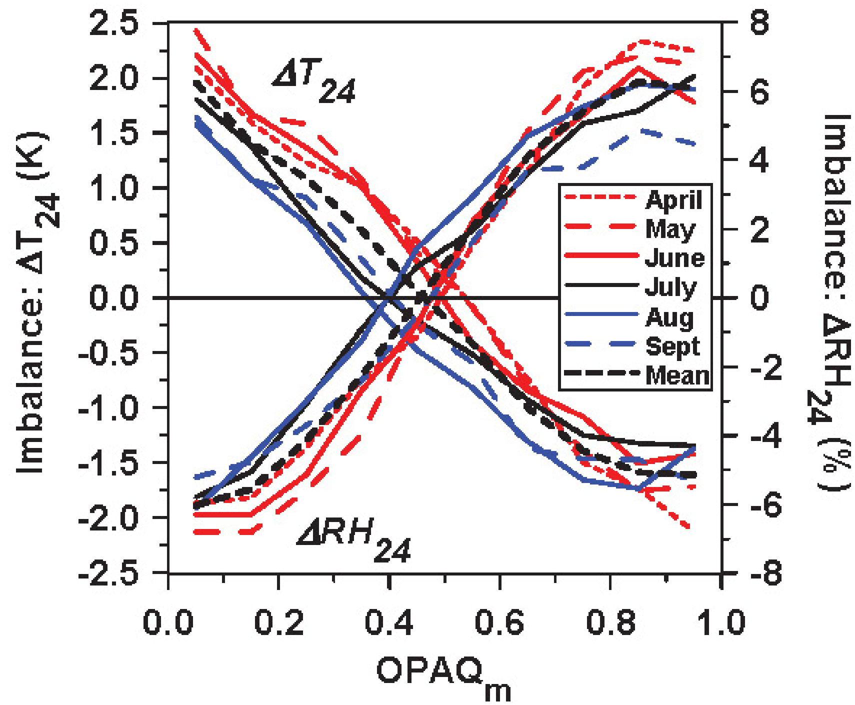
Monthly Diurnal Climatology:
Dependence on opaque cloud



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

Diurnal Ranges & Imbalances

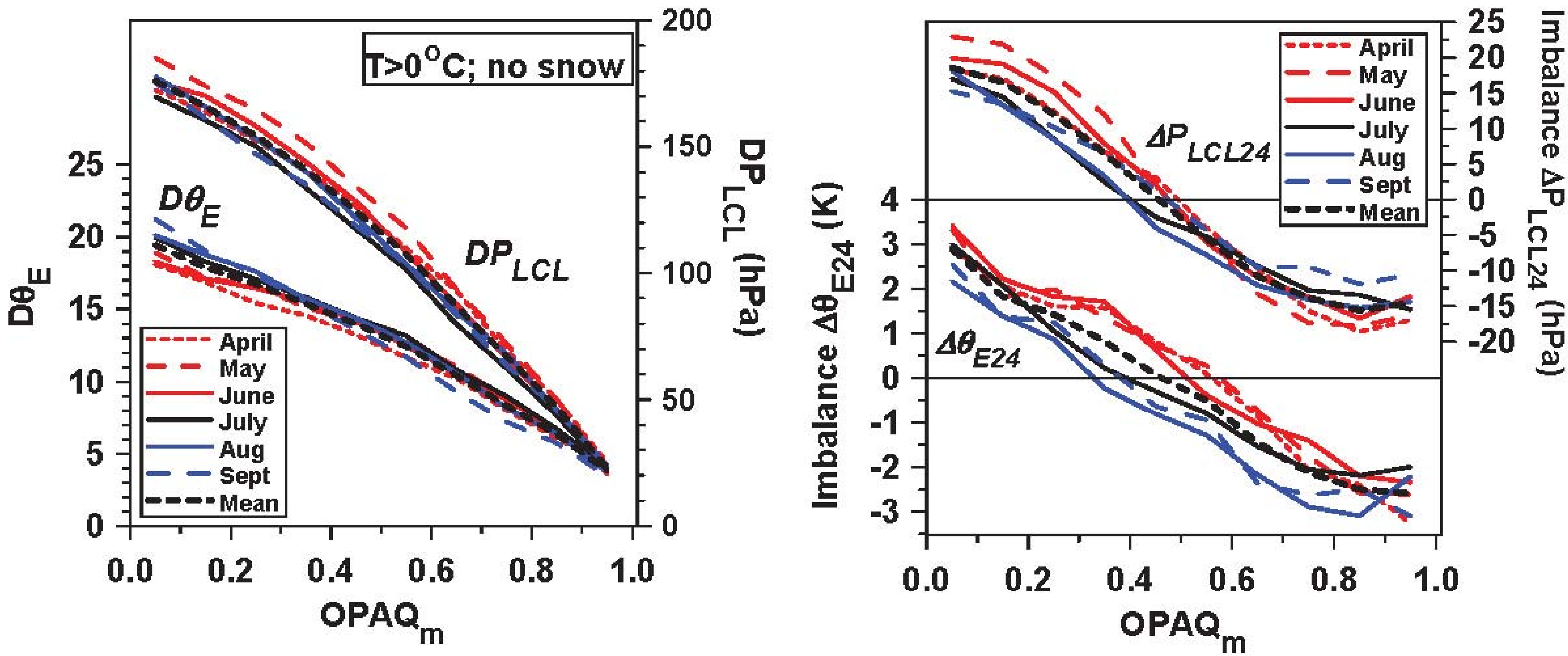




- **April to Sept: <u>same coupled structure</u>**
- **Q: Clear-sky: warmer (+2°C), drier (-6%)**

(Betts and Tawfik 2016)

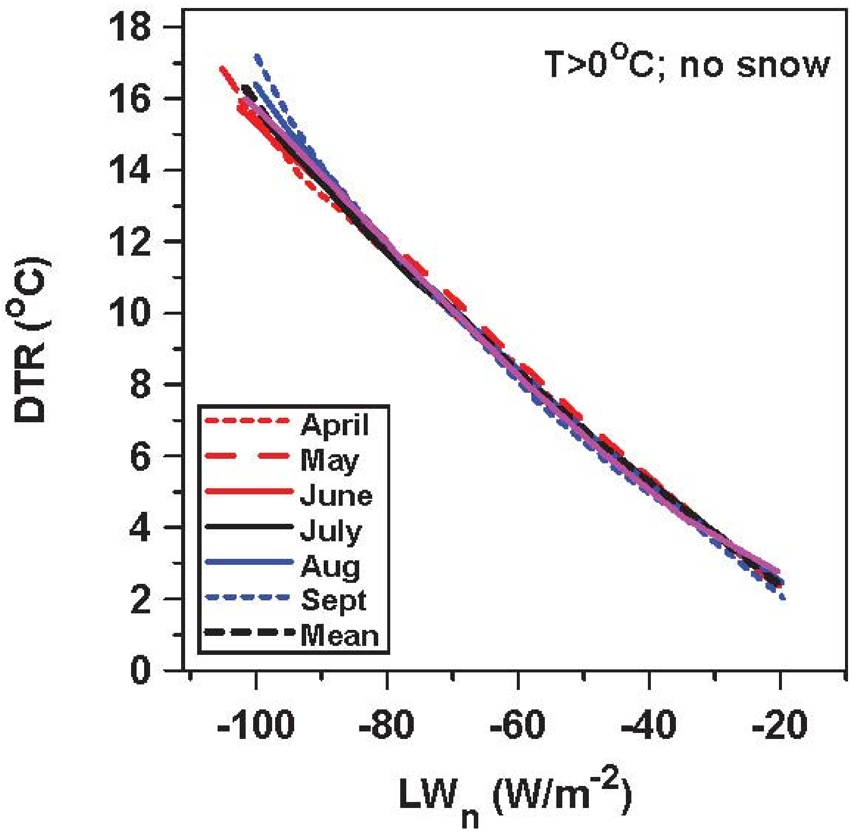
Diurnal Ranges & Imbalances

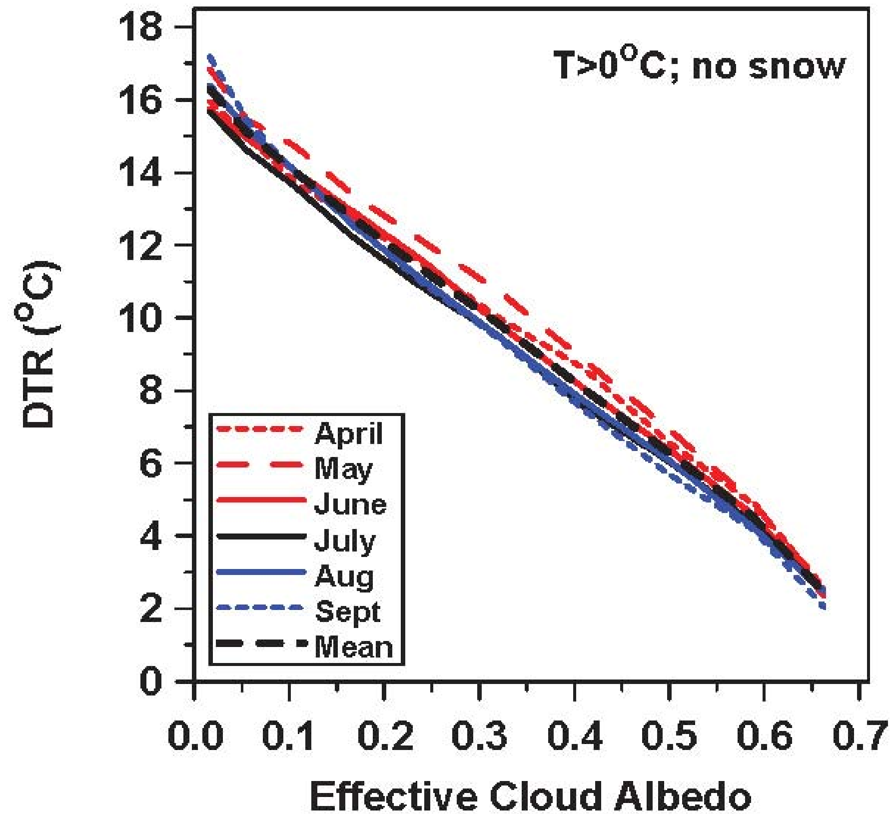


- April to Sept: <u>same coupled structure</u>
- Clear-sky: θ_E (+3K), LCL higher (+18hPa)

(Betts and Tawfik 2016)

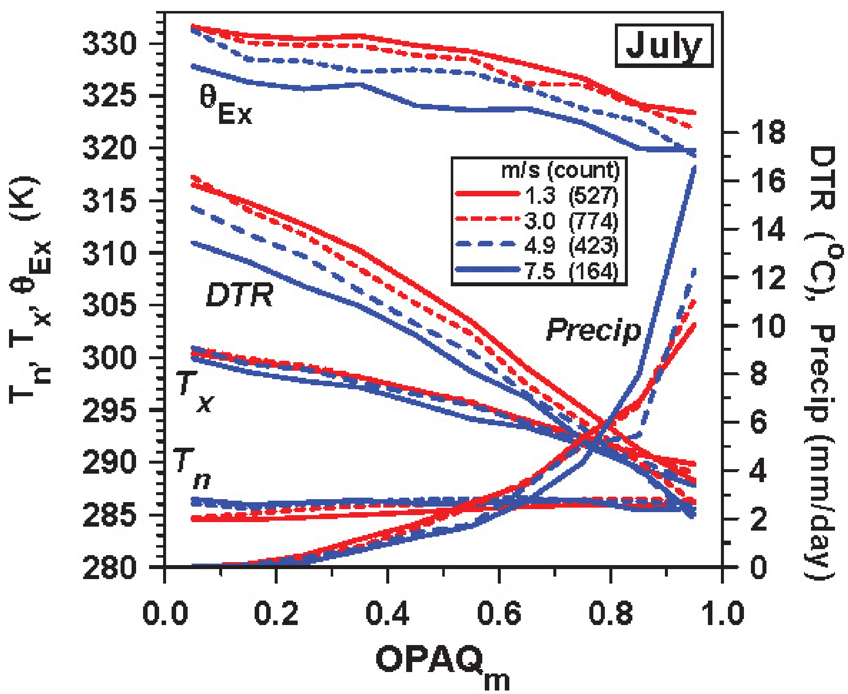
Convert Opaque Cloud to LW_n, ECA using BSRN data

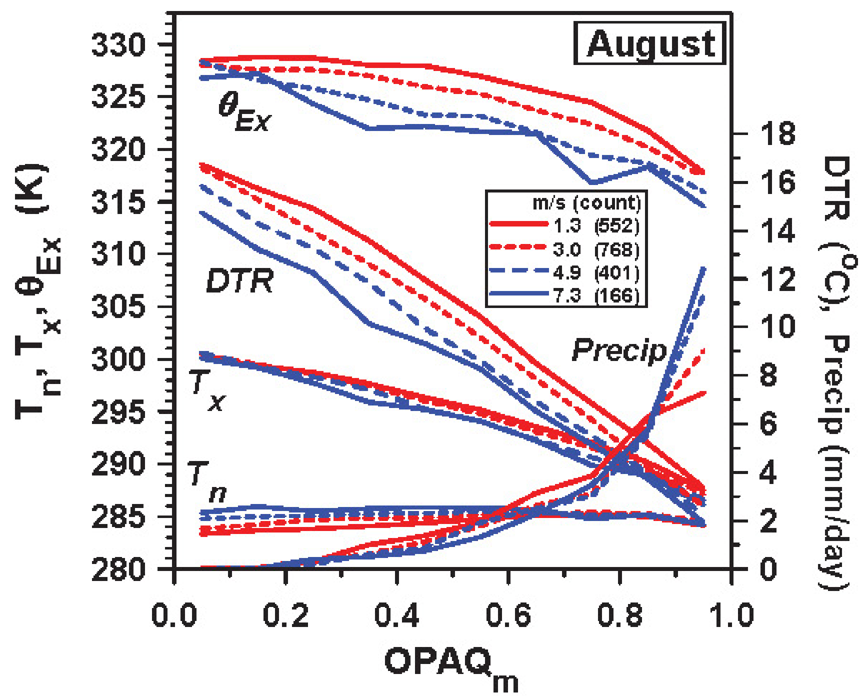




LW coupling tighter than SW

Daily Coupling to Cloud and Windspeed





Decreasing wind

increasing DTR, θ_{Ex}, Precipitation

(Betts and Tawfik 2016)

Warm Season Climate: T>0°C
(May to September: no snow)

- ***Hydrometeorology***
  - ***with Precipitation and Radiation***
  - ***Monthly diurnal cycle of T and RH***
  - **Multiple regression to couple <u>monthly anomalies</u> to opaque cloud and precipitation anomalies back in time**

(Betts et al. 2016)

Multiple Regression on Cloud and lagged Precip. anomalies

- **Monthly anomalies (normalized by STD of means)**
  - **opaque cloud (CLD)**
  - **precip. (PR-0, PR-1, PR-2): current, previous 2 to 5 months**

δDTR = A*δCLD + B*δPR-0 + C*δPR-1 + D*δPR-2 ...

(Month) (Month) (Month-1) (Month-2)

Soil moisture memory

***June, July, Aug:* memory of moisture back to March**

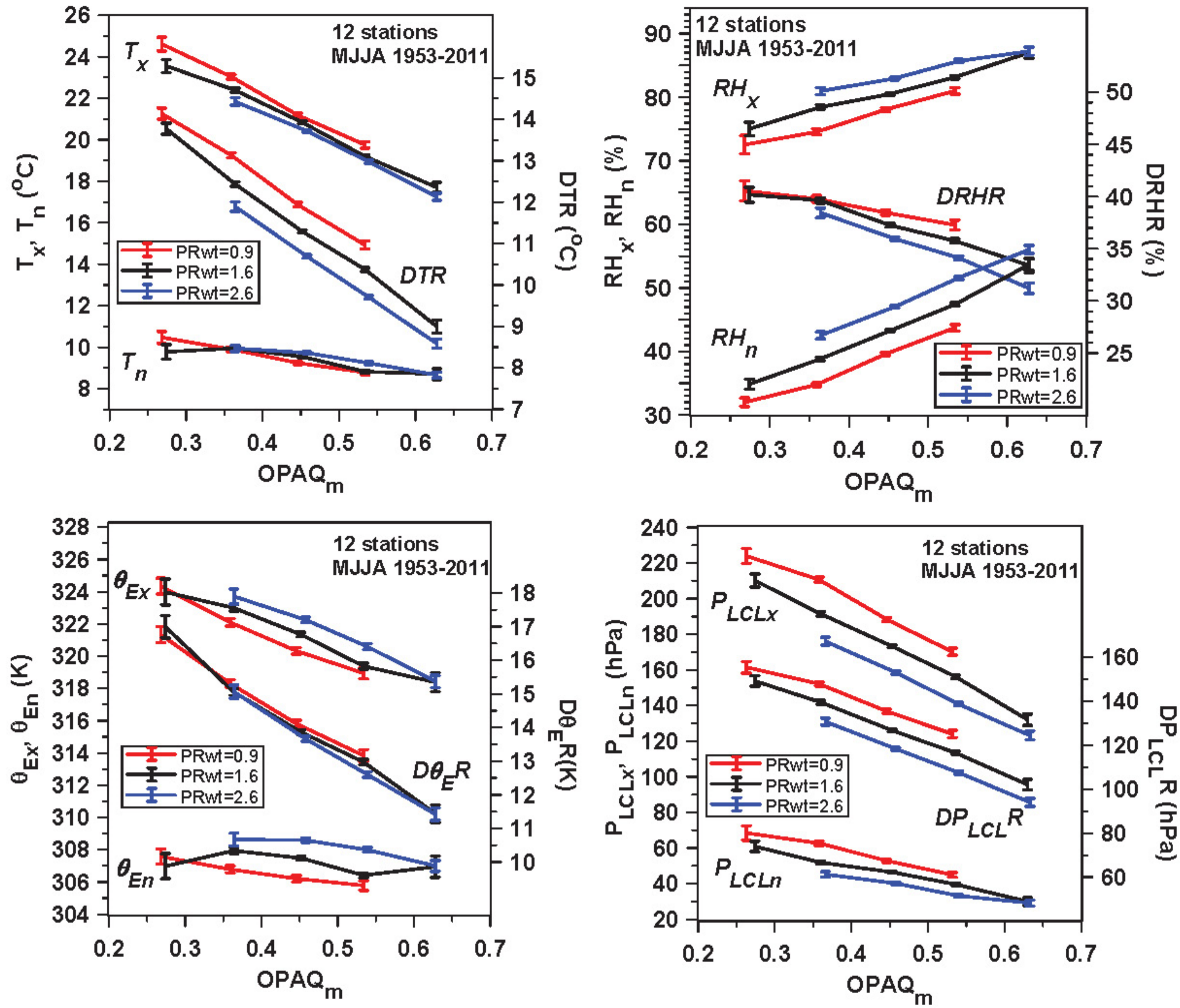
Summer Precip Memory back to March

JULY 1953-2010: 12 stations (614 months)

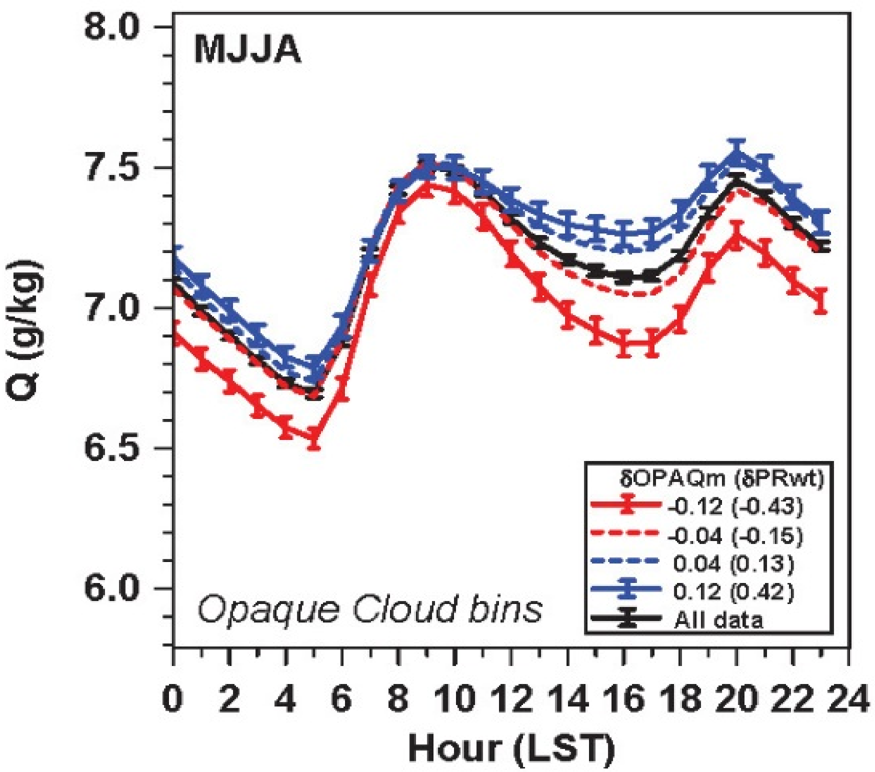
JULY R^2	δDTR 0.68	δRH_n 0.61	δP_{LCLx} 0.62	δQ_{Tx} 0.26
Cloud-July	**-0.56±0.03**	**0.50±0.03**	**-0.63±0.04**	(0.03±0.04)
PR-July	**-0.31±0.02**	**0.37±0.03**	**-0.45±0.04**	**0.34±0.04**
PR-June	**-0.22±0.02**	**0.34±0.03**	**-0.44±0.04**	**0.38±0.04**
PR-May	**-0.12±0.02**	**0.11±0.03**	**-0.16±0.04**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

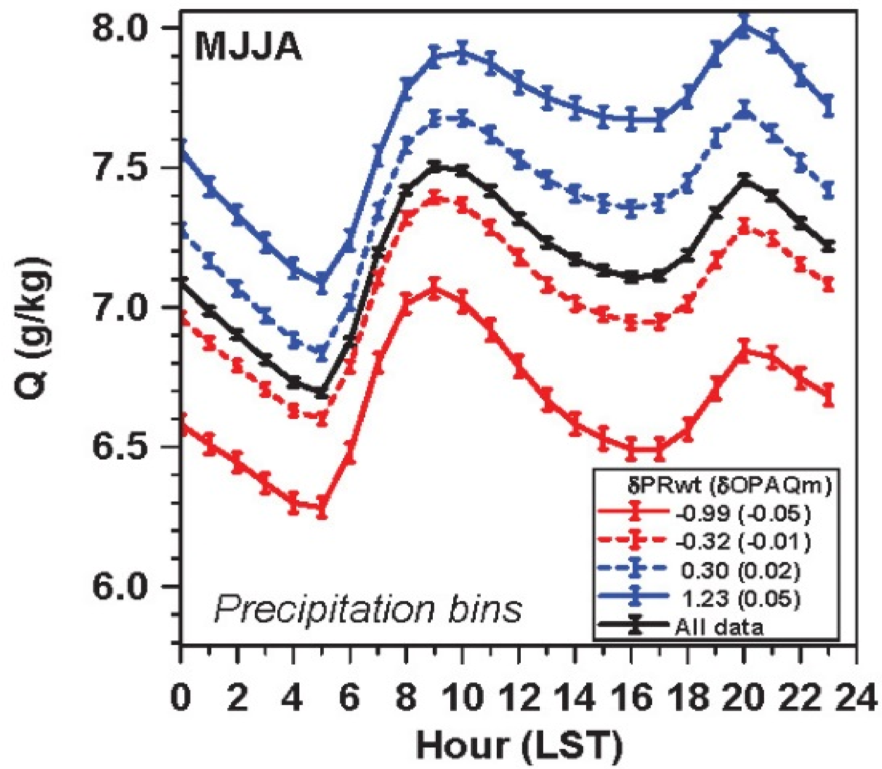
June, July, Aug have precip memory back to March

MJJA on cloud and Precipitation



Diurnal cycle of Q





Dependence on cloud small; on precipitation large

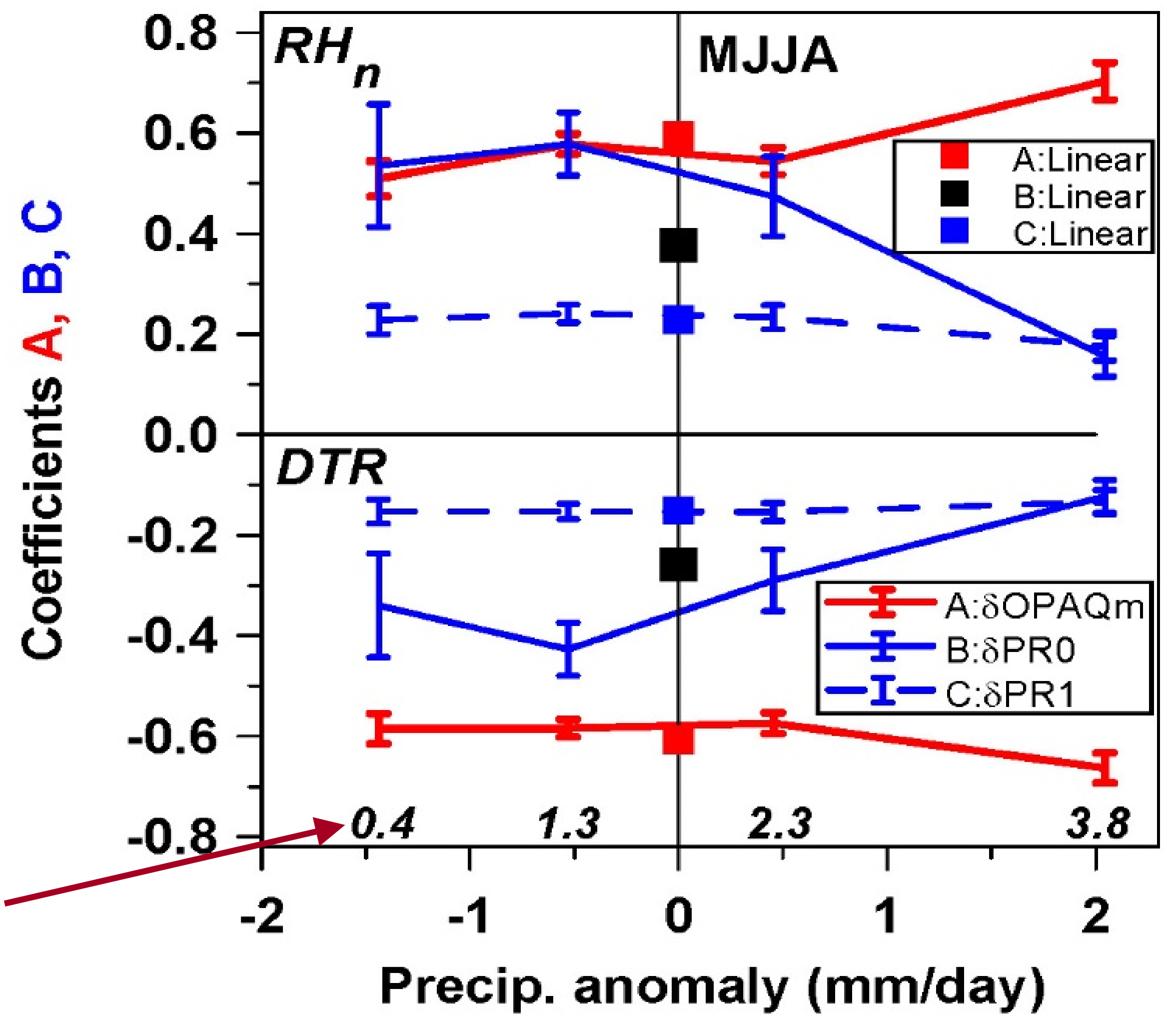
Non-linear coupling to precipitation:

Stratify by precipitation anomaly δPR-0 for current month

A: Opaque cloud
B: δPR-0: this month
C: δPR-1: last month

The solid squares are the A, B, C linear regression coefficients

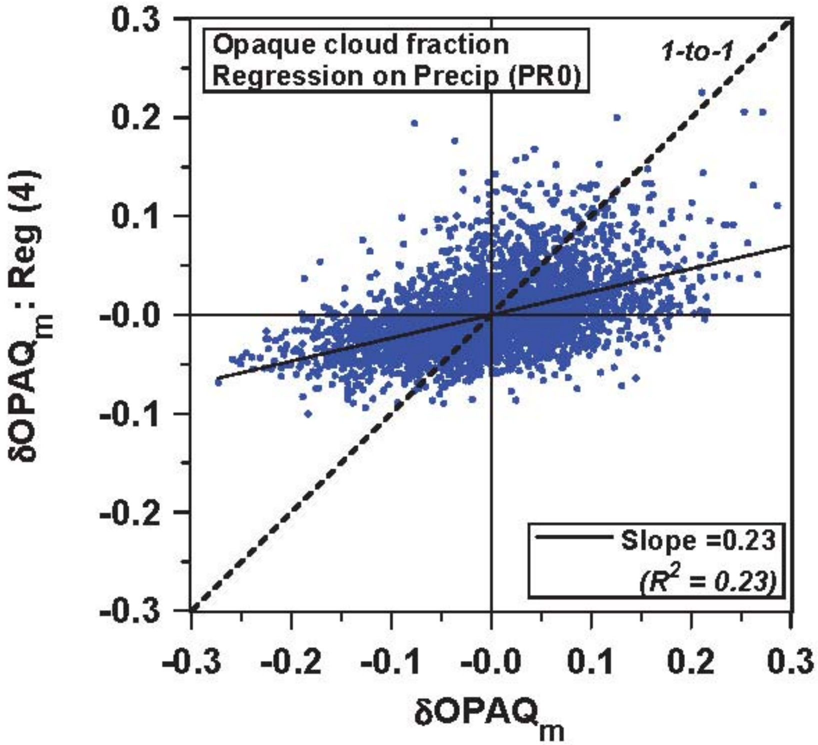
Coupling less in wetter months



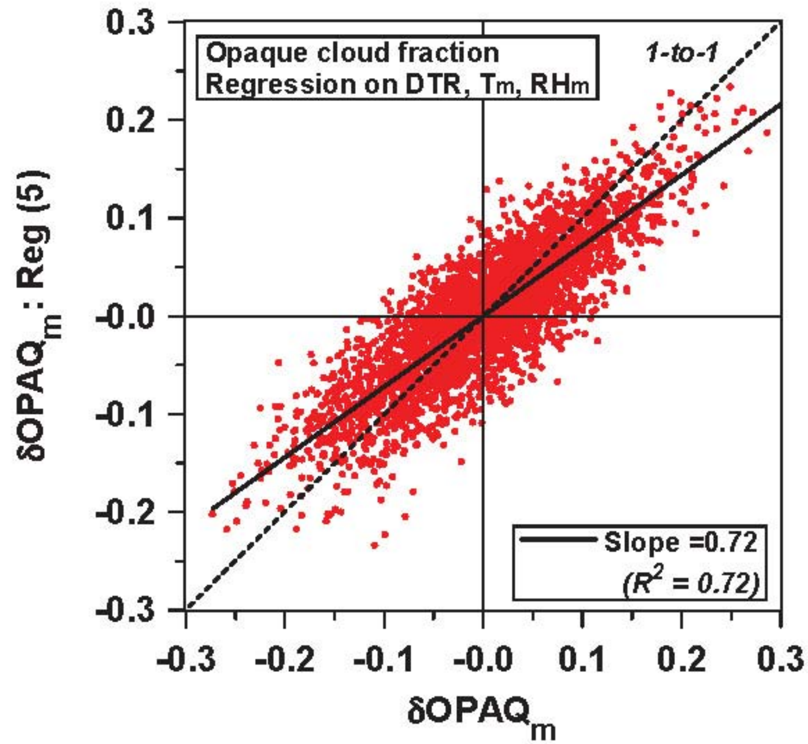
Mean monthly precipitation

Cloud on Climate variables

MJJAS



Precipitation



DTR, T_m, RH_m

Conclusions

- Remarkable dataset with opaque cloud
- Cloud radiative forcing variability dominates diurnal and monthly timescales
- Low wind: greater DTR, θ_{Ex}, Precip.
- Warm season precipitation memory back to March (early snowmelt)
  - Stronger for moisture variables than DTR
- Coupling of monthly climate to precipitation anomalies is non-linear
- *Clouds and climate are tightly coupled on monthly timescale*

April: Precip Memory back to November

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**
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