Understanding Land-atmosphere Coupling in the Warm Season

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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


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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

- \( R_{\text{net}} = SW_{\text{net}} + LW_{\text{net}} \)

Define Effective Cloud Albedo (reflection)

- \( ECA = \frac{(SW_{dn(\text{clear})} - SW_{dn})}{SW_{dn(\text{clear})}} \)

  \text{Clear sky}

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

  \text{Reflected by surface, MODIS, clouds Calibrate Opaque Cloud data with BSRN}
Prairie has 2 climates

T > 0°C

T < 0°C
Warm Season Climate: $T > 0^\circ C$
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 $\Delta RH$ coupled
Calibrate Opaque Cloud to BSRN ECA and $LW_n$

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

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

$$LW_n = -89(\pm 10) + 4.6(\pm 0.3) OPAQ_m + 0.26(\pm 0.03) OPAQ_m^2 + 0.86(\pm 0.03) T_m \quad (R^2=0.82)$$
Regression fits to Opaque Cloud

Daily data: warm season, $T_m > 0$ (to ±0.08)
Opaque cloud gives ECA, $LW_n \rightarrow R_n$
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**

**Monthly timescale: Regression**

\[
\delta \text{DTR} = K + A \delta \text{Precip(Mo-2)} + B \delta \text{Precip(Mo-1)} + C \delta \text{Precip} + D \delta \text{OpaqueCloud}
\]

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

**\(\delta \text{DTR} \) anomalies**

<table>
<thead>
<tr>
<th></th>
<th>K</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>(R^2) All</th>
<th>(R^2) Precip</th>
<th>(R^2) Cloud</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>0 ± 0.8</td>
<td>-0.37 ± 0.05</td>
<td>-0.37 ± 0.04</td>
<td>-1.10 ± 0.05</td>
<td>0.73</td>
<td>0.41</td>
<td>0.66</td>
<td></td>
</tr>
<tr>
<td>Jun</td>
<td>0 ± 0.7</td>
<td>-0.30 ± 0.03</td>
<td>-0.32 ± 0.02</td>
<td>-0.97 ± 0.04</td>
<td>0.69</td>
<td>0.42</td>
<td>0.52</td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>0 ± 0.7</td>
<td>-0.20 ± 0.03</td>
<td>-0.25 ± 0.02</td>
<td>-0.33 ± 0.03</td>
<td>-1.10 ± 0.05</td>
<td>0.67</td>
<td>0.42</td>
<td>0.48</td>
</tr>
<tr>
<td>Aug</td>
<td>0 ± 0.7</td>
<td>-0.07 ± 0.02</td>
<td>-0.21 ± 0.03</td>
<td>-0.40 ± 0.03</td>
<td>-1.24 ± 0.04</td>
<td>0.79</td>
<td>0.46</td>
<td>0.71</td>
</tr>
<tr>
<td>Sept</td>
<td>0 ± 0.8</td>
<td>-0.22 ± 0.03</td>
<td>-0.49 ± 0.04</td>
<td>-1.27 ± 0.04</td>
<td>0.82</td>
<td>0.43</td>
<td>0.75</td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>0 ± 0.8</td>
<td>-0.27 ± 0.03</td>
<td>-0.70 ± 0.07</td>
<td>-1.33 ± 0.04</td>
<td>0.77</td>
<td>0.37</td>
<td>0.70</td>
<td></td>
</tr>
</tbody>
</table>
## Monthly timescale: Regression

\[ \delta RH_{tx} = K + A \delta\text{Precip}(Mo-2) + B \delta\text{Precip}(Mo-1) + C \delta\text{Precip} + D \delta\text{OpaqueCloud} \]

### Afternoon \( \delta RH_{tx} \) anomalies

<table>
<thead>
<tr>
<th>Month</th>
<th>K</th>
<th>A (Mo-2)</th>
<th>B (Mo-1)</th>
<th>C (Mo)</th>
<th>D</th>
<th>( R^2 )</th>
<th>( R^2 )</th>
<th>( R^2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( \pm 3.6 )</td>
<td>( \pm 0.38 )</td>
<td>( \pm 0.22 )</td>
<td>( \pm 0.17 )</td>
<td>( \pm 0.20 )</td>
<td>( 0.72 )</td>
<td>( 0.46 )</td>
<td>( 0.62 )</td>
</tr>
<tr>
<td>May</td>
<td>0</td>
<td>1.30</td>
<td>1.47</td>
<td>2.07</td>
<td>4.75</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jun</td>
<td>0</td>
<td>0.69</td>
<td>1.26</td>
<td>1.96</td>
<td>4.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July</td>
<td>0</td>
<td>0.84</td>
<td>1.71</td>
<td>1.81</td>
<td>4.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aug</td>
<td>0</td>
<td>0.66</td>
<td>1.23</td>
<td>2.42</td>
<td>4.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sept</td>
<td>0</td>
<td>1.40</td>
<td>2.10</td>
<td>4.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oct</td>
<td>0</td>
<td>1.28</td>
<td>5.02</td>
<td>4.58</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**MJJA Growing Season**

\[ \delta Y_\sigma = K_\sigma + B_\sigma \cdot \delta \text{Precip(AMJJA)}_\sigma + C_\sigma \cdot \delta \text{OpaqueCloud}_\sigma \]

<table>
<thead>
<tr>
<th>Variable: ( \delta Y_\sigma )</th>
<th>( K_\sigma )</th>
<th>( B_\sigma )</th>
<th>( C_\sigma )</th>
<th>( R^2_\sigma )</th>
<th>( \sigma(\delta Y) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \delta T_{x\sigma} )</td>
<td>0±0.7</td>
<td>-0.33±0.03</td>
<td>-0.52±0.03</td>
<td>0.52</td>
<td>1.11</td>
</tr>
<tr>
<td>( \delta T_{m\sigma} )</td>
<td>0±0.8</td>
<td>-0.21±0.05</td>
<td>-0.50±0.07</td>
<td>0.38</td>
<td>0.88</td>
</tr>
<tr>
<td>( \delta DTR_\sigma )</td>
<td>0±0.6</td>
<td>-0.55±0.03</td>
<td>-0.39±0.03</td>
<td>0.62</td>
<td>0.83</td>
</tr>
<tr>
<td>( \delta RH_{tx\sigma} )</td>
<td>0±0.6</td>
<td>0.56±0.03</td>
<td>0.35±0.03</td>
<td>0.60</td>
<td>4.35</td>
</tr>
<tr>
<td>( \delta RH_{m\sigma} )</td>
<td>0±0.7</td>
<td>0.51±0.03</td>
<td>0.33±0.03</td>
<td>0.50</td>
<td>4.61</td>
</tr>
<tr>
<td>( \delta PLCL_{tx\sigma} )</td>
<td>0±0.6</td>
<td>-0.56±0.03</td>
<td>-0.37±0.03</td>
<td>0.61</td>
<td>18.6</td>
</tr>
<tr>
<td>( \delta Q_{tx\sigma} )</td>
<td>0±0.9</td>
<td>0.50±0.04</td>
<td>0.03±0.04</td>
<td>0.26</td>
<td>0.58</td>
</tr>
<tr>
<td>( \delta \theta_{Et\sigma} )</td>
<td>0±1.0</td>
<td>0.22±0.04</td>
<td>-0.31±0.04</td>
<td>0.09</td>
<td>1.95</td>
</tr>
</tbody>
</table>
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, $\text{LW}_{\text{dn}}$
  - Cloud, ECA, $\text{LW}_{\text{n}}$ → DTR and $\Delta\text{RH}$
  - *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 $\theta_{Etx}$


**Partition: Cloud + Windspeed**

- **Low wind**: lower $T_n$, higher DTR, $RH_{tn}$
  - Clear-sky radiative cooling

- **Low wind**: higher afternoon $Q_{tx}$, $\theta_{Etx}$
  - Stronger superadiabatic layer?
Day-Night Cloud Asymmetry

- $\Delta OPAQ = (OPAQ_m - OPAQ_{SW}) > 0$
  - Less daytime cloud $\rightarrow$ Larger $R_n$
  - $T_x, T_n$ shift up
  - Higher afternoon $\theta_{Etx}$
  - (Higher precip)
Cloud + δPrecipWT
*(Monthly Precip Anomalies)*

![Graphs showing temperature, dew point, relative humidity, and pressure changes with cloud cover.](image)
Remap: $\text{OPAQ}_m$ to $\text{LW}_n$
Land-surface-atmosphere coupling: daily timescales

• 11 stations: 54000 days in JJA

• **Fully coupled system**

• Diurnal cycle driven by OPAQ\textsubscript{m}
  – RH, wind, day-night cloud asymmetry, monthly precip anomalies
  – *Tight linear* DTR-LW\textsubscript{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 $\theta_E$: 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)
  - \( P_{\text{LCLtx}} \) (0.83)
  - \( RH_{\text{tx}} \) (0.71)

- Cloud to
  - \( T_x \) (0.69)

- Separation

- Month: blend

- Daily: cloud
How good is the regression fit?

- September
  \[ T_x \pm 1.4^\circ C \]
  \[ DTR \pm 0.8^\circ C \]
  \[ RH_{tx} \pm 3.5\% \]
  \[ P_{LCLtx} \pm 13hPa \]

- Some extremes underestimated
  (586 station-yrs)