Response of surface temperature to afforestation in Kubuqi desert, Inner Mongolia

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Study sites

40°32′N, 108°41′ E
ΔT in temperate zone

(ΔT) caused by deforestation

(Lee, 2011) (Luyssaert, 2014)
Purpose

- Evaluate the performance of the modified intrinsic biophysical mechanism (IBPM) theory.

- Evaluating the $\Delta T_s$ caused by afforestation. Quantify the contributions of the composition of $\Delta T_s$ (surface temperature) over the diurnal and seasonal cycles.

- Compare the $\Delta T_s$ decomposition results obtained with the IBPM and the DTM theory.
Energy balance

Winter forest
\[ R_n - G = 0.7x + 7.53 \]
\[ R^2 = 0.75 \]

Spring forest
\[ R_n - G = 0.77x + 27.8 \]
\[ R^2 = 0.91 \]

Summer forest
\[ R_n - G = 0.93x + 28.66 \]
\[ R^2 = 0.95 \]

Autumn forest
\[ R_n - G = 0.72x + 8.74 \]
\[ R^2 = 0.94 \]

Winter shrub
\[ R_n - G = 1.02x + 3.85 \]
\[ R^2 = 0.85 \]

Spring shrub
\[ R_n - G = 1.1x + 10.87 \]
\[ R^2 = 0.84 \]

Summer shrub
\[ R_n - G = 0.96x + 20.82 \]
\[ R^2 = 0.78 \]

Autumn shrub
\[ R_n - G = 0.84x + 8.73 \]
\[ R^2 = 0.92 \]
model \( (T_s - T_a) = \frac{\lambda_0}{(1 + f)}(R_n^* - G) \)
Daytime Balance $\rightarrow \hat{H}$

Hourly results $\rightarrow$ Daily results

$N = 10$

Mean $\pm$ SE
Nighttime

Balance $\rightarrow \hat{H}$

Hourly results $\rightarrow$ Daily results

$N = 10$

Mean $\pm$ SE
Daytime

Half hour results
Nighttime

Half hour results
Prognostic calculation

\[ r_t = r_a + r_{ex} + r_r \]

\[ r_a = \left[ \ln \left( \frac{z - d}{z_0} \right) - \Psi_M \right] \left[ \ln \left( \frac{z - d}{z_0} \right) - \Psi_H \right] \]

\[ r_{ex} = \frac{\ln \left( \frac{z_0}{z_h} \right)}{k u^*} \]

<table>
<thead>
<tr>
<th></th>
<th>Forest</th>
<th>Shrub</th>
</tr>
</thead>
<tbody>
<tr>
<td>( r_r ) day ((60 \leq \text{DOY} \leq 240))</td>
<td>(24.4\exp(-0.5\text{LAI}))</td>
<td>(24.4\exp(-0.5\text{LAI}))</td>
</tr>
<tr>
<td>( r_r ) day ((\text{DOY} &lt; 60, \text{DOY} &gt; 240))</td>
<td>(14.9\exp(-0.2\text{LAI}))</td>
<td>(14.9\exp(-0.2\text{LAI}))</td>
</tr>
<tr>
<td>( r_r ) night ((\text{s m}^{-1}))</td>
<td>(0.0049\text{DOY}^2 - 1.96\text{DOY} + 258)</td>
<td>(0.0011\text{DOY}^2 - 0.6726\text{DOY} + 172)</td>
</tr>
</tbody>
</table>
Daytime

Prognostic model

Half hour results
Nighttime

Prognostic model

Half hour results
DTM model

\[ \Delta T_s = \lambda_0 \Delta S + \lambda_0 \Delta L_\downarrow - \lambda_0 (\Delta LE + \Delta H) - \lambda_0 \Delta G \]

\[ T_s'^4 \approx T_s^4 + 4T_s^3 (T_s' - T_s) \]

\[ \Delta T_s = T_s' - T_s \approx \frac{1}{4T_s^3} (T_s'^4 - T_s^4) \]

\[ = \frac{1}{4\sigma T_s^3} (\sigma T_s'^4 - \sigma T_s^4) \]

\[ = \lambda_0 [\Delta S + \Delta L_\downarrow - (\Delta S + \Delta L_\downarrow - (\sigma T_s'^4 - \sigma T_s^4))] \]

\[ = \lambda_0 [\Delta S + \Delta L_\downarrow - \Delta L_E - \Delta H - \Delta G] \]

\[ = \lambda_0 \Delta S + \lambda_0 \Delta L_\downarrow - \lambda_0 (\Delta LE + \Delta H) - \lambda_0 \Delta G \]

\[ \hat{H} = \frac{\beta}{1 + \beta} (R_n - G) \]

\[ \overline{LE} = \frac{1}{1 + \beta} (R_n - G) \]

\[ R_n = LE + H + G \]
Relationship between half-hour calculated $\Delta T_s$ and observed $\Delta T_s$ in spring according to decomposition temperature metric (DTM) in daytime (a) and nighttime (b).
Nighttime DTM model

(a) Winter
(b) Spring
(c) Summer
(d) Autumn

- $\Delta T_s$
- $\Delta T_{s_DTM}$
- $S$
- $L$
- $H+LE$
- $G$
Important of energy balance

Daytime Energy imbalance IBPM
Nighttime Energy imbalance

IBPM
Daytime
Energy imbalance
DTM
Nighttime Energy imbalance

DTM
Summary

• a) Calculated $\Delta T_s$ of the modified IBPM is close to observed $\Delta T_s$ after considering $\Delta L_\downarrow$ and $T_a$ related term.

• b) The forest has a cooling effect in the daytime and summer night and warming effect in the nighttime of other seasons.
   
   Influence of roughness and Bowen ratio had big seasonal variation.
   
   Influence of radiative and soil heat flux almost kept constant.

• c) For DTM, some of the component contributions are an order of magnitude greater than related term of IBPM.

• d) Energy balance is important for both IBPM and DTM, especially for DTM.
Regional scale study

- 2010 Land use
- 2010 meteorology

Control 1 (c1)

- 2000 Land use
- 2010 meteorology

Experiment 1 (e1)

WRF output
- TSK
- Ta (2m)
- RH (2m)
- Wind speed
- PPT

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Compare with observation

Evaluate model performance

Evaluate the effect of land use change

Weather Research and Forecasting (WRF) Model
Domains
## Hypothesis

<table>
<thead>
<tr>
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<th>Nighttime</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_{forest} – T_{shrub} )</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>-0.8 K</td>
<td>+0.1 K</td>
</tr>
<tr>
<td>Summer</td>
<td>-0.2 K</td>
<td>-1 K</td>
</tr>
<tr>
<td>( T_{vegetation} – T_{openland} )</td>
<td>cooling</td>
<td>warming</td>
</tr>
<tr>
<td>Winter</td>
<td>cooling</td>
<td></td>
</tr>
<tr>
<td>Summer</td>
<td>cooling</td>
<td></td>
</tr>
</tbody>
</table>
c1 Vs real
c1 Vs real
c1 Vs e1

Winter day

Winter night

Summer day

Summer night
Partition (night)
Thank you!