Improvement of Forest Canopy Characterization Based on NoahMP and Its Impact on Land Air Exchange Processes

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Noah-MP workshop, 4 Jun 2024
Key processes: land-air exchange

- **Active components**
  - Dry/Wet deposition
  - Anthropogenic emissions
  - Biogenic emissions

- **Energy budget**
  - Shortwave radiation
  - Longwave radiation
  - Sensible heat
  - Latent heat

- **Soil emissions** (NOx, N2O...)
- **Soil heats**
Vegetation morphology in different models

Hanson et al, 2004; D. Baldocchi., 2016
Parameters of Canopy in Noah-MP

The canopy structure is represented by a simple geometric shape:

- R: Radius of crown
- H_{top}: Canopy top [m]
- H_{bot}: Canopy bottom [m]
- b: Leaf dimension [m]

### MPTABLE.TBL

<table>
<thead>
<tr>
<th>NAME</th>
<th>Used/Defined in Subroutine</th>
<th>Short description [units]</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH2OP</td>
<td>CANWATER</td>
<td>Maximum water intercepted by canopy [mm]</td>
</tr>
<tr>
<td>DLEAF</td>
<td>RAGRB</td>
<td>Leaf dimension [m]</td>
</tr>
<tr>
<td>Z0MVT</td>
<td>ENERGY</td>
<td>Momentum roughness length [m]</td>
</tr>
<tr>
<td>HVT</td>
<td>PHENOLOGY / TWOSTREAM</td>
<td>Canopy top [m]</td>
</tr>
<tr>
<td>HVB</td>
<td>PHENOLOGY / TWOSTREAM</td>
<td>Canopy bottom [m]</td>
</tr>
<tr>
<td>DEN</td>
<td>TWOSTREAM</td>
<td>Tree density [number/m²]</td>
</tr>
<tr>
<td>RC</td>
<td>TWOSTREAM</td>
<td>Crown radius [m]</td>
</tr>
<tr>
<td>FOLNMX</td>
<td>CO2FLUX / STOMATA</td>
<td>Maximum foliage nitrogen factor (see FOLN setting in code) [unitless]</td>
</tr>
<tr>
<td>WDPOOL</td>
<td>CO2FLUX</td>
<td>Wood pool factor used to determine relative wood presence [unitless]</td>
</tr>
<tr>
<td>WRRAT</td>
<td>CO2FLUX</td>
<td>Wood to non-wood ratio [kg/kg]</td>
</tr>
<tr>
<td>MRP</td>
<td>CO2FLUX</td>
<td>Microbial respiration in fast soil carbon pool at 10°C [umol/m²/s]</td>
</tr>
<tr>
<td>SAIM</td>
<td>PHENOLOGY</td>
<td>Monthly stem area index when prescribed [m²/m²]</td>
</tr>
<tr>
<td>LAIM</td>
<td>PHENOLOGY</td>
<td>Monthly leaf area index when prescribed [m²/m²]</td>
</tr>
<tr>
<td>SLAREA</td>
<td>BVOCFUX</td>
<td>Stem-to-leaf area density [unitless]</td>
</tr>
<tr>
<td>EPS</td>
<td>BVOCFUX</td>
<td>Emission capacity for up to 5 different BVOC fluxes at 30°C [ug C/g foliar mass/hour]</td>
</tr>
</tbody>
</table>
The canopy data by earth observation

Felix M. et al., 2020
How to get canopy parameters in our study forest?

Sample site, Subtropical forests in Guangdong, China

Vegetation Types of CN-DIN

- The main tree species are Pinus massoniana.
Using UAV-based Photogrammetry

**UAV photogrammetry**

Structure from motion photogrammetric

Align photos & point cloud

3D reconstruction

Digital surface model

Canopy height model

Digital terrain model

Canopy surface statistics

UAV-based canopy parameters

Atmospheric forcing data

Land surface model

Surface energy budget simulation

Land-atmospheric exchange variables

Parameters look-up table

Graphical representation of the process.

Remote Sensing. 2020
Correction of canopy parameters and its effects

Observation fitting

- UAV-Based Parameter Quantiles
- Model-Original: Deciduous Broadleaf Forest
- Model-Original: Deciduous Needleleaf Forest
- Model-Original: Evergreen Broadleaf Forest
- Model-Original: Evergreen Needleleaf Forest
- Model-Original: Mixed Forest

- Canopy Evaporative Heat to Atmosphere
- Ground Evaporative Heat to Atmosphere
- Canopy Transpiration Heat to Atmosphere

- Latent Heat Flux (LH, W/m²)
- Change of LH (%)

How to get more accuracy canopy parameters?

- **UAV and Airborne LiDAR:**
  - High accuracy
  - Multiple echoes based on different altitudes for canopy.
  - Less affected by occlusions and shadows, can penetrate the canopy and acquire three-dimensional information.

Guo et al., 2021
UAVs and LiDAR setup

- Flight altitude: 100 metres from the landing site
- Flight speed: 4.3 m/s
- Average sampling distance: 7.24 cm
- Heading overlap: 80.0%
- Scanning angle: 37° and 70°
- Relative geographic accuracy
  - X: 95.0%
  - Y: 100.0%
  - Z: 100.0%
- Active remote sensing: unmanned airborne lidar
- Passive optical remote sensing: visible light drones

GT Wu et al. Remote Sensing, 2022
Single Tree Segmentation of Point Cloud in Sample Land Surveying

Data Acquisition

Point Cloud Solving

Single Tree Segmentation

GT Wu et al. Remote Sensing, 2022
Characteristics of field canopy structure

Average values of the canopy structure

<table>
<thead>
<tr>
<th></th>
<th>LPR</th>
<th>VPR</th>
<th>Observed (Reference)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average tree height (HVT, m)</td>
<td>16.35 ± 2.19</td>
<td>16.02 ± 7.07</td>
<td>7.0~16.7</td>
</tr>
<tr>
<td>The diameter at breast height (DBH, cm)</td>
<td>2.22 ± 1.92</td>
<td>1.48 ± 1.60</td>
<td>5.1~21.9</td>
</tr>
<tr>
<td>Canopy radius (RC, m)</td>
<td>3.92 ± 1.78</td>
<td>4.80 ± 2.35</td>
<td>3.0~16.0</td>
</tr>
<tr>
<td>Leaf area index (LAI)</td>
<td>4.28 ± 2.38</td>
<td>0.48 ± 0.43</td>
<td>6.5 ± 0.7</td>
</tr>
<tr>
<td>Canopy cover</td>
<td>0.81 ± 0.18</td>
<td>0.48 ± 0.32</td>
<td>&gt;0.8</td>
</tr>
<tr>
<td>Gap fraction</td>
<td>0.19 ± 0.18</td>
<td>0.52 ± 0.42</td>
<td>0.1~0.2</td>
</tr>
</tbody>
</table>

**LPR:** LiDAR Photogrammetry Results

**VPR:** Visible-light Photogrammetry Results

- Passive optical remote sensing has major limitations in establishing a link with vegetation.
Correction of canopy parameters by using fitting function

- Relationship between average tree height (HVT) and Canopy radius (RC) driven by (a) LPR and (b) VPR.
- Red lines indicate linear fits.

HVT and RC functions for Noah-MP inputs

<table>
<thead>
<tr>
<th>Variables</th>
<th>Default</th>
<th>LPR</th>
<th>VPR</th>
</tr>
</thead>
<tbody>
<tr>
<td>HVT</td>
<td>16.0</td>
<td>HVT from LPR</td>
<td>HVT from VPR</td>
</tr>
<tr>
<td>RC</td>
<td>1.4</td>
<td>-0.09 × HVT + 0.01 × HVT^2 + 3.21</td>
<td>-11.82 × 0.92^{HVT} + 12.29</td>
</tr>
</tbody>
</table>
Results of the simulated canopy temperature and humidity profiles
Diagnosis of the radiation and heat fluxes

(a) Upward shortwave radiation (W/m²)

(b) Upward longwave radiation (W/m²)

(a) Sensible heat flux (W/m²)

(b) Latent heat flux (W/m²)
<table>
<thead>
<tr>
<th>Experimental name</th>
<th>Vegetation canopy parameters</th>
<th>Vegetation canopy structure programme options</th>
</tr>
</thead>
<tbody>
<tr>
<td>D_1</td>
<td>Default</td>
<td>Three-dimensional (3D) canopy morphology</td>
</tr>
<tr>
<td>D_2</td>
<td></td>
<td>Non-vegetated gap</td>
</tr>
<tr>
<td>D_3</td>
<td></td>
<td>Coverage-based</td>
</tr>
<tr>
<td>LPR_1</td>
<td>LPR</td>
<td>Three-dimensional (3D) canopy morphology</td>
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The upward shortwave radiation and upward longwave radiation RMSEs simulated by the LPR are reduced by **9.5%** and **3.6%** compared to the VPR.
Canopy 3D Morphology with LiDAR Photogrammetry

Parameter inputs have Lower RMSE for latent heat flux

- The upward shortwave radiation and upward longwave radiation RMSEs simulated by the LPR are reduced by 9.5% and 3.6% compared to the VPR.
Current Mechanism

Considering canopy gaps

\[ P_c = \min\left\{ \frac{1 - F_{veg}}{P_{bc} + P_{wc}} \right\} \]

\[ P_{bc} = e^{-\rho_t \times \pi \times r^2 \cos(\theta')^2} \]

\[ P_{wc} = (1 - P_{bc}) \times e^{-0.5 \times F_a \times (H_{top} - H_{bot}) \cos\theta} \]

**Current Mechanism**

### Considering canopy gaps

**\(P_c\): total canopy gap probability**

\[
P_c = \min\left\{ \frac{1 - F_{veg}}{P_{bc} + P_{wc}} \right\}
\]

\[ P_{bc} = e^{-\rho_t \times \pi \times r^2 \cos(\theta')^2} \]

\[ P_{wc} = (1 - P_{bc}) \times e^{-0.5 \times F_a \times (H_{top} - H_{bot}) \cos\theta} \]

\[ r \]: tree crown radius

\[ H_{top} \]: height to canopy top

\[ H_{bot} \]: height to canopy bottom

**\(K_{open}\): gap fraction**

\[ K_{open} = 0.05 \]

**\(F_{veg}\): veg fraction**

**No canopy gaps**

\[ P_c = 0 \]

\[ K_{open} = 0 \]
Further work 1: Expressing more refined canopy structure and processes in the model

Extractable from UAV-based photogrammetry:
Height, Length, Volume, Coverage
Canopy closure, Leaf area index, Gap rate, Biomass...

(Lamelas-Gracia et al., 2019)
(Van der Zande et al., 2011)
(Li et al., 2018)
Further work 2: expressing and comparing from other scales
Related Papers


THANKS!