A Brief Tutorial for Running DHSVM-RBM

Files Structure

After unpacking the file, the source code and supporting files will be in **DHSVM_RBM**:
The sub-directories within this directory are:

Create	- contains the Fortran 90 source and **makefile** that build the forcing file for **RBM**
Output	- contains the sample output for the examples provided here
DHSVM	- contains the source code and **makefile** for the hydrologic model, **DHSVM**, which generates the hydrologic data and meteorological data requires by the stream temperature model, **RBM**
RBM	- contains the source code **makefile** for the stream temperature model, **RBM**
Scripts	- contains the pre- and post-processing scripts
tutorial DHSVM v3.1.pdf	
tutorial DHSVM-RBM.pdf	

Run the Model

The stream temperature model, **RBM**, simulates water temperatures using forcing data and topology created by the distributed hydrologic model, **DHSVM**. The files include:

Create Forcing Files

The hydrologic and meteorological forcing files are generated from the **DHSVM** model.

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For DHSVM beginners, follow the tutorial **tutorial DHSVM v3.1.pdf** to prepare DHSVM input and run the model.

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To turn on temperature modeling:

I. In the configuration file, modify the section [**OPTIONS**]. Make
   Stream Temperature = TRUE
   If riparian vegetation is taken into account, then
   Canopy Shading = TRUE
   Otherwise,
   Canopy Shading = FALSE

II. If **Canopy Shading = TRUE**, create a **riparian network file** (e.g. DHSVM/input/rveg.baseline.network) that specifies the riparian parameter values for every stream segment, and enter the path to this network file in the DHSVM configuration file <stream network> section:

```
################ stream network # #############################
   # The following three fields are only used if Flow Routing = NETWORK
```

Stream Map File = ../input/stream.map.dat
Stream Network File = ../input/stream.network.dat
Stream Class File = ../input/adjust.classfile
Riparian Veg File = ../input/ rveg.baseline.network

In the riparian network file, the parameter value from left to right (column) is:

- Stream Segment ID
- Tree Height (m)
- Vegetation Buffer Width (m)
- Monthly Extinction Coefficient (0 ~ 1) from Jan to Dec (12 columns)
- Overhang Coefficient that is a percentage of tree height used to represent overhanging canopy (0 ~ 1)
- Canopy Bank Distance indicating the distance from bank to canopy (m)
- Channel Width (m).

Monthly light extinction coefficient (k) is monthly varied in unit m^{-1}. In application, this parameter should be treated as a calibration parameter. In prior studies, we used LAI/64 as the initial guess of the k values.

Note from literature: *The value of k is typically between 0.001 and 0.1 m^{-1}, representing a low-to-high canopy density (Federer, 1971; Baldocchi et al., 1984; Pomeroy and Dion, 1996; Link et al., 2004), and 0.05 m^{-1} is used to represent an average condition.*

III. Compile DHSVM if use binary I/O:

```
make –f makefile_for_binary
```

If use netCDF I/O:

```
make –f makefile_for_netcdf
```

IV. Run DHSVM.

```
DHSVM/sourcecode/DHSVM3.2 DHSVM/config/Template.Input.GriddedMet
```

The output forcing files will be in the directory **DHSVM/output**.

Outputs of RBM forcing files include:
*** Each file contains time series for each stream segment. The segment ID is consistent with the ID used in the stream.network.dat file. ***

NSW.Only	net shortwave radiation, *W/m²*
ATP.Only	air temperature, °C, for each computational interval and
NLW.Only	net longwave radiation, *W/m²*
VP.Only	vapor pressure, *Pascals*
WND.Only	wind speed, m/s
Inflow.Only	inflow, m^3/s
Outflow.Only	outflow, m^3/s

The format *.Only file is as follows:

<MM/DD/YYYY-HH:MM:SS (start date)> <MM/DD/YYYY-HH:MM:SS (end date)>
<segment number(n), n=1, number of segments>
<MM.DD.YYYY-HH:MM:SS (initial time)>
<MM.DD.YYYY-HH:MM:SS (data time), dhsvm_output(n), n=1,number of segments>

where dhsvm_output(n) are the simulated values of air temperature, shortwave radiation, longwave radiation, vapor pressure, wind speed, inflow and outflow, for each segment. A record is needed for each time step.

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NOTE: The start date of above forcing files, *.Only, is one day behind the start date specified in the DHSVM configuration file, and so is the start date of output stream temperature simulations.

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Create Stream Topology

In this directory, "**Scripts**", compile the program, **make_stream_connectivity.c**, to create the stream topology file, **convergence.txt**.

```
gcc make_stream_connectivity.c –o make_stream_connectivity
```

Copy the executable, **make_stream_connectivity**, to "**Work_Space**".
Execute the program::

```
./make_stream_connectivity <map> <network> <outdir> <no_segments> <skip>
```

Where **<map>** is the stream map file, **<network>** is the stream network file. Both files are input files required by **DHSVM**, and are stored in this directory, "**DHSVM/input**". **<outdir>** specifies the output directory, **<#segments>** is the total segment numbers, **<skip>** is the number of lines in the header of the stream map file, **<map>**.
Example:

```
./make_stream_connectivity ../DHSVM/input/stream.map
../DHSVM/input/stream.network ./  1  9
```

The format for the topology file is as follows:

<segment id> <destination segment id> <length-meters> <depth-meters> <avg azimuth> <upstream segment id>

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NOTE: This file, convergence.txt, must be renamed to: <ProjectName>.dir, where <ProjectName> is a unique name given to this set of simulations. The name will be used to identify a number of additional files required for the simulation.

If more than one segment other than the basin outlet has the "SAVE" indicator in the 7th column in file, stream.network.dat, REMOVE the "SAVE" indicators for these segments before using the network file in this program!! Also, make sure that ONLY the outlet segment has a

value of -1 in the sixth column. If more than one segment has the value of – 1 in the 6th column, reduce the minimum contributing area and rerun the "createstreamnetwork" script to reduce the number of outlets in the stream network created.
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Create RBM Parameter Files

Create a working directory, "**Work_Space**", and copy the topology file, **<ProjectName>.dir**, to this directory.

I. Create the RBM river network file

From the directory, "**Scripts**", copy the file, **build_DHSVM_network.pl**, to the working directory, "**Work_Space**", and run this script as shown below:

1) Execute the Perl script

    perl build_DHSVM_network.pl

2) Enter the **<ProjectName>**. In this example, we use **Mercer** as the project name.

    Mercer

Executing this Perl script creates the network text file, **<Project>.net** and **<Project>.segmap**, required by the stream temperature model, **RBM**.

The file, **<Project>.net,** has the following structure:

Group 1: **<Title>**
Group 2: **<Forcing File>**
Group 3: **<alpha> <beta> <gamma> <mu>** (not used)
Group 4: **<D_a> <D_b> <D_min>** (not used)
Group 5: **<U_a> <U_b> <U_min>** (not used)
Group 6: **<nreach>** Headwater <**nseg>** stream segments in Project <Project>

Headwaters Data:

#_Segments **<#segments**> Headwaters **<temp>** TribCell **<next_id_RBM> <trib_id_DHSVM> <next_id_DHSVM>**

Segment Data:

If #segments = 2, there should be 3 lines in this section.

Seq <seq_id> Path <trib_id_DHSVM> X_0 <seg_x0> X_1 <seg_x1>
Elevation <elevation in ft>

Seq <seq_id> Path <head_id_DHSVM> X_0 <seg_x0> X_1 <seg_x1>
Elevation <elevation in ft>

The file, **<Project>.segmap** contains a mapping from the sequence numbers used by the **RBM** to the segment ID created by **DHSVM** in stream.network.data. This file has the following format:

<u>Group 1:</u> **<nreach> <no_segments>** (where **<nreach>** - number of reaches, **<#segments>** - number of stream segments)

<u>Group 2:</u> Sequence **<RBM_sequence>** Path **<DHSVM_Sequence>** (where **<RBM_sequence>** - segment sequence number for RBM, **<DHSVM_Sequence>** - segment sequence number for DHSVM. There are **<#segments>** lines for Group 2 data.)

II. Make Mohseni parameter file <Project>.Mohseni

The file format is:

Line 1: <θ> smoothing parameter <headwater is closer to air temperature with a large θ>

From line 2 after: <reach #> < α >< β >< γ >< μ >

$$T_{smooth} = (1-\theta)T_{smooth} + \theta T_{air}$$

$$T_{head} = \mu + \frac{\alpha - \mu}{1 + e^{\gamma(\beta - T_{smooth})}}$$

where T_{smooth} is smoothed stream temperature by air temperature. The coefficient α is the estimated **maximum stream temperature**, μ is **minimum stream temperature**, β is a measure of the steepest slope of the function, and γ represents the air temperature at the inflection point. See Mohseni et al. (1998) for details of this equation.

III. Make Leopold parameter file <Project>.Leopold

The file format is:

<reach #> <ua><ub><umin>

<d_a><d_b><d_{min}>

The first 3 numbers are two Leopold coefficients (u_a, u_b) for speed (U in ft^3/s) and threshold speed that sets the minimum velocity (u_{min}) as used in the equation below.

The latter 3 numbers are two Leopold coefficients (da, db) for water depth (D in *ft*) and threshold depth that sets the minimum depth as used in the equation below.

$$U = u_a Q^{u_b}$$

$$D = d_a Q^{d_b}$$

See Yearsley (2012) for description of parameters

IV. Create RBM forcing file <Project>.forcing

In the directory, **Create**/, create the executable, **Create_File**, by executing the make file. Then copy the executable, **Create_File**, to the working directory, **RBM/Work_Space**. Then execute **Create_File:**

./CreateFile <Input Files Directory> <ProjectName>

where **<Input Files Directory>** is the directory with the ***.Only** files, **<ProjectName>** is the project name.

Run RBM

I. In the directory, "**RBM**", create the executable, **RBM**, by typing:

Make

Then copy the resulting executable, **RBM**, to the working directory **RBM/Work_Space**.

In the working directory **RBM/Work_Space**, type

./RBM <ProjectName>

The simulation results will be in the file, **<ProjectName>.temp**. There is output for each segment for every simulation period.

The file **"<ProjectName>.temp**" has the following structure:

<time> <year> <day> <segment sequence#> <in-reach sequence#> <simulated temperature> <headwaters temperature> <air temperature> <depth> <flow velocity> <incoming flow>

Process the Model Results

In **Scripts/**, Compile the script, **Extract.Segment.Temp.scr**, to reformat the stream temperature time series and compute daily average stream temperature for the selected segments.

Before running the script, change the hard coded parameters in this script including:

- Selected segment # <segID>
- Path to the input file <ProjectName>.temp
- Output directory
- Time step of the input file, <ProjectName>.temp
- Start date as in all input forcing files *.Only.

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NOTE: The segment sequence # is the one used by RBM NOT by DHSVM as in the stream network file. If the end date doesn't have a full record from MM/DD/YYYY-00:00 to MM/DD/YYYY-21:00, the averaging script will exclude the last day in the computations.

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In the directory, "**Scripts**", execute the program:

./Extract.Segment.Temp.scr

The output files are stored in the designated directory.

The file, <**segID>.temp.txt**, has the following structure:

<mm/dd/yyyy-hh:mm> <simulated temperature> <headwaters temperature> <air temperature> <depth>

The file, <**segID>.daily.temp.txt**, has the following structure:

<mm/dd/yyyy> <averaged daily stream temperature>

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Please note: if you decide to use this model, please cite the following model development publications:

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Model Development Publications

Sun, N., Yearsley, J., Voisin, N., & Lettenmaier, D. P. (2015). A spatially distributed model for the assessment of land use impacts on stream temperature in small urban watersheds. *Hydrological Processes*, *29*(10), 2331–2345. https://doi.org/10.1002/hyp.10363

Wigmosta, M. S., Vail, L. W., & Lettenmaier, D. P. (1994). A distributed hydrology-vegetation model for complex terrain. Water Resources Research, 30(6), 1665–1679.

Yearsley, J. (2012). A grid-based approach for simulating stream temperature. *Water Resources Research*, *48*(3), W03506. https://doi.org/10.1029/2011WR011515

Yearsley, J. R. (2009). A semi-Lagrangian water temperature model for advection-dominated river systems. *Water Resources Research*, *45*(12). https://doi.org/10.1029/2008WR007629

Relevant Publications

Cao, Q., Sun, N., Yearsley, J., Nijssen, B., & Lettenmaier, D. P. (2016). Climate and land cover effects on the temperature of Puget Sound streams. *Hydrological Processes*, *2304*(March), 2286–2304. https://doi.org/10.1002/hyp.10784

Leopold, L. B., & Maddock, T. (1953). *The hydraulic geometry of channels and some physiographic implications*. Washington, D.C.

Mohseni, O., Stefan, H. G., & Erickson, T. R. (1998). A nonlinear regression model for weekly stream temperatures. *Water Resources Research*, *34*(10), 2685–2692. https://doi.org/10.1029/98WR01877