Simulation of hourly stream temperature at a regional scale: Case of the Loire basin (France)

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Context and issues

- Sensitive to natural environmental factors and human impacts
- No information about river water temperature variations at regional scale
- No physically based modelling applied at a regional scale (> $10^5$ km²)

Atmospheric conditions
- Solar radiation
- Air temperature
- Wind speed / humidity
- Precipitation (rain / snow)
- Evaporation / Condensation
- Phase change (melting...)

Topography
- Riparian vegetation
- Upland shading
- Geology (bedrock)
- Aspect (Stream Orientation)
- Latitude / altitude

Streambed
- Groundwater input
- Conduction (sediment)
- Hyporheic exchange

Stream discharge
- Friction (streambed)
- Volume of water
- Slope / water falls
- Turbulence
- Inflow / outflow

Caissie, 2006 modified
Context and issues

- Presence of riparian vegetation can decrease diurnal variability, mean and maximum stream temperatures
- Potential of riparian vegetation cover to mitigate against climate change impacts
- Many studies relied on calibration to estimate shading from riparian vegetation because of the lack of information at regional scale (> $10^5$ km²)
Objectives

- Development and testing of a physically based model to simulate stream temperature at a regional scale ($10^5$ km$^2$)

- Test and compare two methods to estimate the shading factor into a thermal model
  - Constant shading factor
  - Variable shading factor
Study area: the Loire basin 117 000 km²

Lithology

- Alluviums
- Mag. and Meta. rocks (acid)
- Mag. and Meta. rocks (basic)
- Schists
- Limestones
- Chalk
- Marls
- Claystone
- Sandstone

Meteorology

Air temperature (°C) (1985-2012)
- < 8°C
- 8 – 9.5
- 9.5 – 10.5
- 10.5 – 11.5
- 11.5 – 12.5

Hydrology

Specific discharge (mm/an) (1985-2012)
- < 150
- 150 – 250
- 250 – 350
- 350 – 600
- > 600

Principal network

Riparian vegetation

(Remote sensing - buffer 10 m)

- < 25%
- > 75%

Lithology:
- Schists
- Granites
- Sedimentary Rocks
- Basalts

Hydrology:
- 260 mm/an
- 200 mm/an
- 360 mm/an

Environment:
- 11.2°C
- 11.5°C
- 10.2°C

Alluviums
Mag. and Meta. rocks (acid)
Mag. and Meta. rocks (basic)
Schists
Limestones
Chalk
Marls
Claystone
Sandstone

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Inputs data of the T-NET model

**Meteorological forcing**

- Mesh SAFRAN 8 km x 8 km
- Air temperature [°C]
- Specific humidity [kg.kg⁻¹]
- Wind velocity [m.s⁻¹]
- Global radiation [W.m⁻²]
- Atmospheric radiation [W.m⁻²]

**Hydrological forcing**

- Simulated at 368 subwatershed outlet
- Discharge [m³.s⁻¹]
- Groundwater flow [m³.s⁻¹]
- Groundwater temperature [°C]

**Geomorphological data**

- MNT - 25m et BD CARTHAGE®
- River length [m]
- River slope [m.m⁻¹]
- Riparian vegetation [%]

- Pondered by reach
- Defined by reach

Meteorological variables
- V1
- V2
- V3

Geographical data
- SubWatershed (SW)
- Outlet SW
Principle of the T-NET model

- Hourly temperature simulated by reach

1. Net solar radiation
2. Atmospheric radiation
3. Convection
4. Evaporation
5. Long wave emitted radiation
6. Groundwater inputs

1 - Upstream-downstream temperature propagation

\[ T_{DN} = T_e(x) + [T_{UN} - T_e(x)].\exp\left[\frac{-B.K_e(x)}{\rho_w C_p_w Q} \Delta x\right] \]
Principle of the T-NET model

- Hourly temperature simulated by reach

- 52,200 reaches
- Reach length: 1.7 km

2- Mixing the thermal component of the two headstreams

\[
T_{UN\_3}(t) = T_{DN\_1} \times \left( \frac{Q_{DN\_1}(t)}{Q_{UN\_3}(t)} \right) + T_{DN\_2} \times \left( \frac{Q_{DN\_2}(t)}{Q_{UN\_3}(t)} \right)
\]
The vegetation cover was weighted linearly by a coefficient linked to the Strahler order to account for the influence of river width on shading area.

\[
H_{ns} = (1 - Alb) \times Rg \times (1 - SF)
\]

- \( Rg \): Global radiation [W/m²]
- \( Alb \): Albedo = 3% (Beaufort et al., 2015)

<table>
<thead>
<tr>
<th>Strahler order</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
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</thead>
<tbody>
<tr>
<td>Weighting coefficient</td>
<td>1</td>
<td>0.8</td>
<td>0.7</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
<td>0.2</td>
<td>0</td>
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</tbody>
</table>
Validation data

Annual period 2008-2012 (RNT)

• 128 Stations
• Hourly monitoring between 2008 and 2012
• Median drainage area = 300 km²
• 70% between 50 and 2 000 km²
Good performance for large and small rivers

Drainage area = 20 000 km²
Shading factor = 20%

Drainage area = 100 km²
Shading factor = 95%

Results: Performances with a constant shading

Tw observed
Tw sim RMSE = 0.8°C

Tw observed
Tw sim RMSE = 1.2°C
Results: Performances with a constant shading

Daily simulation

- Median RMSE = 1.6°C; 80% of RMSE < 2°C; 80% of biases are between -1°C et 1°C

Hourly simulation

- Median RMSE = 1.9°C; 60% of RMSE < 2°C; 70% of biases are between -1°C et 1°C
Results: simulation of diurnal variations with SF = cst

- Diurnal variations are overestimated by the model
- Difference of diurnal variations \((T_{\text{sim}} - T_{\text{obs}})\) exceeds 2°C during summer
Variable riparian shading factor calculation (hourly)

- Depending on:
  - Sun position
  - Stream orientation
  - Height of canopy (He)
  - Vegetation cover
  - River width

Li et al., 2012
Performances are contrasted with a shading factor variable

RMSE (hourly Tw) are slightly decreased by 0.3°C on average with variable SF
Simulations of several stations are really improved with a variable shading factor.

Diurnal variations are better simulated.

**Summer 2009**

Drainage area: 500 km²

- **Variable shading**: RMSE = 0.3°C
- **Constant shading**: RMSE = 1.6°C
Results: simulation of diurnal variations

Simulations of diurnal variations are really improved with a variable shading factor especially during summer and for rivers close to the headwater.
Conclusion

- Main key points
  - T-NET model with **constant shading factor** performs well at regional scale (Daily Tw)
    - 80% of biases are between -1°C et 1°C
    - Median RMSE of 1.6°C
    - Diurnal temperature variations are overestimated in summer
  - T-NET model with **variable shading factor** leads to improve performance (Hourly Tw)
    - Improves diurnal temperature variations in summer especially on small and medium rivers

- Perspectives
  - **Refined input data not easily available at a regional scale**
    - Left bank/Right bank
    - Identify deciduous and Coniferous trees
    - Canopy height
    - River width
Many thanks for your attention
Shading factor (SF)

- Rg: Global radiation [W/m²]
- Albedo = 3% (Beaufort et al., 2015)

Very determinant on the water temperature variability

\[ H_{ns} = (1 - Alb) \times Rg \times (1 - SF) \]