What is light pollution?

Inappropriate lighting:
1) too much light
2) too much time
3) not at the right place
4) too white (too much blue)

Typical illuminance

<table>
<thead>
<tr>
<th>Source</th>
<th>Illuminance (lux)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct sunlight</td>
<td>100000</td>
</tr>
<tr>
<td>Overcast day</td>
<td>100</td>
</tr>
<tr>
<td>Living room</td>
<td>50</td>
</tr>
<tr>
<td>Fall room</td>
<td>5</td>
</tr>
<tr>
<td>Big city clear night</td>
<td>1</td>
</tr>
<tr>
<td>Nature clear night</td>
<td>0.001</td>
</tr>
</tbody>
</table>

Important variables involved:
1) installed luminosity
2) ground reflectance
3) color of light (scattering)
4) topography and obstacles

Some related issues

- Human health: more road accidents, higher incidence of breast cancer, stress, productivity reduction, etc.
- Wildlife: interference with bird migration, nesting, etc.
- Security: more crime, etc.
- Environment: higher energy consumption, more use of raw materials, etc.

Our Light Pollution Model

Model name: ILLUMINA

Summary:
- A statistical selection of ray tracing calculations involving 1st and 2nd order of scattering and ground reflectance
- ILLUMINA account for:
  - Heterogeneity of:
    - installed luminosity
    - lamp angular photometry
    - lamp height
    - lamp spectrum
  - ground spectral reflectance (Lambertian)
  - Topography
    - Scattering (1st and 2nd order) by molecules and aerosols
      - Shadowing (resolved and subgrid obstacles)
    - Vertical atmospheric profile

Results for a big city: Montréal

Some observations:
- Zenith radiances for high turbidity show high spatial variability (more pronounced during winter) compared to smoother variability for low turbidity (fig. 1)
- Winter zenith radiances are 2-3x higher than summer (fig. 1)
- Zenith radiances are higher under low turbidity (figs 1 & 2)
- Important angular asymmetry at city center for high turbidity, quasi-symmetry at low turbidity (fig. 2, nine curves)

Modelling experiment

Montreal Canada

Modelling domain:
- 395x290 km @ 1 km

Topography data:
- SRTM

Installed luminosity data:
- derived from DMSP-OLS satellite

Calculations made for:
- Montréal (3M inhabitants) and Sherbrooke (150k inhabitants)
- at 0, 2, 4, 8, 16, 32 km from city center (in images above, green dots = city center and red dots are other sampling sites)
- for 11 zenith angles
- for 2 aerosol loadings (AOD=0.05 (low turbidity) and AOD=1 (high turbidity))
- Subgrid obstacles height and distance, respectively 9m and 13m

Results for a small city: Sherbrooke

Some observations:
- Zenith radiances for high turbidity show higher spatial variability during winter compared to smoother summer variability under low turbidity (fig. 3)
- Winter zenith radiances are 3-6x higher than summer (fig. 1)
- Zenith radiances are higher under low turbidity (figs 1 & 2)
- Important angular asymmetry at city center for high turbidity, quasi-symmetry at low turbidity (fig. 2, nine curves)

Discussion

Zenith radiances for high turbidity show higher spatial variability during winter compared to smoother summer variability under low turbidity (fig. 3)

Winter zenith radiances are 3-6x higher than summer (fig. 1)

Zenith radiances are higher under low turbidity (figs 1 & 2)

Important angular asymmetry at city center for high turbidity, quasi-symmetry at low turbidity (fig. 2, nine curves)

Results by the fact that average snow cover is higher in small cities compared to big cities. Since the snow cover has a higher reflectance than other surfaces, a higher snow cover generate more uplight and then higher sky radiances. This is not the case at low turbidity since an important part of the radiance is coming from remote sites.

Another interesting result is that under high turbidity, sky radiances are clearly lower even if there are more parallaxes to scatter the light. Our study explain this result by an increase of extinction with distance. Fig 5 show that radiance is more strongly correlated to locally installed luminosity under high turbidity.

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Fig. 4 is very interesting as it can be seen as a high level decision tool to help local authorities to constrain light pollution by identifying the most contributing sites. Similar maps can be produced for any other observer position and viewing angle.

Another result of our study is the major impact of snow cover on sky radiances. This explain the apparent angular dependence of ground radiances. For an observer located in Montréal city center, positive angles are oriented toward St-Lawrence river so that under high turbidity, radiances are mostly coming from the opposite side of the river. This is not the case at low turbidity since an important part of the radiances is coming from remote sites.

Acknowledgements and contact

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ILLUMINA model

Fig. 1: Zenith radiances as a function of distance from city center

Fig. 2: Radiance vs zenith angle @ (a) low & (b) high turbidity

Fig. 3: same as fig 1

Fig. 4: Origin of Sherbrooke city center zenith radiances in winter. Blue Scatters is low turbidity and Blue is high turbidity

Fig. 5: Correlation between local installed luminosity and sky radiances