Mechanisms of air pollution transport in urban valleys as a result of the interplay between the temperature inversion and the urban heat island effect

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1. Overview

In urban valleys, the venting of pollutants is limited by the topography and can be further restricted by local meteorological phenomena such as low-level temperature inversions, urban heat island-induced circulations or closed slope-flow circulations, and different mechanisms of recirculation or stagnation of air pollutants.

All these together and the high emission of pollutants from urban areas, illustrates some of the problems involved in the dynamics of the atmospheric boundary layer and the associated mechanisms of air pollution transport in urban valleys.

Here we show that different mechanisms of air pollution transport may arise in urban valleys as a result of the interplay between the temperature inversion, the slope flows, and a urban heat island (UHI).

Three types of air pollution transport mechanisms were identified through idealized simulations performed with the EULAG model (Prusa et al., 2008).

The persistence of these types of mechanisms could cause severe air pollution episodes in urban valleys.

2. Model experiments

Three different aspects were considered

- Expansion of an urban area: 0%-100%
- Topographic shading: Two urban valleys that are the same but for their geographic orientation
- Valley width: Two urban valleys that are the same but for their width

References

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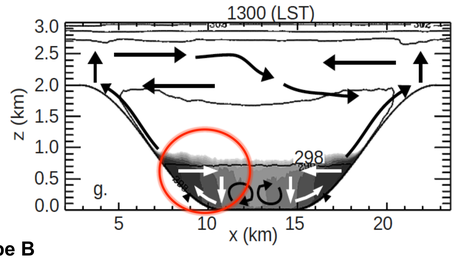
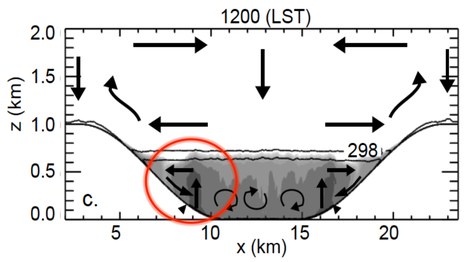
3. Results

Three mechanisms were identified

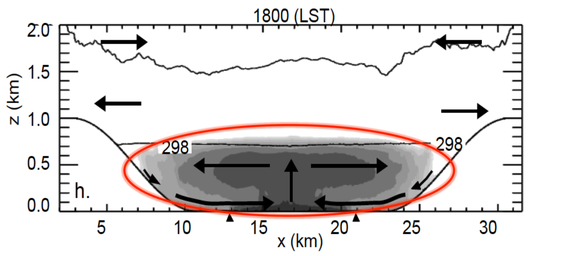
Type A
Transport by a closed slope flow circulation characterized by the occurrence of upslope winds. The upslope winds are deviated toward the center of the valley by the inversion layer.



Type B
Transport by a closed slope flow circulation characterized by the occurrence of downslope winds. UHI forces downslope winds linked to ascending flows that are restricted by the inversion layer.



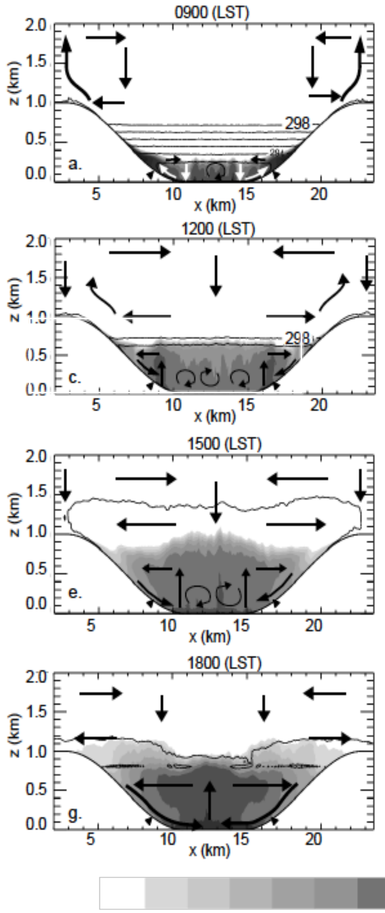
Type C
Transport by a low-level UHI-induced circulation that tends to concentrate pollutants in the valley center and may cause the development of elevated polluted areas.



Potentially severe air pollution problems

The largest concentrations of pollutants are closely related to the presence of the three mechanisms of air pollution transport.

Daytime evolution of the transport mechanisms



Type A

Smog traps over the sidewalls (types A and B).

Type B

Transition

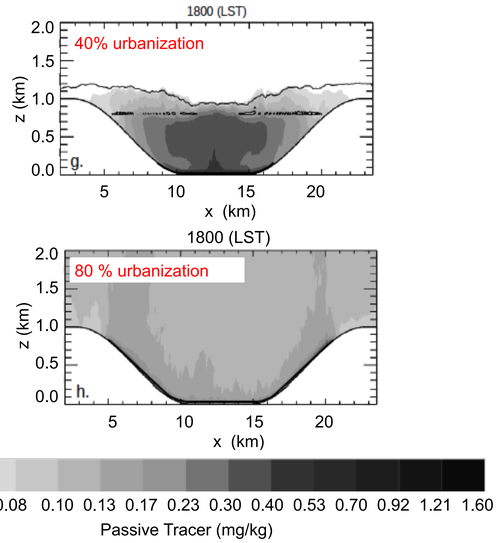
Transition between different mechanisms of air pollution transport

Type C

UHI-induced circulation that concentrates pollutants in the center of the valley and forms an elevated polluted layer (type C).

Effect of urbanization

- More urban land does not necessarily implies worse air quality during the whole day or everywhere within the valley.
- Reducing surface heating may not improve the air quality because of the capping effect of the temperature inversion. This is in contrast with the results of Taha et al. (2010).



4. Conclusions

- The presence of an urban area in a mountain valley substantially modifies the dynamics of the atmospheric boundary layer and the air pollution transport, as compared to rural valleys.
- The interplay between the temperature inversion and the UHI may cause different mechanisms of air pollution transport in an urban valley. The persistence of these types of mechanisms (e.g. smog traps) could cause severe air pollution episodes.
- In urban valleys, the width of the valley affects the lifetime and evolution of low-level temperature inversions mainly because of its influence on the heating of the atmosphere confined within the valley, as well as its effects on the structure of the flow field that develops below the inversion layer.
- The spatial and temporal distribution of the pollutants in an urban valley do not necessarily obey the intuitive rule that more urban land implies worse air quality, even when considering that the amount of pollutants emitted grows with the size of the urban area.

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