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DESCRIPTION OF THE DRAINAGE FLOW MODEL KALM

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1. Introduction

Under certain meteorological conditions, so-called drainage flows can form at night over sloping terrain with cold air produced close to the ground flowing downhill. The thickness of such drainage flows is usually between 1 m and 50 m; in cold air lakes where the cold air accumulates, the thickness can grow up to more than 100 m. The typical flow velocity is in the order of 1 m/s to 3 m/s. See the following figure.

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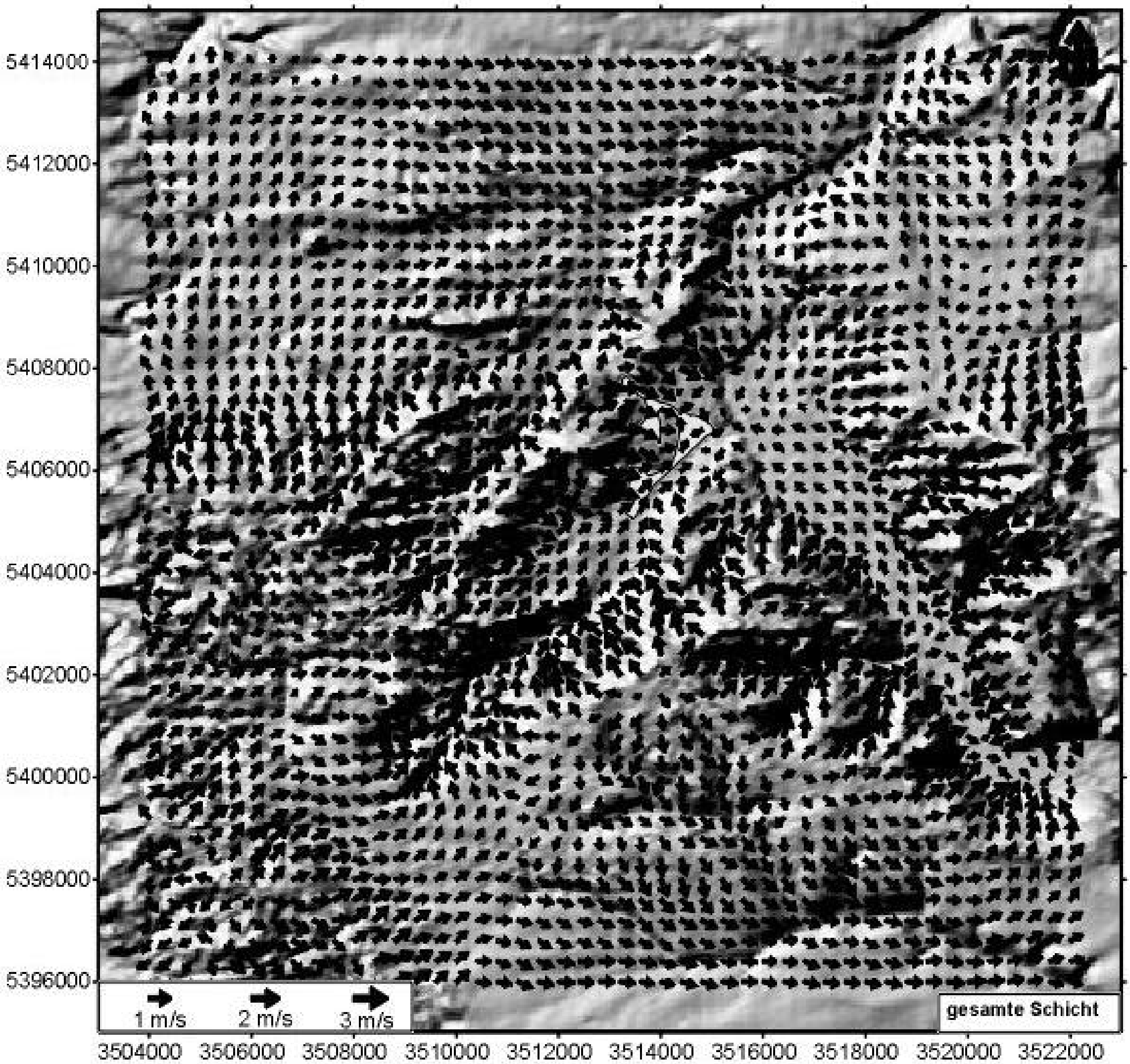

Abb. C.2: Mittlere Strömungsgeschwindigkeit im Gesamtgebiet, gesamte Kaltluftschicht

For drainage flows to form, the following two meteorological conditions must be fulfilled:

i) little cloudiness, so that the ground can become cold and cool the adjacent air layer

ii) low large-scale wind speeds, so that the tendency of the cold air to flow downhill can win over the large-scale wind.

The cold air production rate depends strongly on the land use. Open fields have the highest productivity (about 10 $m^3/(m^2h)$), whereas the data for forests vary; the German Weather Service gives a value of 1 $m^3/(m^2h)$. Built-up areas do not produce cold air, they rather destroy it (c.f. urban heat island).

Under environmental aspects, drainage flows have a twofold importance: on the one hand, cold air can ventilate and cool overheated built-up areas, on the other hand, cold air coming from clean air regions can ventilate polluted areas. However, if cold air meets pollutant sources (vehicle exhaust fumes, odours etc.) on its way, it can transport those pollutants and become a problem. For regional planning it is therefore very important to be able to locate and quantify possible drainage flows. For this purpose, the model described below has been developed.

2. Model description

The model was develloped by Ingenieurbüro Dr.-Ing. Achim Lohmeyer. It uses the so-called shallow-water equations, a simplified (vertically integrated) form of the basic equations of fluid mechanics. This simplification makes it possible to run the model efficiently on personal computers.

The name "shallow-water equations" is a common technical term; however, the equations can be used to describe the motion of any fluid which is more dense than its surroundings, like water or cold air. Such a flow has the following characteristic properties:

- flow over inclined terrain according to the terrain slope
- moving of the "cold air front" also over flat terrain
- filling of basins (cold air lakes)
- influence of the layer thickness on the flow velocity and the flow direction via pressure gradients.

The motion is set up by negative buoyancy; the shallow water equations take account of the following influences on the flow:

- modification of the local flow conditions by the flow conditions in the surroundings (advection)
- land use-dependent friction between the surface and the air (open countryside: low friction, built-up areas: high friction)
- speeding up or slowing down of the flow by variations in terrain height and/or cold air layer thickness
- cold air production dependent on land use.

The equations are solved by finite differences (Arakawa-C grid) with number of nodes and mesh size prescribed by the user; data on topography and land use must be provided at every node. To take larger scale influences like river valleys into account and simultaneously have a high resolution in the area of primary interest, the model can be run in a nested mode.

If no cold air lakes form, the model attains a steady state after approximately 1 hour. In general, it is reasonable to simulate a period of 3 to 6 hours corresponding in the model time scale to a whole night. Such a calculation takes the model less than 5 minutes on 486 PC, when 40 by 40 grid points are used.

3. Input data and results

The optimal situation for drainage flows described in section 1, i.e. a calm and clear night, is assumed. The model calculates the temporal evolution of the drainage flow, starting from a situation of no motion and assuming cold air production rates constant in time. These, as well as the friction coefficients, depend on the local land use. Presently, 5 land use classes are defined: densely built-up areas, loosely built-up areas, forests, fields, and water surfaces. The pertinent production rates, friction coefficients and zero height displacements built into the model can be changed by the user if he desires to do so. Furthermore the model needs a digitised topography. The size of the model domain is arbitrary (in general about 10 km by 10 km).

The model calculates the thickness of the cold air layer and the two horizontal velocity components, averaged over the thickness of the layer. The drainage flow volume flux is then computed from these data.

Different kinds of post processing the results are available, like graphical presentation of the calculated fields, fluxes through selected slices, visualisation of the flow by forward and backward trajectories and output of time series at selected points.

By coupling the wind fields calculated by KALM with Eulerian or Lagrangian dispersion models, pollutant dispersion within drainage flows can be computed and built into immission statistics, for example.

An example for the application of KALM can be found on the CD Stuttgart, see http://www.stadtklima.de/stuttgart/websk21/cd_s21.htm. For further information please contact Achim.Lohmeyer@Lohmeyer.de.

4 Literature

Schädler, G., Lohmeyer, A. (1994): Simulation of nocturnal drainage flows on personal computers. In: Meteorol. Zeitschrift, N.F. 3 167-171.