Large-scale Effects of Alpine Land Use Changes on the Atmospheric Water Cycle

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Abstract

Results of the European project "ECOMONT" (Ecological Effects of Land Use Changes on European Terrestrial Mountain Ecosystems) are presented. To investigate the influence of land use changes on a large scale, the experiences from field campaigns were incorporated into a model of the atmospheric water vapour cycle (WVC). Satellite data were combined with data from numerical weather prediction models to drive the WVC model. The WVC model takes care of non-uniform terrain by considering local advection from non-homogeneous source distributions. The WVC model is used for scaling up the experimental results from a local Alpine site to regional scale.

1. INTRODUCTION

The European project "ECOMONT" (Ecological Effects of Land Use Changes on European Terrestrial Mountain Ecosystems) deals with investigating land-use changes in Alpine areas. One of the basic aims of ECOMONT is the understanding of the influence of land-use changes on the exchange processes between the ecosystems and the lower layers of the atmosphere. Ecosystem gas exchanges and hydrology are sensitive and critical factors for characterizing landscape functions in Alpine areas. The concentration of water vapour and CO2 in the atmosphere over an ecosystem is a product of the activity of the ecosystem and the amount of advected H2O and CO2. The functioning of ecosystems is controlled largely by this advection term and the exchange processes between the atmosphere and the vegetation. Since advection and exchange processes depends strongly on the very complex and heterogeneous atmospheric turbulence, the numerical description of these processes is indispensable for the understanding of the interaction between the local ecosystem and the surrounding landscape.

Because of the extended size of the atmosphere, experimental investigations are never sufficient to reveal a complete picture of the atmospheric behaviour. Each of the instruments used in a field experiment focuses on a certain aspect, limited in space and time by its measurement principle. The first benefit of meteorological modelling lies in an extended support for interpreting atmospheric data. In that sense, modelling is a diagnostic tool. The diagnosis is not only an interpolation, but a mathematical formulation of all the competitive processes involved in the complex behaviour of the atmosphere.

A further benefit of meteorological models is its ability to extrapolate spatially restricted data to a larger area. Models are the first-rate tool for scaling up from experimental scale to landscape or regional scale. For the upscaling procedure, the driving variables of the models have to be parameterized based on data which are known over the large scale area. In context of meteorology, hydrology and landuse data there are two major tools with may serve as a basis for this parameterization. The first tool is the interpretation of satellite data with its very high resolution in space, but a poor resolution in time. These data are available from a varity of satellites and give information about radiation properties of the land surface and of the atmosphere. The second tool is a numerical weather prediction (NWP) model. Such models are running daily on a routine basis and are a complete integration of all atmospheric data available from weather stations around the world. The strenth of NWP models is its high temporal resolution of one hour values. On the other hand, the spacial resolution is rather poor. The combination of both tools has an ideal synergistic effect with respect to temporal and spacial resolution. An example is shown below.

2. THE WVC MODEL APPROACH

As pointed out in the introduction, the scaling up procedure has to take care of the large scale influence of atmospheric water vapour and CO2 advected from aloft and the subsequent interaction between different ecosystems. Ecosystems on a larger scale are all linked via atmospheric advection.

Ecosystems also are influenced by the large weather pattern. To demonstrate this complex interaction, the water vapour content of the atmosphere around Monte Bondone close to Trento, Italy, for June 18 1997 is modelled with a trajectory based water vapour cycle (WVC) model. The model area is shown in Fig. 1.

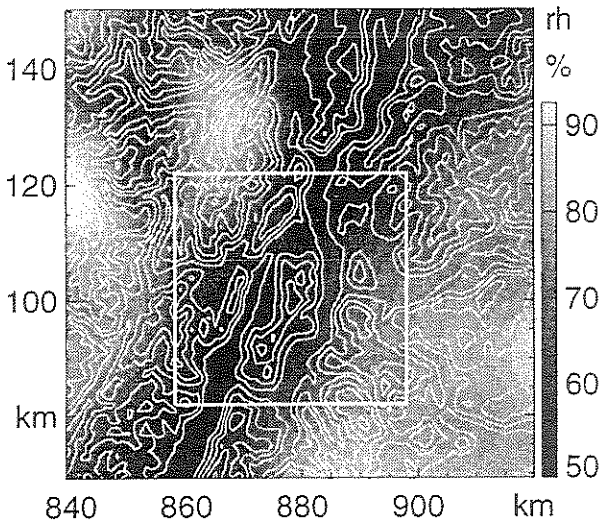

Figure 1: The model area around Monte Bondone, Italy. Topographical elevation contours are shown every 400 m. Relative humidity in percent, from NWP model, is shown as shadows correpsonding to the vertical bar. The white rectangle marks the area with the modelled water vapour.

The trajectories are interpolated from the 4-dimensional information of a high resolution weather prediction model "SM" (Swiss model). This model is operated by the Swiss Meteorological Institute (Schubiger and de Morsier, 1992). The SM was developed in collaboration with the Weather Service in Germany. The SM is driven by the operational "Europa Model" (Majewski, 1991) and by a topographical dataset according to the resolution of 15 km. The SM has a horizontal resolution of 15 km, and a vertical resolution of 20 layers up to a height of 25 km. The layers follow the topography and their vertical spacing is not linear with height: the spacing begins with 10 m close to the ground and increases to 700 m in 3 km above ground. The SM covers an area approximately from 11 deg West to 20 deg East and from 44 to 56 deg North. The SM run starts routinely at 00:00 and 12:00 every day and runs for 36 hours, producing hourly output fields of wind, temperature, humidity, pressure and a variety of other meteorological and turbulent variables. From this output, the four dimensions (3 spacial and 1 temporal dimension) of the 3-dimensional wind (north, west and vertical wind component) and the relative humidity are extracted. The humidity at 12:00 on June 18, 1997, is shown as shadows in Fig. 1., over an area of 80 by 80 km around Trento.

The aera of the model (858 to 898 km East and 82 to 122 km North) is marked as a white rectangle. The shadow intensity corresponds to the relative humidity values in percent, given in the vertical bar. The topography is overlayed over the whole area. It is obvious, that the Northern part of the Trentino valley is considerably dryer than the Southern part and the surrounding ridges. The poor spatial resolution of 15 km gives a rather smooth picture of the general situation.

The trajectories of air parcels moving over Europe are interpolated from the 4-dimensional SM-fields of the 3 wind components. The trajectories where calculated to end at the points of a regular grid of an area of 40 by 40 km around Trento (from 858 to 898 km East and from 82 to 122 km North). Monte Bondone lies on 878 km East and 102 km North with respect to the Swiss kilometer grid, corresponding to 11.0305 deg Eastern longitude and 46.0135 deg Northern latitude. The resolution of the grid is 1 km. Thus, 1600 trajectories were calculated. Six of them are plotted in Fig. 2. As usual in the Alpine region, the wind was very heterogenious. The trajectories show a strong convergence of air masses in the area around Monte Bondone. The Northwestern part of the area is mainly influenced from the West, while the Northern border shows air masses coming from the North. In a large part of the aera, from the Southwestern border to the Southeast, the air is coming from the East. The air at the Eastern border also enters from the East but is first driven towards the Alps and then joins the air masses coming from the North.

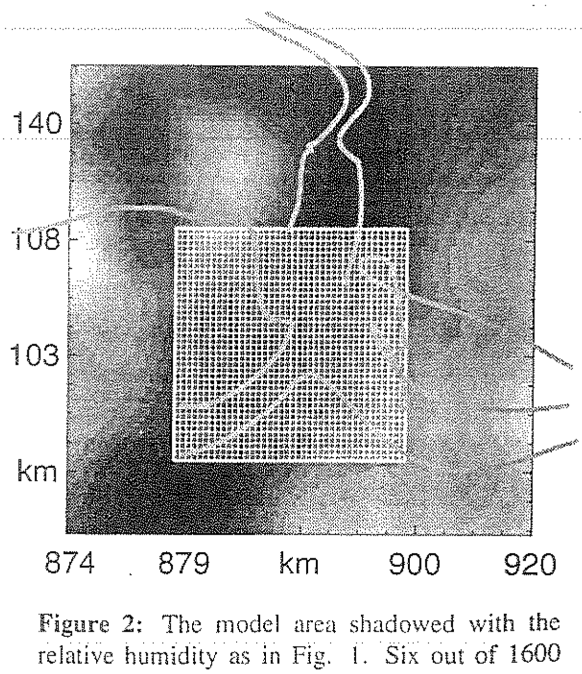

Figure 2: The model area shadowed with the relative humidity as in Fig. 1. Six out of 1600 trajectories from NWP model are shown. The white rectangle marks the area with the modelled water vapour and the model grid.

The spatial resolution of 15 km grid size is very high for weather prediction models, but by far too low for the obviously locally induced patterns of water vapour emissions from the vegetation. As input with an adequate spatial resolution, the "ETC/LC's CORINE Land Cover 250 m grid production database" was made available by the European Topic Centre on Land Cover (ETC/LC). This CORINE database covers Europe with a resolution of 250 m and for most places with 29 different landuse categories. These categories are based on satellite data in combination with locally evaluated data. The evapotranspiration is taken from literature values for each vegetation type among these categories. Non-vegetation landuses, such as buildings and roads, are suggested to have no emissions.

The model then predicts the water vapour at the end-point of each trajectory in the following way: While moving over Europe, the modelled air parcel picks up the local evapotranspiration and exchanges with the upper atmospheric layer. This process is repeated for every point along the trajectory at a distance corresponding to one minute travel time. Thus, the modelled air parcel interacts with its surroundings every minute in a three-fold way: first, part of the air mass is exchanged with the local air close to the ground with a relative humidity corresponding to the local evapotranspiration. Second, an other part of the air mass of the parcel is exchanged with the upper atmospheric relative humidity taken from the general weather induced humidity given by the SM. Third, the air parcel keeps "in mind" its own history by simply not changing part of its volume at the particular time step.

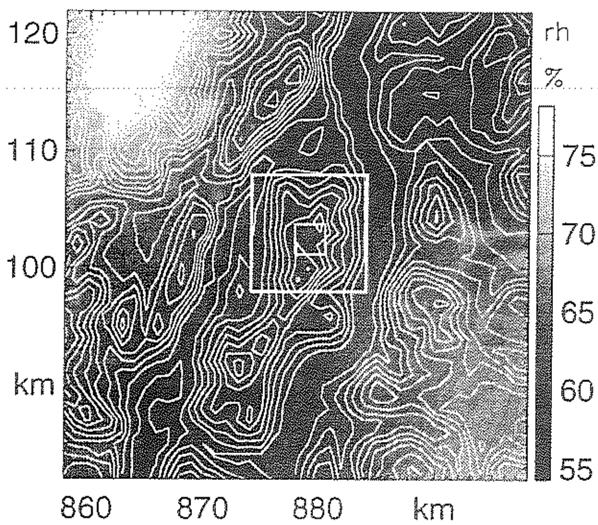

Figure 3: The model area shadowed with the modelled relative humidity according to the vertical bar. Topographical elevation contours are shown every 200 m. The white rectangle marks the area of Fig. 4. and 5.

The information at the end of the travel time of each trajectory is inserted into the gird of Fig. 2. (from 858 to 898 km East and from 82 to 122 km North). The result of the modelled relative humidity is shown in Fig. 3. The high increase in spatial resolution in Fig. 3. is clearly visible. Especially around Monte Bondone in the center of the picture the local topographically induced heterogeneity is obvious.

A detail of the modelled water vapour over the aera 874 to 884 km East and 98 to 108 km North is shown in Fig. 4.

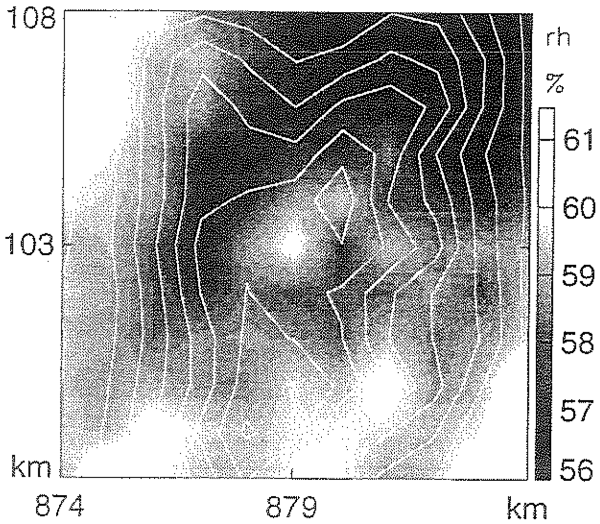

Figure 4: Detail of the model area (insert to Fig. 3) with modelled water vapour as shadows. Topographical elevations are plotted every 200 m.

As a verification, the aircraft humidity measurements are inserted in the modelled water vapour over the same area in Fig. 5. The aircraft measurements give additional details, which are analysed in a budget modelling approach for the local atmosphere by Graber et al. (1998). The agreement of the aircraft measurements with the WVC model approach is encouraging.

3. CONCLUSIONS

Scaling arguments show that the advected changes are of the same importance as local changes, and that under convective conditions the vertical processes evolve in the same time scale as the horizontal processes under consideration.

The first approach with a diagnostic WVC model revealed a good agreement of the water vapour pattern on Monte Bondone with the observed data from aircraft. The modelling effort will be extended to include the turbulent thermodynamic processes in the vertical exchange with a Penman-Monteith (Monteith, 1975) approach. Furtheron, the wind field calculation will be extended to give higher resolution down to 250m, corresponding to the satellite database available. The windfield model will be driven by the output from the SM and by a high resolved topographical dataset.

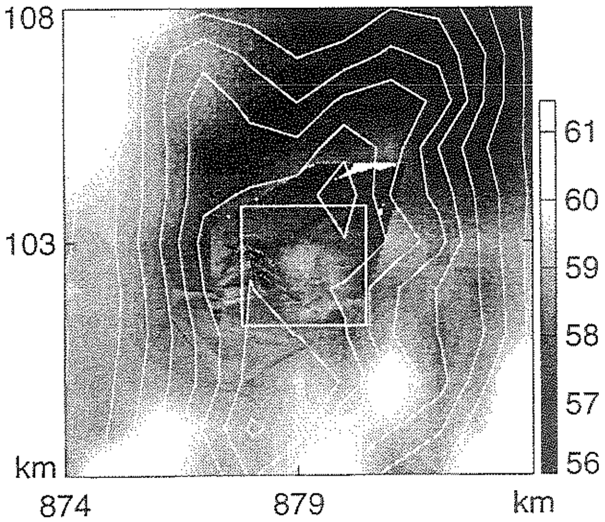

Figure 5: Same as Fig. 4. but with inserted water vapour from aircraft measurements.

The combination of satellite data with data from a numerical weather prediction (NWP) model has proven to meet the requirements for the scaling up procedure. The local investigations on the experimental sites of ECOMONT in the Alps will be used to calibrate satellite and NWP data to estimate the driving variables of the Penman-Monteith formula. Along with the high resolution wind field, the output of the trajectory model can be improved.

The water content of the atmosphere in mountainous terrain is controlled by a negative feedback: The evapotranspiration of the plants lead to cumuli clouds over the mountains and therefore reduce the insulation by forming shadow. It is well known that evaporation decreases significantly, when vegetation is abandoned. Consequently, the cumuli cloud formation will be reduced or stopped after land use change. This leads to a positive feedback, by an increases of radiation, followed by an increase of water loss, up to the complete drying out of vegetation and soil.

In future the WVC model will be used to calculate scenarios. Only models allow the manipulation of landuse changes over large areas. The main question is the influence of landuse changes on a large scale. To what extent is the decrease of evapotranspiration from abandoned vegetation relevant on the regional level? What would be the influence, if large parts of the Alpine meadows will be abandoned? The answers to these questions include a major socio-economic impact. Consequently, the WVC model described above can be addressed as a decision making tool.

ACKNOWLEDGEMENTS

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