On the influence of the geostrophic wind direction on the atmospheric response to landuse changes

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Summary:

Simulations alternatively assuming a landscape with and without urbanization plus open-cast mining were performed with a non-hydrostatic model. It is examined whether the atmospheric response to landuse changes is sensitive to the direction of the geostrophic wind. The results of simulations with the same geostrophic wind direction show that except for the cloud and precipitating particles the daily domain-averages of the variables of state hardly differ for the different landscapes. Nevertheless, the local weather may be affected appreciably over and downwind of the altered surfaces. The significant differences in the cloud and precipitating particles, however, are not bound to the environs of the landuse changes. Generally, the most significant differences occur for the cloud and precipitation particles, the soil wetness factors and the vertical component of the wind vector. The latter changes strongly influence the cloud and precipitation formation by the interaction cloud microphysics-dynamics. The results also indicate that for most of the quantities the local magnitude of the atmospheric response changes for the various directions of the geostrophic wind. However, the differences of the domain-averaged 24h-accumulated evapotranspiration are similar for all geostrophic wind directions.

Zusammenfassung:

Um zu untersuchen, ob die atmosphärische Antwort auf Landnutzungsänderungen sensitiv zur Richtung des geostrophischen Windes ist, wurden Simulationen durchgeführt, bei denen alternativ eine Landschaft mit und ohne Urbanisierung plus Tagebauten angenommen wurde. Die Simulationsergebnisse zeigen, daß - außer für Wolken- und Niederschlagspartikel - die täglichen Gebietsmittelwerte der Zustandsvariablen sich kaum für die beiden Landschaften unterscheiden. Trotzdem kann das lokale Wetter merklich über und im Lee der Oberflächen mit veränderter Landnutzung beeinflußt werden. Die signifikanten Differenzen in den Wolken- und Niederschlagspartikeln sind jedoch nicht an die unmittelbare Nähe der Landnutzungsänderungen gebunden. Generell treten die signifikanten Unterschiede bei den Wolken- und Niederschlagspartikeln, der Bodenfeuchte und der Vertikalkomponente des Windvektors auf. Letztere beeinflussen stark die Wolken- und Niederschlagsbildung durch die Wechselwirkung Wolkenmikrophysik-Dynamik. Die Ergebnisse zeigen außerdem, daß lokal der Grad der atmosphärischen Reaktion für die meisten Größen bei unterschiedlicher Richtung des geostrophischen Windes anders ausfällt. Die Differenzen der Gebietsmittelwerte der 24h-akkumulierten Evapotranspiration gleichen sich jedoch für alle Richtungen des geostrophischen Windes.

1. Introduction

Since human began to grow crop and to build settlements, the land cover was modified. Different landuse types and slopes yield different fluxes of momentum, moisture and heat due to variations in water availability, surface temperature, plant and soil parameters (e.g., Avissar and Pielke, 1989). These differences also affect evapotranspiration, cloud and precipitation formation (e.g., Anthes, 1984; Chen and Avissar, 1994) as well as runoff by complicate non-linear feedback mechanisms. Recent studies investigated the effect of anthropogenic or natural landuse changes on the local (e.g., Groß, 1988; 1989), regional (e.g., Anthes, 1984; Charney, 1975; Savenije, 1995; Xue, 1996), continental wide (Copeland et al., 1996) or global climate (e.g., Dickinson, 1992; Zheng et al., 1996; Zhang et al., 1996; Sud et al., 1996). The most important aspects of different landuse types are (1) changes in the partitioning of energy into sensible and latent heat fluxes (e.g., Kerschgens and Drauschke, 1986; Cotton and Pielke, 1995), (2) the changes in the fraction of solar radiation reflected back to space (e.g., Cotton and Pielke, 1995), (3) changes in the structure of the atmospheric boundary layer (ABL; e.g., Pielke et al. 1990), and (4) changes in cloudiness and precipitation (e.g., Anthes, 1984; Changnon and Huff, 1986; Brubaker et al., 1993; Otterman et al., 1990). Hence, the landuse changes may affect the local atmospheric energy and water cycle under calm wind conditions. Under such conditions the cloud and precipitation formation is mainly forced by the underlying surface and the recycling of water within a region.

The previous studies of the effect of landuse changes on the local scale usually investigated the atmospheric response for the main direction of the near-surface wind because they were undertaken as planing studies (e.g., Gross, 1988; 1989). The global studies, however, examined the potential effect of landuse changes for longer time scales. Herein, of course, different directions of wind occur. Nevertheless, no evaluation was carried out whether the atmospheric response to the landuse changes is sensitive to the direction of the geostrophic wind. This question is addressed in this paper. In doing so, simulations are performed with the non-hydrostatic meso-β-scale meteorological model GESIMA (Kapitza and Eppel, 1992; Eppel et al., 1995) in its Leipzig's version. Four different directions of the geostrophic wind are assumed in a landscape with and without urbanization and open-cast mining.

2. Brief description of the model

The dynamical part of GESIMA is based on the anelastic equations (Kapitza and Eppel, 1992; Eppel et al., 1995). The prognostic equations are solved with a predictor/corrector scheme. Advection of momentum and potential temperature is determined with a MacCormack scheme modified for the applications to incompressible flow. The transport of passive quantities is formulated according to Smolarkiewicz (1984).

Tab. 1. Parameters (from Deardorff 1978, Eppel et al. 1995, Wilson et al. 1987) as used for the different landuse types. The letters k_s, c_i, ε, α, z_0, w_k, α_c, and g_l are the thermal conductivity of the soil, the heat capacity, the emissivity, the albedo, the roughness length, the field capacity, the capillarity, and the maximal evaporative conductivity, respectively. The quantities indicated by * are calculated by the model.

Landuse type	k_s	c_i	ε	α	z_0	w_k	α_c	g_l
	$10^{-6}m^2/s$	$10^6J/(m^3K)$			m	m	$10^{-3}kg/(m^3s)$	m/s
Water	0.15	4.2	0.94	*	*	1.0	1000	-.-
Open-cast mining	0.84	2.1	0.90	0.30	0.0004	0.002	0.9	-.-
Grassland	0.56	2.1	0.95	0.25	0.02	0.010	8.0	0.04
Agriculture	0.74	2.9	0.95	0.18	0.04	0.003	3.0	0.04
Deciduous forest	0.70	2.5	0.97	0.20	0.8	0.010	8.0	0.023
Mixed forest	0.70	2.5	0.975	0.175	0.9	0.010	8.0	0.023
Coniferous forest	0.70	2.5	0.98	0.15	1.0	0.010	8.0	0.023
Suburb/village	1.0	2.0	0.90	0.20	0.8	0.003	1.0	-.-
City	1.0	2.0	0.95	0.15	1.0	0.002	0.9	-.-

Cloud processes are considered by a parameterization of bulk-microphysics. It takes into account the condensation and deposition of water vapor, the rainwater formation by autoconversion, coalescence, and melting of both ice and graupel, the riming of ice and graupel by cloud water, the homogeneous freezing of cloud water and rainwater, the evaporation of cloud water and rainwater, the sublimation of ice and graupel, the sedimentation of rainwater, ice and graupel (Mölders et al., 1997). A simplified two-stream method calculates the radiative transfer (Eppel et al., 1995).

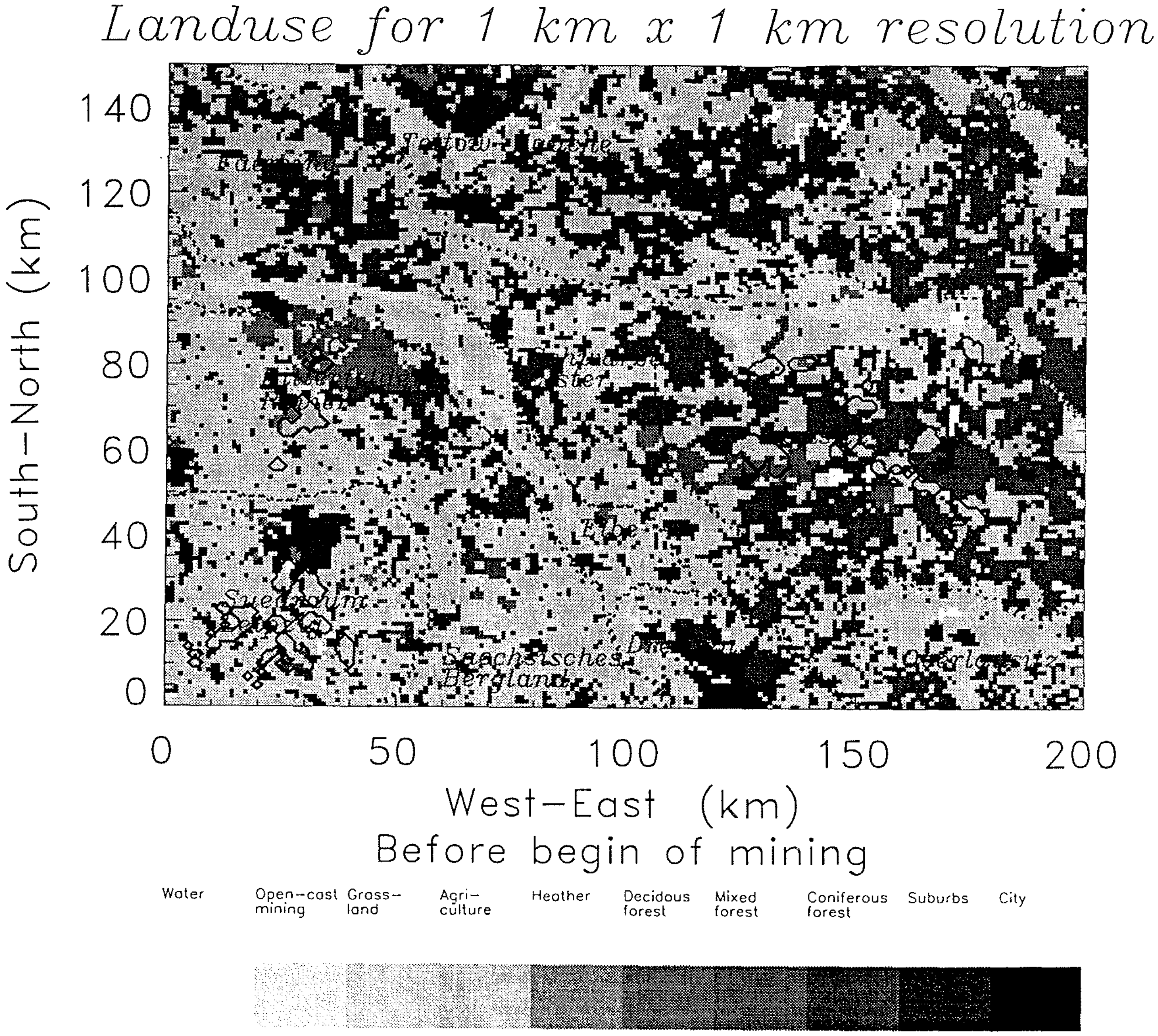

Fig. 1. Distribution of plant and soil characteristics according to Tab. 1 for REF. The thick contour lines indicate the *open-cast mining* in MINURB. The thin lines represent the boundaries of the districts discussed further in the text.

At the surface the calculation of the fluxes is based on a bulk-parameterization. Soil wetness is determined with a force-restore-method. The transpiration of plants is considered by a Jarvis-approach (1976). The soil heat flux and soil temperature are calculated by a diffusion equation (see also Eppel et al., 1995). The surface stress and the near-surface fluxes of heat and water vapor are expressed in terms of dimensionless drag and transfer coefficients with the parametric model of Kramm et al. (1995) that is based on the Monin-Obukhov similarity theory. Above the atmospheric surface layer a one-and-a-half-order closure scheme determines the turbulent fluxes of momentum.

The anthropogenic landuse changes are considered on a subgrid with a resolution of 1 x 1 km^2 using an explicit subgrid scheme (Seth et al., 1994; Mölders et al., 1996). This scheme determines the water and energy fluxes, soil wetness factor, soil and surface temperature on a finer grid resolution (1 x 1 km^2) than that used in the model (5 x 5 km^2). This modeling strategy means that in the domain-average the total change of land surface cover may be small, but when considering the local scale the landuse change is large.

The model encompasses the troposphere over southern Brandenburg and northern Saxonia (Fig. 1) from the surface to 10.5 km height. In the reference landscape, denoted as REF hereafter, the fractional coverage of *water*, *grassland*, *agriculture*, *deciduous forest*, *mixed forest*, *coniferous forest*, *suburbs/village*, and *city* amounts 266, 3238, 13677, 296, 959, 9121, 2305, and 138 km^2, respectively. In the landscape with open-cast mining and urbanization, called MINURB hereafter, these landuse types cover 260, 3191, 12857, 292, 973, 9074, 2798, and 138 km^2. In addition 417 km^2 of *open-cast mining* exist (Fig. 1). *Open-cast mining* occur in the Lausitz, in the Bitterfelder Revier, and the Südraum Leipzig. Since mining practice is to quarry on one side of the open-cast mining and to deposit the mining debris on the other side, only a small strip of coal (about 100 m width) is in contact to the atmosphere. Hence, the main part of an open-cast mining consists of tertiary and quatiary sands of different colors. Therefore, the soil characteristics of *sand* are taken for *open-cast mining* (Tab. 1). In the orographic data set of MINURB the average depth of each 1 x 1 km^2 area is applied as the terrain height of the open-cast mining.

The vertical resolution of the model varies from 20 m close to the ground to 1 km in 10 km height. Eight levels are located below 2 km and 8 above that height.

3. Initialization and design of the study

After describing the meteorological situations (section 4) the atmospheric response to the landuse changes will be separately investigated for four directions, namely, from 10°, 100°, 190° and 280°, respectively (section 5). In section 6 it will be examined whether the atmospheric response to the landuse changes is sensitive to the geostrophic wind direction. The notation of the simulation is that of the landscapes plus the direction of the geostrophic wind, i.e., REFxxx and MINURBxxx where xxx =10, 100, 190, and 280, respectively. Note that xxx will only be appended when the results of the simulations with the different geostrophic wind directions are discussed simultaneously.

Fractional differences, $\Delta = (\chi_i - \chi_j)/(\chi_i + \chi_j)$ of the predicted quantities, χ, are determined to obtain a measure how the sensitivity of the atmospheric response to the landuse changes varies with the direction of the geostrophic wind. Here, i and j represent REF and MINURB, respectively. This measure ranges from -1 to 1, with negative and positive values indicating larger values for MINURB and REF, respectively. If both simulations predict the same, Δ will be zero. A factor of 1.1 or 2 in agreement, for instance, results in a Δ of ±0.05 and ±0.33, respectively. Moreover, significance tests were performed for the pairs of the different landscapes but of the same wind directions.

In nature the rawins profiles would slightly differ in the ABL if they were measured over the different landscapes. Usually the synoptic conditions of different geostrophic wind directions are associated with different pressure, temperature and humidity regimes. Nevertheless, to avoid additional degrees of freedom and for comparability here all the simulations are initialized with the same profiles of humidity, air and soil temperature as well as the same speed of the geostrophic wind of 7.5 m/s. These profiles are adjusted to homogeneous terrain by a 1D-simulation of GESIMA. A surface pressure of 1003 hPa was assumed. In the radiation simulation the 122nd Julian day is applied. The soil wetness factors were set equal to 0.5. Throughout the entire simulation the water surface temperatures and the soil temperature in 1 m depth were hold constant at 285 K and 282.6 K, respectively. Analyzing Gerstengarbe's and Werner's (1993) weather regime data geostrophic winds around 100° (HNFA, SEZ, SA, TM, SEA), 190° (SWA, SWZ, TRM, HM), 280° (WA, NWA, BM) and 10° (NEA) existed in 9.4 %, 18.1%, 17.1 % and 2.4 % of the time from 1881 to 1992 in the domain of interest. Note that the local recycling of water is of minor importance when fronts pass the domain because then precipitation is mainly advected. Since the main focus is on the effect of the landuse changes on the local water cycle, the investigations are restricted to synoptic situations without frontal activities in the domain of interest.

4. The meteorological situations for the different directions of the geostrophic wind

4.1. Situation for a geostrophic wind from 10°

The surface temperatures are more sensitive to the cloud distribution than to that of landuse. The cities do not develop a worth mentioning heat island effect. At noon the near surface air temperatures increase from 8°C in the west to 11 °C in the eastern part of the model domain except for the area between Wittenberg and Leipzig, the Oberlausitz and the eastern Sächsisches Bergland. In the first mentioned area the temperatures exceed 10°C while in the latter two areas the temperatures are 1 °C cooler than in their surroundings. During the nighttime the temperatures vary among 5 °C in the Sächsisches Bergland and values higher than 7 °C along a line Leipzig-Torgau-Luckenwalde.

Evapotranspiration is slightly lower in areas of thick cloudiness than in the adjacent cloudfree areas of the same landuse type. Note that this is true in all the simulations. In xxx10 the distribution of evapotranspiration is more similar to that of the clouds than to that of the landuse types. During the daytime the humidity of the ABL is about 1 g/kg higher in the north of Leipzig, over the Fläming as well as north and over the Lausitz than in the other parts of the domain. In the nighttime the humidity exceeds 5.4 g/kg in the middle of the domain. It is less than 4.8 g/kg in the east and the west.

During the daytime cloud bands form along a line from the Fläming over Leipzig to the Sächsisches Bergland and in the eastern part of the model domain. Except for the orographically induced clouds over the Sächsisches Bergland the cloud fields form along convergence lines of the wind field. In their upper part they are strongly iced. During the nighttime two north-south-orientated partly iced cloud bands form which provide precipitation.

4.2. Situation for a geostrophic wind from 100°

In contrast to a geostrophic wind from 10° the distribution of surface temperatures is governed by the distribution of the prevailing landuse for a geostrophic wind from 100°. Since the heat capacities and the thermal conductivity of the soil assumed for *agriculture* and *settlements* exceed those of *grassland* or *forest*, the former areas heat more strongly than the latter. Hence, in the south-western part of the model domain slightly higher surface temperatures are achieved due to the larger fractional coverage by *settlements* and *agriculture* than in the north-eastern part. During the daytime, for instance, surface temperatures range from 14 °C in the immediate vicinity of *waters* and 34°C in Dresden and Leipzig.

In the diurnal course air temperatures vary between 4° and 15°C within the near surface layer. Here, low air temperatures occur in the Sächsisches Bergland, the Fläming and downwind of largely extended *grassland*. Over the cities of Dresden and Leipzig the air is slightly warmer during the nighttime than in their environs.

During the daytime the humidity of the near surface layer is strongly related to that of evapotranspiration and the prevailing landuse (about 4.4 g/kg for *agriculture* and *settlements*, more than 5 g/kg for *grassland*, and intermediate values for *forest*). The areas dominated by *forest* or *grassland* evapotranspirate more strongly than those dominated by *agriculture* or *settlements* because of the higher field capacity and capillarity of the former than of the latter. Therefore, more water is restored from the ground water, and, despite the stronger evapotranspiration, the soils of *forest* and *grassland* are moister than those of *agriculture*. During the nighttime humidity slightly depends on topography. High values occur in the upper ABL of areas with low terrain elevation.

At the top of the ABL relatively flat clouds form over the Lausitz, the Sächsisches Bergland and the Südraum Leipzig during the daytime. In the early evening and the nighttime cloudiness decreases within the domain (Fig. 2). Downwind of Leipzig great amounts of cloud and precipitating particles occur. Here, intense precipitation reached the ground in the early evening. Moreover, intense precipitation occurs over and downwind of Dessau. Precipitation bands exist in the northern Niederlausitz and the Oberlausitz.

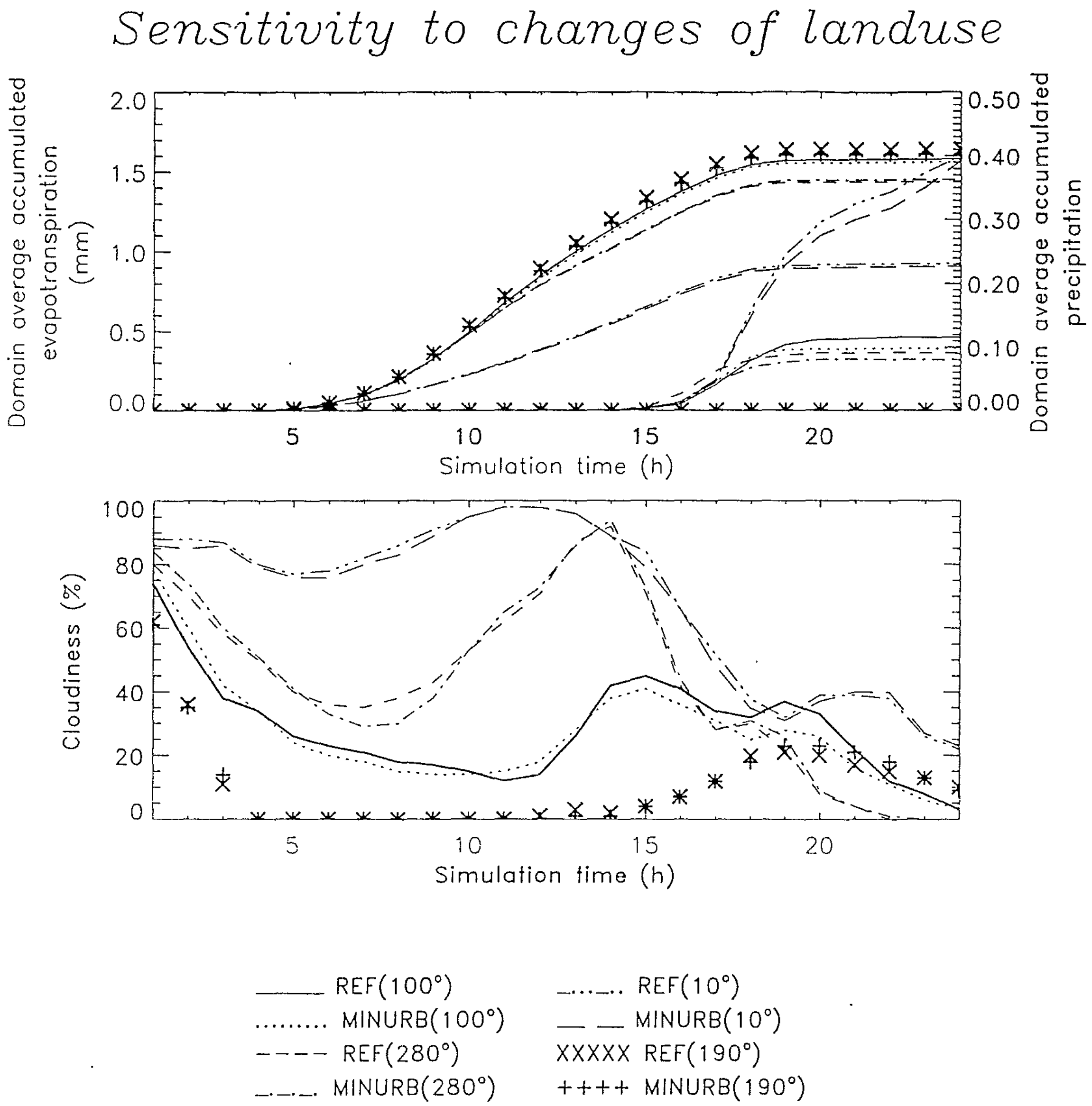

Fig. 2. Temporal development of the domain-averaged accumulated evapotranspiration and precipitation (upper part) as well as cloudiness (lower part) for different directions of the geostrophic wind.

4.3. Geostrophic wind from 190°

Like for a geostrophic wind from 100°, the distribution of surface temperatures is strongly related to that of the prevailing landuse for a geostrophic wind from 190°. In the ABL the temperatures are higher in the flat terrain of the northern part (about 13 °C at noon) than in the mountainous southern part of the model domain (lower than 10 °C). During the nighttime temperatures vary between 11 °C (Halle-Leipzig-Bitterfeld-area and along the river Elbe) and 8 °C (Sächsisches Bergland). There is a slight inversion of temperature below 100 m above ground.

Like for a geostrophic wind from 100°, evapotranspiration and, hence, the humidity of the lower ABL clearly depend on the distribution of the prevailing landuse during the daytime (5 g/kg and more over *forest* and *grassland*, about 4 g/kg for *agriculture* and large cities). During the nighttime the humidity does not exceed 3.4 g/kg in the Ober- and Niederlausitz. Values of more than 3.8 g/kg occur west of Leipzig and in the water meadows of the Odra.

During the daytime clouds only exist over the Oberlausitz. During the nighttime stratiform clouds form over and south of the Fläming. Their most southern boundaries reach the South of Halle. A further cloud field builds between Luckenwalde and Lindenberg. Both cloud fields are partly iced. Although some rainwater develops, no precipitation reaches the ground during the entire simulation time (Fig. 2).

4.4. Situation for a geostrophic wind from 280°

During the daytime the surface temperatures are related to the distribution of landuse only in the cloudfree southern part. Here, surface temperatures reach up to 33.1 °C at Dresden, for example. At noon the near surface air temperatures range from less than 10 °C in the Sächsisches Bergland and the Fläming to more than 13 °C at the Polish boarder. During the nighttime they range from less than 7 °C in the Sächsisches Bergland to more than 9 °C at Leipzig, Dresden and in the western part of the model domain.

During the daytime the distribution of humidity is strongly related to the landuse of the underlying surface. Values of humidity lower than 4.4 g/kg occur in the areas dominated by *agriculture* and about 4.8 g/kg in areas prevailingly covered by *forests* and *grassland*. Humidity is up to 0.2 g/kg lower over the larger cities (e.g., Leipzig, Wittenberg, Dresden, Cottbus) than over the adjacent vegetated land. At noon, for instance, humidity is slightly lower between Luckenwalde and Lindenberg than in the other areas prevailingly covered by *forest* and *grassland*. During the nighttime humidity exceeds 4.4 g/kg south of a line Halle-Torgau-Cottbus. Values less than 4.0 g/kg are achieved in the Fläming.

In the daytime broken stratus cloud fields form at the top of the ABL. At noon, for instance, cloudfree areas exist between Leipzig-Riesa-Meißen and in some parts of the Lausitz. Except for some locations over the Sächsisches Bergland no clouds exist during the nighttime (see also Fig. 2).

In the late afternoon and early evening precipitation occurs (e.g., Fig. 2) along a line Halle-Bautzen and in the Sächsisches Bergland. In the lee of Leipzig and Riesa precipitation is enhanced as compared to the other areas with precipitation. A third precipitation field exists east of the Lausitz.

5. The atmospheric response to the landuse changes for different geostrophic wind directions

Settlements as well as *open-cast mining* have similar thermal (thermal conductivity of the soil, heat capacity) and hydrologic (field capacity, capillarity) characteristics. The main differences are in the albedo and in the roughness length (Tab. 1). This means that the two landuse changes have similar effects except for dynamics and radiation. It is well known that dry, sandy areas evapotranspirate significantly less and heat more strongly the atmosphere than the vegetated areas. The expected drying and warming effect of the atmosphere occurs in the immediate vicinity of the landuse conversions for MINURBxxx. This, on average, leads to a slightly warmer and drier atmosphere for MINUBxxx than for REFxxx. Moreover, recent studies showed that urban areas increase convection (e.g., Landsberg, 1970) and precipitation in and downwind of a large city (e.g., Changnon and Huff, 1986). This effect is sometimes found for larger cities, too.

For all directions of the geostrophic wind the variability of wind, temperature and humidity grows in the areas of the landuse changes when approaching the Earth's surface. Generally, the landuse changes do not influence the predicted quantities of state above the ABL in all the simulations. In most of the cases the predicted variables of state as well as the water and energy fluxes differ over and downwind of the landuse changes. Because of the higher energetic input during the daytime, then the fluxes predicted for the various landscapes differ more strongly than during the nighttime. As compared to REFxxx in MINURBxxx the w-component of the wind vector significantly changes (Tab. 2) over the converted areas due to the stronger heating than the formerly vegetated land. This is due to the aforementioned different thermal behavior of *sand* and *settlements* on the one hand side and that of vegetated land on the other (see Tab. 1). Significant differences occur in the cloud and precipitating particles, the vertical component of the wind vector, the soil wetness factors, and evapotranspiration for all the directions of the geostrophic wind (Tab. 2).

In the case of the same geostrophic wind direction the domain-averaged daily values of the surface and air temperatures as well as humidity of REF and MINURB hardly differ. Nevertheless, for all the directions of the geostrophic wind there exists a larger variance of the humidity of the lower ABL in MINURB than for REF. For geostrophic winds from 190° or 10° the variance is higher for most of the quantities and fluxes in REF than in MINURB. The opposite is true for geostrophic winds from 100° or 280°. For all geostrophic wind directions the cloud and precipitating particles significantly change after the landuse conversions. These differences are not bound to the location of the altered landuse. The soil wetness factors of REF and MINURB significantly differ (Tab. 2) because of the dry up by the urbanization and the mining activities. In the case of xxx = 10, 100, 280 also the significantly different precipitation distributions and intensities play a role. This again affects evapotranspiration. If precipitation occurs, the domain-averaged 24h-accumulated precipitation will be reduced by the occurrence of *open-cast mining* and urbanization (Fig. 2).

Tab. 2. Comparison of maximum significance, s, and area, A, (km^2) for which the landuse changes cause significant differences (90 % confidence and higher) in the predicted quantities for the various directions of the geostrophic wind. Bold numbers emphasize the changes that are at least 95 % significant. Note that no precipitation reached the ground in REF190 and MINURB190, respectively.

Geostrophic wind from	10°		100°		190°		280°	
Significance/area size (km^2)	s	A	s	A	s	A	s	A
Ice	**99.99**	3750	**99.99**	6925	**99.99**	5925	**99.99**	10850
Rainwater	**99.99**	3250	**99.99**	4725	**99.99**	5675	**99.99**	11775
Cloud water	**99.99**	350	**99.99**	2000	**99.99**	7350	**99.99**	3775
Total liquid and solid water	**99.99**	750	**99.99**	2125	**99.99**	4025	**99.99**	5275
w-component of wind vector	**99.99**	1950	**99.99**	1725	**99.99**	3425	**99.99**	2650
Soil wetness factor	**99.99**	675	**99.99**	1325	**99.99**	675	**99.99**	2525
Graupel	**99.99**	1200	**99.99**	4250	**99.99**	350	**95**	350
Precipitation	**99.99**	1950	**99.99**	5450	-.-	-.-	**99.99**	19000
Evapotranspiration	**95**	350	**99**	300	**95**	300	**99.99**	650
Temperature	**99.99**	1300	90	75	68	0	**99.7**	225
Surface temperature	68	0	**95**	25	**95**	25	68	0
u-component of wind vector	45	0	68	0	45	0	90	75
Humidity	45	0	45	0	90	75	68	0
Sensible heat fluxes	68	0	68	0	45	0	90	25
v-component of wind vector	45	0	45	0	68	0	90	25

5.1. The atmospheric response to the landuse changes for a geostrophic wind from 10°

As compared to the reference landscape the soil heat fluxes rise appreciably in the open-cast mining and in the grown conurbation. Consequently, in these areas the surface temperatures of MINURB exceed those of REF. The predicted air temperatures of MINURB significantly grow in the western Bitterfelder Revier, the northern Lausitz, the Südraum Leipzig, and over Leipzig.

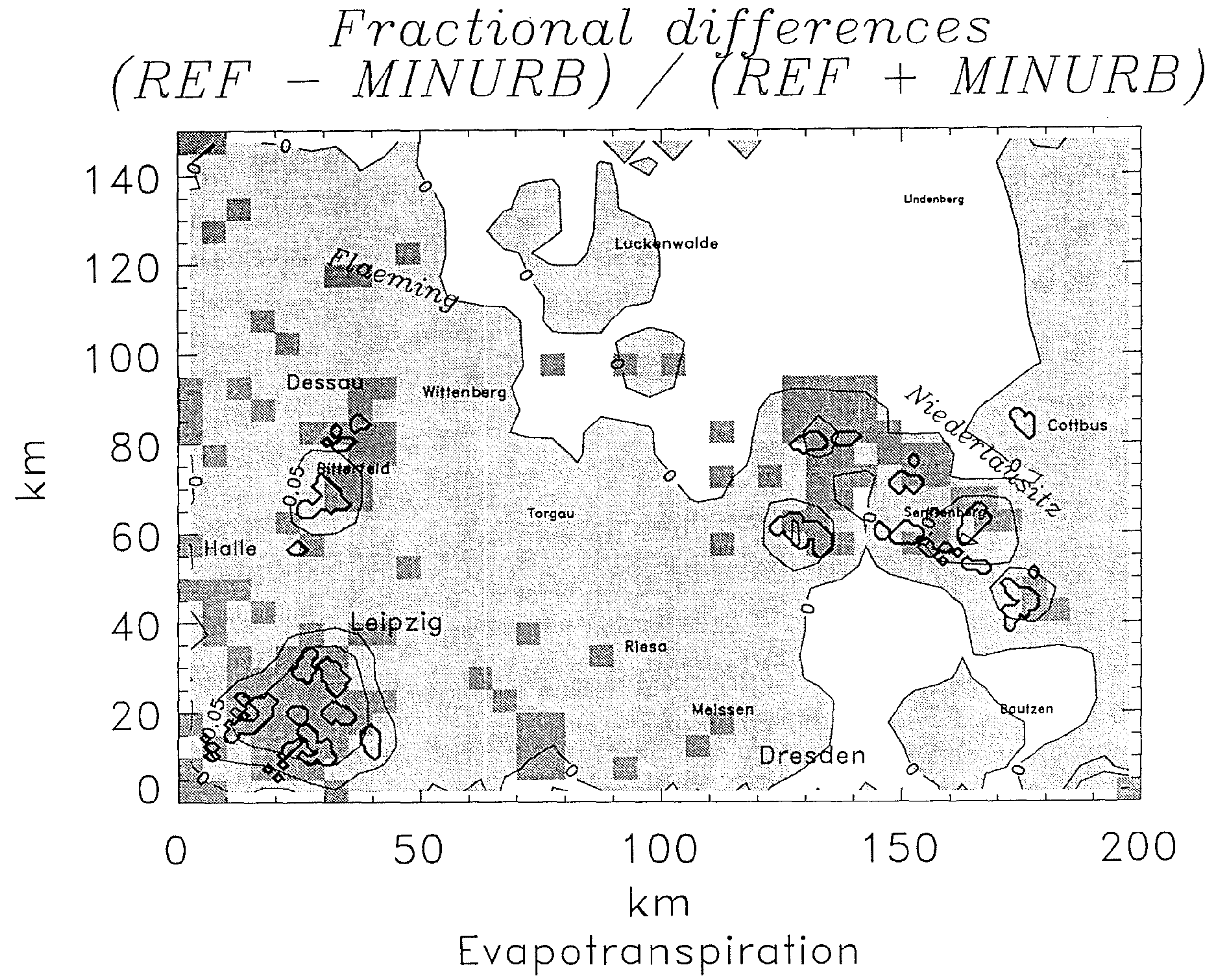

Fig. 3. Fractional differences of evapotranspiration at noon for a geostrophic wind from 10°. Grey shaded and white areas stand for positive and negative values, respectively. The dark grey boxes indicate grid cells for which at least one of the following quantities, namely, air temperature, evapotranspiration, the vertical component of the wind vector or soil wetness, differ at 90 % or better statistical significance level due to the landuse changes (Tab. 2).

In addition to the ABL over all the open-cast mining, the vertical component of the wind vector also significantly changes (e.g., Tab. 2) in the Sächsisches Bergland. Due to the grown conurbation evapotranspiration and soil wetness factors are appreciably reduced around Torgau, Riesa, Meißen, and Cottbus (e.g., Fig. 3). They are significantly reduced in the grown conurbation of Dresden, in the open-cast mining of the Südraum Leipzig and the Lausitz. In the latter region the extension of the area with significantly lower soil wetness factors are less than in the Südraum Leipzig. Nevertheless, significantly less water evapotranspirates only in the Südraum Leipzig and the southern Lausitz (e.g., Fig. 3). Consequently, on average, the air is slightly drier over and in the lee of the open-cast mining districts in MINURB than in REF. The drying effect of the sandy open-cast mining is greater in the lee of the Bitterfelder Revier and the Südraum Leipzig than in the lee of the Lausitz (e.g., Fig. 3). This may be partly due to the concurrently occurring urbanization that is greater in the former than in the latter region. Furthermore, in the lee of the open-cast mining the slightly enhanced near surface air temperatures may increase more strongly the evapotranspiration in the adjacent *forest* and *grassland* of the Lausitz than in the adjacent *agriculture* of the Südraum Leipzig and the Bitterfelder Revier (e.g., Fig. 3).

Tab. 3. Maximum hourly precipitation (mm) in the districts as obtained for the simulation REFxxx and the respective differences, Δ = REF - MINURBxxx. Areas that achieved both landuse changes, namely, urbanization and open-cast mining are given in bold letters.

Geostrophic wind direction	10°		100°		280°	
District as indicated in Fig. 1	REF	Δ	REF	Δ	REF	Δ
Fläming	0.0	0.0	0.1	0.0	0.0	-0.1
Teltow-Zauche	1.5	0.1	1.0	0.0	0.0	-0.1
Elbe	1.3	-0.6	0.3	-0.2	0.7	-0.5
Bitterfelder Revier	**0.0**	**0.0**	**0.8**	**-0.1**	**0.1**	**-0.4**
Leipzig-Südraum Leipzig	**0.1**	**0.0**	**0.7**	**-0.2**	**0.9**	**-0.2**
Sächs. B.-Dübener Heide	1.4	-0.5	0.7	0.1	0.9	-0.2
Schwarze Elster	0.7	-0.1	0.4	0.0	0.8	-0.7
Oberlausitz	2.6	0.3	0.0	0.0	0.7	0.2
Lausitz	**2.3**	**0.1**	**1.1**	**0.0**	**0.6**	**-0.5**
Conurbation of Dresden	1.5	-0.6	0.1	0.0	0.1	0.0
Odra	0.0	-1.6	0.3	0.3	0.0	0.0

Over the Bitterfelder Revier the cloud mixing ratio are significantly affected by the landuse changes. Here and over the valley of the river Elbe rainwater formation significantly changes due to the landuse conversion. Note that the latter leads to significant differences of the precipitation over the Elbe from Dresden to Torgau. In contrast to the liquid phase, the ice mixing ratios are significantly modified for all cloud fields. Nevertheless, the mixing ratios of the total cloud and precipitating particles are significantly influenced by the landuse changes (e.g., Tab. 2) only over the Bitterfelder Revier and the conurbation of Dresden. Precipitation is appreciably enhanced in the lee of Meißen. The hourly district-maximum precipitation rates grow in the area of the Elbe, the Odra, Dresden and the Sächsiches Bergland (Tab. 3).

On summarizing, in addition to the significant changes common to all directions of the geostrophic wind, the landuse changes significantly affect air temperature and evapotranspiration for a geostrophic wind from 10°.

5.2. Geostrophic wind from 100°

Only in the Lausitz surface temperatures significantly increase (e.g., Tab. 2) about 0.7 K for the change from REF to MINURB. The ABL is slightly warmer in MINURB than in REF, especially, over the open-cast mining (up to 0.3 K) and the conurbation (up to 0.2 K). Positive differences in air temperature go along with regions prevailingly covered by high vegetation (e.g., south of Bitterfeld, north of Senftenberg) while negative values arise in connection with a dominance of low vegetation (e.g., south of Leipzig, south of Cottbus). This substantiates that the landuse adjacent to the accumulated landuse changes, i.e., the simultaneous occurrence of two landuse changes within a small area, also strongly influences the kind of change in the temperature of the ABL.

In the ABL the vertical component of the wind vector will significantly change over the Lausitz, the Bitterfelder Revier, the Südraum Leipzig and some locations of the Fläming and the Sächsisches Bergland if the origin landscape changes to a landscape with *open-cast mining* and increased *settlements*.

In MINURB the humidity decreases more than 0.3 g/kg over and south of Leipzig, the Lausitz (especially around Cottbus) and the Bitterfelder Revier. Here, both the effects the drying up by urbanization and the low water holding capacity of the *open-cast mining* contribute to the significantly lower water supply to the atmosphere as compared to the formerly vegetated land (Fig. 4). On the contrary, in the conurbation of Dresden the humidity appreciably goes down by the urbanization alone. Here, the effect of urbanization on the distribution of water vapor is nearly as strong as the effect due to urbanization and *open-cast mining* around and in the Südraum Leipzig. There are several reasons. In the conurbation of Dresden a lot of smaller cities exist (Fig. 1) that all grow. Here, *grassland* changes to *settlement* while around Leipzig *agriculture* converts to *open-cast mining* or *settlement.* Consequently, in the former the surface characteristics change more strongly than in the latter area (e.g., Tab. 1). In the areas around Luckenwalde and Lindenberg urbanization is also the only landuse change. Due to the low density of *settlements* in this area the effective urbanization rate is low, too. Hence, the urbanization marginally reduces evapotranspiration (e.g., Fig. 4) and humidity in MINURB as compared to REF. This indicates that the local urbanization rate is also decisive for the magnitude of the atmospheric response.

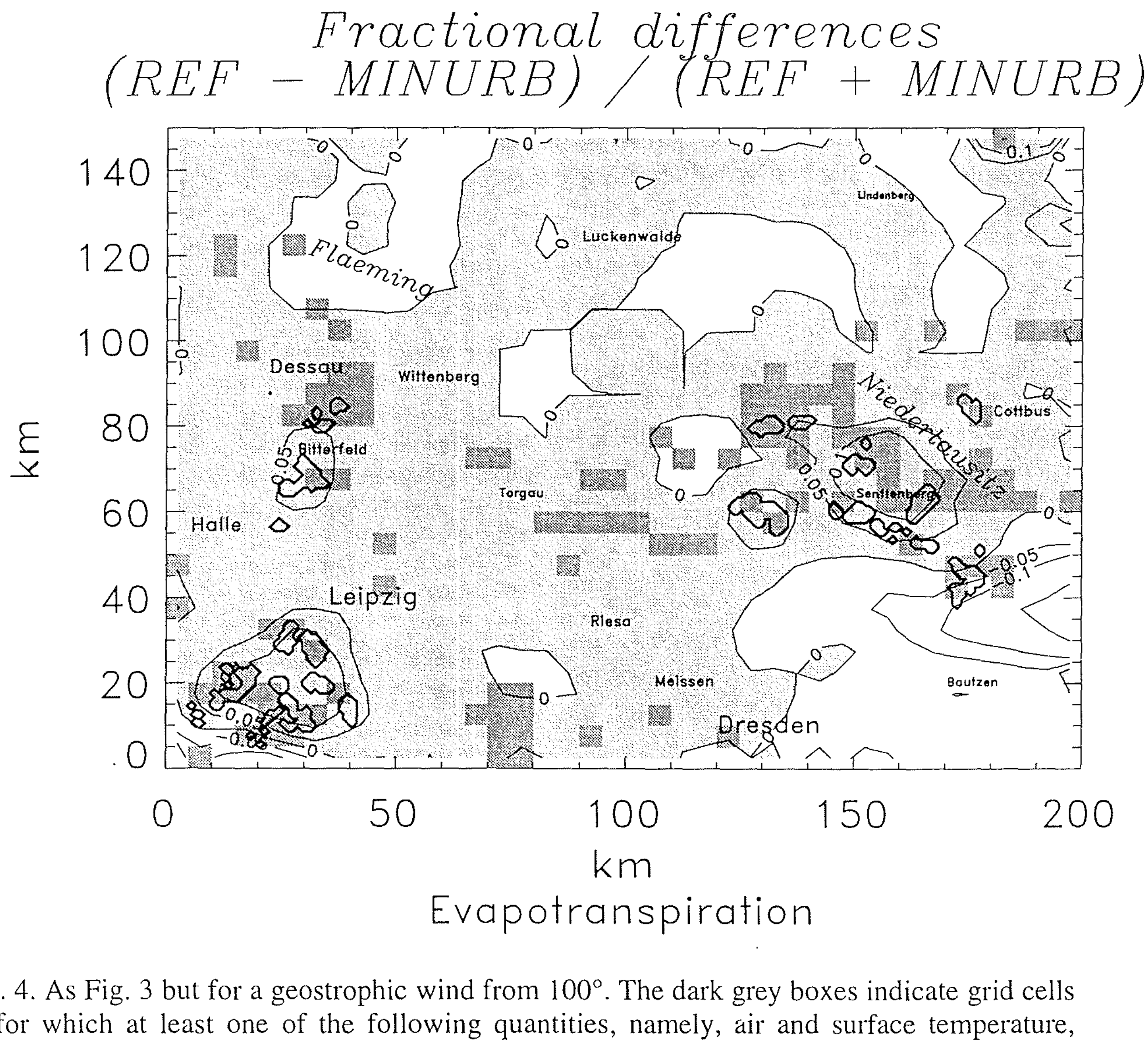

Fig. 4. As Fig. 3 but for a geostrophic wind from 100°. The dark grey boxes indicate grid cells for which at least one of the following quantities, namely, air and surface temperature, evapotranspiration, the vertical component of the wind vector or soil wetness, differ at 90 % or better statistical significance level due to the landuse changes (Tab. 2).

During the daytime the cloudiness predicted by MINURB increases over the Sächsisches Bergland, the river Neiße as well as over the Fläming while it is reduced over the Lausitz. Cloudiness significantly decreases downwind of Dresden, the Südraum Leipzig, the Bitterfelder Revier and the Lausitz. The assumed accumulated landuse changes result in a lower cloud coverage during the nighttime (Fig. 2).

During the nighttime the mixing ratios of cloud water and ice are significantly greater in the lee of Leipzig in MINURB than in REF. Consequently, MINURB provides significantly more rainfall downwind of Leipzig than REF. The extensions of the precipitation fields are reduced in MINURB. The domain-averaged 24h-accumulated rainfall of MINURB does not reach that of REF (Fig. 2), but MINURB achieves a higher maximum of the 24h-accumulated rainfall (1.4 mm) than REF (1.3 mm). The hourly maximum precipitation increases in the Bitterfelder Revier, along the Elbe and in the Südraum Leipzig (Tab. 3). While REF predicts rainfall in the Odra-district, here no rainfall occurs in MINURB (Tab. 3).

On summarizing, in addition to the significant differences, which are common for all directions of the geostrophic wind, the surface and air temperatures significantly differ. In the lee side of Leipzig the modified moisture convergence results to higher local rainfall maxima in the late afternoon and early evening.

5.3. The atmospheric response to the landuse changes for a geostrophic wind from 190°

Surface temperatures are significantly enhanced (e.g., Tab. 2) in the open-cast mining of the Lausitz. During the nighttime the air is slightly warmer over and in the lee of the grown cities (e.g., Halle, Bitterfeld, Leipzig, Dresden) as well as in the northern part of the Lausitz. The fluxes of sensible heat only slightly differ while the soil heat fluxes differ more strongly (e.g., Tab. 2).

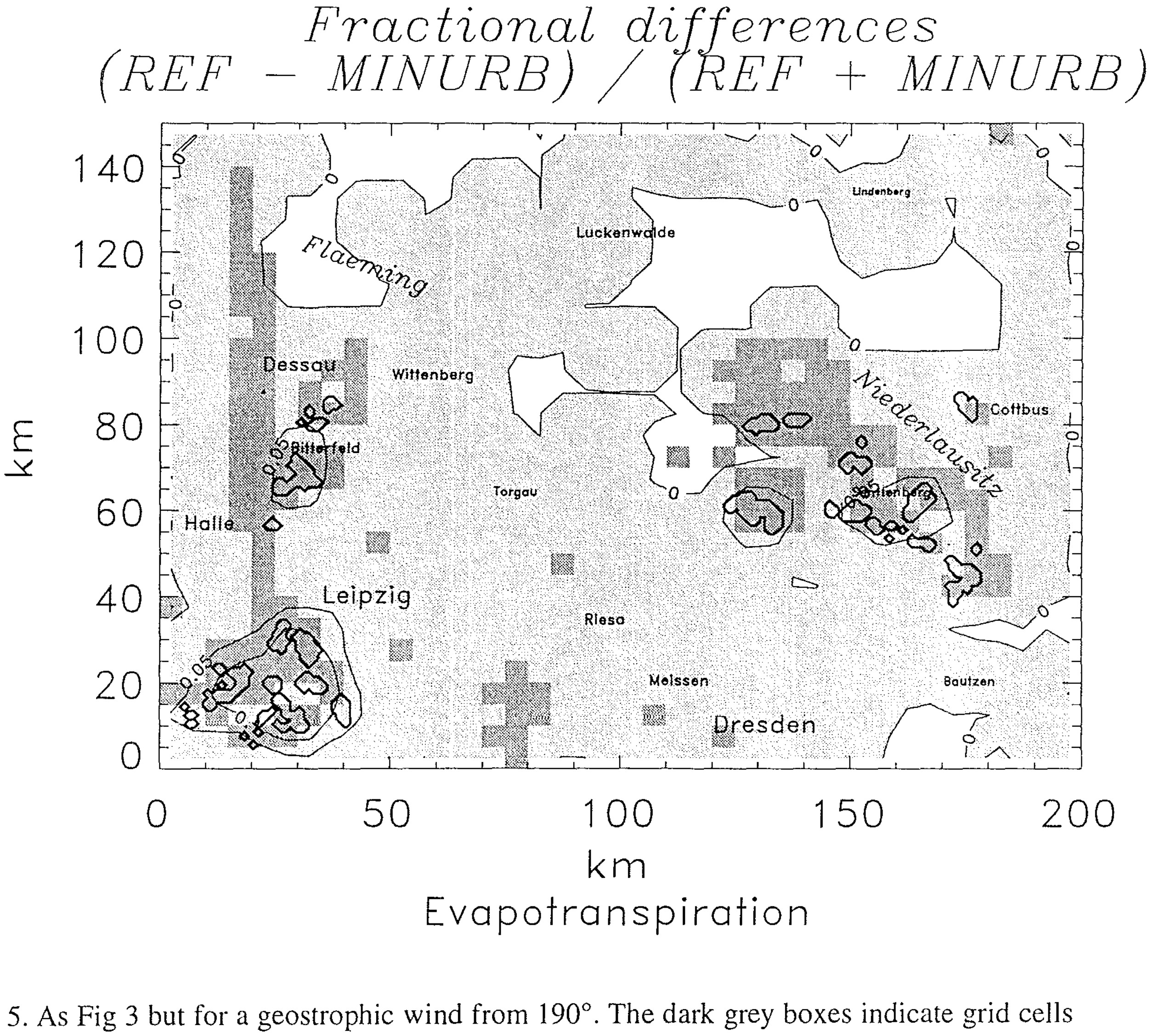

Fig. 5. As Fig 3 but for a geostrophic wind from 190°. The dark grey boxes indicate grid cells for which at least one of the following quantities, namely, surface temperature, evapotranspiration, humidity at reference height, the vertical component of the wind vector or soil wetness, differ at 90 % or better statistical significance level due to the landuse changes (Tab. 2).

Due to the different heating of vegetation and *open-cast mining* or of vegetation and *settlements* the vertical component of the wind vector is significantly modified by the landuse changes over all open-cast mining districts as well as the western part of the Sächsisches Bergland.

In MINURB evapotranspiration and soil wetness factors significantly decrease in the Südraum Leipzig. They are appreciably reduced in the grown conurbation (e.g., Fig. 5; see also Tab. 2). Note that the horizontal extension of the areas with a significantly reduced evapotranspiration is greater in the Südraum Leipzig than in the Lausitz (e.g., Fig. 5). In the former region humidity even decreases significantly (e.g., Tab. 2). In the nighttime the humidity of MINURB is still appreciably lower (about 0.2 g/kg) over and in the lee of the open-cast mining and the grown cities than in REF. As compared to REF the soil wetness factors significantly decrease (e.g., Tab. 2) in the Südraum Leipzig, the Bitterfelder Revier, the Lausitz as well as in the grown conurbation of Leipzig and Dresden in MINURB.

The cloud water and rainwater of REF and MINURB significantly differ (e.g., Tab. 2) over the Sächsisches Bergland, in the lee of the Fläming and in the lee of the Lausitz. On the contrary, the amount of ice is significantly affected by the landuse changes (e.g., Tab. 2) north of the Lausitz. The total condensed and frozen water, however, is significantly influenced (e.g., Tab. 2) in the lee of the Lausitz, in the Oberlausitz, over Leipzig, and over the Südraum Leipzig. This means that the paths of the cloud and precipitation formation are appreciably modified due to the atmospheric responses to the landuse changes. During the nighttime cloudiness increases in the lee of Dessau, Bitterfeld and Leipzig due to the growing of the cities. The mixed phase cloud field that builds between Luckenwalde and Lindenberg in REF becomes totally iced in MINURB. Furthermore, during the nighttime the mixing ratios of the cloud and precipitating particles of those cloud fields, which are predicted in both the simulations, are, on average, lower in MINURB than in REF. No precipitation reaches the ground in both the simulations (e.g., Fig. 2, Tab. 2).

On summarizing, in addition to the significant changes which occur for all directions of the geostrophic wind, the humidity, the surface and air temperatures of MINURB significantly differ form that of REF (Tab. 2).

5.4. The atmospheric response to the landuse changes for a geostrophic wind from 280°

Surface temperatures appreciably increase in the grown conurbation and the larger one of the open-cast mining. They decrease where thicker clouds form in MINURB than in REF or where the clouds exists over a longer time in MINURB than in REF so that insolation is appreciably reduced. In the Bitterfelder Revier the soil heat fluxes significantly change (Tab. 2). The turbulent fluxes of sensible heat provided by MINURB and REF differ up to 50 W/m^2 in the lee of the open-cast mining. At noon, for instance, the sensible heat fluxes decrease more than a factor of 2 in the Lausitz, the lee of the Bitterfelder Revier (e.g., Fig. 6). They increase more than a factor of 1.1 in the Südraum Leipzig, in the water meadows of the river Elbe between Riesa and Meißen, and south-west of the Fläming (e.g., Fig. 6). It seems that whether an increase or decrease is obtained mainly depends on the prevailing landuse of the patches adjacent to the land use conversion, namely, low and high vegetation for an increase and decrease, respectively. In Leipzig the sensible heat fluxes even significantly increase due to the urbanization (e.g., Fig. 6). Nevertheless, significant increases in air temperatures (Tab. 2) are only found over the open-cast mining of the Lausitz. As compared to REF the air temperatures of MINURB slightly increase in the lee of the open-cast mining during the daytime. During the nighttime the air is appreciably warmer in the conurbation of Leipzig, Dresden, Riesa, Meißen and Cottbus.

The horizontal wind field is hardly affected by the modified roughness and the changed terrain elevation except for the Lausitz where the predicted u- and v-components of the wind vector significantly differ (e.g., Tab. 2). On the contrary, the vertical component of the wind vector significantly changes over all the open-cast mining due to the stronger heating of the latter than the vegetated land (e.g., Tab. 2).

Since in the open-cast mining as well as in the urbanized areas the soils are significantly drier than the formerly vegetated land of REF (e.g., Tab. 2), evapotranspiration is significantly reduced (e.g., Fig. 7). Therefore, over and in the lee of the open-cast mining as well as over and in the lee of the grown conurbation of Dresden and Leipzig the water vapor decreases about 0.2 g/kg in the lower ABL. As pointed out already in the Leipzig area the urbanization rate is high and *open-cast mining* occurs simultaneously. Here, the effects of the landuse changes enhance each other and provide a larger response towards lower humidity than in the other open-cast mining districts or areas with high urbanization rates (e.g., Fig. 7). During the nighttime the humidity of the air is appreciably reduced in the Südraum Leipzig and along the Elbe north of Dresden in MINURB. The former is due to the *open-cast mining* and urbanization while the latter results from urbanization alone. As aforementioned, here, the old and the new thermal, hydrologic and dynamic characteristics extremely differ (Tab. 1).

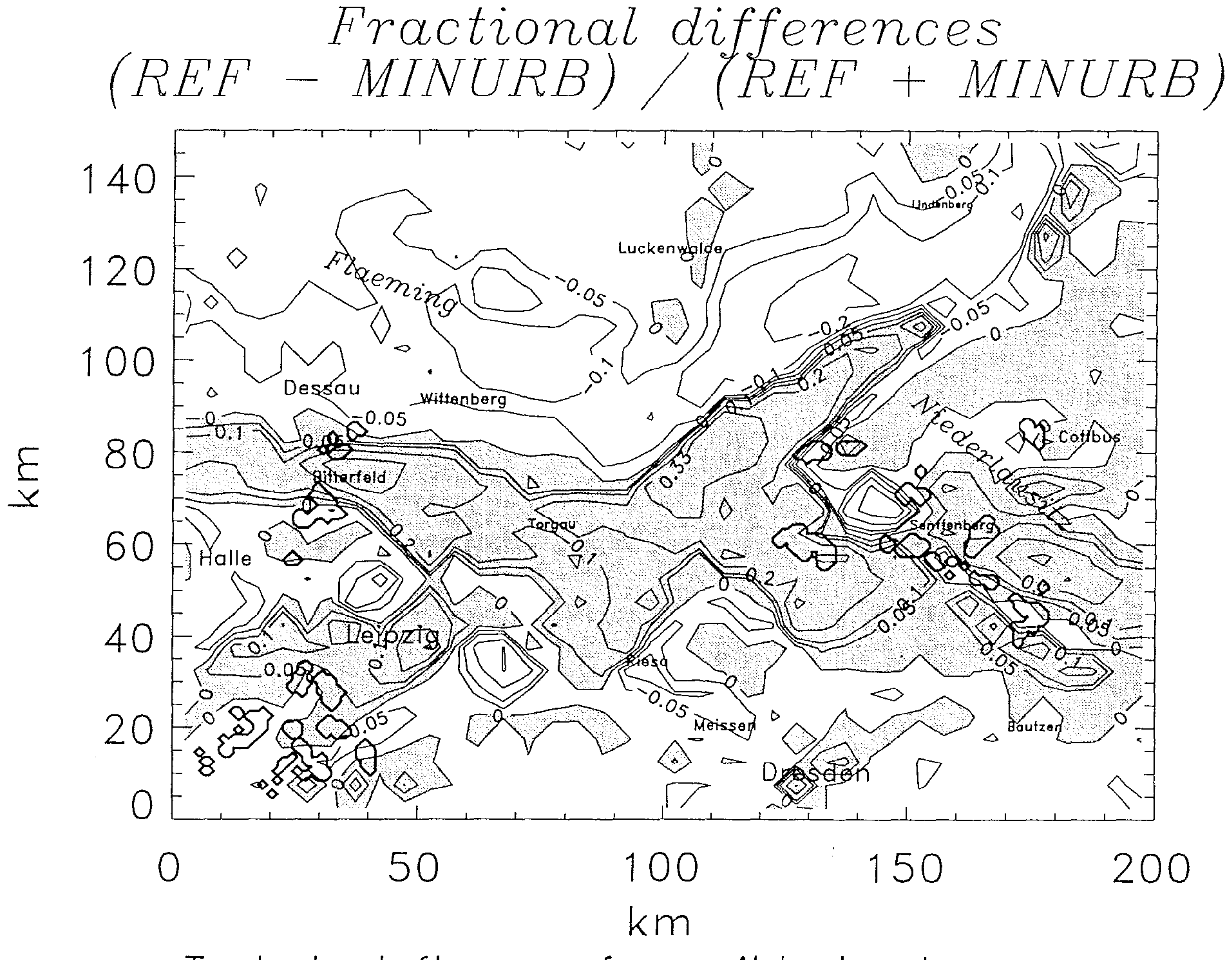

Fig. 6. Fractional differences of the fluxes of sensible heat at noon for a geostrophic wind from 280°. The dark grey boxes indicate grid cells for which at least one of the following quantities, namely, air temperature, evapotranspiration, the sensible heat fluxes, the w-, u- and v-component of the wind vector or soil wetness, differ at 90 % or better statistical significance level due to the landuse changes (Tab. 2).

On average, cloudiness decreases in the landscape with *open-cast mining* and urbanization (Fig. 2). During the daytime less rainwater forms in the lee of Leipzig, the Südraum Leipzig and the Lausitz while more rainwater is built over the water meadows of the river Elbe. Here, the higher air temperature caused by the urbanization enhances evapotranspiration and hence, the cloud and rainwater formation. In the lee of the open-cast mining as well as over and in the lee of Leipzig the amount of ice is greater in MINURB than in REF due to the changed vertical motion and moisture convergence. During the nighttime there exists a higher degree of icing in MINURB than in REF. The district-maximum hourly precipitation increases in the Lausitz as well as in the districts adjacent East or West of the Elbe (Tab. 3).

On summarizing, in the lee of larger cities the vertical lifting and the moisture convergence grow by urbanization. This may locally enhance cloudiness. While evapotranspiration is reduced the most significantly in the Südraum Leipzig, air temperature significantly increases in the Lausitz only. This may be related to the adjacent dominating landuse. Besides the significant differences, which occur for all directions of the geostrophic wind, the landuse changes also significantly affect the u- and v-component of the wind vector, the sensible heat fluxes, the air and surface temperatures.

6. The sensitivity of the differences between REF and MINURB to the directions of the geostrophic wind

The landuse changes modify the heating, the vertical mixing, and the stability resulting in appreciable, and at some locations significant, differences between the cloud and precipitating particles of REF and MINURB. The significant changes occur in different regions for the different directions of the geostrophic wind (see also Tab. 3). Moreover, it depends on the geostrophic wind direction which quantities or fluxes significantly change (Tab. 2).

The results substantiate an obvious relationship among the distributions of surface cover and water vapor for geostrophic wind from 100°, 190°, and 280°. This is due to the water availability, the hydrologic behavior of the underlying surface (e.g., field capacity, capillarity), and hence, evapotranspiration and soil wetness factors. In REF10, however, the atmosphere becomes more cloudy than for the aforementioned synoptic situations. Therefore, the reduced insolation lessens evapotranspiration and heating. Note that in xxx10 in reference height the domain-averaged air temperatures are about 2 K lower than for the other wind directions.

6.1. The Fluxes

Net radiation is hardly affected by the landuse changes for all directions of the geostrophic wind. Generally, the *open-cast mining* and the grown *settlements* heat more strongly. They hold longer the heat than the vegetated areas occurring in REF at the same place. The most sensitive component of the energy budget to the landuse changes is the latent heat flux, followed by the sensible and soil heat fluxes (Tab. 2). Note that significant changes of the fluxes of sensible heat only occur for a geostrophic wind from 280° (Tab. 2).

Of course, the domain-averaged 24h-accumulated evapotranspiration depends on the direction of the geostrophic wind. It is the greatest for REF190 and the lowest for MINURB10 for which evapotranspiration does not exceed 2/3 of that provided by REF190 (Fig. 2). In the domain-average, slightly less water evapotranspirates in the simulations with a geostrophic wind direction of 100° and 280° than in that of 190°. On average, less water evapotranspirates in MINURBxxx than in REFxxx for all directions of the geostrophic wind. There is a higher significance that the changes in evapotranspiration are due to the landuse changes for geostrophic winds from 100° and 280° than for the other directions (Tab. 2). The fact that the differences in the domain-averaged evapotranspiration are similar and the fact that a lower correlation between the landuse changes and the differences in evapotranspiration is yield for geostrophic wind directions from 280° and 100° means that evapotranspiration is more strongly modified in the lee of the landuse changes for these two geostrophic wind directions than for the other geostrophic wind directions.

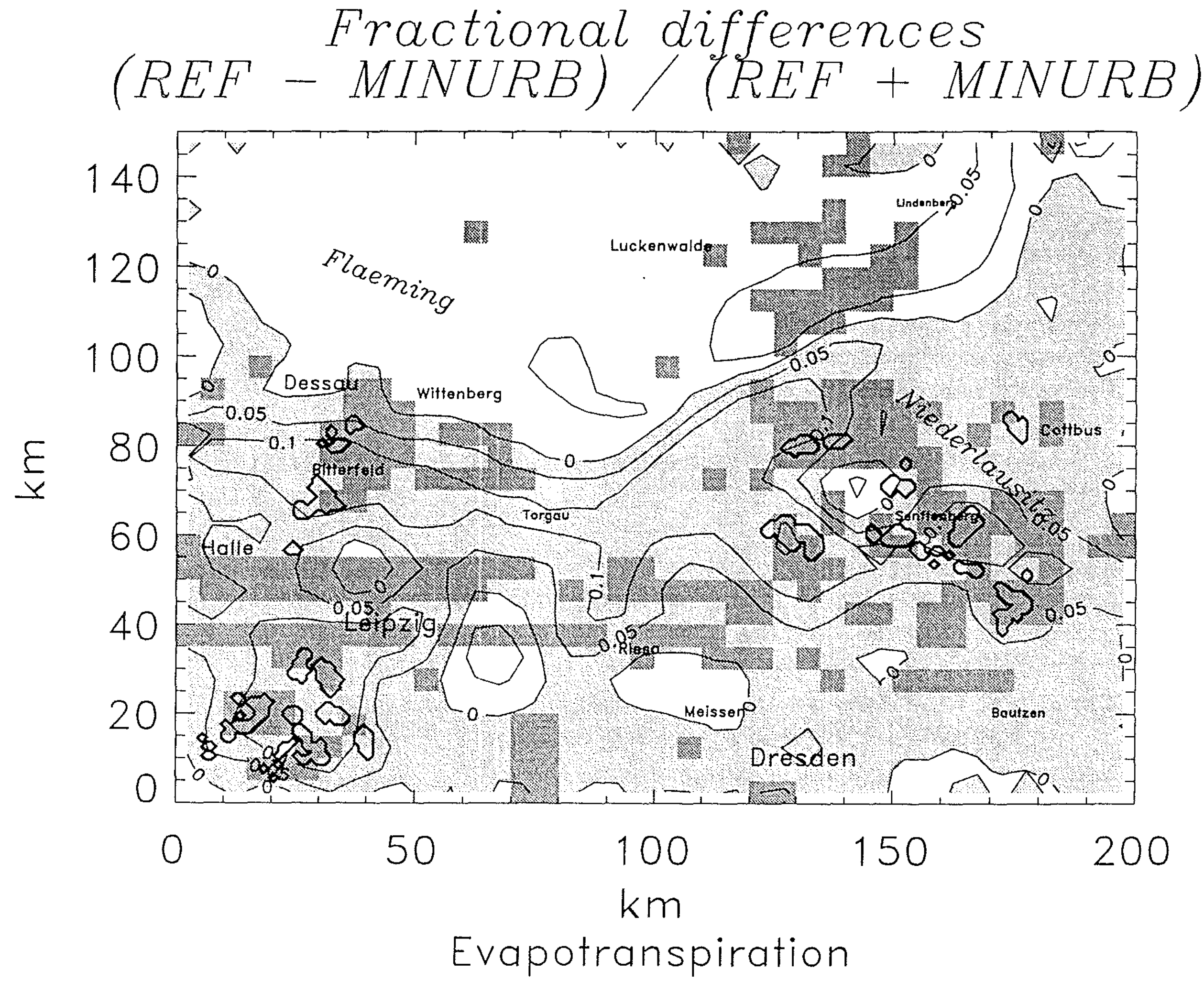

Fig. 7. As Fig 3 but for a geostrophic wind from 280°. The dark grey boxes indicate grid cells for which at least one of the following quantities, namely, air temperature, evapotranspiration, the sensible heat fluxes, the w-, u- and v-component of the wind vector or soil wetness, differ at 90 % or better statistical significance level due to the landuse changes.

Generally, the domain-averaged 24h-accumulated precipitation is greater for REF than for MINURB for all directions of the geostrophic wind except for a geostrophic wind from 190°. As pointed out already in xxx190 no precipitation reaches the ground (Fig. 2). In MINURBxxx the horizontal extension of the precipitation pattern is less than in REFxxx. Although the domain-averaged precipitation decreases, when urbanization and *open-cast mining* take place, the local 24h-accumulated maxima of MINURBxxx exceed those of REFxxx in the lee of larger cities. This means that in MINURBxxx more intense precipitation falls (e.g., Tab. 3) at fewer places than in REFxxx.

The differences in the 24h-accumulated precipitation do not correspond to that in the 24h-accumulated evapotranspiration for all directions of the geostrophic wind (Fig. 2). This means that the differences in the local water cycle which are caused by the landuse changes strongly depend on the geostrophic wind direction and the related orographically or roughness induced modification of the wind field. For a geostrophic wind from 10° the landuse changes affect the domain-averaged 24h-accumulated precipitation as well as the temporal development of the precipitation the greatest of all wind directions investigated here (Fig. 2).

On summarizing, for all directions of the geostrophic wind the landuse changes significantly affect evapotranspiration. Evapotranspiration is noticeably enhanced or reduced when the near surface wind passes both the landuse types immediately one after the other. The tendency of an increased moisture convergence in the lee of the grown, conurbation as well as the difference between REF and MINURB in the domain-averaged evapotranspiration seem to be independent of the geostrophic wind direction.

6.2. The variables of state

Comparison of the fractional differences shows that the air temperatures are the most sensitive to the landuse changes for a geostrophic wind from 10° and 100° and the less sensitive for 190°. Nevertheless, the greatest correlation between the landuse changes and the resulting differences in air or surface temperature is obtained for a geostrophic wind from 190°. This indicates that there exists only a slight, but continuous, change in temperature over the entire area of landuse conversion. Surface temperatures, however, significantly alter for the landuse changes under a geostrophic wind from 190° (Tab. 2). Note that for a geostrophic wind from 100° the landuse changes significantly influence both air and surface temperature (Tab. 2).

Due to the stronger heating of the grown conurbation and the open-cast mining the vertical mixing is significantly enhanced for all directions of the geostrophic wind at these locations (Tab. 2). Nevertheless, these significant changes occur in different regions for the different geostrophic wind directions.

In contrast to a geostrophic wind from 100° and 280° the near surface horizontal wind field is strongly determined by the underlying surface for a geostrophic wind direction of 10° and 190°, respectively. Here, convergence occurs because the flow is directed by orography. Note that for a geostrophic wind direction of 10° and 190° cloud formation mainly occurs along these convergence lines. The landuse changes significantly influence the v- and the u-component of the wind vector only for geostrophic wind from 280° (Tab. 2).

If REF or MINURB provides the larger cloud coverage can not be generalized (Fig. 2). The cloudiness of REF and MINURB differs the largest for a geostrophic wind from 280° in the morning and for a geostrophic wind from 100° in the late afternoon and early evening (Fig. 2). In REF10 the cloud coverage exceeds that of all simulations (Fig. 2). The increased cloudiness of REF10 results from the higher evapotranspiration than in MINURB10. The larger cloudiness of xxx10 may be due to the enhanced vertical motion by the convergence of the wind field and the orographically induced cloud formation at the Sächsisches Bergland. In all simulations with urbanization (MINURBxxx) there exists a tendency for increased humidity and an initiation of cloud formation or even an increased cloud formation in the lee of larger cities.

On summarizing, a stronger sensitivity of the local water cycle to landuse changes was detected for geostrophic wind directions from 100° and 280° than for the other geostrophic wind directions examined here (e.g., Tab. 2). This may be partly explained by the nearly orthogonal orientation of the near surface wind field towards the landuse pattern and the *open-cast mining*. The orographically directed flow and the more or less parallel flow to the stripes of the prevailing landuse seem to lessen the effects of the landuse changes for the two other directions of the geostrophic wind.

7. Conclusions

The study investigates the effect of *open-cast mining* and urbanization on the local and mesoscale weather for various directions of the geostrophic wind. It was motivated by the actual landuse changes occurring in large areas of eastern Germany. Eight 24h-simulations were performed with the Leipzig's version of GESIMA by assuming a landscape with and without urbanization and *open-cast mining* under four directions of the geostrophic wind. Significance test were performed to evaluate the sensitivity of the atmospheric response to the landuse changes. Moreover, the fractional differences of REF and MINURB were determined. The results substantiate the following:

- The landuse changes significantly influence soil wetness factors, the vertical component of the wind vector, cloud and precipitating particles as well as evapotranspiration for all directions of the geostrophic wind.
- The domain-averaged evapotranspiration and, if precipitation occurs, also the domain-averaged precipitation are always lower in MINURB than in REF.
- Independent of the direction of the geostrophic wind direction urbanization leads to an enlarged moisture convergence over and in the lee of larger cities. This may enhance cloudiness and rainfall in their lee side.
- The magnitude and location of the changes as well as, whether the other variables of state and/or the other fluxes are affected by the landuse changes, varies for the different geostrophic wind directions.
- Whether the effects of the accumulated landuse changes enhance each other or counteract, depends on their location to each other along the surface wind direction and on the prevailingly adjacent landuse.
- For a geostrophic wind direction from 280° the landuse changes significantly influence the most quantities all the wind directions investigated here. Moreover, the areas that achieve significant changes are larger for a geostrophic wind direction from 280° than for the other directions.

Considering these findings it may be concluded that the atmospheric response to the local landuse changes is sensitive to the direction of the geostrophic wind. The stronger sensitivity of the local weather to landuse changes for geostrophic winds from 100° and 280° seems to depend on the specific constellation of the landscape investigated (flatter terrain in the north than in the south, preference for *forests* and *grassland* in the north-eastern part and for *agriculture* in the south-western part, a higher urbanization rate in the south-western part than in the north-eastern part; Fig. 1). Therefore, future studies should examine if the higher sensitivity of the local weather to landuse changes that was detected for geostrophic winds from 100° and 280° can be found for other mid-latitude landscapes, too. It has to be expected that in very complex terrain mountain circulation will prevail. Hence, here the influence of the geostrophic wind direction on the atmospheric response to the landuse changes will depend on whether the geostrophic wind directions leads to another wind regime in the valley or not.

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References

Anthes, R.A., 1984: Enhancement of convective precipitation by mesoscale variations in vegetative covering in semiarid regions. *J. Clim. Appl. Met.*, **23**, 541-554.

Avissar, R., Pielke, R.A., 1989: A parameterization of heterogeneous land surface for atmospheric numerical models and its impact on regional meteorology. *Mon. Wea. Rev.*, **117**, 2113-2136.

Brubaker, K.L., Entekhabi, A., Eagleson, P.S., 1993: Estimation of continental precipitation recycling. *J. Clim.*, **6**, 1077-1089.

Changnon, S.A., Huff, F.A., 1986: The urban-related nocturnal rainfall anomaly at St. Louis. *J. Clim. Appl. Meteor.*, **25**, 1985-1995.

Charney, J., 1975: Dynamics of desert and droughts in the Sahel. *Q. J. R. Meteorol. Soc.*, **101**, 193-202.

Chen, F., Avissar, R., 1994: Impact of land-surface variability on local shallow convective cumulus and precipitation in large-scale models. *J. Appl. Met.*, **33**, 1382-1401.

Copeland, J.H., Pielke, R.A., Kittel, T.G.F., 1996: Potential climatic impacts of vegetation change: A regional modeling study. *J. Geophys. Res.*, **101D**, 7409-7418.

Cotton, W.R., Pielke, R.A., 1995: *Human impacts on climate*. Cambridge University Press.

Deardorff, J.W., 1978: Efficient prediction of ground surface temperature and moisture, with inclusion of a layer of vegetation. *J. Geophys. Res.*, **84C**, 1889-1903.

Dickinson, R.E., 1992: Change in landuse. *Climate System Modeling*, K.E. Trenberth (ed.), Cambridge Press, 689-701.

Eppel, D.P., Kapitza, H., Claussen, M., Jacob, D., Koch, W., Levkov, L., Mengelkamp, H.-T., Werrmann, N., 1995: The non-hydrostatic mesoscale model GESIMA. Part II: Parameterizations and applications. *Contrib. Atmos. Phys.*, **68**, 15-41.

Gerstengarbe, F.-W., Werner, P.C., 1993. Katalog der Großwetterlagen Europas nach Paul Hess and Helmuth Brezowsky 1981-1992. *Ber. DWD* **113**.

Groß, G., 1988: A numerical estimation of the deforestation effects on local climate in the area of the Frankfurt International Airport. *Contrib. Atmos. Phys.*, **61**, 219-231.

Groß, G., 1989: Anwendungsmöglichkeiten mesoskaliger Simulationsmodelle dargestellt am Beispiel Darmstadt Teil I: Wind- und Temperaturfelder. *Meteorolo. Rdsch.*, **43**, 97-112.

Jarvis, P.G., 1976: The interpretation of the variation in leaf water potentail and stomatal conductance found in canopies in the field. *Phil. Trans. R. Soc. Lond.*, B., **273**, 593-610.

Kapitza, H., Eppel, D.P., 1992: The non-hydrostatic mesoscale model GESIMA. Part I: Dynamical equations and tests. *Contr. Phys. Atmos.*, **65**, 129-146.

Kerschgens, M., Drauschke, R.L., 1986: On the energy budget of a wintry mid-latitude city atmosphere. *Contrib. Atmos. Phys.*, **59**, 115-125.

Kramm, G., Dlugi, R., Dollard, G.J., Foken, T., Mölders, N., Müller, H., Seiler, W., Sievering, H., 1995: On the dry deposition of ozone and reactive nitrogen compounds. *Atmos. Environ.*, **29**, 3209-3231.

Landsberg, H.E., 1970: Man-made climatic changes. *Science*, **170**, 1265-1274.

Mölders, N., Raabe, A., Tetzlaff, G., 1996: A comparison of two strategies on land surface heterogeneity used in a mesoscale β meteorological model. *Tellus*, **48A**, 733-749.

Mölders, N., Kramm, G., Laube, M., Raabe, A., 1997: On the influence of bulk-parameterization schemes of cloud microphysics on the predicted water-cycle relevant quantities - a case study. *Met. Zeitschr.*, **6**, 21-32.

Otterman, J., Manes, A., rubin, S., Alpert, P., O'Starr, D.C., 1990: An increase of early rains in southern Isreal following land-use change? *Bound.-Layer Meteor.* **53**, 333-351.

Pielke, R.A., Dalu, G., Snook, J.S., Lee, T.J., Kittel, T.G.F., 1990: Non-linear influence of mesoscale landuse on waether and climate. *J. Clim.*, **4**, 1053-1069.

Savenije, H.H.G., 1995: New definitions for moisture recycling and the relationship with land-use changes in the Sahel. *J. Hydrol.*, **167**, 57-78.

Smolarkiewicz, P.K., 1984: A fully multidimensional positive definite advection transport alogorithm with small implicit diffusion. *J. Comp. Phys.*, **54**, 325-362.

Seth, A., Giorgi, F., Dickinson, R.E., 1994: Simulating fluxes from heterogeneous land surfaces: explicit subgrid method employing the biosphere-atmosphere transfer scheme (BATS). *J. Geophys. Res.*, **99D**, 18651-18667.

Sud, Y.C., Yang, R., Walker, G.K., 1996: Impact of in situ deforestation in Amazonia on the regional climate: General circulation model simulation study. *J. Geophys. Res.*, **101D**, 7095-7109.

Wilson, M.F., Henderson-Sellers, A., Dickinson, R.E., Kennedy, P.J., 1987: Sensitivity of the biosphere-atmosphere transfer scheme (BATS) to the inclusion of variable soil characteristics. *J. Clim. Appl. Met.*, **26**, 341-362.

Xue, Y., 1996: The impact of desertification in the Mongolian and the inner Mongolian grassland dson the regional climate. *J. Climate*, **9**, 2173-2189.

Zhang, H., Henderson-Sellers, A., McGuffie, K., 1996: Impacts of tropical deforestation. Part I: Process analysis of local climate change. *J. Clim.*, **9**, 1497-1517.

Zheng, N., Dickinson, R.E., Zheng, X., 1996: Climatic Impact of Amazon deforestation - A mechanistic model study. *J. Clim.*, **9**, 859-883.

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