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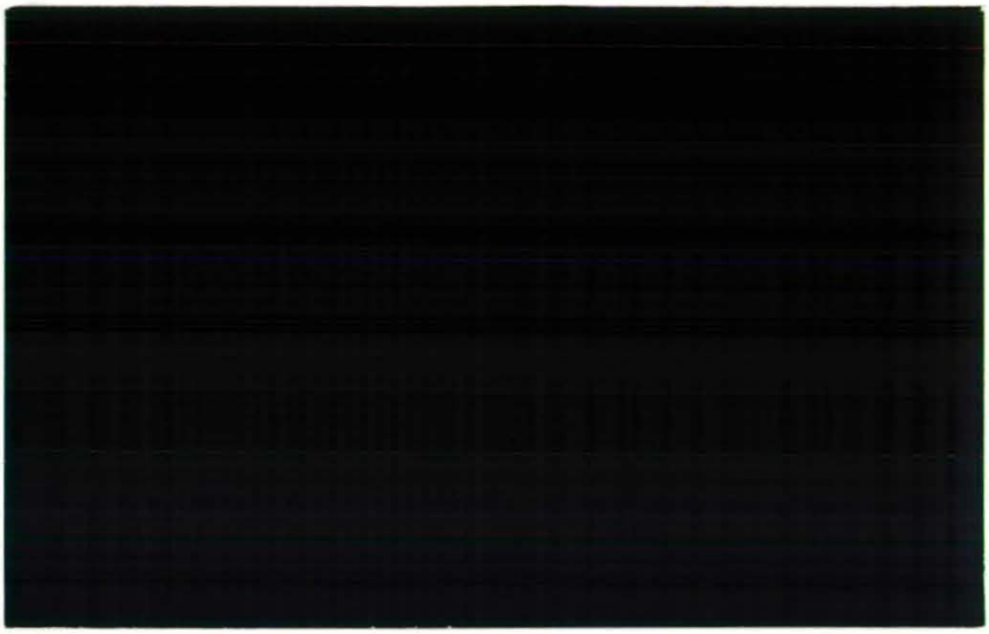

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A PRELIMINARY STUDY OF EVAPORATION FROM PARTIALLY WETTED MESO-SCALE AREAS

Progress report 1991 ALLIANCE project
Mesoscale modelling with spatially variable surface conditions.
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SUMMARY

Results of the initial phase of the Alliance project "Mesoscale modelling with spatially varying surface conditions" are described. A mesoscale model was used to simulate weather patterns on the 5th June 1986 during the HAPEX-Mobilhy experiment in south-west France. The model is capable of simulating realistically the structure of rainfall as occurred in the observations. Some differences are observed in the actual timing and location of the front. The results obtained by two sensitivity test suggest that the roughness length of the vegetation is important in determining the location of the front and that high evaporation rates from wet canopies may enhance rainfall through a positive feedback loop with atmospheric humidity.
The results of the model runs are of sufficient quality to be used in the next phase to develop averaging schemes for evaporation from partially wetted mesoscale areas.

INTRODUCTION

The present project aims to investigate the potential of meso-scale meteorological models in synthesizing area-average surface fluxes and near surface weather variables. Such area average descriptions are required in Global Circulation Models (GCM) which have a typical grid size of typically 250 by 250 km. Previous studies by André et al. (1989) and Bougeault et al (1990) have shown the usefulness of mesoscale models in providing area average descriptions of surface energy exchange in dry conditions. This study attempts to use a mesoscale model when the surface, or substantial parts of it, are wet as a result of precipitation falling in part of the (model) domain. The ultimate aim is to develop an aggregation scheme which reflects the subgrid distribution of precipitation and is sufficiently simple to be used in a GCM. To achieve this aim, the mesoscale model of the french meteorological service, PERIDOT, is used for a rainy day during the HAPEX-MOBILHY experiment in 1986. HAPEX-MOBILHY was an international meteorological experiment which took place in 1986 as part of the World Climate Programme and attempted to measure and model the energy and water fluxes over an area of roughly 100 by 100 km in the South-West of France (Figure 1). During this experiment surface fluxes and near surface weather variables were measured by a number of groups at several locations in the HAPEX grid square. The existence of such a database can be used to test the performance of the mesoscale model. A comparison between modelled and measured fields of meterological variables is a necessary first step in investigating the use of meso-scale models as synthesizing models for GCMs.

Within the special observation period, the 5^{th} of June was chosen for this study. Mahfouf (1988) and Mahfouf and Jacquemin (1989) showed that on this day, the evolution of a front in the mesoscale model was determined mainly by the lateral boundary conditions and was not much affected by the surface. This allows various sensitivity studies to be performed on this day as the location and amount of rainfall does not change much with changing surface properties. Figure 2 shows a series of Meteosat images showing a banded structure of the frontal clouds, which is fairly typical for this area. The cloud contrast results in strong differences in near surface conditions of radiation and wetness.

In section 2 the PERIDOT model, which is used to simulate this weather, is described, while in section 3 the available data is briefly described. Section 4 gives an overview of the synoptic situation on 5 June on the basis of satellite and ground based measurements. In sections 6 and 7 the modelled situation is compared with the measurements and the quality of the simulation is assessed in both the absolute sense and its usefulness for developing aggregation schemes for partially wetted GCM grid square areas. Some initial results from sensitivity tests are presented in section 7. In the final section some preliminary conclusions about the quality of the simulation are drawn and recommendations are made for the development of aggregation schemes using the model simulation.

2 DESCRIPTION OF THE MESO-SCALE MODEL PERIDOT

The model used in this study is PERIDOT, a finite difference hydrostatic model which uses the primitive equations with sigma (pressure) coordinates in the vertical. The 43 by 43 horizontal grids are roughly 10 by 10km. There are 30 grid points in the vertical with finer spacing near the surface: the first level is at 18m and the resolution in the boundary layer is approximately 100m. The lateral boundary conditions are linearly interpolated from a large scale analysis (Mahfouf and Jaquemin, 1989) and are updated every six hours.The radiation scheme calculates radiation flux divergence at every model level and subsequently modifies the temperature. The scheme also calculates the radiation at the surface by parameterizing the effects of the clouds: the fractional cloudiness is a function of the relative humidity and a critical humidity and is defined at low (between the ground and 2.5km), middle (between 2.5 and 7km) and high (between 7 and 20km) levels. The radiation at the surface is adjusted from these values. A weakness of the scheme is that it reduces the radiation at the surface by too much because the radiation scheme was designed for a low resolution (in the vertical) version of the present model. A modification was introduced so that a minimum radiation of 100 W m^{-2} reaches the surface at midday with a sinusoidal variation with time either side. There are two types of precipitation in the model. The large scale rainfall produced by a condensation scheme at the grid scale and the convective rainfall is modelled by a subgrid scale convection scheme. On the 5^{th} of June only large scale rainfall occurred. In the condensation scheme the temperature and specific humidity are calculated at all model levels. If the air is supersaturated the humidity is adjusted to the saturation value in one time step and the air is heated taking into account the release of latent heat. The condensed water is assumed to fall out as rain immediately into the grid below where it might be partially or totally re-evaporated if the air there is not saturated.

The scheme developed to model the surface-atmosphere interface ensures an energy balance between the incoming radiation and the heat fluxes going into the soil and into the atmosphere (latent and sensible). The water balance between rain, evaporation, transpiration and soil water flow is maintained with a storage on the leaves of the vegetation and the soil. These interlinking and complex processes are modelled with a relatively low number of variables; at each grid point there is a soil type, a vegetation type, the percentage cover of vegetation and the depth of the soil. The soil consists of only two reservoirs, each characterised by a temperature and a water content. The evaporation flux (which is found in both the energy balance and the water balance) is the sum of the evaporation from the bare soil and the evaporation from the vegetation cover, which consist of water which is re-evaporated after being intercepted by the leaves of the vegetation and transpiration from the plants. More details of the operation and implementation of this scheme can be found in Noilhan and Planton (1988) and Bougeault et al (1991)

3 AVAILABLE DATA

Goutorbe and Terrieu (1991) describe the HAPEX-MOBILHY database in some detail. The measurements which are used in this analysis are as follows. The energy balance was monitored at 11 sites using SAMER stations (Goutorbe, 1991). These stations measure the wind gradient, temperature gradient, net radiation and ground heat flux at 15 minute intervals. Using the aerodynamic method, the flux of sensible heat is calculated from the gradients and the latent heat flux is given as the residual of the energy balance. A critical evaluation of the accuracy of these measurements is given in Goutorbe (1991) A network of 18 PATAC (Prevision Ameliorée, Technique d'Affinement de la Climatologie) stations recorded rainfall, air temperature, relative humidity, wind velocity and solar radiation every 30 minutes. Radiosoundings were launched from Lubbon at 0, 6, 12, and 18 hrs GMT. The soundings extended from the surface to an altitude of 16 km. The vertical resolution of the soundings was 60 m. Recorded were pressure, temperature, humidity and wind speed. Infrared METEOSAT images are available at 7:30, 10:00, 13:00 and 15:00 showing the cloud cover at these times (Figure 2)

4 SYNOPTIC SITUATION OF 5 JUNE 1988

Cazalens and Sejourné (1987) describe the synoptic situation over the HAPEX square in France for June 5th 1986. At 500 kPa a depression extended from the North Sea to north Italy and a high, centred on the Azores in the Atlantic, reached up to Iceland. A NNW wind of 65 kt travelled along the isobars down through France. The situation at ground level was roughly the same with the depression centred over west Denmark, the high still over the Azores and a NNW wind through France. These pressure fields had been established on the previous day when a front passed over the HAPEX square producing only a small amount of rainfall (2mm). On the 5th it rained more heavily (6mm). The cold front arrived at the HAPEX square from the north at about 9am and travelled through the square until about 3pm. Infra-red METEOSAT pictures (Figure 2) show the movement of the front, starting at 7am with a line of convergence stretching from Ireland to the Landaise coast. By 10am the front had penetrated the Aquitaine basin and it subsequently moved south and east down to the Mediterranean. The pictures also show distinct bands of cloud running NW-SE at the Atlantic coast. This feature is usually characteristic of cold fronts and can be indicative of the presence of symmetric instability. By studying the data from the SAMER and PATAC stations the position of the front at any time is easily identifiable by the weather before and behind it: conditions before the front are moist, warm and cloudy with a fairly strong wind from the west whereas behind the front the air is cooler and dryer, the sky is clear and the wind is weak and from the north. Figures 3a, 4a and 5a showing the measured fields of radiation, wind and temperature at midday illustrate this point showing the front to lie roughly east-west about 2/3 of the way up the HAPEX square. The magnitudes of the temperature, wind and radiation are as follows. The temperatures measured at noon before the front had a gradient in the east-west direction with values around 14.5 °C in the west and 13.5 °C in the east. Above the line of the front the east-west gradient still existed, but the temperatures range from 13.5 °C in the west to 12 °C in the east. All but one of the wind vectors to the north of the front had a magnitude of less than 5 m s^{-1} while only 5 out of the 18 wind vectors below the front were less than 5 m s^{-1}. The increase in solar radiation reaching the surface after a cold front has passed is much slower. At 12am for instance the whole of the HAPEX square is clearly under cloud with values of global radiation at about 150 W m^{-2}. Further north however the sky is clear and the global radiation is about 400 W m^{-2}.

The time series of wind, humidity and temperature in figure 6a show the precise time that the front passed Lubbon, one of the SAMER sites: at 12am the wind drops from 5 m s^{-1} to 3.5 m s^{-1} the temperature drops from 14 °C to 11.5 °C and the humidity drops from 10 g kg^{-1} to 8.5 g kg^{-1}

simultaneously. Soon after, at 12:30 pm the net radiation increases rapidly from 100 W m^{-2} to 300 W m^{-2} and the rainfall stops. The same pattern of events (with roughly the same values) occurred at Courrensan (a site 15km further south) about 1:30 hours later, although there was also clear sky conditions at Courrensan in the morning until 10 am. The other sites do not show any of these characteristics. This is reasonable in most cases as the front does not pass these sites (with the exception of site 2 at Casteljaloux however). In the early morning the southern SAMER stations (3, 9, 10 and 11) and site 2 in the far north of the HAPEX square experienced clear sky conditions and the net radiation rose steadily between 6am and 8am. After this it dropped down to a mean cloudy condition of about 100 W m^{-2}. The other stations (except Lubbon and Courrensan) stayed at the mean cloudy condition of about 100 W m^{-2} throughout the day although the western stations had a slightly higher mean cloudy net radiation of about 150 W m^{-2} and showed evidence of only patchy cloud in the afternoon with peaks of net radiation up to 600 W m^{-2}.If the rainfall not produced by the front (i.e. the rainfall in the mountains and in the Basque region) is taken away from the total for 5th June (see Figure 7), we are left with a patch of rain in the north-east corner of the HAPEX square reaching 8mm and a band of rain oriented roughly NNW-SSE from Bordeaux to Sabres (SAMER station 6). The minimum total amount of rainfall in this band is 6mm and the maximum is 8mm. There is also a patch of high rainfall (maximum 8mm) just to the east of this band. The minimum rainfall for the area is 3mm apart from a small dry area north of Bordeaux. The time series of rainfall show that it started to drizzle throughout the area at about 5am. It stopped raining at the northern stations first however. By 3pm it had stopped raining everywhere except in the hills.

5 MODEL RESULTS

A model run was executed with realistic land surface conditions to assess the capability of the model to simulate the complex pattern of front movement and precipitation. The parameters describing the surface (roughness length, leaf area index, percentage of vegetative cover, soil texture and initial soil water content) were taken from maps and measurements of the area (see Bougeault et al., 1991a, 1991b and Noilhan et al. 1991a and 1991b for more details). Figure 1b shows a map of the vegetation in the area. Initial comparisons of the model with the data show that the passage of the front in the model is late by a few hours so that it only reaches the top of the HAPEX square from the north by 10am instead of 9am and the observed position of the front at 12am is not achieved in the model until 2pm. It is also positioned too far to the east, so that while the observed front at 12am stretches from the Atlantic coast to the Massif Centrale, the modelled front starts some 10km inland from the Atlantic (see the modelled wind field at 12am in Figure 4b). This is probably due to the poor quality of the data used for the lateral boundary conditions. Despite the mispositioning (too far east) and the mistiming (too late) of the front however the model shows some degree of realism. The radiation before the front is low, about 100 W m^{-2} at 12am and behind the front the cloud begins to clear in patches with values reaching up to 600 W m^{-2} (Figure 3b). The modelled wind is a 5-10 m s^{-1} westerly before the front and a much weaker northerly behind it (Figure 4b). The temperatures at 2m are also well represented at 12am (Figure 5b): before the front the temperatures vary from 14.5 °C by the atlantic to 13.5 °C on the east edge of the HAPEX square as with the observations. Behind the front the temperatures drop to 13.0 °C above the west edge of the square and have a sharper gradient than the observations, falling to 11 °C above the east edge as opposed to 12 °C. The one bulk property that was observed but not simulated was the high radiation in the early morning over the southern part of the square. This is probably due to a weakness of the radiation scheme employed. The radiation scheme was designed for a model with a lower vertical resolution, and tends to decrease the radiation in the presence of clouds by too large an amount. Rain was also recorded during this period so some clouds must have been present and in this case the model reduces the radiation everywhere.

The most difficult parameter to model well is rainfall. The bulk of the rain from the front fell further east than observed (see Figure 7). This is consistent with the convergence of the wind fields also being too far east. The model predicts the early morning drizzle over the whole area and the stopping of the rain between 12 and 3pm depending on the latitude. The amount of modelled rainfall seems to be similar to that observed. A feature which the model simulated particularly well are the rain bands observed to lie in a NE-SW direction. Figure 8, which shows a contour diagram of water stored on the leaves of the vegetation, shows evidence of the rainbands in the model with the same alignment and the same length scale. These bands can also be seen in the fields of temperature, wind, humidity and rainfall.

It can be concluded that the model is capable of simulating realistically the overall aspects of a moving front although in detail there are some differences between the model results and observations. For the present purpose however, this is not of crucial importance, and the fact that the patchy structure of rainfall is so well predicted makes this run especially suitable for testing and developing aggregation schemes.

6 MODEL RESPONSE TO SURFACE ENERGY EXCHANGE

A perfect simulation of the actual weather on June 5th is not required but a realistic rainfall event with the accompanying variations in net radiation and wind speed. The comparisons described above show this criterion is easily met with the present simulation. However, the model response to the rainfall event in terms of surface energy balance is very important.

Unfortunately in non-clear conditions this is difficult to test as the response is very sensitive to cloud cover, the wetness of the vegetation and the wind speed. Although these variables are represented reasonably well on average the timing is not perfect so a comparison of modelled and measured evaporation rates shows considerable differences. Although there are some discrepancies, the model produces very interesting regional variations in the field of evaporation (see Figure 9). There is strong transpiration occurring in the north of the domain where the clearing of the sky has allowed the vegetation to dry out, and where the stomatal resistance of the vegetation in the area is low. In the Landes forest however the transpiration is low because of the extensive cloud cover and the low fraction of the canopy which is dry and allowed to transpire, while the evaporation is high because of the high wind, the wetness of the vegetation and the high aerodynamic resistance of the trees. Since the net radiation is low the sensible heat flux is negative over this area to maintain an energy balance. This has been observed before (Stewart, 1977). To the south of the forest, are crops which have a much lower vegetation cover than the forest. The sky is still cloudy so there is no transpiration but the 100 W m^{-2} of evaporation are provided equally by evaporation from the wet leaves and from the bare soil. Each of these processes is taken into account in the surface scheme (Noilhan and Planton, 1988).

7 OTHER MODEL EXPERIMENTS

The weather as simulated on June 5th is the result of the interaction of the large scale forcong of the atmosphere and the atmosphere and the underlying surface. To be able to determine the effect of the land surface on the simulation two further experiments were executed where the surface in the model domain was replaced by complete forest cover and complete grassland cover. Forest has a high roughness length, high leaf area index and high percentage of vegetative cover and therefore high storage of intercepted water and high minimum stomatal resistance. Grassland has on the contrary a low roughness length, medium leaf area index and percentage of vegetative cover and consequently medium storage of intercepted water and low minimum stomatal resistance. These experiments serve a double purpose. They allow the important parameters in the land surface atmosphere interaction to be identified and provide new mesoscale conditions on which to test the aggregation schemes. Some preliminary results will be presented below.

Initial comparisons of the results of these simulations with the control run shows that the surface has a slight effect in changing the position and amount of rainfall. These effects have not yet been fully quantified but it appears that the rougher surface slows down the wind and therefore the rain falls in a slightly different place. Since the wind direction changes with position in the domain, the change in position of the rainfall is not uniform. There appears also to be a positive correlation between the rainfall and the quantity of water held on the leaves of the vegetation. This could be due to a feed-back mechanism of an increased atmospheric humidity in the presence of water at the surface. Figure 7 shows contours of water stored on the leaves at 13:00 hrs for the control run and the two sensitivity runs. In all cases the water has been evaporated in the far north of the domain (where transpiration is now taking place) and there is still some water left on the vegetation in middle of the domain. The variation of the water stored in the control run is however not just a function of the atmospheric forcing, but also of the variation in vegetation type and amount of bare soil. The two sensitivity runs have almost identical patterns of water storage although the magnitudes are different.

These initial comparisons show two important features. First the vegetation can influence the position of the rainfall, and secondly, the amount of rainfall may also be influenced by the vegetation. The last observation corroborates the findings of André et al (1989) who reported a similar phenomenon.

8 DISCUSSION AND FURTHER RESEARCH

The results obtained sofar indicate that the PERIDOT model is capable of simulating a realistic passage of a front. The prediction of rainfall in a banded structure agrees well with the observations and increases confidence in the ability of mesoscale models to cope with increasingly complex weather phenomena.

The results of the three model runs can now be used to develop aggregation schemes for evaporation from partially wetted mesoscale areas. The strategy for this is to identify target squares in the model domain and to apply several averaging schemes currently under development at the Institute of Hydrology, to calculate evaporation from these squares. A 1-D version of the 3-D mesoscale model, forced by advection obtained from the 3-D model, will be used to obtain the best averaging operator.

9 ACKNOWLEDGEMENT

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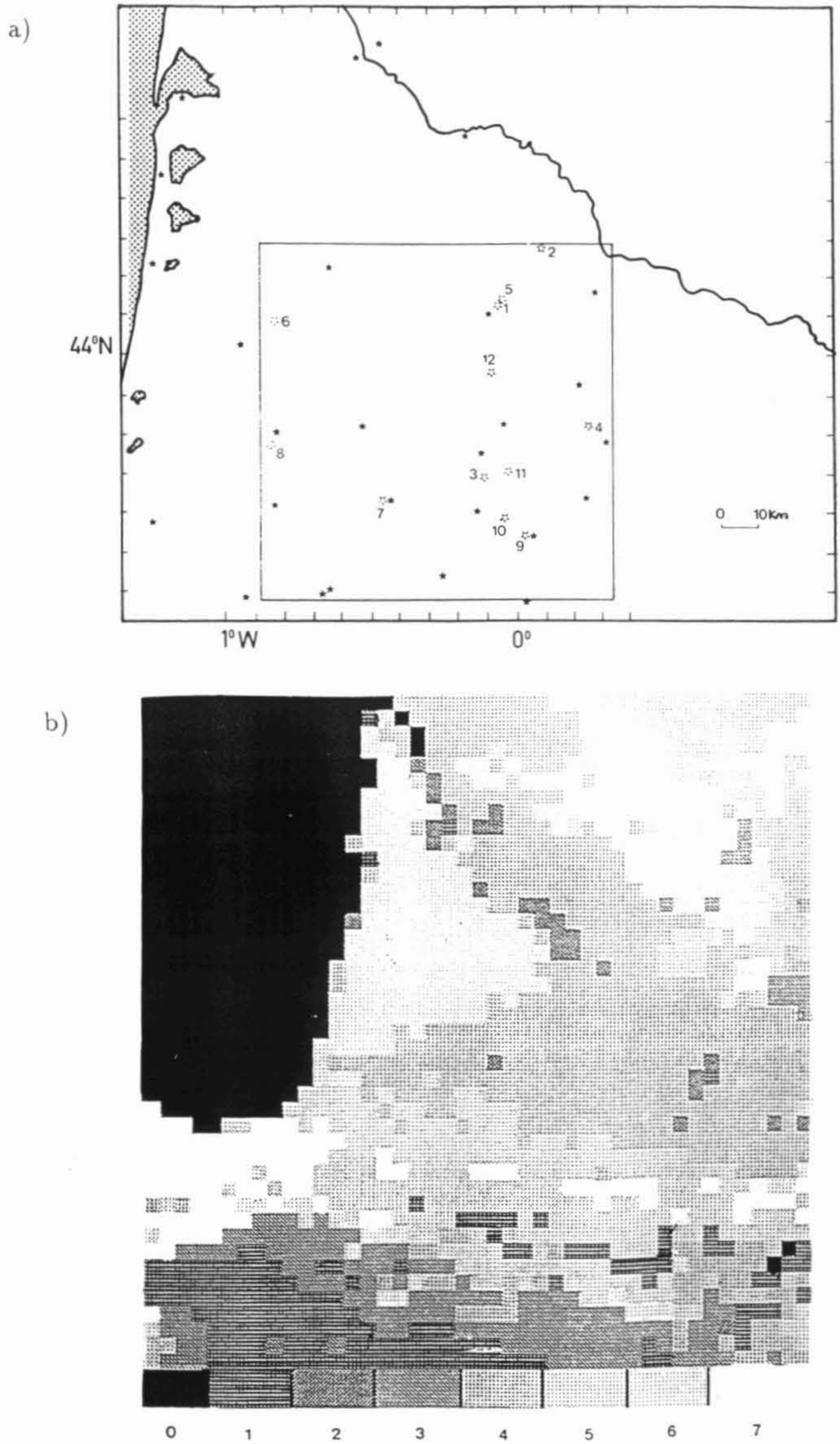


1: semi-desert; 2: vineyards; 3: mediterranean vegetation; 4: cereals; 5: grasslands; 6: coniferous forest; 7: deciduous forest.

Figure 1 a) Geographical location of HAPEX-MOBILHY programme. Open stars; SAMER stations, full stars; PATAC stations.
b) Map of vegetation types used in the model.

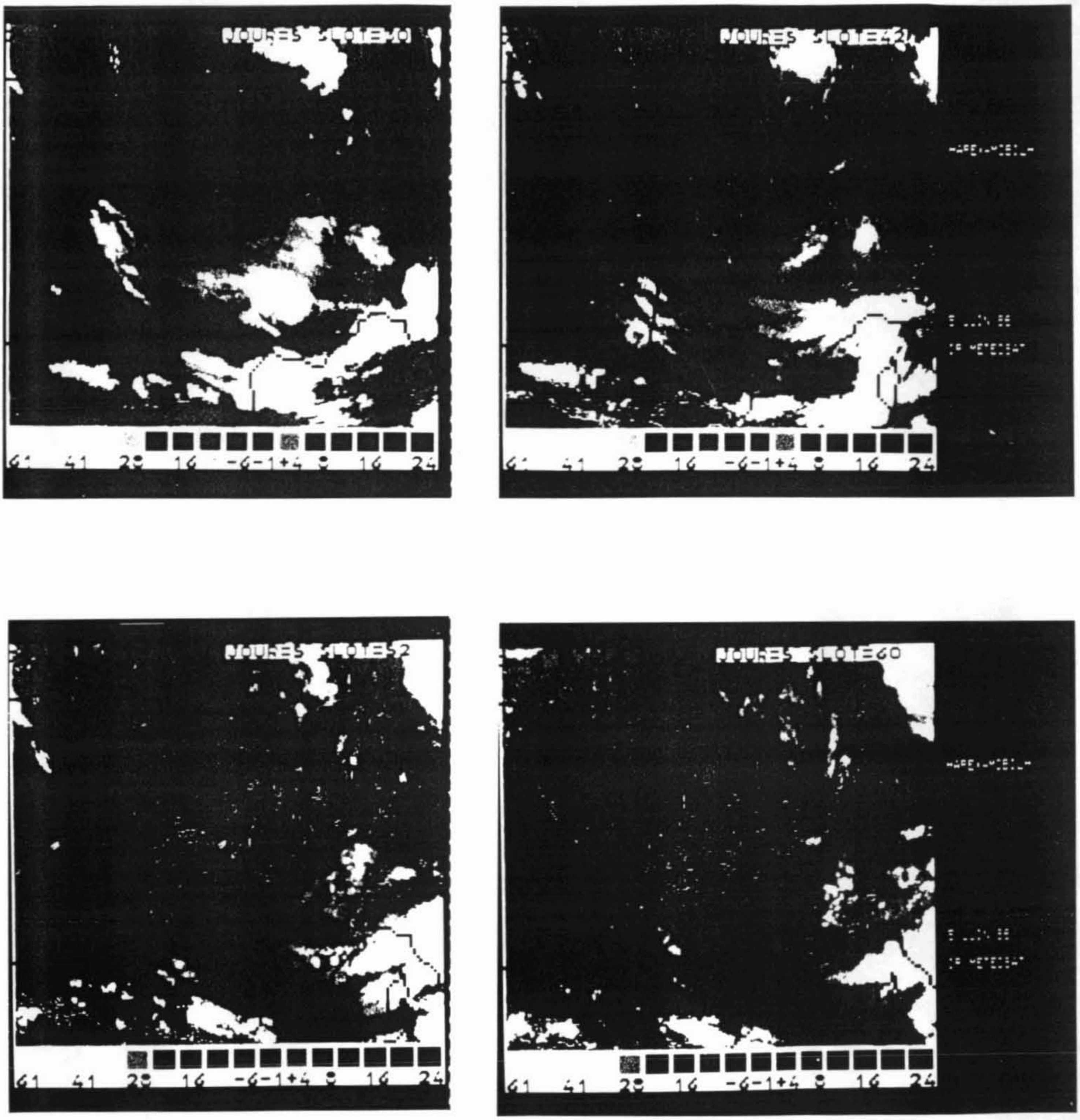


Figure 2 METEOSAT infra-red images taken on June 5th 1986.
a) 7:30 am b) 10:00 am c) 13:00 pm d) 15:00 pm.

a) b)

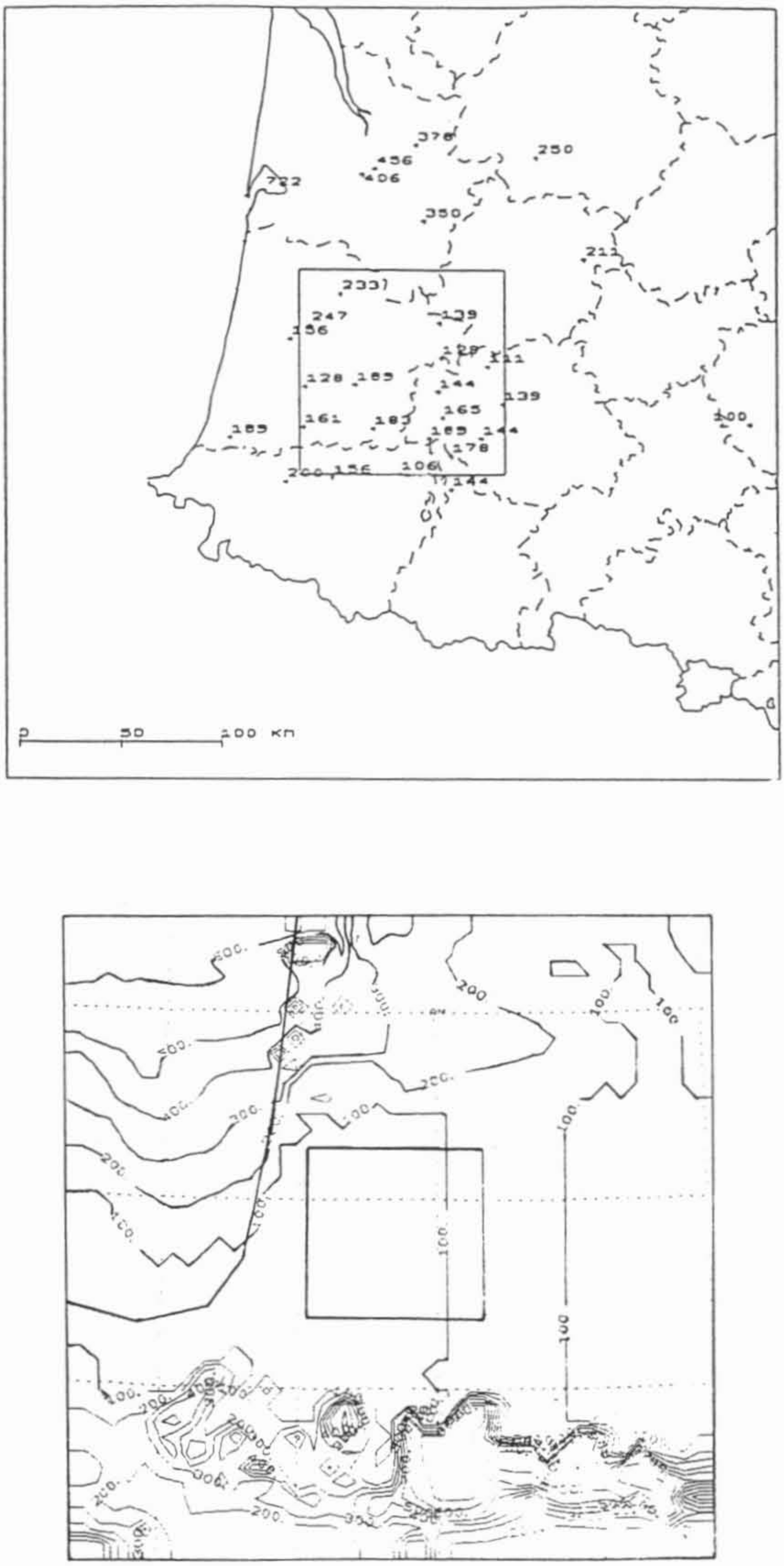


Figure 3 a) Measured values of radiation at 12:00 am in W m^{-2}

b) Contours of modelled radiation at 12:00 am in W m^{-2}.

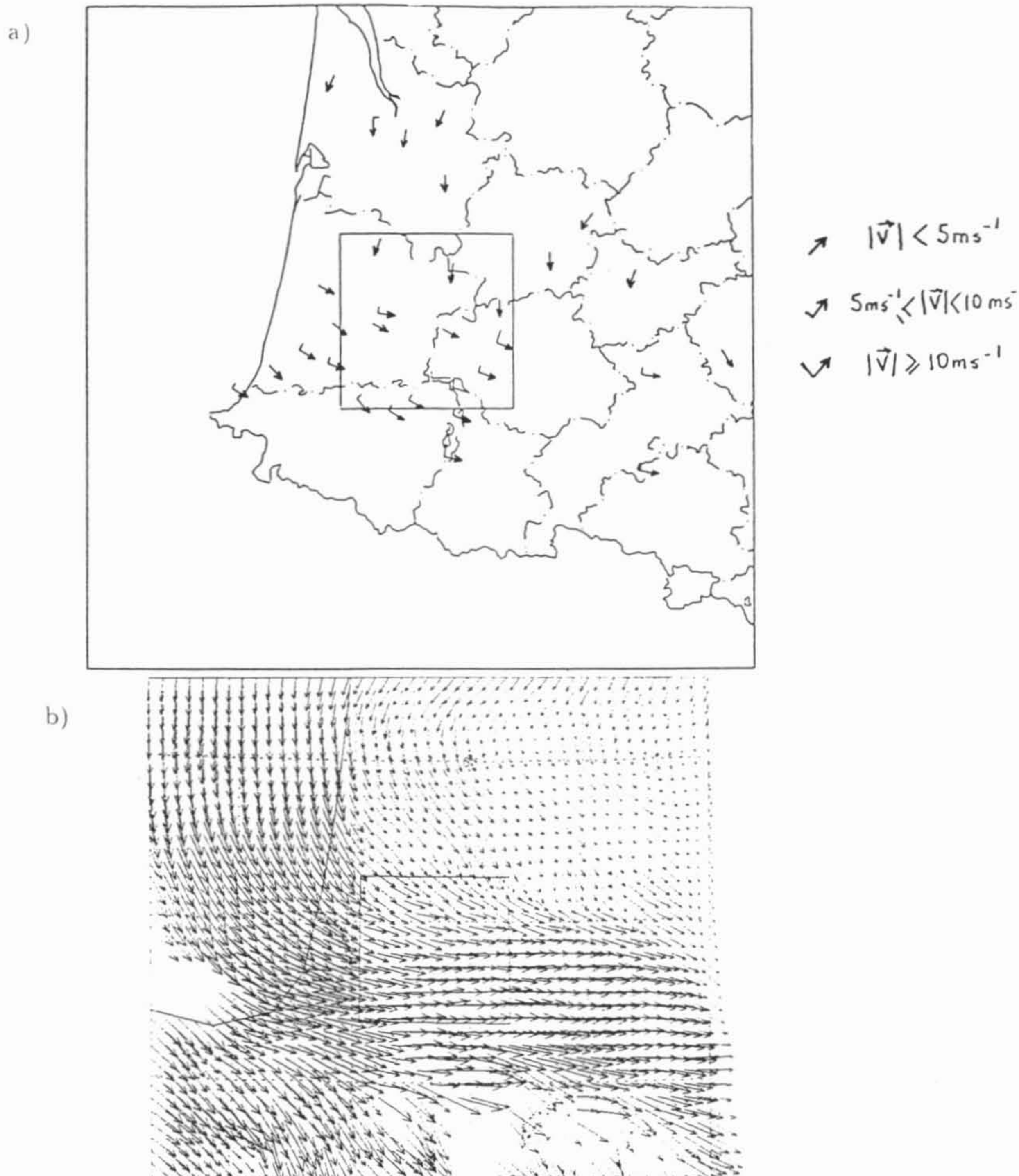
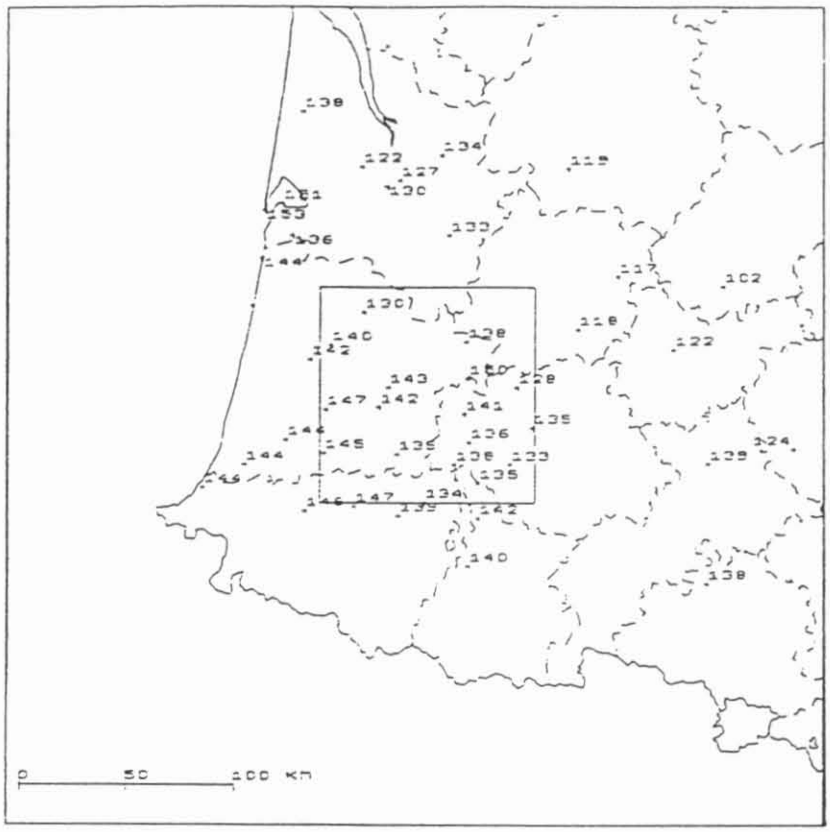


Figure 4 a) Measured values of wind at 12:00 am
b) Modelled wind field at 12:00 am.

a)



b)

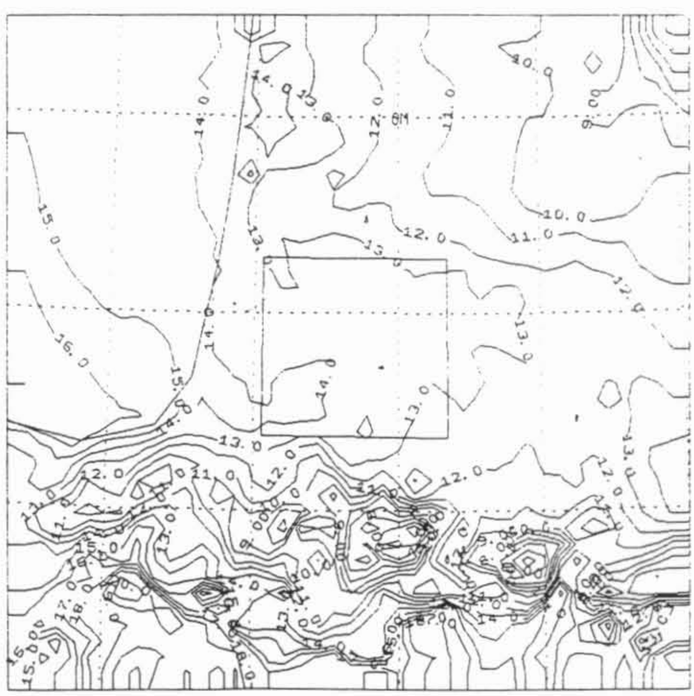


Figure 5 a) Measured values of temperature at 12:00 am in 0.1°C
b) Contours of modelled temperature at 12:00 am in °C.

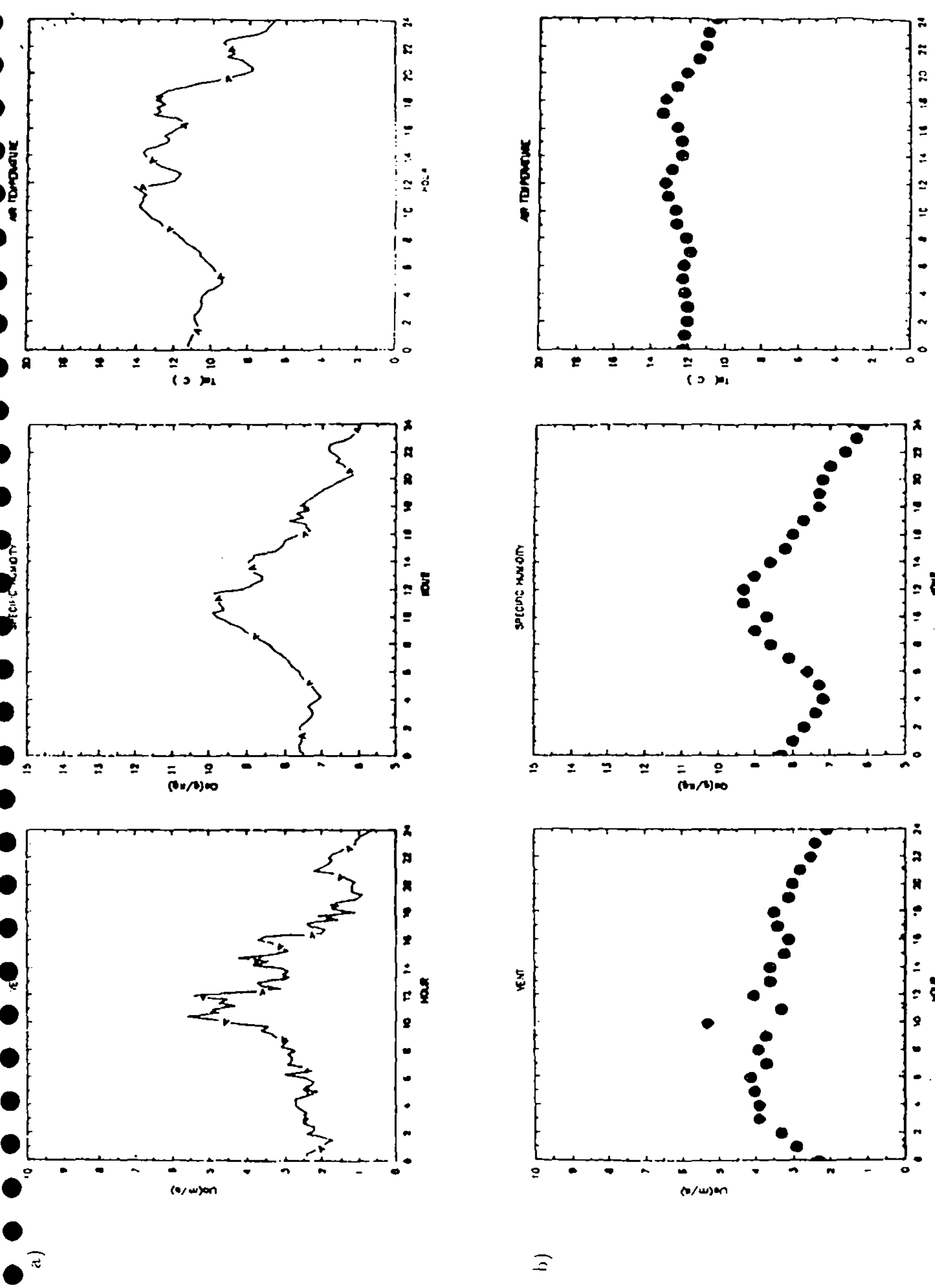


Figure 6 a) Time series of wind speed, humidity and temperature measured at SAMER site, Lubbon
b) Modelled time series of wind speed, humidity and temperature at Lubbon.

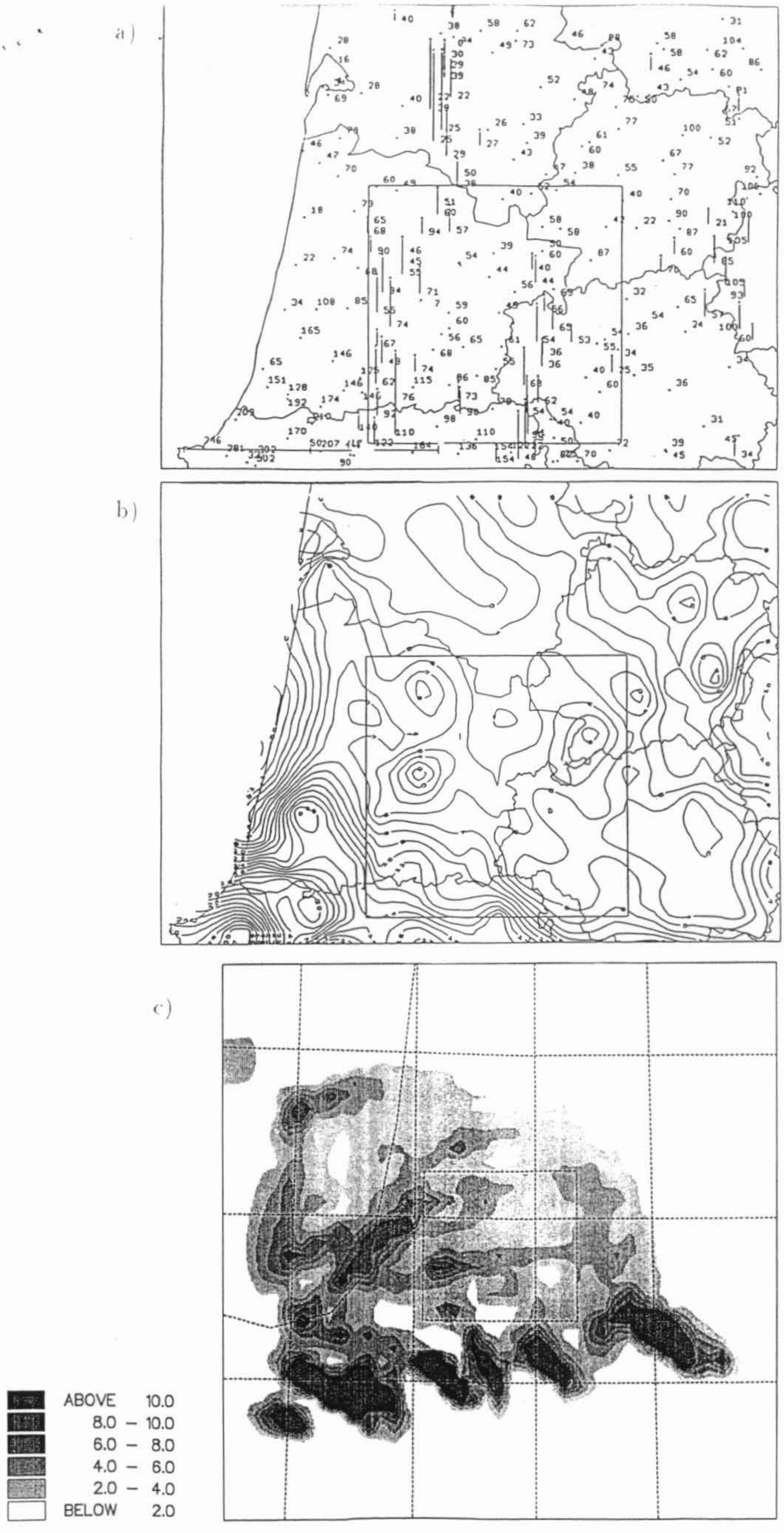
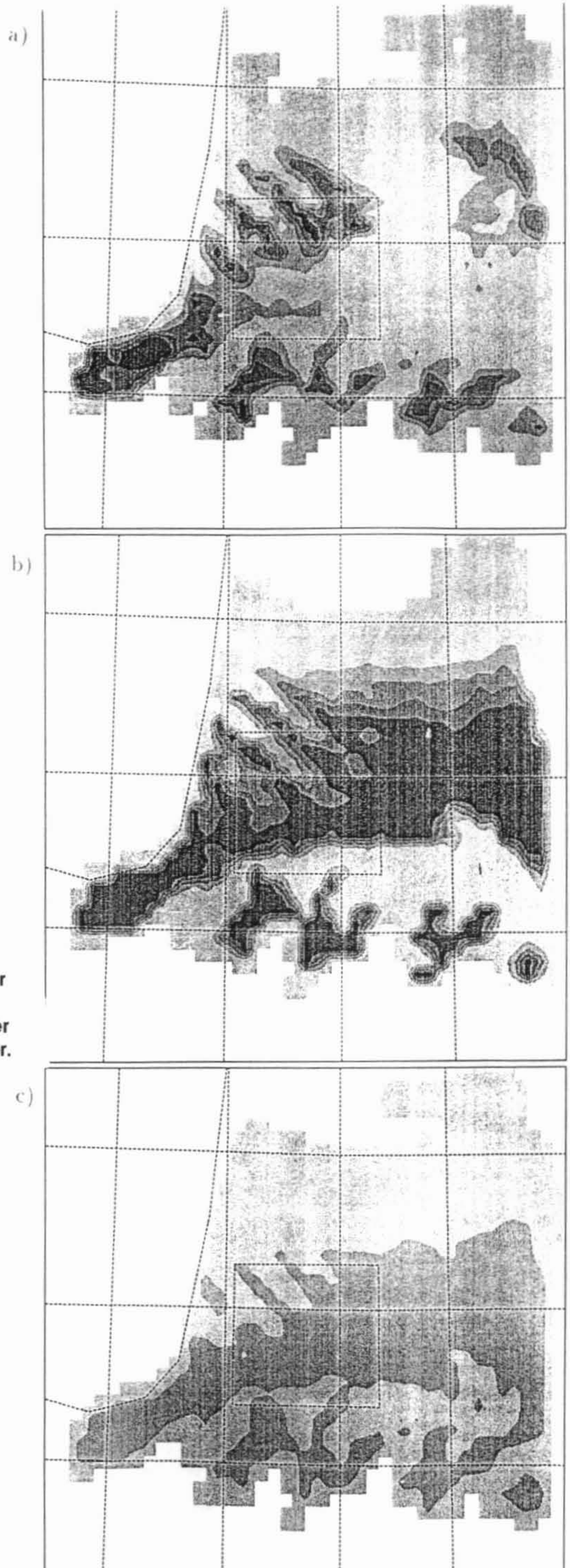
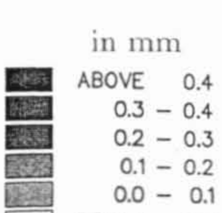


Figure 7 a and b) Total rainfall measured over 24 hours from 6 am on 5/6/85 to 6 am on 6-6-86 in 0.1mm
c) Total rainfall modelled over 24 hours on 5/6/85.





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Contours of intercepted water
control run at 13:00 pm
sensitivity run with forest cover
sensitivity run with grass cover.

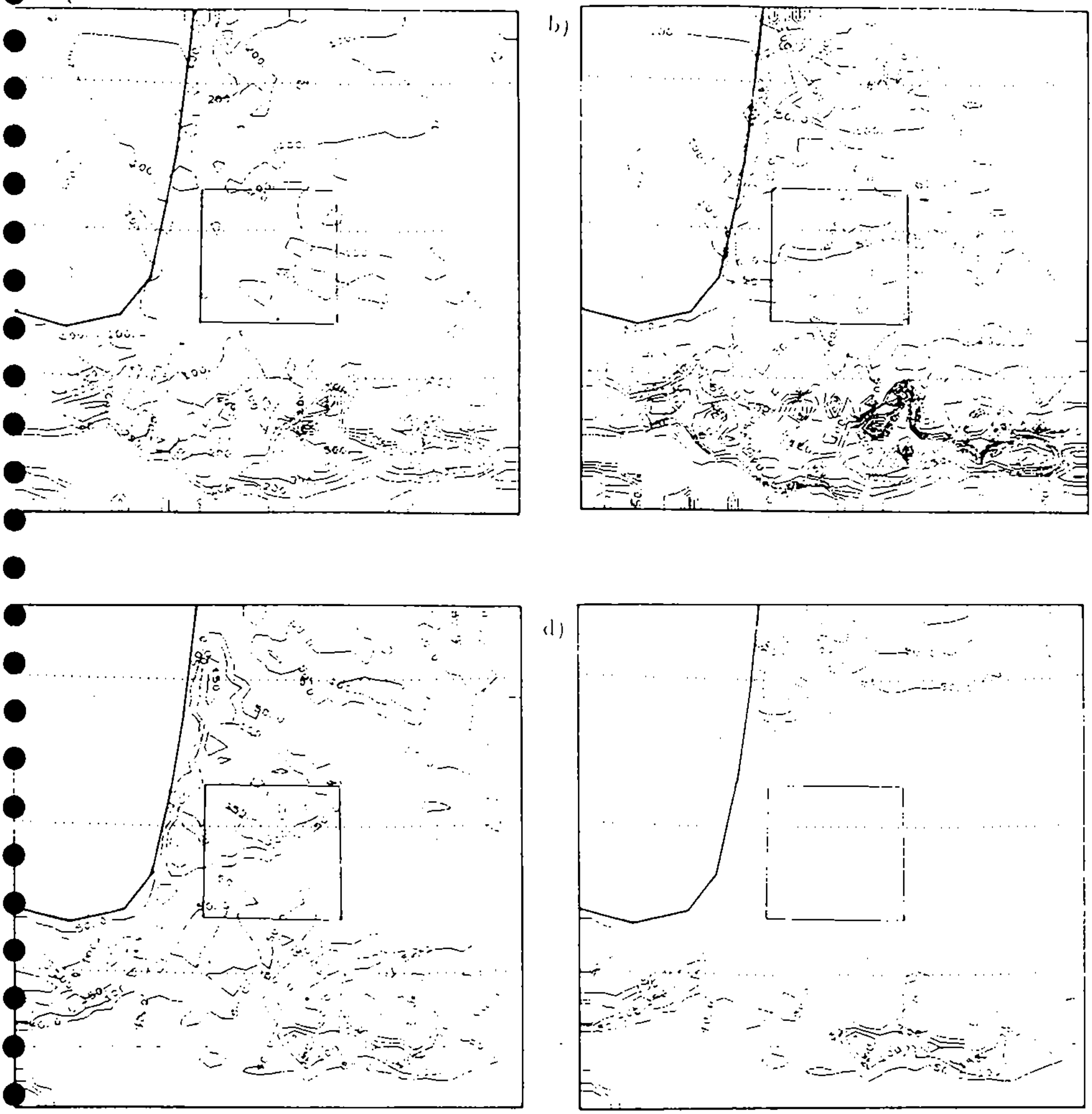

Figure 9

a) Contours of modelled latent heat at 12:00 in W m^{-2}
b) Contours of modelled latent heat from bare ground at 12:00 in W m^{-2}
c) Contours of modelled latent heat from evapotranspiration of vegetation at 12:00 in W m^{-2}
d) Contours of modelled latent heat from transpiration of vegetation at 12:00 in W m^{-2}.

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