Flux estimation with the MESONH model over the Alpilles.

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ABSTRACT - 3D models tend to account for surface processes with more and more accuracy to reproduce realistically meteorological events and climatological patterns. With the increasing satellite imagery resolution, identification of smaller areas with a well-pronounced contrast is a straightforward task. We have used such a model: MesoNH with a high spatial resolution (50m) to estimate surface fluxes over the Alpilles area. The land surface parameterisation schema used in MESONH is the ISBA model. All the surface parameters were provided from remote sensing data acquired during the experiment in 1997 at a high resolution (20m). Albedo, LAI and vegetation fraction were derived from the POLDER images. Simulations were done for the days where radio soundings were acquired over the site every 2 hours for two periods in April and June 1997. The simulated fluxes are strongly correlated to the surface parameters, as expected. Their large variability on the whole area is well reproduced by the model and is in accordance with the measurements. We have compared MESONH-simulated temperatures against remotely sensed temperatures acquired with the airborne thermal infrared camera INFRAMETRICS 760 and observed a good agreement between images and simulations. Instantaneous values estimated at 2m above the surface showed coherent structures due to the turbulence, which disappeared when the values were averaged at hourly scale. It was the first time that such structures are observed at this scale. The simulation performed at 50m with MesoNH provided more realistic lower boundary conditions to land surface schemes, which can help to improve the numerical simulation of the atmosphere.

1 INTRODUCTION

The evolution of Agriculture during these last years, such as irrigation of large areas or deforestation modifies not only the landscape but also the regional climate (De Ridder et Gallée, 1998). Numerous studies have shown the effect of the different surfaces on the atmospheric circulations (Segal \textit{et al}, 1988, 1998). But until now, most of them dealt with large spatial scales (>100km\textsuperscript{2}) using 3D atmospheric models where the various surfaces were represented with a grid mesh rarely below 200m, most of the time around 1km. At this spatial scale, it is not possible to consider the crop variability, which can present high contrasts, and consequently induce important variability in climate. This is particularly the case in the agricultural regions in the South East of France where the fields are often small but very contrasted with irrigated crops beside dry wheat or orchards. With the increasing resolution of pixel, remote sensing can provide useful information to identify the different types of crops.

- The aim of this paper was to show the influence of the different cultivated surfaces characterized by remote sensing data, on the variability of the air temperature and energy fluxes for a small region (<20km\textsuperscript{2}). For this study, we worked with a 3D atmospheric model called MESONH (http://www.mesoos-mipfr-mesonh) usually applied to large areas (>1000km\textsuperscript{2}). It was the first time that this model was used at a so fine spatial resolution (50m for the horizontal grid mesh to describe better the different crops). The input data were derived from different remote sensing data (POLDER, SPOT).

- The second aim of this study was to validate MESONH for this situation. We used the Alpilles – Reseda dataset (http://www.avignon.inra.fr/reseda/) corresponding to an intensive experiment, which took place in 1997 on a small area in the South East of Avignon. A lot of data were available both to calibrate and validate the model. We have analysed in particular the infrared thermal images acquired by an airborne camera during flights performed all along the experiment.
The next paragraph will present the main characteristics of this site and the measurements used, then a brief description of the model MESONH will be made. We will explain the different options chosen for the implementation to simulate the Alpilles area. Lastly, we will show the first results obtained for some days simulated and the comparison with ground measurements. A discussion about the turbulence will close this paper.

2 SITE AND DATASET

The Alpilles area is located around 30km South-East of Avignon. It is a flat area of 4 x 5 km, chosen for the ReSeDA project because of various types of crops and the field size was large enough (~4ha) for remote sensing studies. The aim of the project was to provide a substantial dataset for assessing crop and soil processes from remote sensing data in order to propose methods to estimate net primary production, evapotranspiration and crop yields (Prevot et al, 1998). A lot of ground measurements were acquired over the year 1997: micrometeorological stations were set on seven fields (mainly wheat but also sunflower and alfalfa). The evolution of soil moisture and vegetation structure (LAI, crop height) was monitored during the crop cycle (details can be found in Olioso et al, 2002). Different types of images were collected covering all wavelengths and for different spatial resolutions using space borne sensors (NOAA, SPOTERS, RADARSAT) or airborne ones (IRT camera inframetrics 760, POLDER, ERASME). A specific part of the experiment was dedicated to the spatialization of surface processes (mapping) and to scaling (Olioso et al. 1998). In this frame, a CNRM team performed radio soundings in April and June every two hours from 4:00 am to 20:00 pm.

We have chosen to simulate precisely two days in each of these two periods (16,18/4; and 10,12/06/1997), because these days corresponded to different stages for crop development and at different climatic conditions (figure 1). In April, it was after a long dry period without rain, the soil surface was dry. Sunflower was recently sown and very low, like bare soil for some fields. Wheat was already grown and well green with a leaf area index (LAI) around 1-2 at 60 cm for crop height. The spring was exceptionally dry in 1997, so in June, sunflower (which was not irrigated) growth was very irregular for most of the fields, with sparse flowers. Wheat was dry, ready to be harvested. At this time only irrigated grasslands or alfalfa had not suffered from the water stress and showed green surfaces.

Figure 2 and table 1 show the main climatic characteristics of the four days studied. The highest thermal contrast between surface and the atmospheric layers above was observed for the 18/4, where the wind speed was low, the sky very clear, while for the 16/4, there was a very strong wind from the north. The two days in June were partially covered by clouds.

![Figure 1. Rain and wheat LAI evolution during the Alpilles experiment. (The vertical dotted lines corresponded to the radio soundings performed by the CNRM and to the 4 days simulated with the 3D model, 16&18/04 and 10&12/06).](image)

<table>
<thead>
<tr>
<th>Days</th>
<th>Wind direction (degree)</th>
<th>Wind speed At 2m (m/s)</th>
<th>Air temperature at 12h (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16/4</td>
<td>360 N (strong mistral)</td>
<td>6</td>
<td>17.6</td>
</tr>
<tr>
<td>18/4</td>
<td>30(weak windy, clear sky)</td>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>10/6</td>
<td>250 NE (cloudy windy day)</td>
<td>6</td>
<td>29</td>
</tr>
<tr>
<td>12/6</td>
<td>340 N (sparse clouds)</td>
<td>0.6</td>
<td>28.6</td>
</tr>
</tbody>
</table>
3. MESONH MODEL

This model has been developed since several years by different teams, mainly by the CNRM and the LA1 from Toulouse and is still evolving, in particular on the atmosphere chemistry part. It is a non-hydrostatic atmospheric model, which means no assumption on vertical wind speed gradients is made. Its complete description can be found at the following address: http://www.aero.obs-mip.fr/~mesonh.

It allows simultaneous simulations of several scales by the so-called interactive grid nesting. It allows also for the transport and diffusion of passive scalars to be coupled with a chemical module. This model is applicable from large (synoptic) to small (eddy) scales, but most of applications were on large scale (>200m).

There are different ways to use it according to the spatial and temporal scales. The model can simulate the cloud formation and takes into account orography and lakes. The different stages of water (ice, liquid water and vapour) can be chosen by options, as the turbulence schemes according to the scale (1D, 3D).

The radiative scheme comes from the ECMWF2 and calculates the radiative fluxes (direct, diffuse components for long wave and short-wave ranges).

The surface interacts with the atmosphere via the energy fluxes applied at the base of atmospheric layers. By providing more realistic lower boundary conditions, land surface scheme can help to improve the atmosphere simulation.

3.1 The surface scheme

Here the land surface scheme is ISBA initially described by Noilhan and Mahlouf (1996), then completed by different authors, among them, Calvet et al (1998) for the stomatal resistance. ISBA simulates the surface fluxes and the evolution of surface variables using the force-restore method of Deardorff (1978). There are 5 prognostic equations for deep soil temperature ($T_2$), deep soil water content ($w_2$), surface temperature ($T_s$), soil water content ($w_g$), and interception water storage ($w_r$). The main surface parameters involved in the flux computation are the canopy albedo, the canopy emissivity, the momentum and thermal roughness ($z_0$ and $z_0h$), LAI, and the stomatal resistance ($r_s$). Several models are proposed for the calculation of $r_s$ (Jarvi’s model, or Jacob’s model accounting photosynthesis). Only one energy balance is considered for the whole system ground vegetation. Latent heat flux is obtained by the sum of the evaporation of liquid water from both the soil surface ($E_g$) and vegetation ($E_v$). $E_v$ is computed using classical equations, where $v$ is the fraction vegetation cover derived from LAI, $h$ is the exchange coefficient depending on stomatal ($r_s$) and aerodynamical resistances ($r_a$).

$$LE=LE_g+LE_v$$

$$Ev=vpaCHhv[gsat(Ts)−qa]$$

$$h_i=(1−δrs/(rs+ra))+δ$$

δ is a power function of the moisture content of the interception reservoir (Deardorff, 1978).

3.2. Implementation of the model to simulate the Alpilles area.

A good representation of land surface characteristics is necessary to reproduce real climatological patterns. Most of input data have been derived from remote sensing data acquired on the site at a fine spatial resolution (20m). They are summarized in the table 2.

- LAI and veg were computed from POLDER images, acquired by an airborne sensor at 3000 m above the surface (spatial resolution 20 m). First hemispherical and nadir reflectance at 443, 550, 670 and 865 nm were computed by inverting the Walthall kernel-driven model over the POLDER multi-angular data set (Jacob et al. 2002a). Next LAI and veg were calculated by feeding a Neural Network (NN) using nadir and hemispherical reflectance estimated in the POLDER

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channels. The NN were previously calibrated over a database simulated with the SAIL model for a wide variety of crops and LAI as proposed by Weiss and Baret (1999). Validations were performed mainly on wheat by Weiss et al. (2002). The estimation of veg gave generally good results. LAI was slightly less good, but let us notice that the measurements of LAI were also debatable according to the various wheat fields. Nevertheless LAI estimation could be considered as reliable for our application.

- Visible and Near Infrared albedos were calculated by Jacob et al. (2002b) as linear combinations of POLDER hemispherical reflectances ($\rho$) using coefficient sets proposed by Liang et al., (1999).

$$\alpha_{vis} = 0.3511 \rho_{blue} + 0.3923 \rho_{green} + 0.2603 \rho_{red}$$

$$\alpha_{nir} = 0.6088 \rho_{red} + 0.1442$$

The other surface parameters like emissivity, roughness (z0veg) and parameters linked to the computation of the stomatal resistance ($\gamma$, rgl, rsmin) were derived from the land use map obtained from SPOT images. Values were assigned to each crop type according to its development (crop height and season).

All these surface parameters were provided as 2D maps at 20m resolution to the MESONH model which made then its own spatial interpolation according to the grid mesh defined (50m in our case) and to the geographical projection used (here degree, min for latitude and longitude).

The Alpilles area was represented by a box of 100x100 horizontal meshes of 50m and 31 vertical levels from 2 m from the surface to 4000 m altitude, the first levels being squeezed near the surface (5m). It has to be noticed that it was the first time that this model was used at a so fine resolution, and this was possible because of the input dataset of Alpilles. Also, due to this fine spatial resolution, the turbulence scheme must be the Large Eddy Simulation (LES) mode, that means, the mixing length depended on the mesh size. The time step must also be short. We have chosen 1 second.

Simulations were perfumed for 4 days initialised by a radio sounding measured at 10:00 am. The boundary conditions were cyclic. Neither grid nesting, nor nudging was used. We simulated 4 hours (from 10:00 to 14:00) without injecting atmospheric data like ARPEGE profiles. The model ran alone for 4 hours on a super computer at IDRIS (Institut Du Développement et des Ressources en Informatique Scientifique, ORSAY). One simulation lasted around 5 hours.

### Table 2. Different remote sensing data sources used to derived input parameters for MESONH

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Sources</th>
<th>Model/ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible albedo</td>
<td>POLDER</td>
<td>Liang et al., 1999</td>
</tr>
<tr>
<td>Near infrared albedos</td>
<td>POLDER</td>
<td>Jacob et al., 2002b</td>
</tr>
<tr>
<td>LAI</td>
<td>POLDER</td>
<td>Weiss et al., 2002</td>
</tr>
<tr>
<td>Veg=(1-F0)</td>
<td>SPOT land use map</td>
<td>Values according to land use classes (bibliography)</td>
</tr>
<tr>
<td>Z0veg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Z0h</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emissivity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stomatal resistance min</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\gamma$, rgl, rsmin</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CV</td>
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<td></td>
</tr>
</tbody>
</table>

4. RESULTS

MESONH allows different types of outputs: instantaneous variables as 2D maps of temperature at each atmospheric level, wind speed (vertical and horizontal components),... surface fluxes, or mean values of these same variables averaged for one hour. We can also extract vertical maps anywhere on the simulated area or atmospheric profiles for each variable.

4.1. Validation of the model

In a first time, we have analysed the 2D maps of the main energy fluxes at the surface ($R_n, G, H, LE$), and extracted the mean values for each field where micrometeorological measurements were performed in order to compare simulations to observations. Figure 3a and b shows the good correlations obtained for both the net radiation and latent heat flux on the 18/4/97 at 12:00am. High values (around 300W/m²) were observed for alfalfa (n°203) and wheat well irrigated (field 120) and the lowest values (100W/m² see figure 4) corresponded to sunflower or cornfields, which were like bare soils at this period. Wheat fields presented great variations between 150 to 250W/m², some ones were sown in spring (n°214) and less developed than others irrigated (n°120) or sown in November (n°101).
The comparison of the surface temperature simulated by MESONH to the thermal infrared image acquired by the inframetrics airborne camera gave also satisfactory results (figure 4b and c). High temperatures (in red) were observed for bare soils, and low values (in blue) for surfaces well supplied in water.

4.2. Turbulence phenomenon at fine spatial scale

For the clearest days with weak wind (ex:18/4), the map of instantaneous LE was well correlated with the surface parameters like LAI and veg, and the fields were well identified with clear shapes. While for windy or cloudy days (16/4, 10-12/6), these field boundaries were less visible on instantaneous maps, particularly for air temperature map, which seemed to be not correlated to the surface heterogeneity. For these situations, field boundaries could be recognized only on hourly averaged maps (Figure 5). The instantaneous values seemed to be particularly influenced by the vertical wind speed. At 2m above the surface, air temperature seemed to be already mixed with the above atmospheric layers. A vertical cut of the vertical wind speed (w) in the middle of the simulated area showed positive and negative values between 150 and 1500m (figure 6a). These patterns were observed for all days simulated and indicated that small convective cells appeared in the surface layer. The wavelength of these structures seemed to be in order of magnitude of the simulated area, e.g. around 4-5 km. Figure 6 b and c show these coherent structures according to horizontal cuts made at 100m above the surface in the atmosphere. We saw well the good correlation between spatial variations obtained for temperature and vertical wind speed. This turbulence phenomenon was not yet well known at this small spatial scale. Other simulations made by Lacarrere from Meteo-France have shown similar figures for small scale (200m) in Florida, but more simulations and validation measurements are necessary to understand better their formation.

5. DISCUSSION - CONCLUSION

The first results obtained with the MESONH model used with a grid mesh of 50m were satisfactory. The spatial variability of the surface fluxes was well reproduced by the model, in comparison with the ground measurements. We have showed that, even at this small spatial scale, the crop types seemed to induce significantly variations, both on the temperature and on the surface fluxes. This was particularly when there was weak wind. The energy fluxes were strongly correlated to the surface parameters like LAI.

The spatial variations of air temperature at 2m above the ground were not negligible (around 2 degrees in April). This had direct consequences on the crop development and could explain the yield differences observed. Small convective cells appeared in the surface layer between 150 and 1500m. This could be due to these high thermal gradients induced by the different surfaces. Until now, this phenomenon not yet well analysed, will need more investigations to understand better its formation. Other simulations must be performed in order to confirm these results with various atmospheric conditions.

The high resolution chosen to describe the different crops allowed to better represent the exchanges between soil, plant and atmosphere by giving appropriate surface parameters for each type of crop. Remote sensing giving us data at a resolution of 20m was an indispensable tool to provide accurate inputs.

Acknowledgements
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6 REFERENCES


