6.11 SIMULATION OF THE PLUME EMITTED BY A MUNICIPAL WASTE INCINERATOR LOCATED IN THE MADEIRA ISLAND

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INTRODUCTION

The study of meteorological circulations in small islands has been quite limited with the majority of the research published concerning the analysis of the eolic potential for energy production (Tombrou etal., 1998; Alves et al., 2000; Duic and Carvalho, 2004) Other researchers focused on the description of the dispersion of gases emitted by volcanic activity (Graziani et al, 1997). In this paper, a mesoscale meteorological and dispersion model was applied to simulate the behaviour of the plume of a municipal waste incinerator (MSW) that was constructed in the southern slope of the Madeira island at an altitude of 1380 m.

Madeira is a Portuguese island located in the Atlantic Ocean at approximately 32º 40'N and 16º 52'W with a clear East-West development. The island is relatively small (60 x 20 km^2) but is characterized by very complex orography with maximum peaks reaching 1800 m. The fact that the orography has the same East-West development creates a very strong distinction between the northern and the southern slopes. The northern slope is strongly exposed to the prevalent synoptic flows and the southern slope is much warmer, quiet and where the majority of the population lives. The climate is very mild with small thermal amplitudes and maximum temperatures between 18 to 28ºC. Sea temperature during summer rises to 22-23ºC.

THE AIR POLLUTION MODEL

TAPM is a PC-based, 3D, nestable, prognostic meteorological and air pollution model. It uses global input databases of terrain height, land use, sea-surface temperature, and synoptic meteorological analyses. A complete description of version 2.0 of the model used here is given by Hurley (2002). The meteorological component of TAPM predicts the local-scale flow, such as sea breezes and terrain induced circulations, given the larger scale synoptic meteorological fields. The model solves the momentum equations for horizontal wind components, the incompressible continuity equation for the vertical velocity in a terrain-following coordinate system, and scalar equations for potential virtual temperature, specific humidity of water vapour, cloud water and rain water. Pressure is determined from the sum of hydrostatic and optional non-hydrostatic components, and a Poisson equation is solved for the non-hydrostatic component. Explicit cloud micro-physical processes are included. Wind observations can optionally be assimilated into the momentum equations as nudging terms. The turbulence closure terms in these mean equations use a gradient diffusion approach, including a counter-gradient term for the heat flux, with eddy diffusivity determined using prognostic equations for turbulence kinetic energy and eddy dissipation rate. A weighted vegetative canopy, soil and urban land-use scheme is used at the surface, while radiative fluxes, both at the surface and at upper levels, are also included. Boundary conditions for the turbulent fluxes are determined by Monin-Obukhov surface-layer scaling variables and parameterisations for stomata resistance.

The air pollution component of TAPM uses the predicted meteorology and turbulence from the meteorological component, and consists of an Eulerian grid-based set of prognostic equations for pollutant concentration and an optional Lagrangian particle mode (used here) that can be used on the inner-most nest for pollution for selected point sources to allow a more detailed account of near-source effects, including gradual plume rise.

METEOROLOGICAL STUDY

A meteorological field campaign was performed in Meia-Serra by the National Meteorological Institute (Carvalho et al., 2003) between February 18th and March 1st 2003 and included direct observations of total cloudiness, number and type of clouds, horizontal visibility and cloud base level, automatic sensing at 2 and 10 m height of temperature, relative humidity, atmospheric pressure, wind velocity and wind direction. The field campaign was complemented by upper-air measurements with radiosondes launched roughly twice a day.

A large simulation domain (70 x 70) with nested resolutions of 30, 10, 3 and 1 km was used. Finer grid included the entire island and some of the surrounding water in order to adequately simulate the complexity of the atmospheric flow.

Model predictions of meteorology were extracted at the nearest grid point to the Meia-Serra meteorological monitoring site on the 2 finer grids (3 and 1 km spacing) at 10 m above the ground for winds and at surface level for temperature and were compared with meteorological measurements.

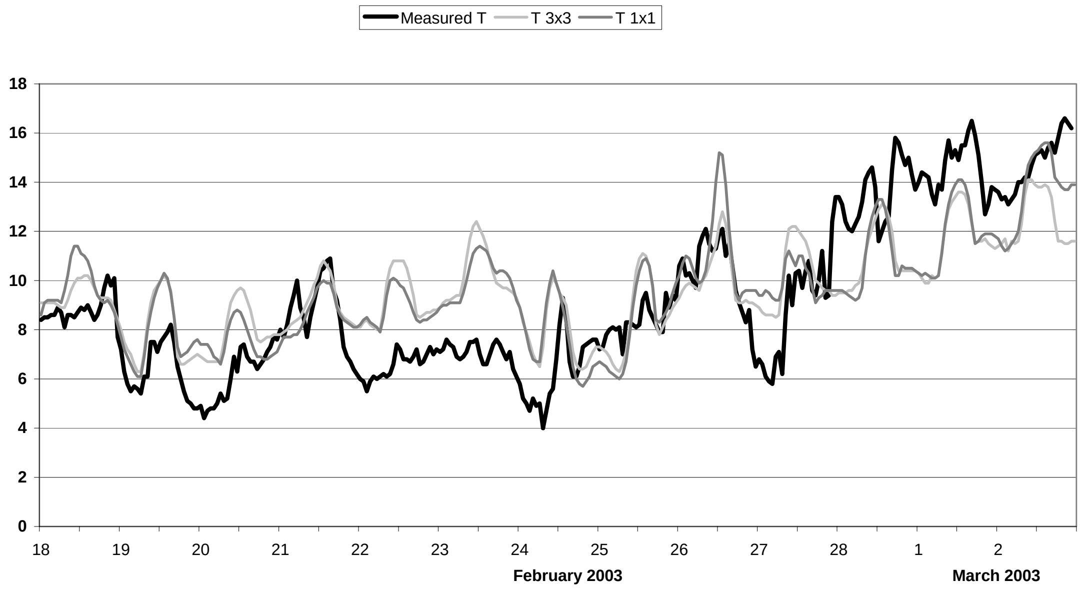

Figure 1. Comparison of measured surface temperature (°C) with TAPM simulations.

During the field campaign, temperature levels fluctuated between a minimum of 4.0°C and 16.2°C, with an average value of 9.2 ± 3.2°C. Simulation results (see Figure 1) follow the measured trend that indicates a warmer period in the last 3 days of the field study. Modelling results obtained with 3 x 3 and 1 x 1 km grids show a similar behaviour – temperature average calculated with the finer grid is 9.7 ± 2.1°C. Nevertheless, modelling result depict a marked daily pattern that is not always observed in meteorological measurements.

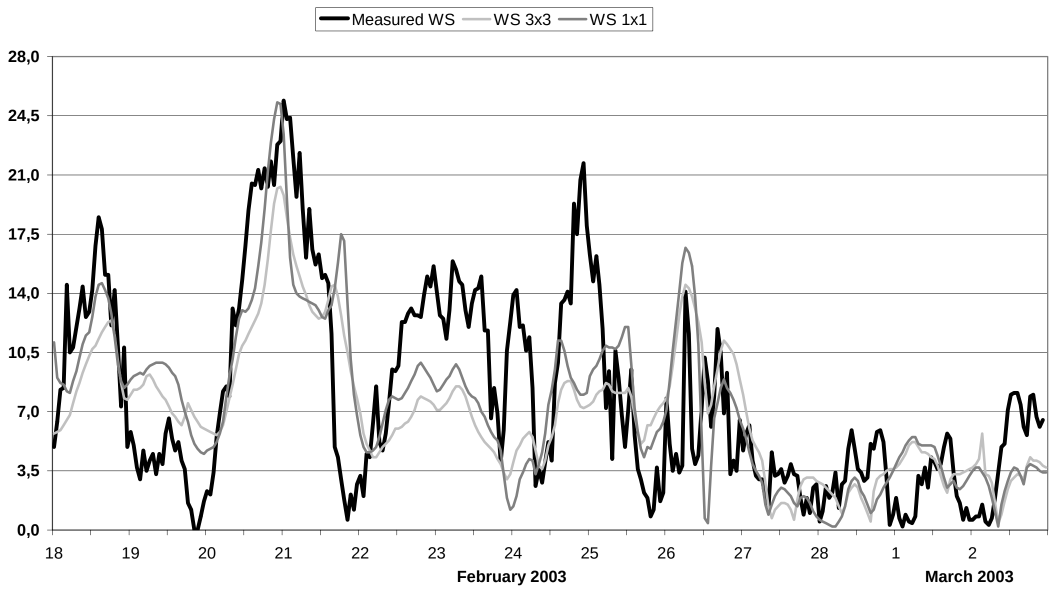

Figure 2. Comparison of measured wind velocity (m.s^{-1}) with TAPM simulations.

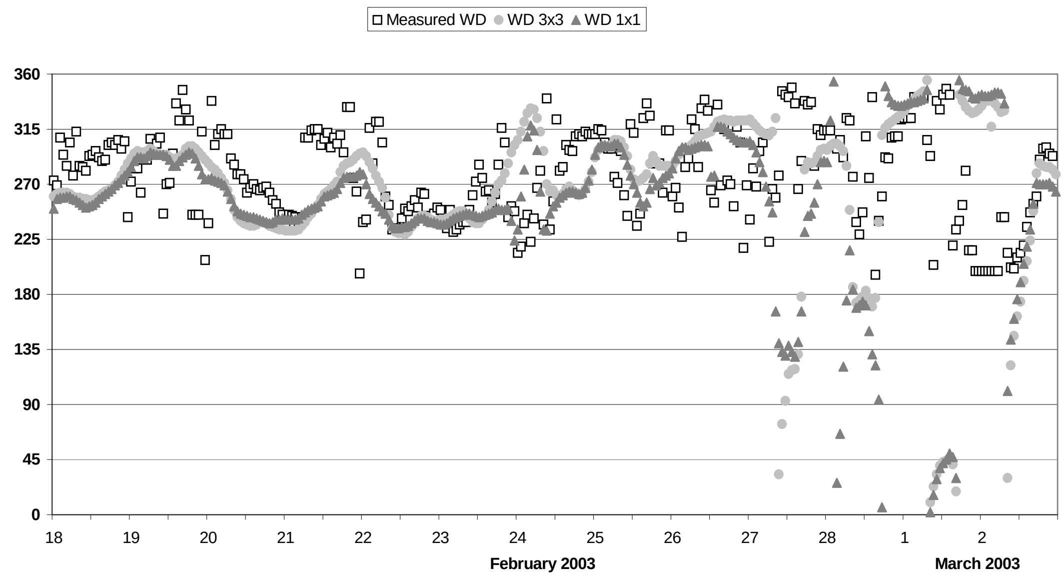

Figure 3. Comparison of measured wind direction (°) with TAPM simulations.

The same comparison can be applied to wind velocity and direction analysing Figures 2 and 3. As far as wind data, two different periods occurred during the campaign. From February 18 to 26 strong winds occurred with maximum velocities above 14 m.s^{-1} and E-SE direction. TAPM modelling results follow this behaviour with a under-estimation of peak velocities. After February 26, wind velocity was lower, probably caused by a reduction of the synoptic forcing. Under these specific circumstances agreement between model and measurements was reduced: model tends to veer the wind direction to NE-E which was not verified in meteorological data. As observed in the temperature plots results with 3 km and 1 km resolution do not differ substantially.

The index of agreement (IOA) between observations and model predictions is shown in Table 1 and is based on the recommendations of Willmott (1981). The IOA is a measure of how well predicted variations about the observed mean are represented, with a value greater than about 0.50 considered to be good, as judged by several other published prognostic modelling studies (Hurley, 2000). An IOA equal to 1.0 would indicate a perfect agreement.

Table 1. Index of agreement between modelling results and meteorological measurements.

IOA	3 km resolution	1 km resolution
Wind velocity	0.696	0.679
U – component	0.723	0.695
V- Component	0.512	0.548
Temperature	0.786	0.823

Taking into account the IOA presented in Table 1 there isn't a clear benefit from using the 1x1 km resolution when compared with the 3x3 km grid. As a result of this analysis the larger grid will be used in future studies. IOA is larger than 0.50 for all parameters indicating a good agreement with measurements. Nevertheless it is important to stress the poorer IOA obtained with the V-component of the wind vector. This fact can be explained by the location of the site. Meia-Serra is located at 1380 m of altitude near the ridge of the island that shows a East-West orientation causing that subtle variations in the micro-meteorological conditions result either in a northerly or southerly flow.

DISPERSION STUDY

TAPM was applied for the simulation of the dispersion of the emissions of the MSW incinerator that is under operation since 2001 in Meia-Serra. The model was applied for 2003 and results of the 3x3 km grid were analysed. The incinerator has a 60 m height stack with a diameter of 1.3 m. An average stack velocity of 11.8 $m.s^{-1}$ with a temperature of 413 K was considered in the dispersion study. Modelling was performed for a 1000 $g.s^{-1}$ non-reactive tracer source.

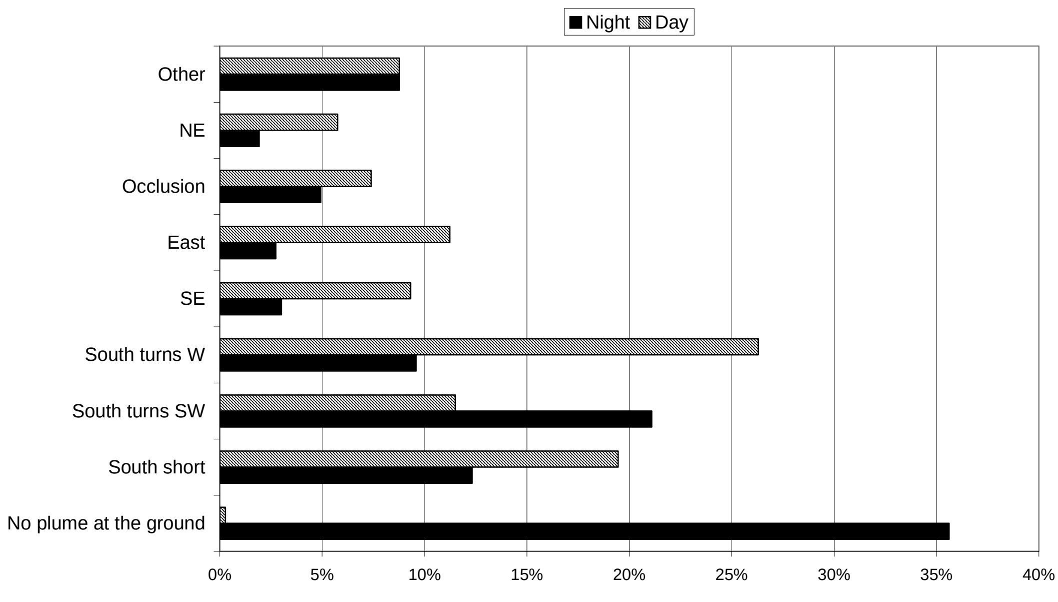

Figure 4. Frequency of occurrence of several types of plumes during day and night in 2003.

Concentration results obtained with this source were extremely low with a maximum of *circa* 1 $\mu g.m^{-3}$ for the 98th percentile of NO_x and increase of 0,7 fg (I-TEQ).m^{-3} of dioxins and furans.

The use of a 3D dispersion model such as TAPM, in opposition to a traditional Gaussian model, enables the study of the path of the emitted plume and the characterization of the frequency of occurrence of several types of plume trajectories (see Figure 4) during day and night. In 35% of the studied period the plume does no show any impact at ground level during the night as a consequence of the plume being trapped aloft an inversion layer. During daytime in more than 55% of the days the plume travels down slope in the south direction reaching the Atlantic Ocean. In two thirds of these situations the plume is trapped by the synoptic flow and turns either SW or West. The later occurs when a short sea breeze upslope flow transports the plume to the coastline. The most complex situation was typified as “occlusion” and occurs when a perfect balance between up and down slope flows is created and the plume spreads at ground level around both North and South slope of Madeira.

CONCLUSIONS

TAPM simulates very well the atmospheric flow that occurs under strong synoptic forcing. Application of validation tools reveals the complexity of the atmospheric flow around the island and inside the inner valleys. Nevertheless the validation study shows that it is sufficient to use a 3x3 km grid. Results obtained with the model also show that the path of the plume emitted by the incinerator follows a typical diurnal cycle and that concentration levels estimated at ground level are extremely low. This conclusion is coherent with monitoring data available for this site.

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