Industrial and Environmental
Fluid-Dynamic Research
Group
DICA, University of Trieste

LUNES
"Large Eddy Simulation at Urban Neighborhood Scale"

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Abstract

The present discussion aims to provide a trace of the steps necessary to construct the CALMET and CALPUFF modeling system. The attached folder collects the programs (pre-processing and post-processing) used during the LUNES project. All the results of the CALMET-CALPUFF simulations for different case studies also provided here. During the LUNES project (15th Dec. 2018-15th June. 2018), first; I spent some time to learn about the model and some exercises with some case studies supplied in the CD, version 5. After that I worked with version 6, due to some difficulties with the resolution of the land use/land cover. Meanwhile I also taught in 6 hours to some MSc student the model and helping them with their projects (material of the class provided).

The case study is located near Trieste and the meteorological data of stations cover the entire year "2008". In particular, the reconstruction of the meteorological field is described for both long term and short term simulations.

Chapter 1

Introduction

1.1 CALMET-CALPUFF modeling system

CALMET [2] is a meteorological model composed of a module for calculating the wind field and micro-meteorological modules studied for the boundary layers both on water and the ground. CALMET generates 3D fields of wind and temperature, fields 2D mixing height, friction speed, precipitation rate etc and surface parameters such as roughness, albedo, etc. The diagnostic model for the calculation of the wind field is structured in two phases. The first phase consists of adapting the initial test field into based on the kinematic effects of the terrain, on the slopes and on the blocking effects of the land. The second phase, on the other hand, foresees the use of the data observed for determine the final wind field.

The model used for the simulation studies in this research, the CALPUFF modelling system, is described here. The CALPUFF Modeling System is available from Exponent without charge [2]. The main models (CALMET, CALPUFF, and CALPOST), associated GUIs, and related processors are available for download. Many dispersion models typically assume steady, horizontally homogeneous wind fields instantaneously over the entire modeling domain and are usually limited to 50 kilometers from a source. However, for applications with emission source hundreds of kilometers away, other models or modeling systems. At these distances, the transport times are sufficiently long that the mean wind fields cannot be considered steady or homogeneous. CALPUFF is one such modeling system, consisting of three components: CALMET, a meteorological preprocessor that utilizes surface, upper air, and on-site meteorological data to create a three-dimensional wind field and derive boundary layer parameters based on gridded land use data; CALPUFF, a puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport, removes pollutants through dry and wet deposition processes and transforms pollutant species through chemical reactions; and CALPOST, a postprocessor that takes the hourly estimates from CALPUFF and generates estimates at specified hours as well as tables of maximum values (Scire *et al.* (2000b) [1]).

CALPUFF is a transport and dispersion model that advects puffs of material released from modelled sources. It requires 3-dimensional fields of wind and temperature, along with associated 2-dimensional fields such as mixing heights, surface characteristics and dispersion properties. To develop these fields, a deterministic meteorological processor (CALMET) was created. CALMET requires both hourly surface and twice-daily upper-air data to construct the meteorological fields. CALMET cannot forecast meteorology, but has a Diagnostic Wind Module (DWM) that adjusts wind and temperature fields due to the influence of terrain and vegetation. There are several switches in the CALMET model that must be set by the modeller to reflect the unique geophysical characteristics within an air-shed (Scire *et al.*, 2000 [1]). The model accounts for a variety of effects such as spatial variability of meteorological conditions, causality effects, dry deposition and dispersion over different types of land surfaces, plume fumigation, low wind-speed dispersion, primary pollutant transformation and wet removal. CALPUFF has various algorithms to include the use of turbulence-based dispersion coefficients derived from a similarity theory or observations. The individual components of the modeling system are described in detail in the following sections.

CALMET Diagnostic Meteorological Model

CALMET is a diagnostic meteorological model that develops hourly wind and temperature fields on a three-dimensional gridded modelling domain, including two-dimensional fields such as mixing height, surface characteristics and dispersion properties. The CALMET model operates in a terrain following vertical coordinate system using equation 1.1

$$Z = z - h_t, \tag{1.1}$$

Where Z is the terrain-following vertical coordinate (m), z is the Cartesian vertical coordinate (m) and h_t is the terrain height (m).

The vertical velocity, W, in the terrain-following coordinate system is defined by equation

$$W = w - u\frac{\partial h_t}{\partial x} - v\frac{\partial h_t}{\partial y}. \tag{1.2}$$

Where w is the physical vertical wind component (m/s) in Cartesian coordinates and u , v are the horizontal wind components (m/s).

The diagnostic wind field module in CALMET uses a two-step approach in the computation of wind fields (Scire et al., 2000). In the first step, an initial-guess wind field is adjusted for kinematic effects of terrain, slope flows and terrain blocking effects to produce a Step-1 wind field. CALMET parameterizes the kinematic effects of terrain using the approach of Liu and Yocke

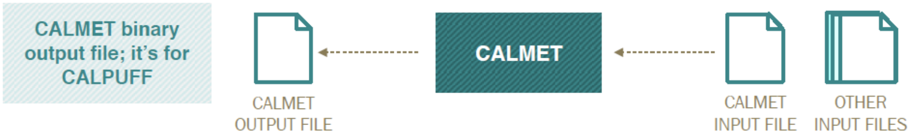

Figure 1.1: The CALMET is to be run with the input file and the associated input data files.

(1980). More details regarding the parameters and the model can be found in the USER-GUIDE.

CALMET reads hourly surface observations of wind speed, temperature, cloud cover, ceiling height, surface pressure, relative humidity, and precipitation (only if wet removal is to be computed). The twice-daily upper air observations required by CALMET include vertical profiles of wind speed, wind direction, temperature, pressure, and elevation. CALMET also requires geophysical data, including gridded fields of terrain elevations and land use categories. Gridded fields of other geophysical parameters, such as the surface roughness length, albedo, Bowen ratio, soil heat flux parameter, anthropogenic heat flux and vegetation leaf area index are also required. CALMET consists of two boundary layer meteorological modules for overland and over water applications (Scire et al., 2000 [1]). For overland surfaces, the energy balance method of Holtslag and Van Ulden (1983) is used to compute hourly gridded fields of the heat flux, surface friction velocity, Monin-Obukhov length, and convective velocity scale. Mixing heights are determined from the computed hourly surface heat fluxes and observed temperature soundings. The model also determines the Pasquill-Gifford stability classes and optional hourly precipitation rates.

In order to run CALMET, the model needs some meteorological data sets and the input file which we can set all the boundary conditions and initial conditions. see figure 1.1

CALPUFF model

The basic equation for the contribution of a puff at a receptor by CALPUFF is by equation (3)

$$C = \frac{Q}{2\pi\sigma_x\sigma_y} g[exp(\frac{-d_a^2}{2\sigma_x^2})exp(\frac{-d_c^2}{2\sigma_y^2})], \tag{1.3}$$

where C is the ground-level concentration (g/m^3), Q is the pollutant mass (g), σ_x, σ_y and σ_z are the standard deviations (m) of the Gaussian distribution in the along-wind direction, cross-wind and vertical directions respectively, d_a

Figure 1.2: The CALPUFF is to be run with the input file and the associated input data files.

and d_c are the distances (m) from the puff center to the receptor in the along-wind and cross-wind directions respectively and g is the vertical term (m) of the Gaussian equation.

The vertical term, g, is given by equation (4)

$$g = 2\frac{2}{(2\pi)^1/2\sigma_z}\sum_{n=-\infty}^{\infty} exp[-(H_e + 2nh)^2/(2\sigma_z^2)] \tag{1.4}$$

where H_e is the effective height (m) above the ground of the puff center and h is the mixed-layer height (m). The key modelling consideration in CALPUFF is the specification of the horizontal and vertical Gaussian dispersion coefficient, σ_y and σ_z, for a puff (or each end of a slug) at the start and end of a sampling step, and also for each receptor at which the cloud has a computed contribution during the step. The coefficients for the puff location at the start of a step are equal to those found at the end of the preceding sampling step, because cloud-size is continuous between sampling steps. Those at the end of the step, or at nearby receptors during the step, are computed according to an ambient turbulence growth relationship and possibly a source-related constant variance. The growth due to ambient turbulence may be formulated as either a function of time, or as a function of distance.

CALPOST

CALPOST is used to process output files from CALMET and CALPUFF,producing tabulations that summarize the results of the simulation, identifying the highest and second highest 3-hour average concentrations at each receptor. The application of CALMET/CALPUFF modelling system is well known, and several validation tests have been published (Dios et al., 2013, Dresser and Huizer, 2011, Fishwick and Scorgie, 2011, Ghannam and El-Fadel, 2013, Hernandez et al., 2014, Levy et al., 2003, Protonotariou et al., 2004). Most of them were based on specific experiments with passive tracers and a large compilation of surface and aloft meteorological measurements during the experiments, in order to achieve the best model performance evaluation. However, with actual pollutants sources and limited meteorological datasets, uncertainties arise

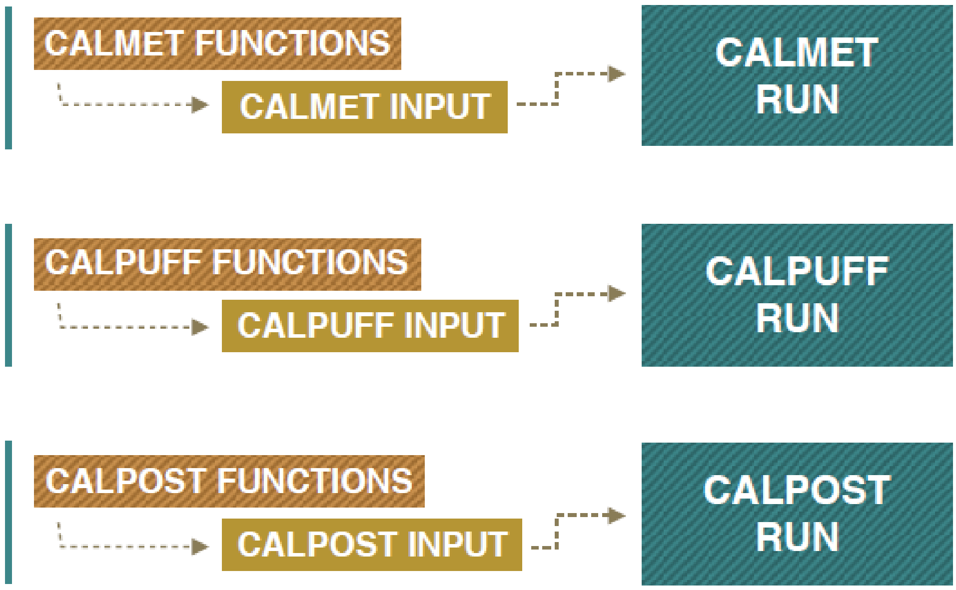

Figure 1.3: From CALMET to CALPOST- Its functions all the way down.

(both in measurements and models results) and worse models performance is expected.

1.2 Pre-processors

Regardless of the type of simulation you want to adopt, choice to do by evaluating various factors, both in terms of availability and goodness of the data, convenience and precision of the result you want to obtain, in general the files required in input from CALMET are the following:

- ✓ GEO.data
- ✓ UP.dat
- ✓ SURF.dat
- ✓ SEAn.dat
- ✓ PRECIP.dat
- ✓ 3D.dat
- ✓ PROG.dat (optional)
- ✓ WT.dat (optional)

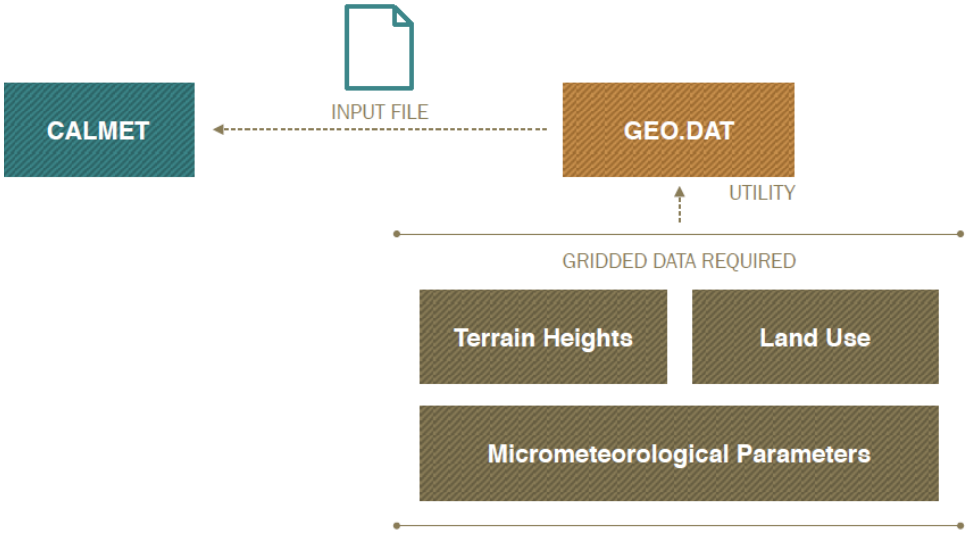

Figure 1.4: Steps for creating the geo.dat file with MAKEGEO pre-processor.

GEO.DAT

The GEO.dat or the geophysical data file contains the information on the topography, land use (land cover) and parameters such as roughness, albedo, Bowen report etc ..., The latter may be related to the classes of ground and then calculated according to them, or introduced separately compared to land use categories. All the above data are shown in the geo.dat file as a grid. The processor in charge of the generation of the geophysical data file is named *makegeo*, which to create the "geo.dat" it also need TERREL.dat and LULC.dat files according to the diagram shown in figure 1.4. These two files can be created with TERREL and CTGPROC processors, which explained in the next section.

TERREL

The TERREL processor has the function of generating the TERREL.dat, which contains the information on the topography of the terrain. The files to be provided as input to the TERREL they must be included in the following types:

• (USGS90) designates USGS 1-deg DEM files (90m) • (USGS30) designates USGS 7.5-min DEM files (typically 30m) • (ARM3) designates ARM3 terrain data files (900m) • (3CD) designates 3CD (binary) 1-deg DEM files (90m) • (DMDF) designates Canadian DMDF files (100m) • (SRTM1) 1-sec designates Shuttle RADAR Topo Mission files (30m) • (SRTM3) 3-sec designates Shuttle RADAR Topo Mission files (90m) • (GTOPO30) designates

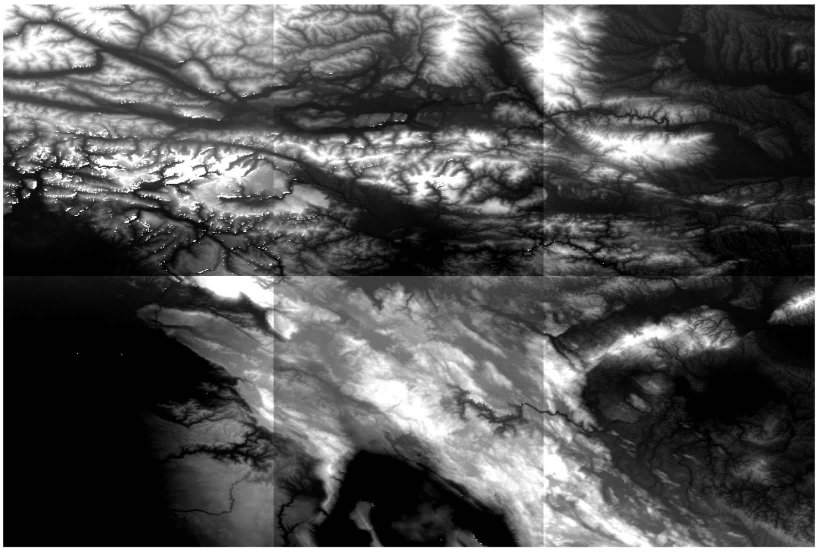

Figure 1.5: The terrain data of N45E013, N45E014, N45E015, N46E013, N46E014 and N46E015 files using global-mapper.

GTOPO30 30-sec data (900m) • (USGSLA) designates USGS Lambert Azimuthal data (1000m) • (NZGEN) designates New Zealand Generic data files • (GEN) designates Generic data files

In the TERREL folder, the TERREL.inp must be presented (or can be downloaded from [2].) that is, the control file from which the TERREL program will read the parameters (from set) required by the program to work. Some of these are set by default and others such as the characteristics of the domain must obviously must be set up. Regarding the land files, SRTM1 data can be found in the United States and in some parts of the world, for all of Italy is free to find SRTM3 files, which they own a resolution of $\sim$ 90 m, 3 arc-sec.The SRTM3 are characterized by the lack of corresponding values of high-altitude points in mountain ranges, this problem can be remedied using the same TERREL setting the interpolation to fill the empty cells, in this case it is necessary to fix the interpolation radius. The site from which to download the files with **.HGT** extension (for SRTM3) for the whole globe are different, is `http://www.webgis.com/srtm3.html` [3]. The **.HGT** are raster files that can be viewed and manipulated using the classic GIS programs like GlobalMapper and QGIS. I have been using globalmapper software for all my visualization. See figure 1.5 which plotted for 6 files N45E013, N45E014, N45E015, N46E013, N46E014 and N46E015 plotted using GlobalMaper, the terrain data can be downloaded from here `https://dds.cr.usgs.gov/srtm/version2_1/SRTM3/Eurasia/`

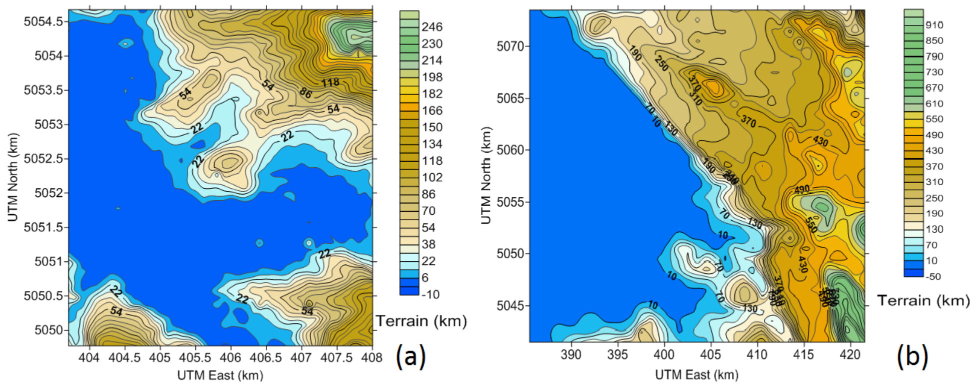

Figure 1.6: Terrain domain plotted with TERREL processors for both; (a) the short-term simulation and (b) the long-term simulation

Running TERREL without files of terrain, the program ask for them (see TERREL.lst), all the information as well as the errors are written in that file. If the area under study contains a portion of both sea and land to process the shoreline is used from USGS Global Self-consistent Hierarchical High-resolution Shoreline Database (GSHHS). The GSHHS version 2.3.7 can be downloaded from here `https://www.ngdc.noaa.gov/mgg/shorelines/gshhs.html` [4]. The program extracts the coast line of interest from the database. It can get a higher or lower resolution depending on the resolution of the file chosen within the database folder.

As the SRTM data are affected by noise near the coast, lakes and oceans, there is the possibility of setting a threshold which it is believed that the measure is subject to this phenomenon and therefore the data is not reliable. In the example shown, it was decided to establish this threshold ZNOISE = 0 and INOISEREP = 1 or if the measure is below 0 m the value will be considered missing and therefore interpolation will be performed. Obviously in zones where it is expected that the level can be less than zero you will have to use another other threshold value.

By default, UTM (Universal Transverse Mercator) is set as projection and WGS-84 for datum for Trieste area. It is instead indicated use the LCC (Lambert Conformal Conic) projection in the case of the domain it is extended to a very large area since this projection takes into account in a way significant of the terrestrial curvature (used in Sydney case study). For practical matters, the settings of defaults are to be preferred unless this is the case just described.

Always in the same section the calculation domain must be defined: XREFKM and YREFKM correspond respectively to the latitude and longitude of the corner point at the bottom left of the domain, obviously defined in the projection and datum above established. A useful application present within the CALPUFF package by which you can convert coordinates to depending on the datum and the projection or using the websites available. Finally to define the grid, it is necessary to set the number of cells in the x and y direction (NX and NY) and the spacing step (DGRIDKM). In addition to the TERREL.dat and the TERREL.lst (report file) other output file is TERREL.grd, format supported by the surfer software, through which you can view the topography calculated based on the domain of interest. Figure 1.6(a-b) represents the altitude of the land through level lines and is obtained with SURFER choosing from the menu contour map (see the SURFER user guide for more information)

CTGPROC

CTGPROC is a land use preprocessor which reads compressed CTG land use data files, USGS Global Dataset format land use data files, USGS NLCD files, or two types of generic land use format, and computes the fractional land use for each grid cell in the user-specified modeling domain. The types of LULC data format accepted by CTGPROC are the following:

• (CTG) designates USGS CTG (compressed) • (NLCD92) designates NLCD (National Land Cover Data) 1992 • (NZGEN) designates New Zealand Generic • (GLAZNA) designates USGS Global (Lambert Azimuthal) for North America • (GLAZSA) designates USGS Global (Lambert Azimuthal) for South America • (GLAZEU) designates USGS Global (Lambert Azimuthal) for Eurasia - europe • (GLAZAS) designates USGS Global (Lambert Azimuthal) for Eurasia - Asia • (GLAZAF) designates USGS Global (Lambert Azimuthal) for Africa • (GLAZAP) designates USGS Global (Lambert Azimuthal) for Australia- Pacific

which are from the GUI version 5. As I communicate with "european-calpuff-user-discussion-group", I understood there is some difficulties to use CTGPROC for the resolution of $\sim$ 100 m. The data for the $\sim$ 1 km resolution is provided in a folder named $gls-euro-v2-1$. Moreover, using GUI v.6, has this option to directly upload the ".tif format" (see figure 1.7). The Zipped TIFF format with world file, raster data file can be downloaded directly from `https://www.eea.europa.eu/data-and-maps/data/global-land-cover-2\000-europe` [5].

The resolution is around 1000 m and the LULC categories are classified according to the USGS standard and therefore in accordance with the calmet standard. For the short term simulation the resolution is obviously too low, therefore it was decided to use another database or the corine land cover 2006. Figure 1.8 (a) shows the LULC with 100 m resolution and (b) is with the 1 km resolution around Trieste area, respectively.

The project of the european union Corine Land Cover was born in 1990 for the purpose of detect and monitor coverage characteristics (forests, water surfaces, beaches etc ..) and the use of the land according to the socio-economic functions of the territory (agricultural soils, inhabited centers, etc.). Every

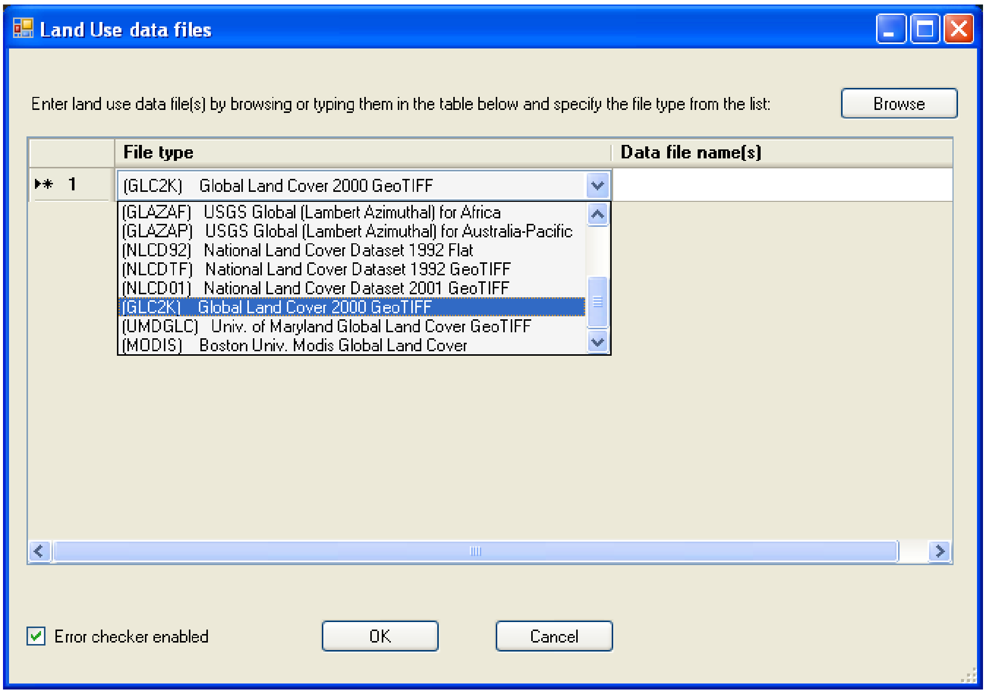

Figure 1.7: Land use land cover preprocessor using GUI version 6. showing how directly uploading a Global Land Cover 2000 Europe in CTGPROC for the resolution of 1 km.

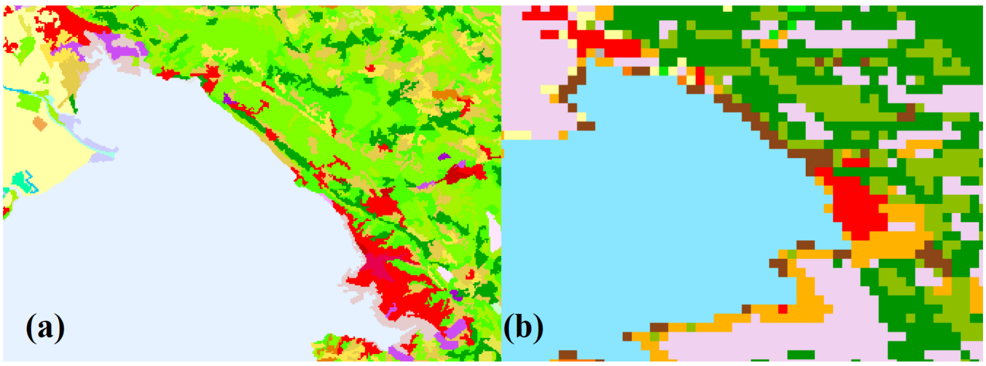

Figure 1.8: Land use land cover database with (a) 100 m resolution and (b) $\sim$ 1 km resolution.

5-10 years have been performed database updates, the last version dates back to 2006. The categories are in total 44 against the 38 of the USGS. The LULC map area covers the whole European Union and extends from north to south from the Faroe Islands to the Canary Islands and from west to east from the canary islands to the Greek islands of kastellorizon. Corine Land Cover has two degrees of resolution at 250 and 100 m, the two sets of data can be downloaded from the website [5]. Obviously for our needs 100 data were downloaded and modified (explained below). At this point the problem is to prepare the data in a format acceptable by CTGPROC. Theoretically both GLAZEU and NZGEN could be suitable for the purpose. In the first case in order to format the data in the form GLAZEU coordinates must be projected according to the parameters shown on the USGS website.

Processing Corine Land Cover data is a bit complicated and I try to explain them here. First, we need to make a new location in GRASS, with the same projection as the original CORINE data (I think it is LAEA but check the details in downloaded file). I imported glc.tiff from EEA using r.in.gdal. We can import current 2012 corine file zipped from EEA [5]. I prepared *categories_reclass.csv* (attached to this mail) manually using my judgement - that is the transformation from CORINE classes to US classes. Once you have the file you use "r.reclass" in grass to re-class the map to new coding. Note that the map created by r.reclass is just "virtual", it exists only while the original map exists. To get a real reclassed map, you need to apply final step:

r.mapcalc $< newrastermap >=< reclassedmap >$. The input file for CTGPROC processor is a xyz csv file containing lon, lat and the code. So as a last step, you need to export the map from grass using r.out.xyz

MAKEGEO

MAKEGEO generates a GEO.DAT file that provides the geophysical data inputs required by the CALMET model1. These inputs include land use types, elevation, surface parameters (surface roughness length, albedo, Bowen ratio, soil heat flux parameter, vegetation leaf area index), and anthropogenic heat flux. MAKEGEO requires 3 input files: a gridded elevation file (e.g. produced by TERREL)2, a gridded land use file (e.g. generated by CTGPROC), and a user input control file (MAKEGEO.INP). The geo.dat files for both 100 m and 1 km resolution is provided. (can be find: report-calmet-calpuff/CALMET-CALPUFF-CLASSES-students/DATA-Project-CALPUF
F2018/Project-calmet)

Observational Data from Stations

UPPER AIR

The formatted files, UP.DAT, is a file containing the pressure, elevation, temperature, wind speed, and wind direction at each sounding level. The first level of each sounding is assumed to represent surface-level observations. If the surface level is missing from the sounding, it must be filled in before running CALMET. The tricky part of CALMET is the the format. CALMET is able to read that format only, more details of the header and column structures is written in the user-guide. The program MATLAB named **upperair.m** reads the data downloaded from the site for the whole year 2008 in the campoformido station and produces the file "up.dat" in one of the formats accepted by CALMET (can be fined: Data-Calmet/Pre-Processing/DATA-Stations/Data-format).

Surface and precipitation data files

Getting the data to prepare the surf.dat is more complex than the previous point, it contains the processed hourly data for all the stations. Data for 2008 measured at the local meteorological stations are provided by the harp and contain measures relating to; hourly precipitation (mm/h), temperature (C) at 2m, relative humidity at 2m, wind direction (degrees) to 10 m, wind intensity (m/s) at 10 m, pressure (hP a) at 2 m, hourly solar radiation. The formatted surf.dat file can be fined in the same folder. The precipitation code is optional, it can be omitted as it is necessary only if we proceed with the CALPUFF simulation and we intend to evaluate the wet removal. So while the regional data show the solar radiation measurements, the CALMET it requires cloud cover and cloud heights. This problem was remedied by recovering the cloud cover in Trieste and in some Slovenian stations. Another possibility is to extract the cloud cover from the output file of the wrf model. The missing values of temperature, cloud cover, height clouds, pressure and relative humidity are replaced internally with the values of nearby stations not missing. For every hour of simulation at least one valid value for each parameter must be available in at least one station. As a result, the coverage data does not contain hourly data, but they are were collected only for a few hours of the day, it was necessary to replace them missing data with the nearest time values. The surf.dat folder contains: the initial meteorological data, the program **surfdat3.m** which is used to format the starting data in the desired format and finally the files precip.dat and surf.dat.

In the next chapter, detailed information about the meteorological and geological data of Trieste is provided.

Chapter 2

The study area

The location of the Central is planned in the Zaule area, approximately in the geographical coordinates zone 45.61 Lat. North, 13.79 Long. East ($x = 405.651km, y = 5051.429km$) in the UTM system, WGS-84). The settlement of the plant is planned at the coast-line, in the heart of the industrial area of Trieste. The urban area of Trieste is located north of the Central, while the city center is located in a north-west direction, beyond the Servola hill. To the east lies part of the industrial area of Trieste, the terminal part of the motorway and an area with a low population density which then goes up towards the Carsico plateau. To the south, beyond the sea-side of the south-eastern part of the Muggia bay, lies the village of Aquilinia and then, going south-west, the village of Muggia. Immediately to the west of the plant is the planned site for the Gas Natural company's reclassification plant, then the Siot terminals and finally the Muggia bay to the open sea (see figure 2.1)

2.1 Meterorological data

The evaluation of pollutant dispersion is carried out considering both long-term and short-term scenarios. In order to consider a sufficiently long and significant time period for the evaluation of the dispersion and the relapse of pollutants, for the long-term simulations the meteorological data relative to the duration of one year are considered. To this end, in response to a formal request from the executors of the present study, the following have been made available:

- from ARPA-FVG the meteorological data recorded with hourly frequency at the ARPA control units located in the Friuli Venezia Giulia region for a whole calendar year (2008).
- from the Environmental Agency of the Republic of Slovenia, meteorological data recorded with hourly frequency at the control units located in the cross-border area for a whole calendar year (2008).

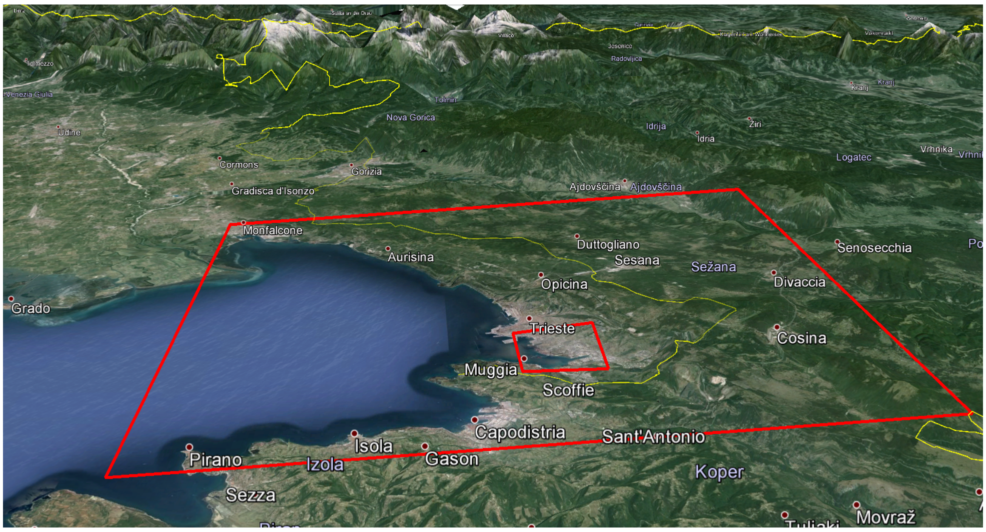

Figure 2.1: The area of the study, Trieste in the geographical coordinates zone 45.61 Lat. North, 13.79 Long. East ($x = 405.651km, y = 5051.429km$) in the UTM system, WGS-84.

For the reconstruction of meteorological data, the CALMET model provides for two types of approach. The first consists in the use of output of typical meteorological models, for example of the MM4 and MM5 models; the second is to use data recorded by centraline sites in the territory of interest and then to appropriately interpolate such data on the calculation grid. In the present study the second approach was chosen due to the wealth of meteorological data measured near the site of interest and made available by various bodies [6].

For the reconstruction of the meteorological field in the area of interest, surrounding the site of settlement of the Central and including both the inhabitants of the province of Trieste and the cross-border territory located within a radius of 10 km from the site of the Central location, data were used coming from:

- a series of control units positioned on the ground and located within the province of Trieste, in the surrounding provinces of the FVG region and in the cross-border area adjacent to the studied region;
- altitude data from radio soundings carried out every 12 hours (at 0 UTC and 12 UTC) in Campoformido station at different heights in the atmosphere. These data can be downloaded from the website: `http://weather.uwyo.edu/upperair/sounding.html`;
- data from the control units placed at sea in the area of interest.

As regards the ground-based control units, the following data were measured with an hourly frequency during the year 2008:

- precipitation (precision 0.2 mm (ITA), 0.1mm (SLO));
- temperature measured at 2.0 m above the ground (accuracy 0.5 K (ITA), 0.1K (SLO));
- relative humidity measured at 2.0 m above the ground (accuracy 5
- wind direction measured at 10.0 m from the ground (accuracy 1 degree);
- wind speed measured at 10.0 m above the ground (accuracy 0.2 m/s (ITA), 0.1 m/s (SLO));
- pressure measured at 2.0 m above the ground (accuracy 0.5 hPa (ITA), 0.1 hPa (SLO))

Among the data measured in the Radio Soundings of Campoformido were used:

- vertical profiles of wind speed;
- vertical profiles of the wind direction;
- vertical pressure profiles;
- vertical temperature profiles

Among the data measured by the control units placed at sea, the following were used:

- - wind speed and direction at 10.0 m above the ground;
- relative humidity at 2.0 m above the ground;
- air temperature 2.0 m above the ground;
- sea surface temperature 1.0 m below the minimum tide level.

The choice of ground control units was made based on the following parameters: (1) proximity to the area of interest (2) sufficiently large spatial distribution in order to allow a good quality of data interpolation at the points of the calculation grid (3) a sufficiently large number of data (excluding stations with data missing on continuous periods longer than 3 consecutive days). The management of missing data is carried out in such a way as to preserve the accuracy of the spatial reconstruction of the data. Details on the methodology are given in [1].

The ground control units considered for the reconstruction of the meteorological field are shown in table 2.1. It is noted that the control unit placed at

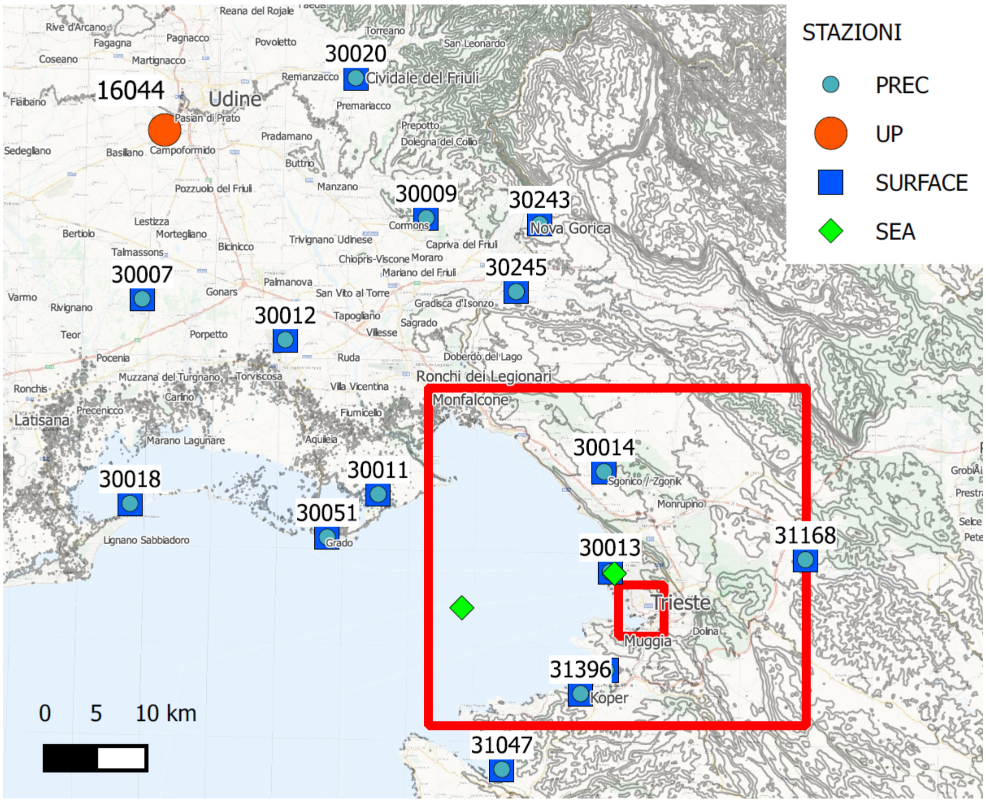

Figure 2.2: Map containing the location of the meteorological units used for the reconstruction of the three-dimensional field. The control units on the ground are red; in red with black dot the ground power stations located in the Republic of Slovenia; in yellow the location of the control unit for the data at height; in green the measuring station for cloud cover; in blue the control units placed at sea; in blue with the black dot the two Slovenian power stations with meteorological data, cloud cover and ceiling height (image from Google Maps).

Stazione di Misura	LAT [gradi N]	LON [gradi E]	z [m]
Talmassons	45.883	13.157	16
Capriva D. F.	45.959	13.513	85
Fossalon di Grado	45.716	13.460	0
Cervignano del Friuli	45.850	13.338	8
Trieste	45.651	13.753	1
Sgonico	45.739	13.743	268
Lignano	45.703	13.148	15
Cividale del Friuli	46.081	13.421	127
Grado	45.677	13.396	2
Nova Gorica (SLO)	45.956	13.657	113
Portoroz (SLO)	45.476	13.621	2
Koper (SLO)	45.543	13.718	56
Koper Luka (SLO)	45.565	13.749	0
Skocjan (SLO)	45.664	13.998	420
Bilje (SLO)	45.896	13.629	55

Table 2.1: Geographical data of the measurement units located on the ground, used for the reconstruction of meteorological data. The z-column shows the height of the measuring station at l.m.m.

Gradisca d'Isonzo was not considered, as it satisfied the first two requirements but not the third. In fact, data for the month of March 2008 are not available for this control unit. Similarly, one of the control units located in Slovenian territory (a boa), having a considerable amount of missing data, has been excluded from the calculation. The geographical coordinates of the measurement stations are shown in table 2.2. Finally, table 3 shows the geographical data of the control units placed at sea. It should be noted that the first of the sea stations shown in table 2.3 is managed by ISPRA and the data were downloaded from the `www.mareografico.it` site in the section relating to the Trieste station. As for ground stations, even those at sea record data with an hourly frequency.

An overall map containing the location of the control units used for the reconstruction of the meteorological field is shown in Figure 2.2. For the purposes of characterizing vertical mixing in the air column it is important to know the degree of solar radiation and the height of the air column below the clouds. The ARPA-FVG control units measure the solar radiation but do not provide information on the degree of cloud cover and therefore, appear 'blind' in this aspect during the night hours. The Radiosundation of the Campoformido Station does not provide information on cloud cover, as well

Stazione di Misura	LAT [gradi N]	LON [gradi E]
Campoformido (radiosondaggio)	46.03	13.19
Trieste-Hortis (copertura nuvolosa)	45.647	13.765

Table 2.2: Geographic data of the stations used for the reconstruction of the meteorological data

Stazione di Misura	LAT [gradi N]	LON [gradi E]
Molo Fratelli Bandiera	45.649	13.75
Boa ITT	45.617	13.567

Table 2.3: Geographical coordinates of the offshore power stations used.

as measurement stations at sea.

Cloud coverage data in the area of interest are as follows:

- estimates made at the Piazza Hortis station in Trieste (see Table 2) every day at 10 am for the whole year 2008 (Department of Earth Sciences of the University of Trieste)
- 2/3 daily measurements for the whole of 2008 performed at the Bilje power station in Slovenia
- 2/3 daily measurements for the whole of 2008 performed at the onshore power station of Portoroz in Slovenia

The cloud cover data for Portoroz (SLO) were also used for the ground-based control units of Koper, Koper-Luka as they are located in a related climatic zone (coastal environment). The data measured in Piazza Hortis were used for the Trieste control unit, while the data measured in Bilje were used for all the remaining Italian and Slovenian control units.

In addition to the data described above, the CALMET pre-processor requires knowledge of the ceiling height and the over water mixing height.

Specifically, the ceiling height measurements are only available for the Slovenian control units of Portoroz and Bilje, as described above. The ceiling height data relating to the Portoroz control unit were also used for the ground control units of Koper and Koper-Luka and Trieste, while the data from Bilje were used for all other ground-based control units.

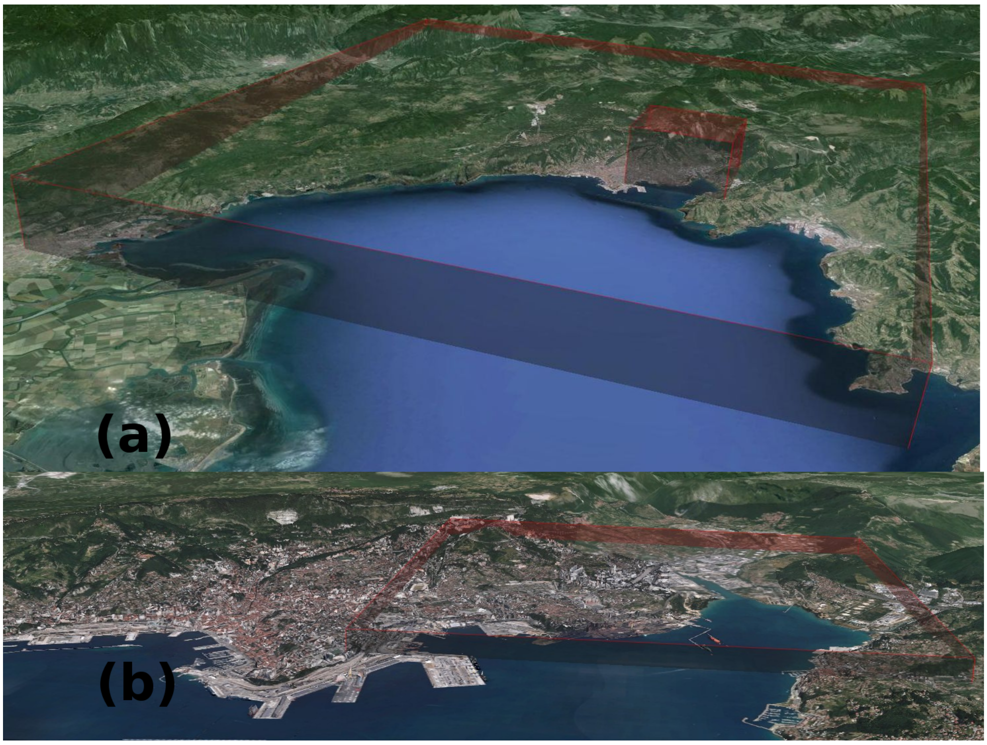

Figure 2.3: Calculation domain used for the reconstruction of the three-dimensional meteorological field (image from Google Maps). (a) domain used in long-term simulation (b) domain used in short-term simulation.

The data necessary for the reconstruction of the ground features, the characterization of the coastline and the intended use of the surface of the calculation grid were respectively obtained from the following three databases:

- Terrain data: Shuttle Radar Topography Mission (SRTM), definition $\sim$ 90 m, 3 arc-sec used board: N45E013, N45E014, ..
- Coastal Data, new version: "Global Self-consistent, Hierarchical, High-resolution Database" (GSHHS)
- Data of intended use: The Global Land Cover Characterization Database "(GLCC), definition $\sim$ 1000 m, 30 arc-sec Eurasia data optimized for Europe

The grid for the reconstruction of the meteorological field was arranged with the origin at sea in the point of coordinates x = 385.0 km (13.5276909 Long East), y = 5041.0 km (45.5130463 Lat. North) in the UTM system WGS-84. The domain has an extension of $37km \times 33km$ respectively in the

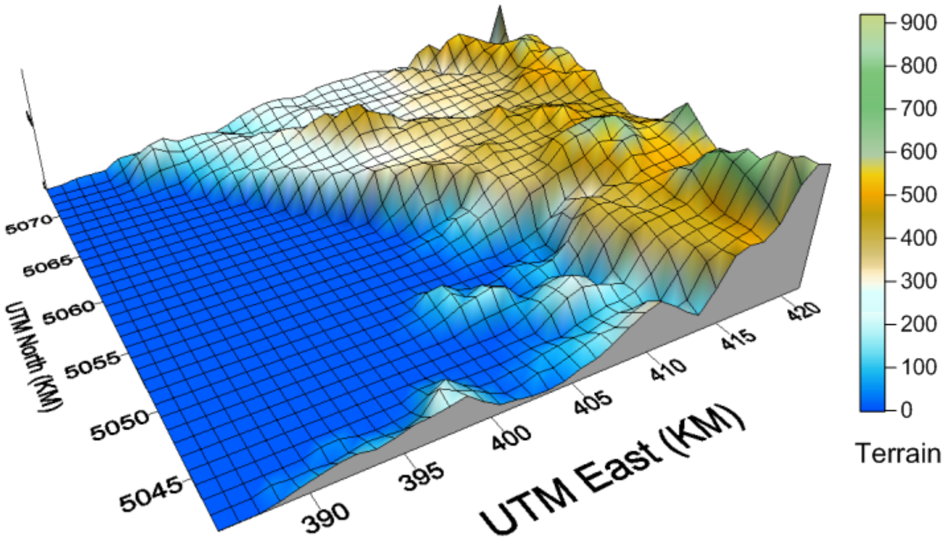

Figure 2.4: 3D View of the calculation domain used for the reconstruction of the meteorological field

east-west and south-north directions. A 1 km grid spacing was used in both horizontal directions, consistently with the GLCC database spacing.

Figure 2.3 contains a satellite view of the considered domain for both short-term and long-term simulation . It is noted that the domain includes the cities of Piran and Koper in the south and the cities of Kozina and Sezana in the east for the Slovenian part of the domain, and the entire province of Trieste. Finally to the north the domain borders with the city of Monfalcone.

Figure 2.4 contains a 3D map of the calculation domain as reconstructed from the CALMET model.

Analysis of the meteorological field

For the reconstruction of the meteorological field at altitude, 12 levels were considered, respectively z = 20, 50, 100, 150, 200, 250, 300, 400, 500, 600, 800, 1,000. The heights are expressed in meters. In the wind field reconstruction procedure the CALMET default values were used. The interpolation was carried out using a technique of type 1/R with a maximum radius of 10 km using a maximum number of control units for each point equal to 10. This method allowed to reconstruct the meteorological field in the various points

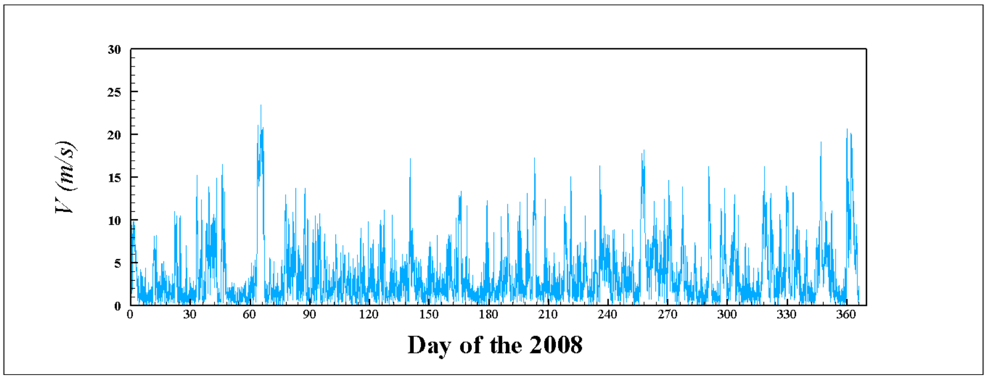

Figure 2.5: Time trace of 2008 of the wind intensity

of the grid considering as more important, the data coming from the control units placed closest to the calculation point and, at the same time, allowed to exclude from the calculation of the values in a point the data coming from distant areas and characterized by different microclimate conditions. This is the methodology suggested by the developers of the CALMET-CALPUFF modeling chain [1].

Figure 2.5 shows the trend of the wind speed and direction, of the temperature and of the mixing height of the air column during the whole calendar year 2008, at the grid point of coordinates x = 406.0 km, y = 5051.0 km UTM WGS-84, next to the location of the plant. It is observed that the events with higher wind intensity are strongly correlated with a wind direction coming from the first quadrant. This is a typical trend for the

It should be noted that the conditions observed in the third decade of February 2008, do not represent the norm, rather they are to be considered as an exceptional event and therefore as a case of strongly conservative meteorological forcing. In general, low values of mixing height are observed in the autumn-winter period. This size tends to assume higher values in the spring-summer period. This tendency is locally interrupted by the Bora events which tend to raise the mixing height in the fluid column. It is also observed the presence of very weak breeze conditions coming from the third and fourth quadrant during the spring-summer period. These meteorological conditions are those that tend to transport the pollutants produced in the industrial zone of Trieste towards the neighboring districts.

The scatter-plot of the wind intensity as a function of the direction (Figure 2.6), relative to the values shown in Figure 2.5, confirms that the events with higher wind intensity are associated with a direction of origin contained in the first quadrant. It is also observed the presence of a not inconsiderable number of events characterized by breezes coming both from north-west and south-east, while apart from isolated events with intensity between 2 and 4

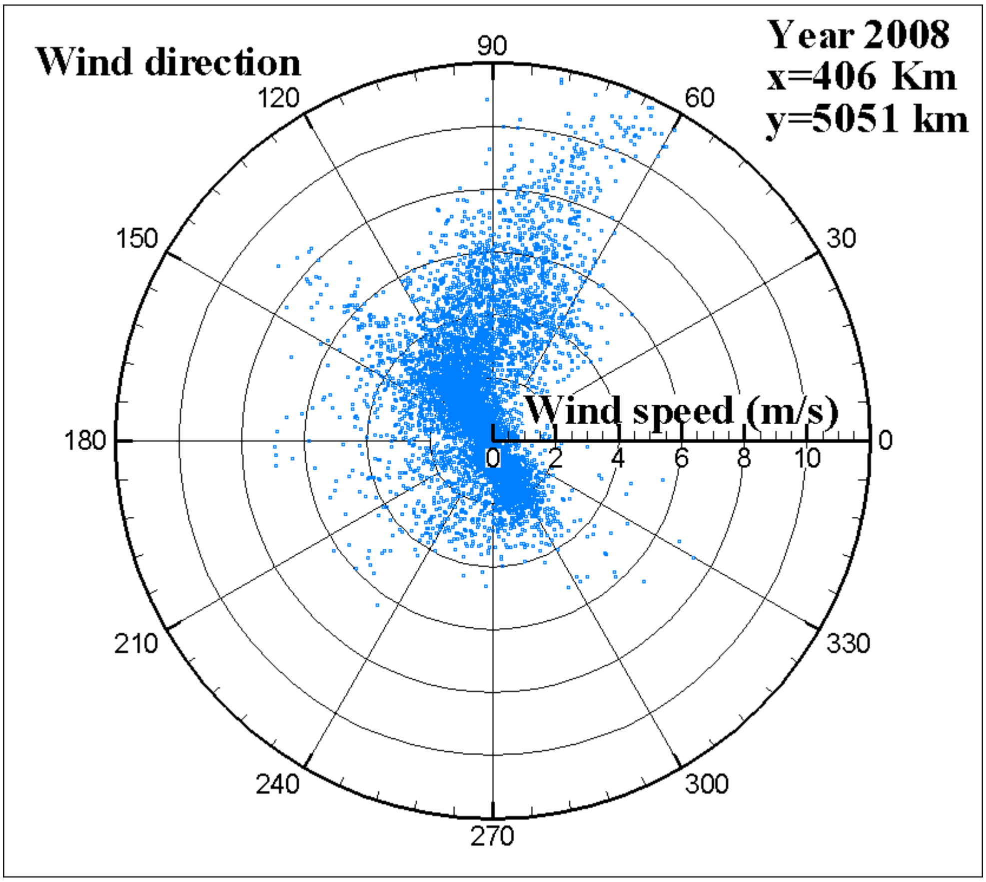

Figure 2.6: Wind plot obtained at the first grid point (z = 20 m). Data calculated at the point of coordinates x = 406.0 km, y = 5051.0 km (UTM WGS-84)

m/s From the south-western quadrant come breezes at very low intensity.

2.2 Short-term case

The analysis of the short-term scenario is necessary to identify any peak concentrations that follow particularly critical meteorological events. This scenario considers a discretized limited amplitude domain with a much higher resolution than the one used in the previous scenario.

The choice of the spatial dimensions of the computational domain is performed starting from the concentration scenario obtained in the long-term numerical simulations. In particular, the domain to be considered will include the areas of the region of interest characterized by significant values of the concentrations of the pollutants considered in the study. The analysis of the

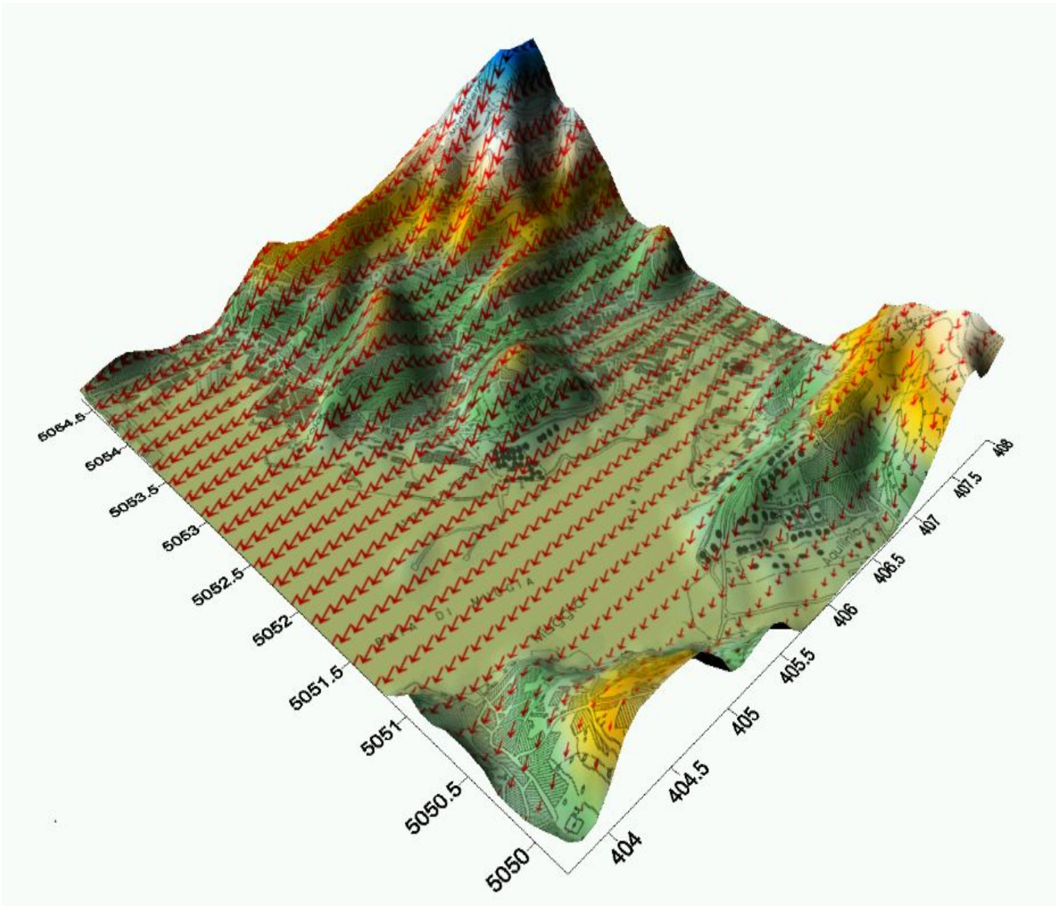

Figure 2.7: 3D view of Trieste. the arrow shows the direction of the wind on 22 July 2008.

dispersion of the pollutants of interest, reported in the Final Report and in Attachment 2 to the same, shows that the most relevant concentration values are recorded at the San Sabba, via Pitacco, Monte San Pantaleone, via Carpineto and via Svevo, ie in the city areas adjacent to the settlement area of the main industrial plants of Trieste. The effect of industrial plants on cross-border areas is negligible, while low but still appreciable concentration values are observed in the Muggia area (see figure 2.4)

The domain extends for 4.4 km in the east-west direction and for 5 km in the south-north direction. Note that the domain includes most of the south-eastern districts of the city of Trieste and part of the municipality of Muggia, which are the areas most affected by emissions from the industrial sector. The data necessary for the reconstruction of the orographic features of the soil, the characterization of the coastline have been obtained from the same databases used in the long-term scenario, while the database "Corine Land" was used for the intended use of the surface of the calculation grid Cover "(CLC), definition $\sim$ 100 m, provided by the European Environment Agency (EEA).

Note that compared to the long-term case, a different database was used to define the land use destination. This choice follows from the fact that the database used in this case has a resolution of up to 100 m, and is therefore suitable for simulation on very high-performance grids, typical of short-term analyzes.

The grid for the reconstruction of the meteorological field was arranged with the origin in the coordinate point x = 403.652 km (13.7647065 Long East), y = 5049.725 km (45.5943891 Lat. North) in the UTM WGS-84 system. As anticipated, the domain has dimensions $4.4km \times 5km$ and 44×50 calculation points are used in the two directions respectively. This choice leads to a resolution of 100 meters on each horizontal direction. it should be noted, since our aim is on a specific day on 22 July 2008, hereafter the results presented for the short-term case (see figure 2.7).

The calmet.dat is the output file of the calmet simulation contains the results of the simulation. Using the PRTMET application you can print temperature, vertical speed, and direction wind speed (horizontal plane) for each layer. Also you can choose which part of the domain to print according to the i, j and k index for a range of time set. Direction and intensity of the wind can be obtained in format VEC or GRD. The VEC format contains for each longitude latitude row direction and intensity of the wind, choosing from the menu of surfer post map you can create a vector map which can be superimposed for example to a cotour map.

The following figures 2.8(a-b) show the spatial distribution of wind speed vectors and 2.8(c-d) temperature distribution at height of 20 meters above the ground, at specific hours of the day of 22 July 2008. At 00.00, the wind comes mainly from the east with deviations to the south in the area industrial due to the hill relief. We observed that the maximum value of the speed of the wind is equal to 1.71 m/s. Figure 2.9 shows distribution of the wind and temperature at time 18:00 and 23:00 respectively.

2.3 CALPUFF

Figures 5, 6 and 7 show the spatial distributions in all the grid points respectively calculation in the order of; annual average values, maximum values of the average over 24 hours (1 day); maximum values of hourly average. It is noted that annual average values of the order of 4 mg/m3 can only be detected in one area restricted around industrial plants. Daily peak values between 10 and 20 mg/m3 are observable in the bay area up to the village of Muggia and in the neighborhoods surrounding the area industrial.

Finally peak values of the hourly average of the order of 250 mg / m3 are observable near the pollutant emission chimneys and the peak values of

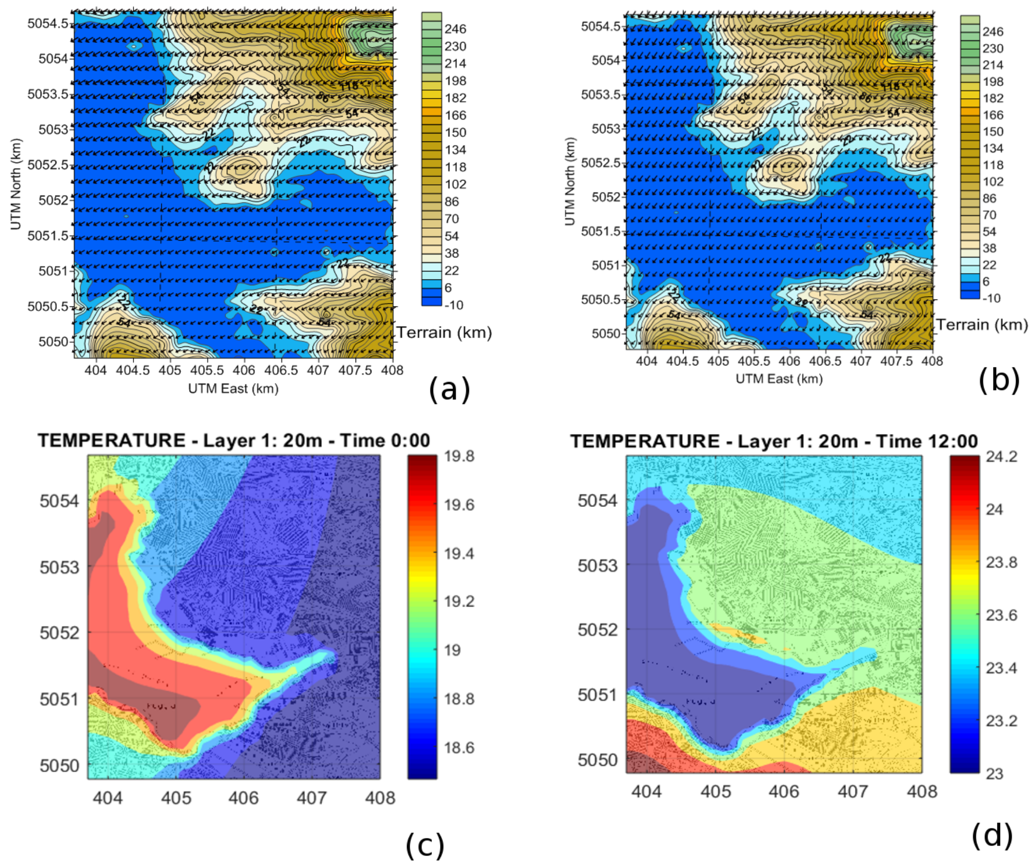

Figure 2.8: Spatial distribution on the area of interest of (a-b) the wind field vectors and (c-d) temperature at a height of 20 m above the ground. Data relating to time 00.00 (a,c) and 12:00 (b,d) of 22 July 2008 respectively.

the hourly concentration decay to values in the range 130-170 mg / m3 in the neighboring areas , especially in neighborhoods adjacent to the industrial area.

Acknowledgment

I would like to express my deepest appreciation to all those who provided me the possibility to complete this report. A special gratitude I give to Mr. Paolo Martinis member of AREA science park Trieste, whose contribution in stimulating suggestions and encouragement, helped me to finish my project.

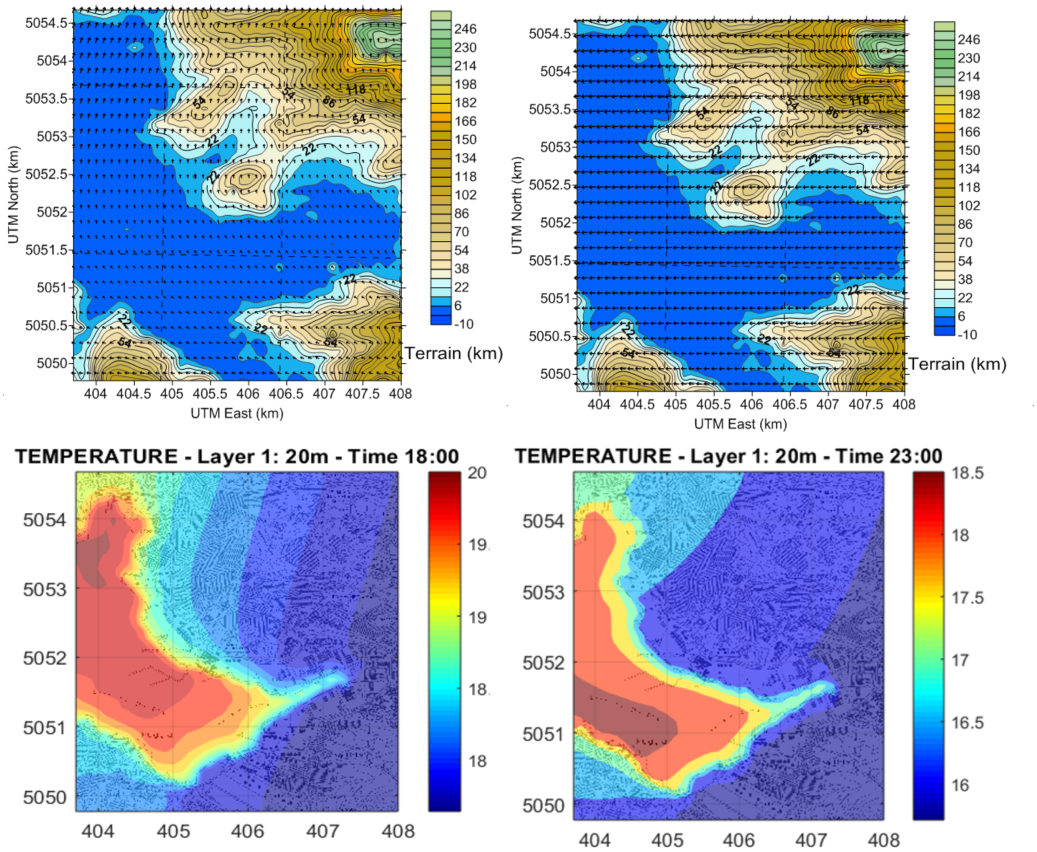

Figure 2.9: Spatial distribution on the area of interest of (a-b) the wind field vectors and (c-d) temperature at a height of 20 m above the ground. Data relating to time 18:00 (a,c) and 23:00 (b,d) of 22 July 2008 respectively.

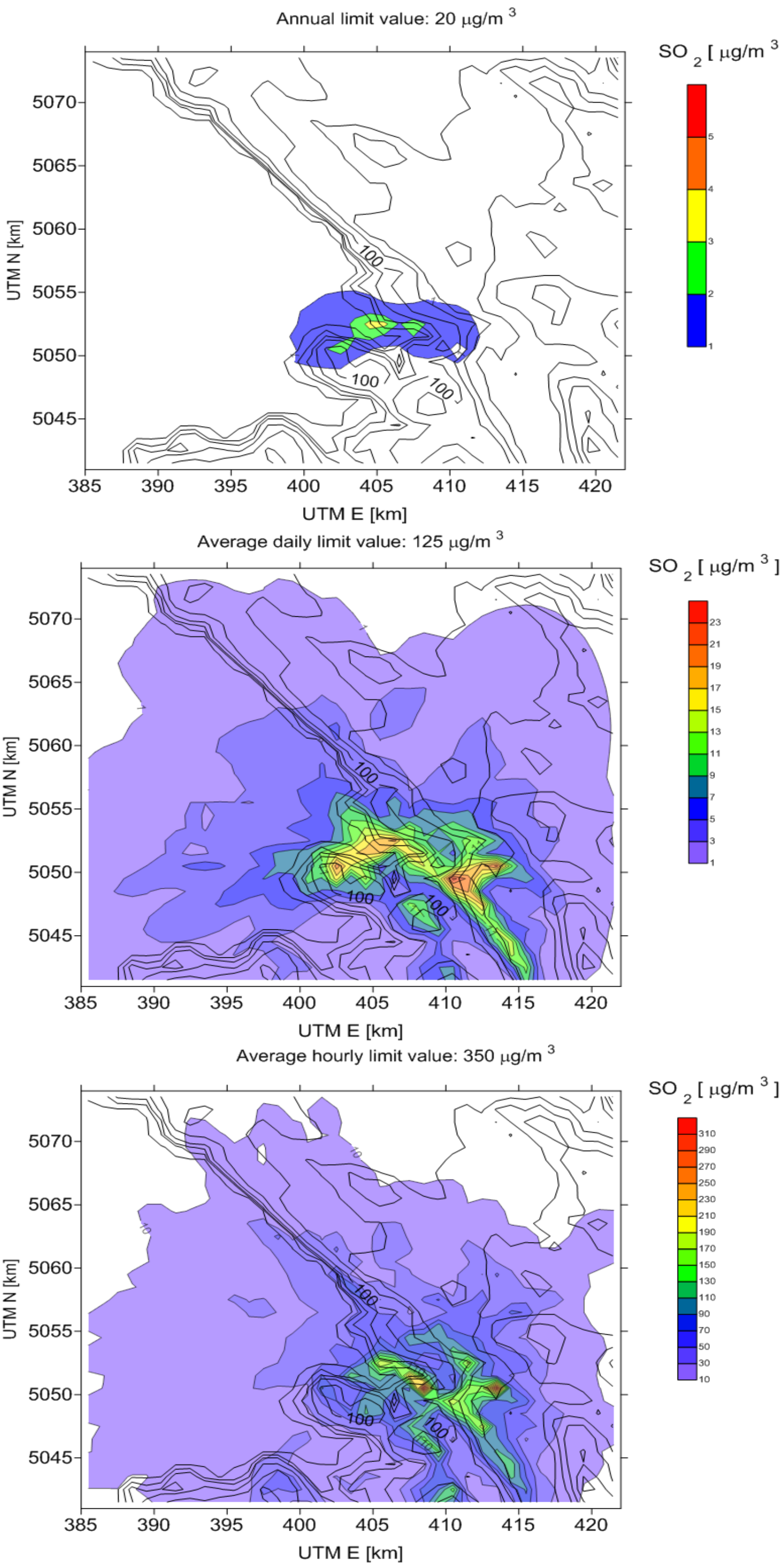

Figure 2.10: Spatial distribution of (top) annual average (mid) a 24 hours (bot.) a 1 hour, SO_2 values for the year 2008.

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