Evaluation of environmental impact through computer simulations

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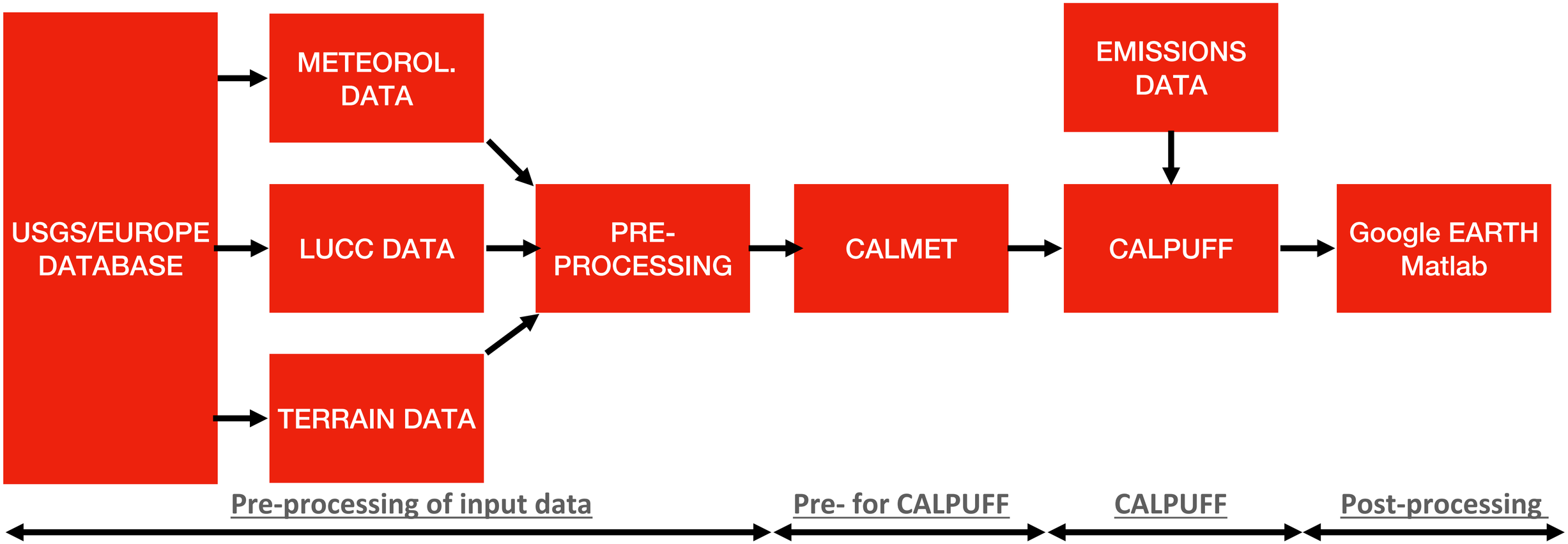
To study the environmental impact, we employ the CALPUFF software suite.
The main workflow of the study can be described as follows:
Pre-processing of input data: input of terrain elevation data, land use and cover change data, meteorological data.
Pre-processing for CALPUFF: data processed at the previous step are read by CALMET and the respective input file for CALPUFF is g
Main simulation (CALPUFF): CALMET input files and emissions data are read by CALPUFF and the main simulation is run.
Post-processing (Google Earth and Matlab): Visualizations of the results obtained.



Pre-processing of input data:
Location of the production sites (ITALY):
Time zone: 33

- Quarry Pietra Piasentina - “Noglar”

46.14038777000248 N, 13.456136579839253 E
(46° 8’ 25.396” N, 13° 27’ 22.091” E)

- Quarry Tarpezzo

46.1373722 N, 13.50398888888889 E
(46° 8’ 14.54” N, 13°30’ 14.36 E)

- Quarry Clastra

46.1306083 N, 13.511447222222221 E
(46° 7’ 50.19 N, 13°30’ 41.21 E)

<u>All production sites are located between 46°N - 47°N and 13°E and 14°E.</u>

Definition of computational domain:

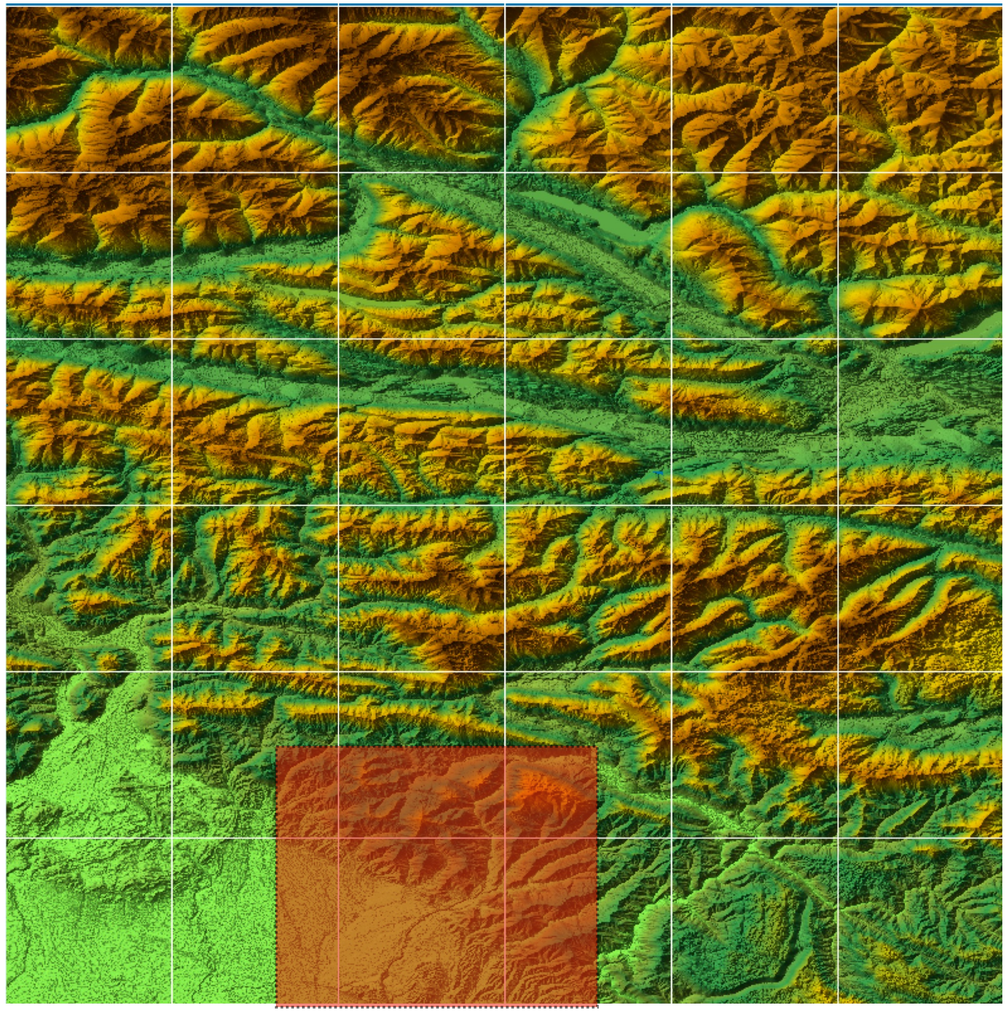
NE corner (46.25 N, 13.60 E)
NE corner (46°15’ N, 13°36’ E)

22 km (0.20 degrees)

SW corner (46.05 N, 13.30 E)
SW corner (46°3’ N, 13°18’ E)
Corresponding to
(WGS-84)
XREF: 368.5 km
YREF 5101.0 km

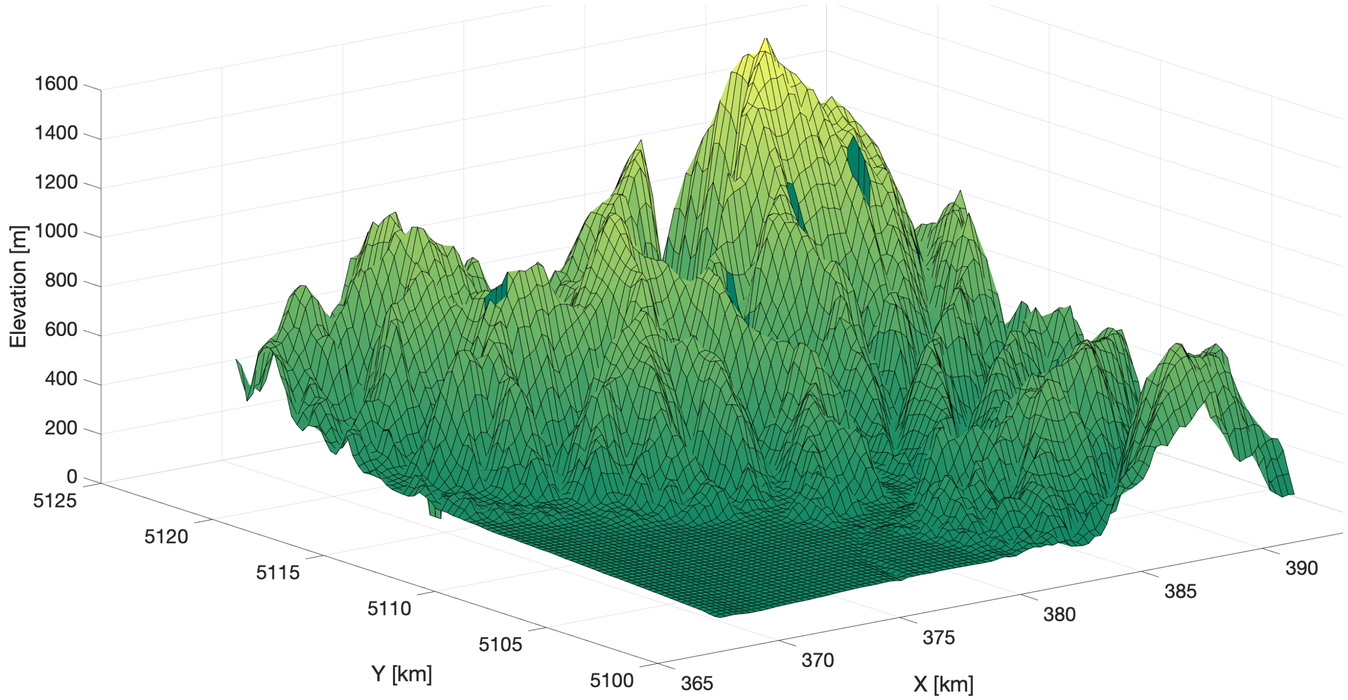
Terrain DATA

We use the SRTM1 files (1 arc-second resolution = 30 m resolution).
File: 46NE13 (GeoTIFF or hgt): from 46N,13E (SW) to 47N,14E (NE).



Green= flat, brown=mountains

Resulting 2D elevation field:



At the end of this process, we have the TERREL.DAT file.

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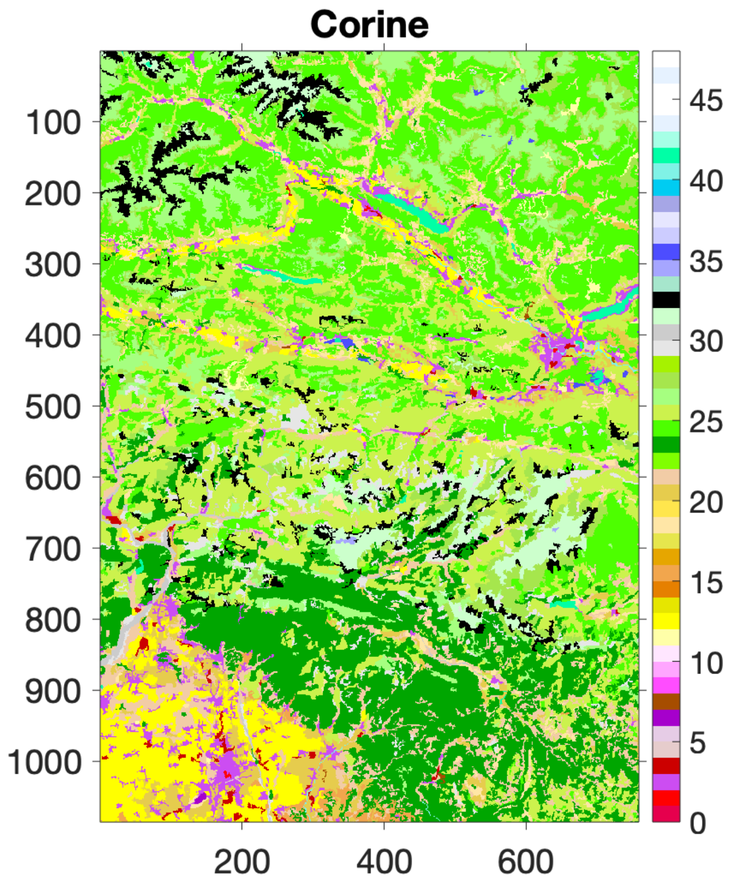
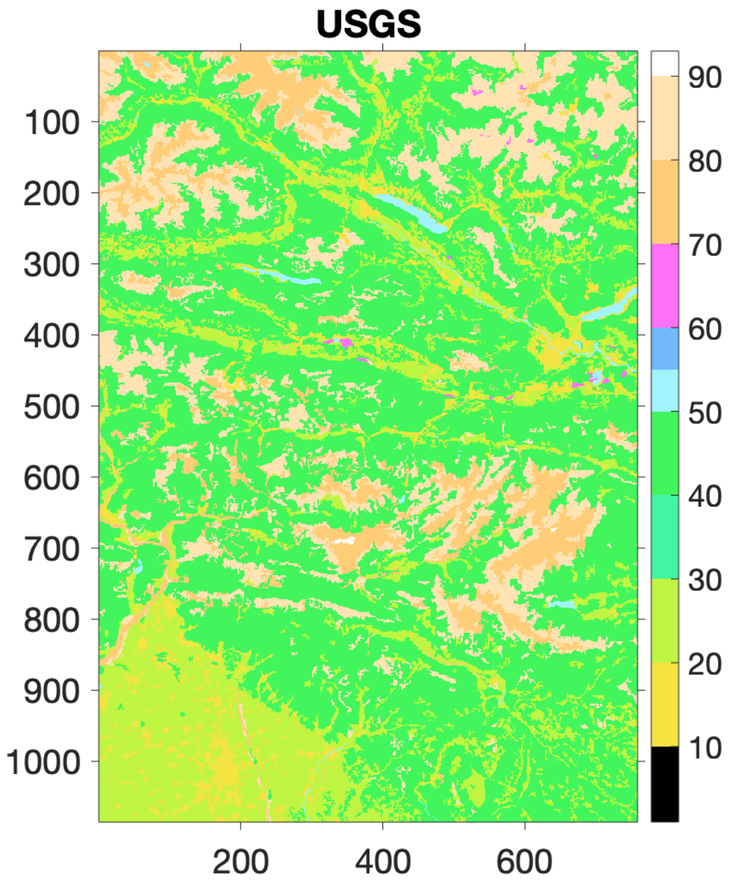
Land use and cover change data

We rely on the CORINE database as it is the most up to date. However, some work is required to adapt the Corine categories to the calpuff categories (simplified USGS categories)

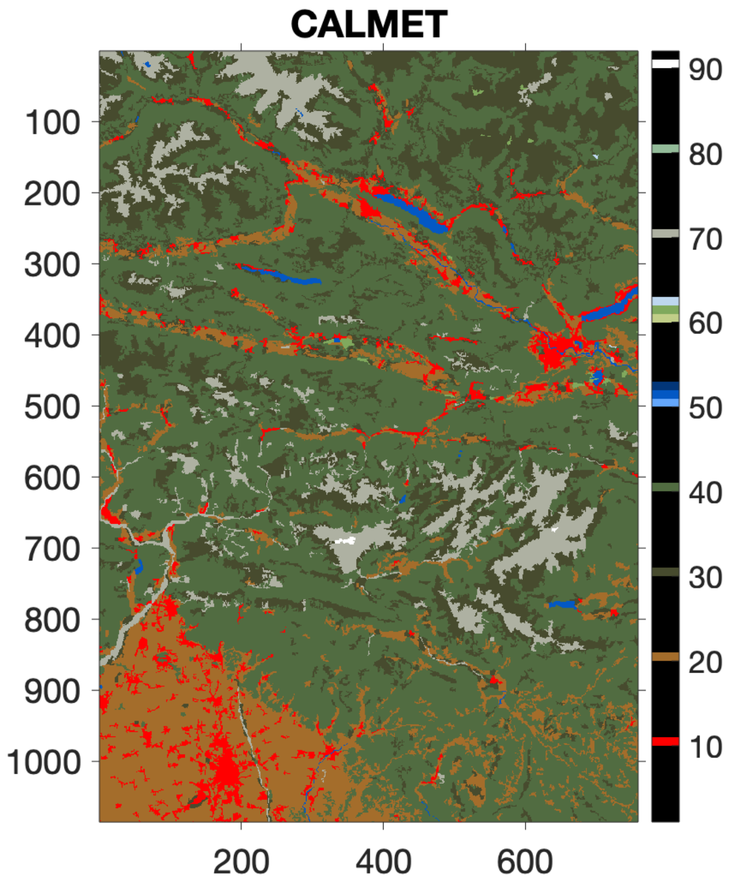
Corine Database (1-999 levels)



USGS Categories (38 categories)

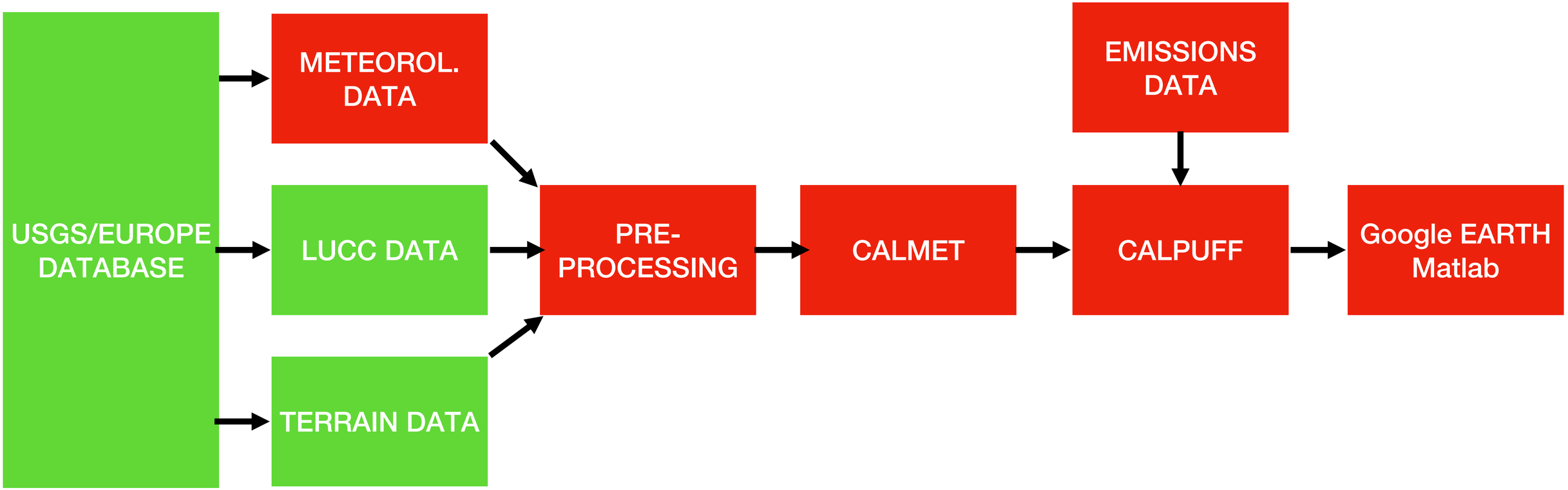


CALMET Categories (14 categories)



TERREL.DAT (Terrain elevation) and LU.DAT files have been generated.
Next step is to use MAKEGEO and generate the GEO.DAT file. This file contain the following information:

- Elevation
- Gridded zo
- Gridded Bowen ratio
- Gridded soil heat flux
- Gridded anthropogenic heat flux
- Gridded leaf area index field

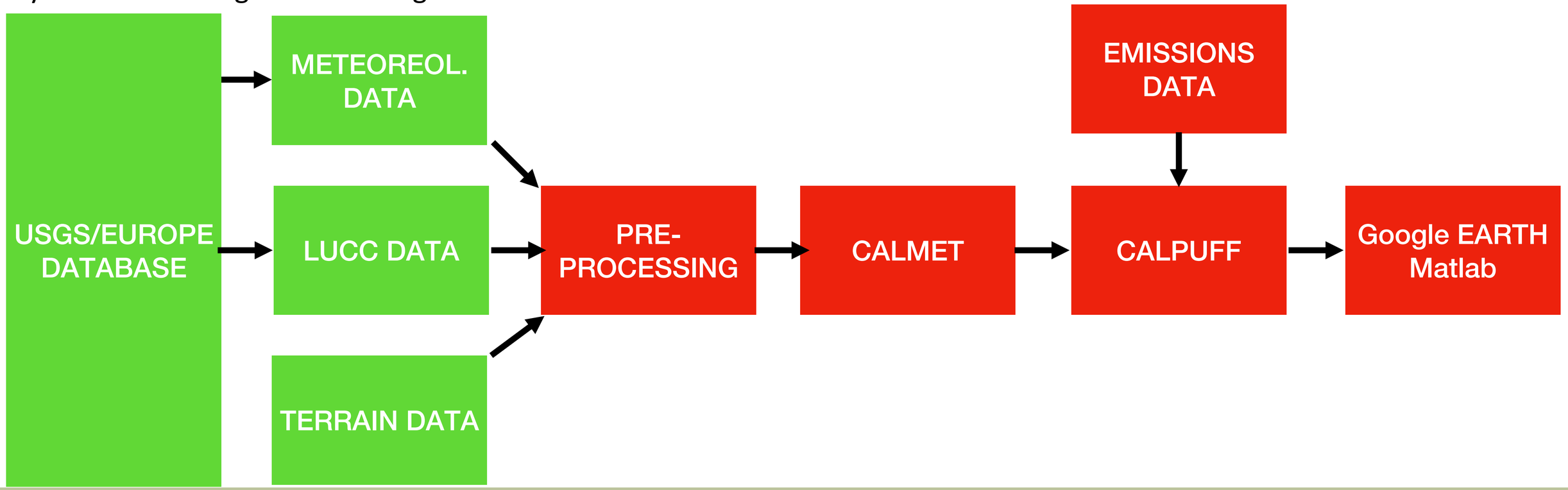


Meteorological data

We move now to the pre-processing of the meteorological data.

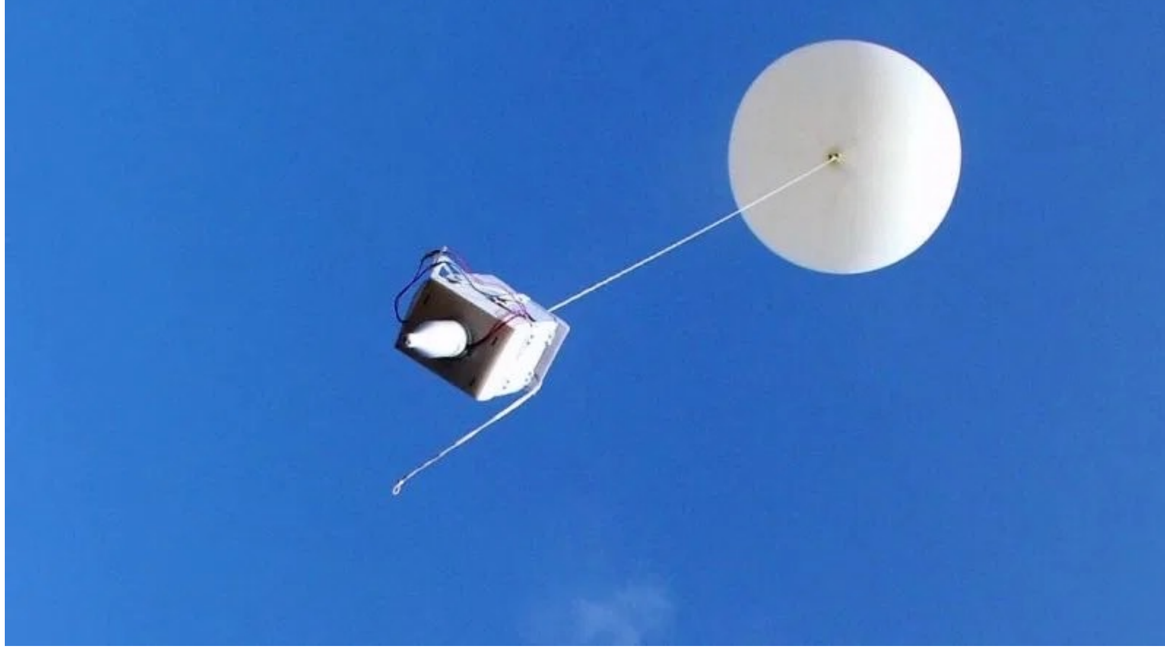
The following meteorological files are required by CALMET:

- **UP.DAT**, upper air DATA information (along the vertical direction)
- **SURF.DAT**, surface meteorological data (temperature, cloud cover, humidity, wind) at the surface of the computational domain (in one or more stations).
- **PRECIP.DAT**, precipitations during the different times of the day in one or more meteorological stations.
- **3D.DAT** or MM4/MM5 files, prognostic files. The 3D.DAT file consists of three-dimensional data spanning many vertical layers and covering a horizontal grid and domain.



Upper air information (UP.DAT)

Upper air information are obtained through radiosonde.
Information can be downloaded from NOAA (IGRA Database) or Aeronautica Militare.
The closest location where these information are available (twice per day) is the Rivolto Air Base (Campo Formido) located at 45.97N, 13.03 E.
Information are collected in a FSL file:



```
  254      0      1      JAN    2019\
    1  99999  16045  45.97N 13.05E    52   2300\
    2    100   1890    930     132  99999      3\
    3          LIPI                 99999     ms\
    9  10240     52      8     -21     60     15\
    5  10210     76     46     -24  99999  99999\
    6  10110    157  99999   99999     95     51\
    5  10050    205     66     -14  99999  99999\
    6  10010    239  99999   99999    105     77\
    4  10000    248     64     -16    105     77\
    5   9910    322     62     -18  99999  99999\
```

→ File header (location, day, time of the day).

→ Each line represents a certain elevation and the different columns identify:
Pressure, Elevation, Temperature, Dew point, Wind direction and speed.

*Data are in tenth of (mbar, °C, m/s)

Surface meteorological data and precipitation data (SURF.DAT and PRECIP.DAT)

Meteorological data at the surface and precipitation data are obtained (and integrated) from two different sources:

- ARPA (OSMER) in CSV format.
- ECMWF - Copernicus (ERA5) in Grib format.

In particular, from the ARPA database we extract information on temperature, wind speed and orientation, Relative humidity, pre

Example of OSMER Database:

tabella

Stazione: Cividale del Friuli

(Alt: 127 m. slm - Lat: 46.080442 - Lon: 13.420014)

aprile 2019

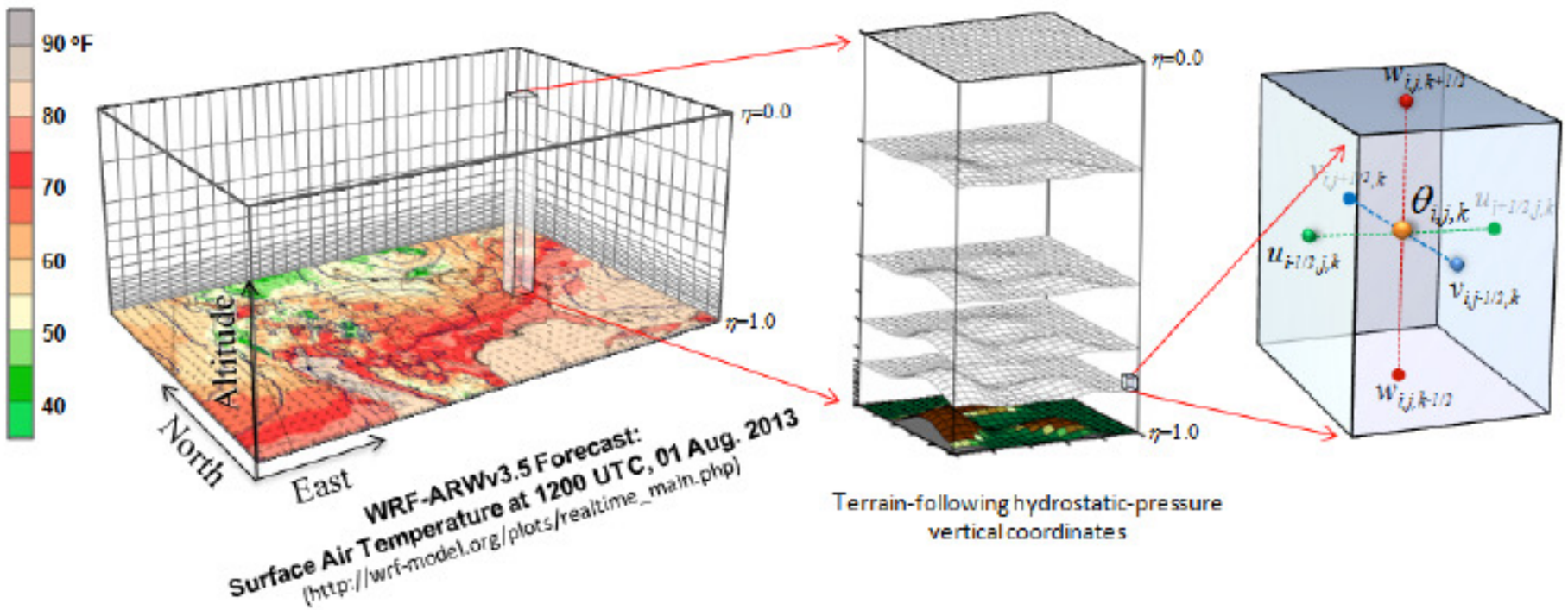
mese	giorno	ora UTC*	Pioggia mm	Temp °C	Umidità %	Vento med km/h	Direzione Vento	Vento max km/h	Direzione Vento max	Radiaz. KJ/m2	Pressione hPa	Bagnatura Fogliare min
4	2	1.00	0.0	14.9	42	14	ENE	27	ENE	0	998.6	-
4	2	2.00	0.0	12.7	46	17	ENE	29	ENE	0	998.4	-
4	2	3.00	0.0	11.9	49	20	ENE	31	ENE	0	998.3	-
4	2	4.00	0.0	11.5	51	21	NE	32	NE	0	998.5	-
4	2	5.00	0.0	11.0	53	18	ENE	27	ENE	18	998.7	-
4	2	6.00	0.0	12.3	50	23	ENE	35	ENE	323	998.5	-
4	2	7.00	0.0	14.8	45	21	ENE	34	ENE	925	997.8	-
4	2	8.00	0.0	17.6	35	21	ENE	33	NE	1626	997.1	-
4	2	9.00	0.0	19.6	31	16	E	30	E	2124	996.6	-

Prognostic meteoreolgical data (3D.DAT)

To generate the prognostic meteorological data, we start from the fields available from NOAA (28km resolution) and we perform a WRF simulation on the domain of interest with a finer resolution (up to 2 km resolution).

WRF model

The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system. It is made of a series of pre-processing tools (WPS) and the real weather model (WRF).



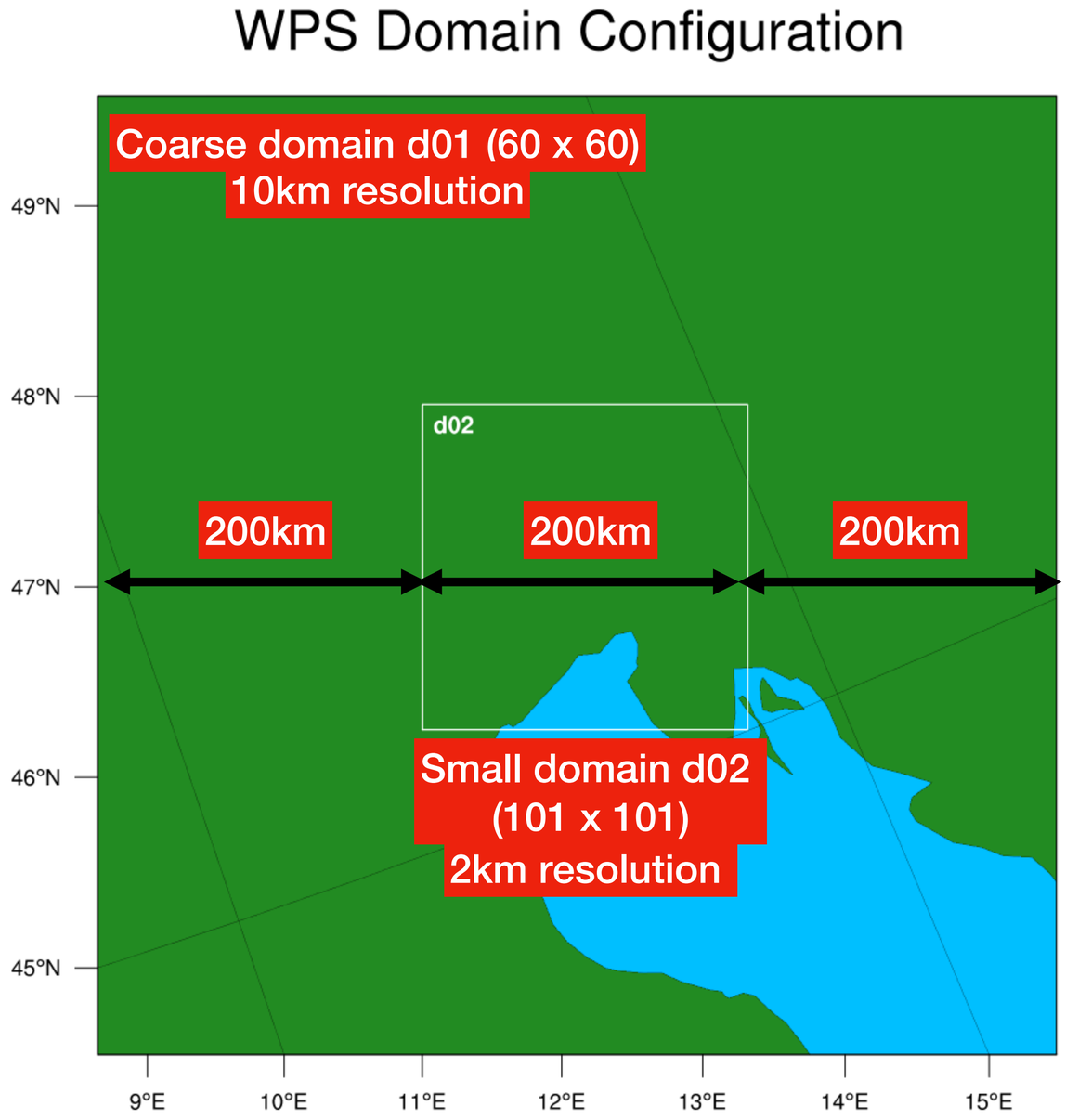
Simulation domain (WPS)

Parameters of the simulation:
Input data from WRF. Considering that meteo files (GFS from NCEP) have resolution of 28 km. We use two nested domains having resolution 10km (d01) and 2km (d02), respectively.

The center of the finer domain is located at 46.15N, 13.45E as in the other CALPUFF domains.

1/3 of the coarse domain is present on each side of the finer domain (as suggested by WRF).

The coarse domain is discretised using 60 x 60 nodes while the central domain is discretised using 101 x 101 nodes.



WRF (main application)

This is the main program that generate the forecast.
It can be run in parallel (present case has been run on a 32 cores machine). WRF.exe time marching, generates a wrfout file (netCDF format) every hour. These files represent the main output of the code, which can be then analysed by CALWRF. For each domain, a wrf_out file is generated (total 4 TB).

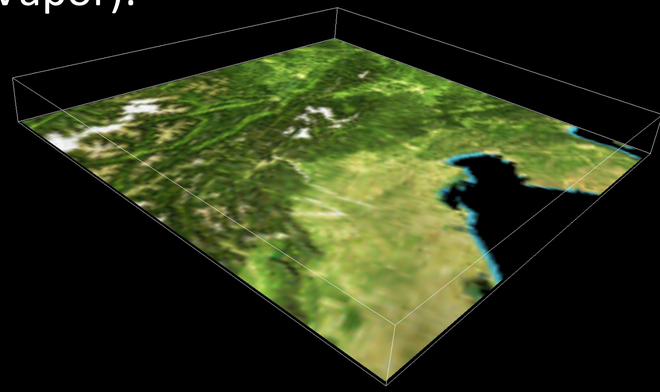
The namelist.input file is used to control the resolve physics (microphysics, long- short-wave radiation, surface later physics, Urban surface, lake/water physics, cumulus Parameterization, etc.).

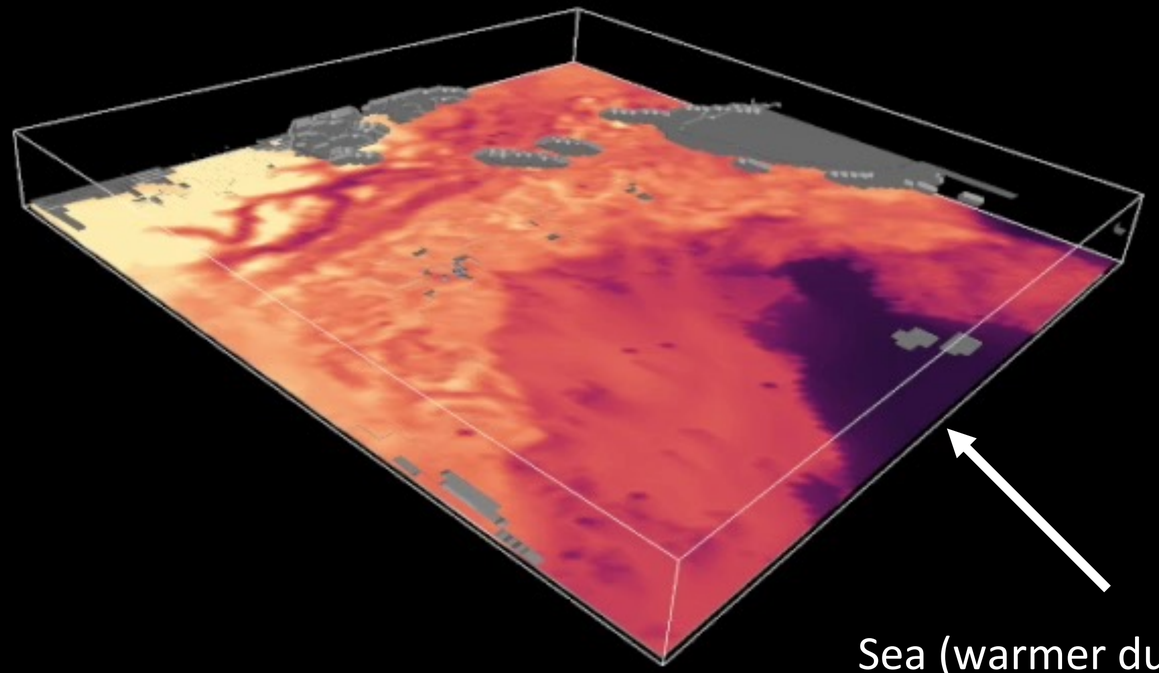
The results can be visualised using ncview (NCAR), Panoply (NASA), Vapor (UCAR) or any other program able to work with NetCDF files.

Example of WRF output visualisation (Vapor):
Day: 2019-01-01.
Time: from 0AM to 6PM.

- Temperature at 2 meter (yellow-low,; violet-high)
- Cloud fraction (iso-surface)

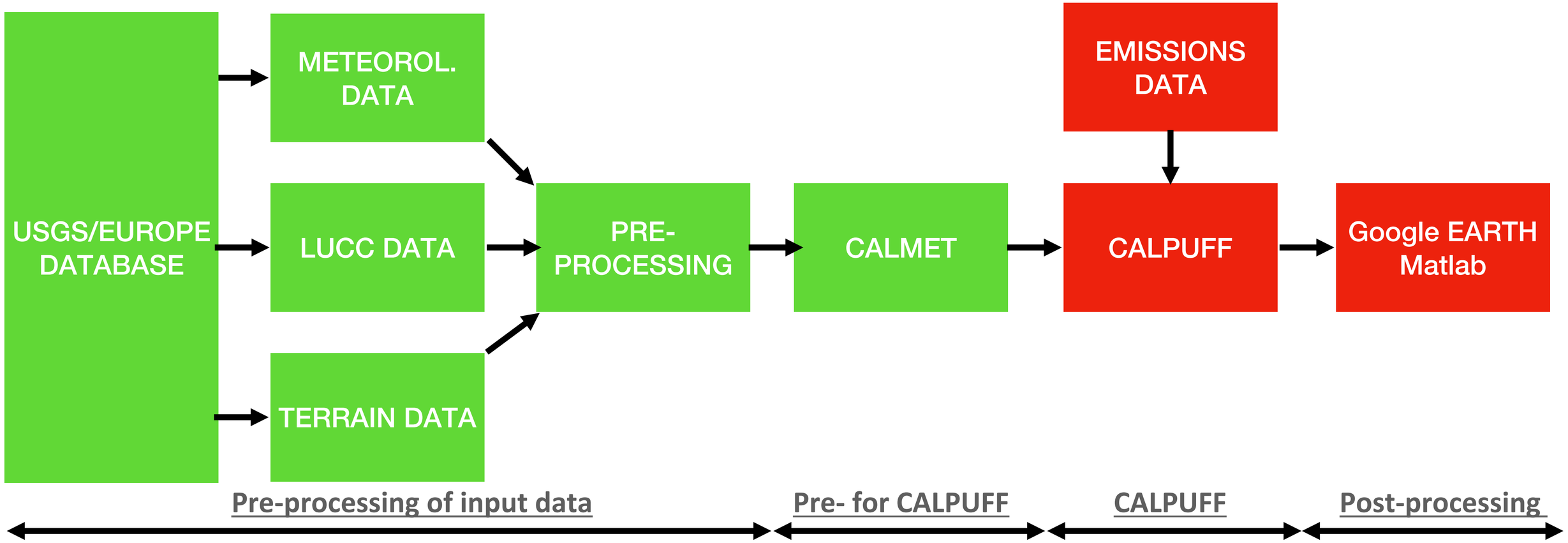
Domain d02





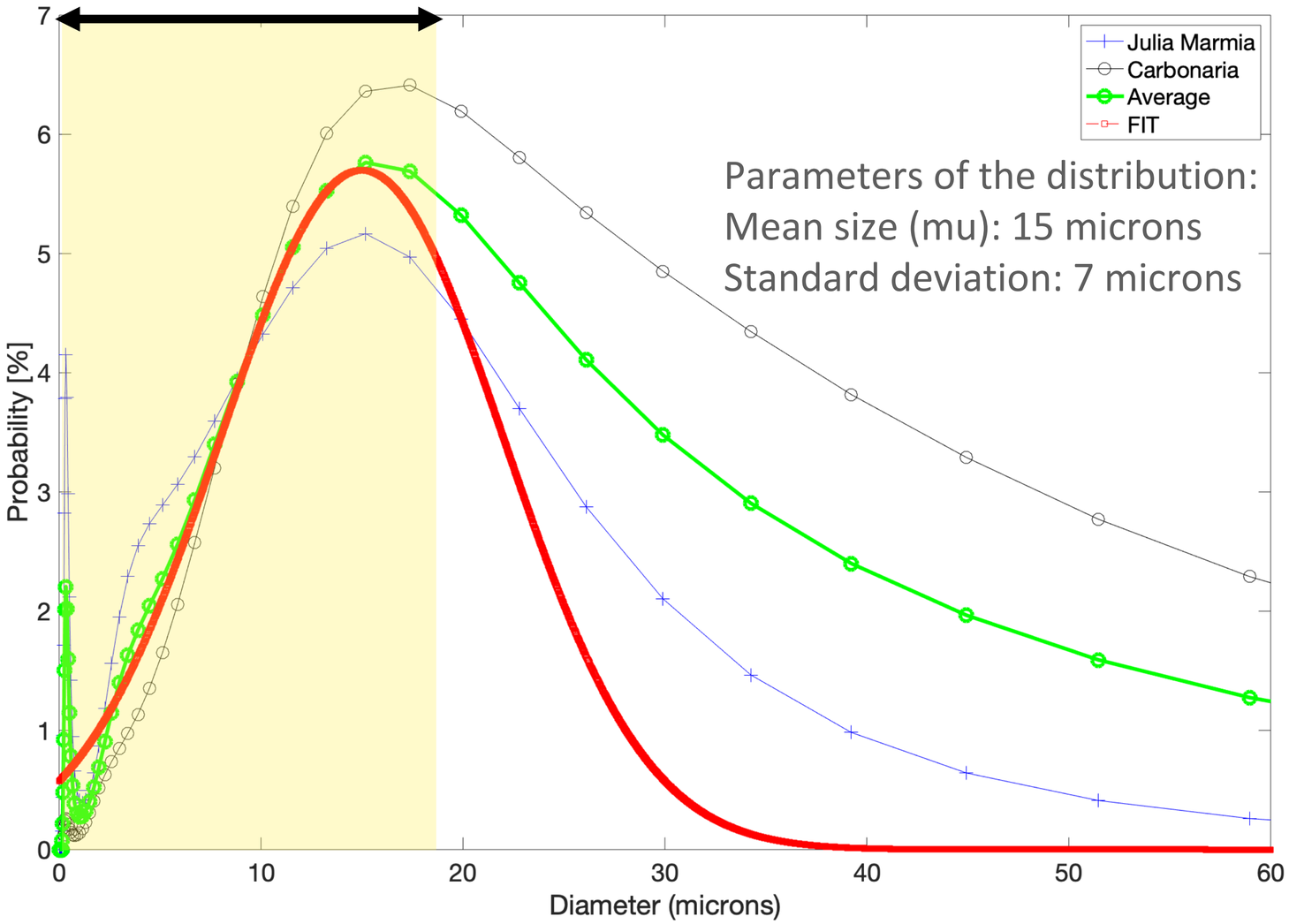
Sea (warmer during winter)

After running WRF, we can run CALMET and generate the CALMET.DAT file.
Once defined the emissions data, we are ready to run the CALPUFF model.



Emissions data

We consider an average distribution and we fit with a Gaussian distribution, we consider the left side only for the fitting. We are n



To estimate the emissions, we consider the correlations proposed by EPA.

We consider the following type of emissions of PM10 (stone powder):

- Extraction of stone with mechanical vehicles.
- No extraction operations performed using explosions (e.g. mines).
- Cutting operations on stone.
- Transit of vehicles on paved roads
- Transit of vehicles on unpaved roads
- Wind erosion

Considering 4000 ton/year removed, we obtain the following PM10 emissions:

- 1.40 kg/h [0.38 g/s] (during working time)
- 0.23 kg/h [0.06 g/s] (during non working hours, only wind erosion)

Data obtained from the research group of Prof. Maschio.

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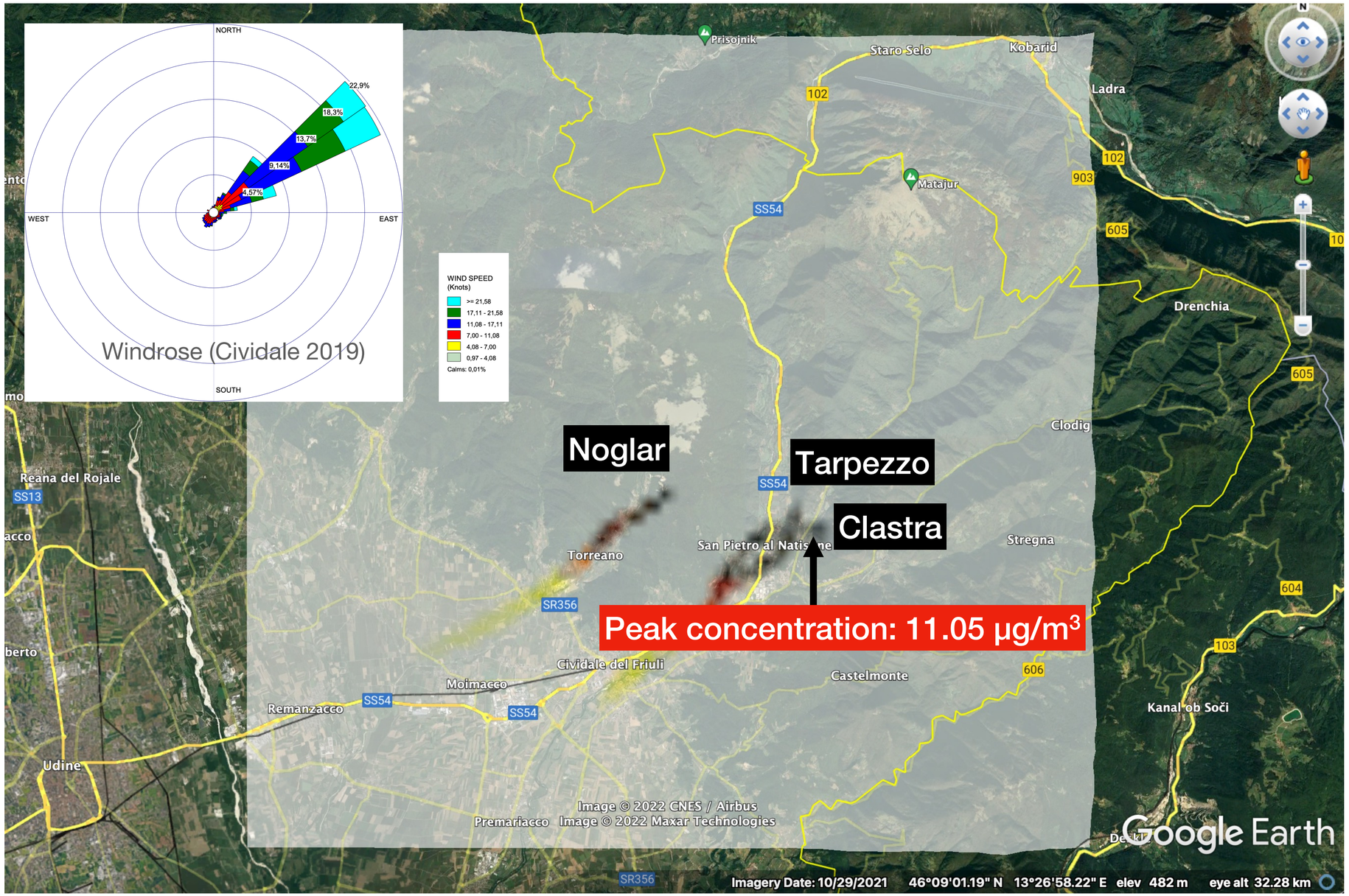
We can now run **CALPUFF** and we obtain the following map:



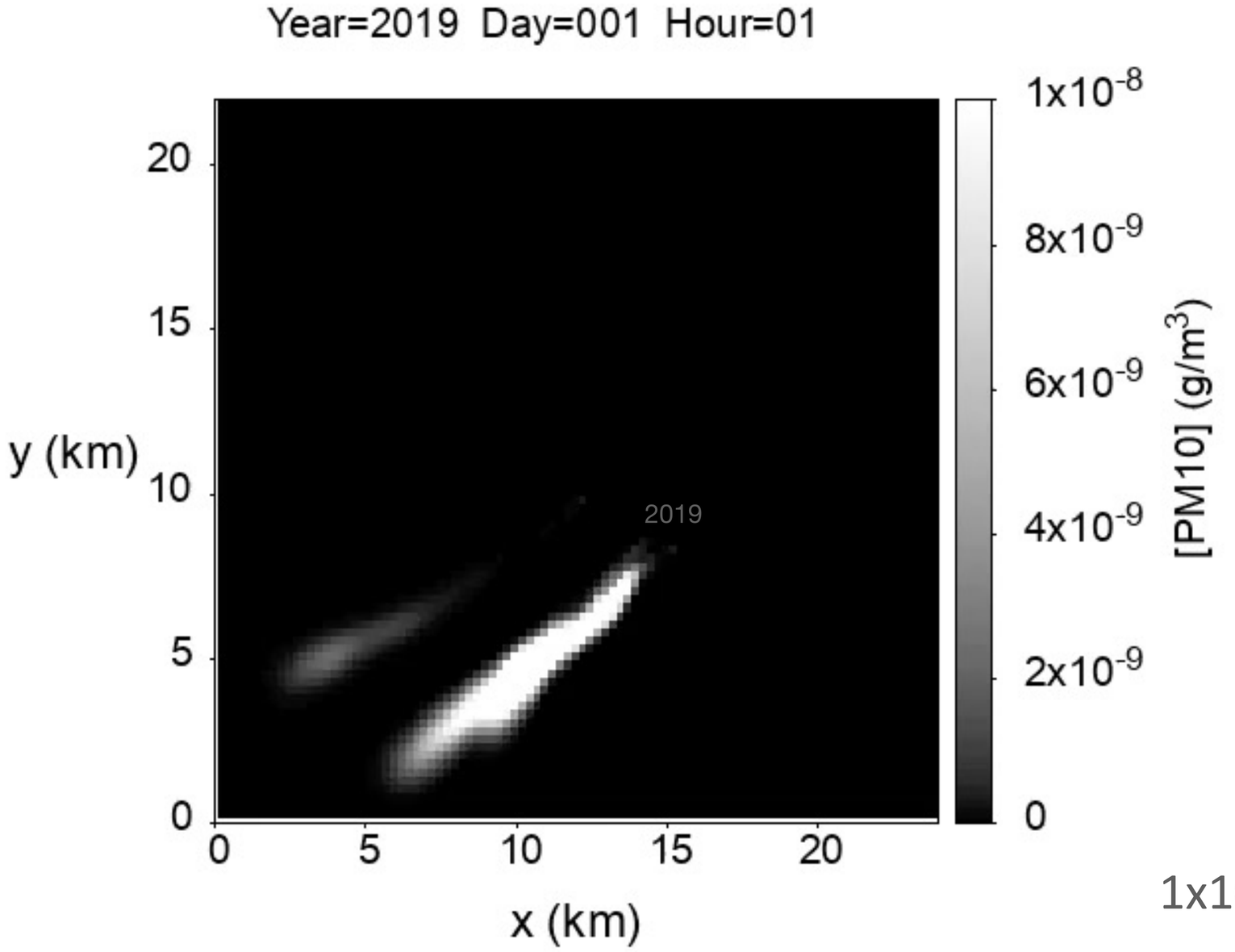
0.1 µg/m^3

0.05 µg/m^3

0.01 µg/m^3

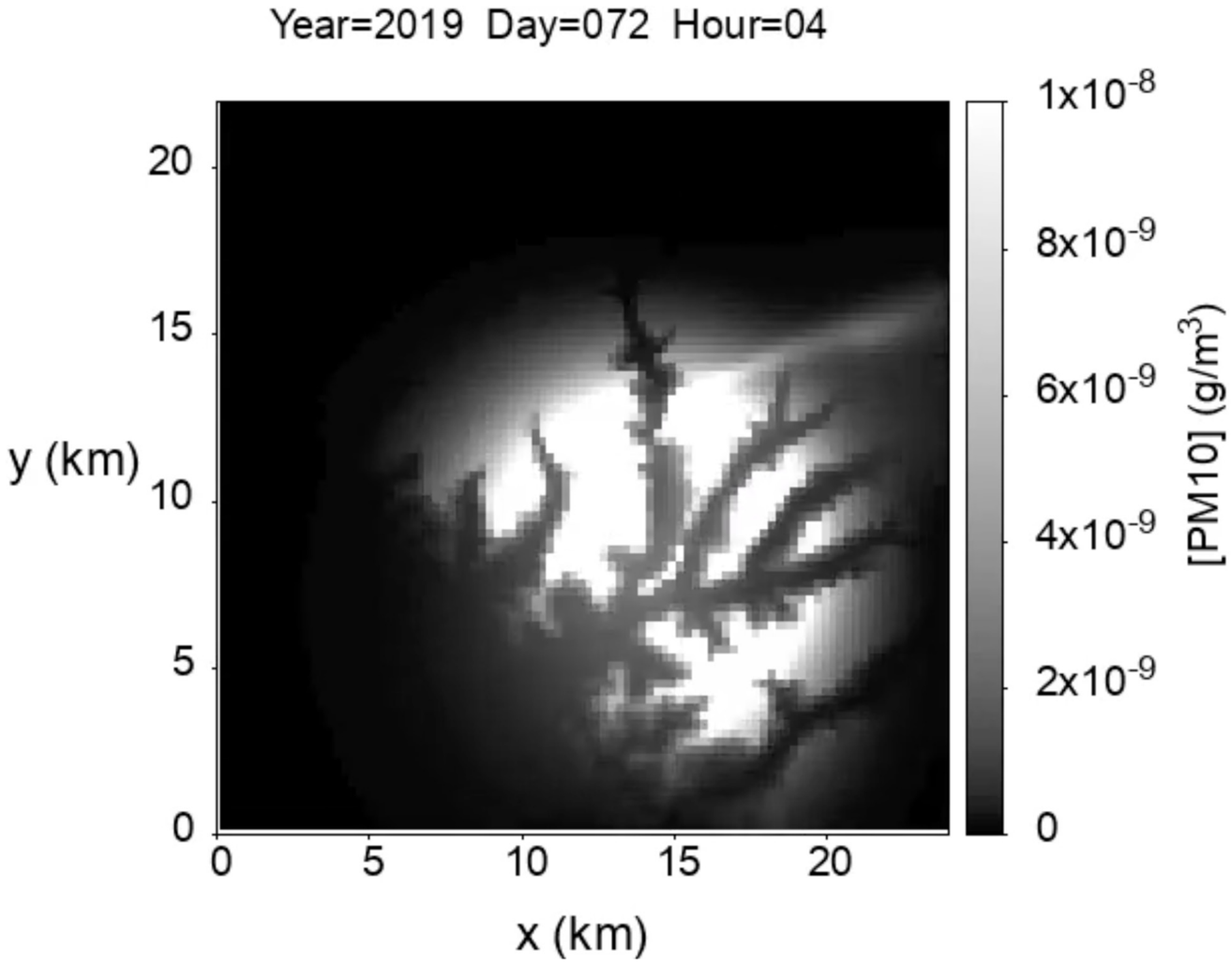
Law limits (Italy):
Daily average: 50 µg/m^3
(Can be exceeded 35 times during a year)
Annual average: 40 µg/m^3

Simulation of year 2019.

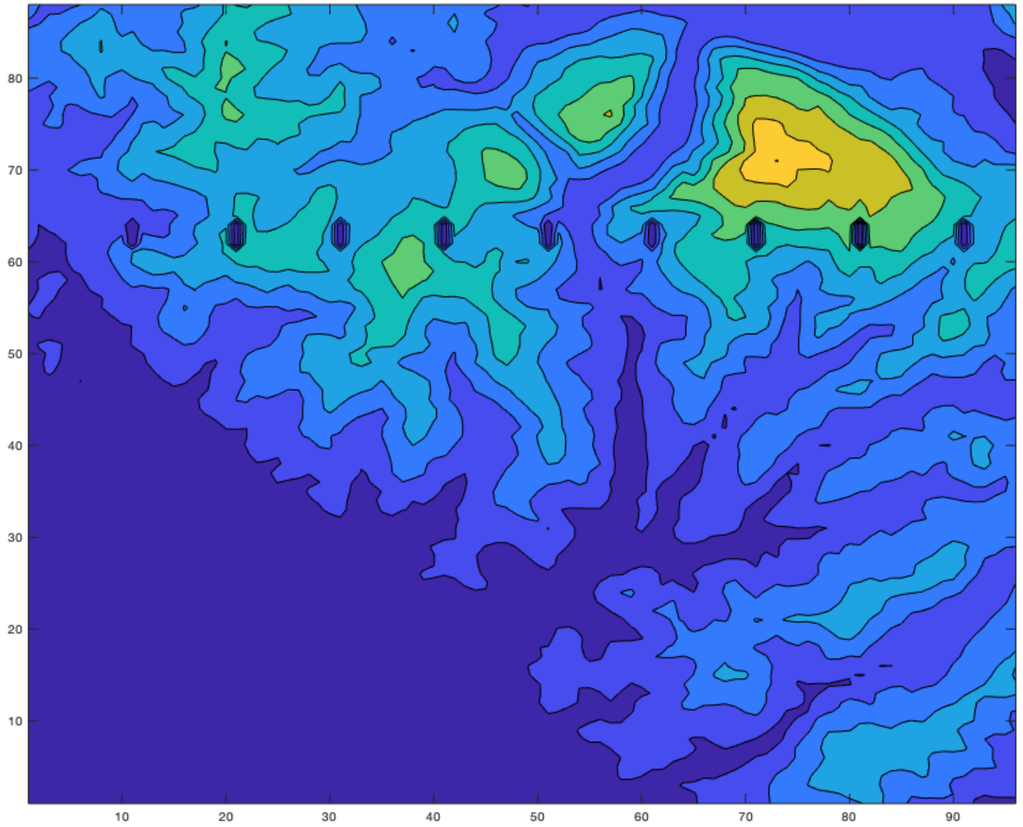


$1x10^{-6}$ g/m^3 =0.01 µg/m^3

Concentration correlates with the valleys location (when the wind is very low).



Elevation in the domain (yellow-high, blue-low)



Results obtained from this WP:

- Git repository of the code updated with the most recent database available (CORINE, etc.).
- Prognostic meteorological fields of the FVG region for the entire 2019 with grid resolution 2km, database available upon request (4 TB overall).
- Meteorological data from Cividale and Rivolto during the entire year 2019.
- Data on the size distribution of the powder generated during quarry activities.
- PM10 concentration on the computational domain for the entire year 2019.