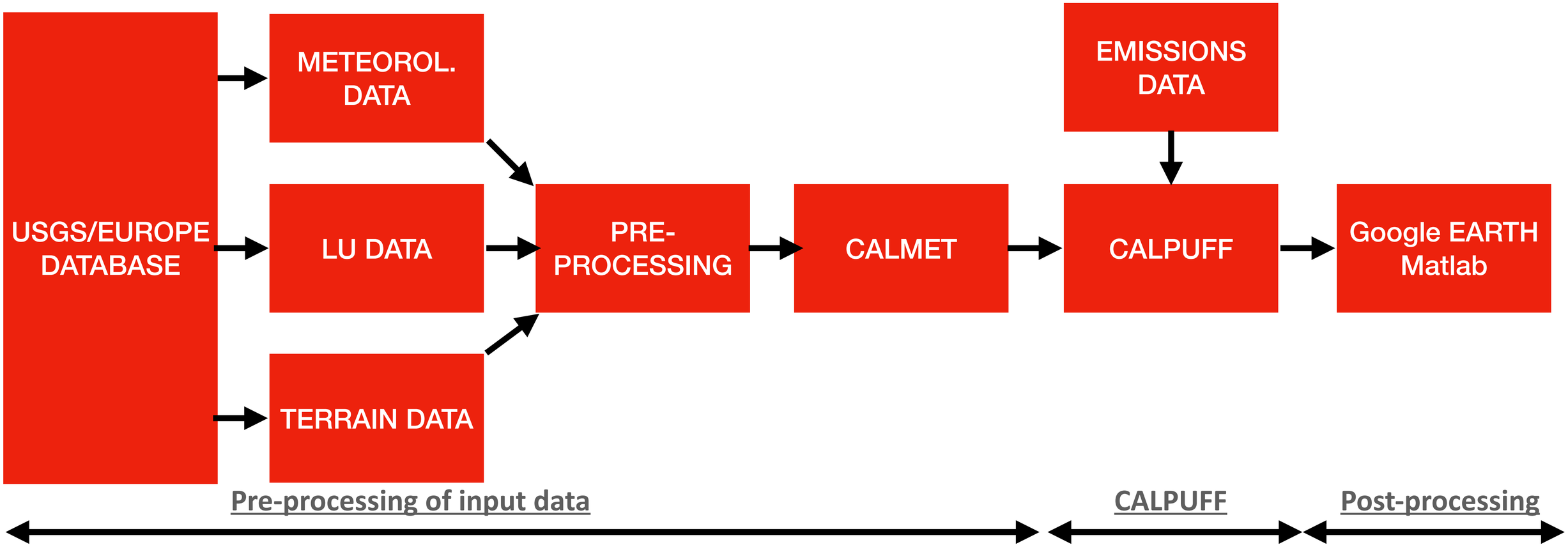
Interreg
Italia-Österreich
European Regional Development Fund

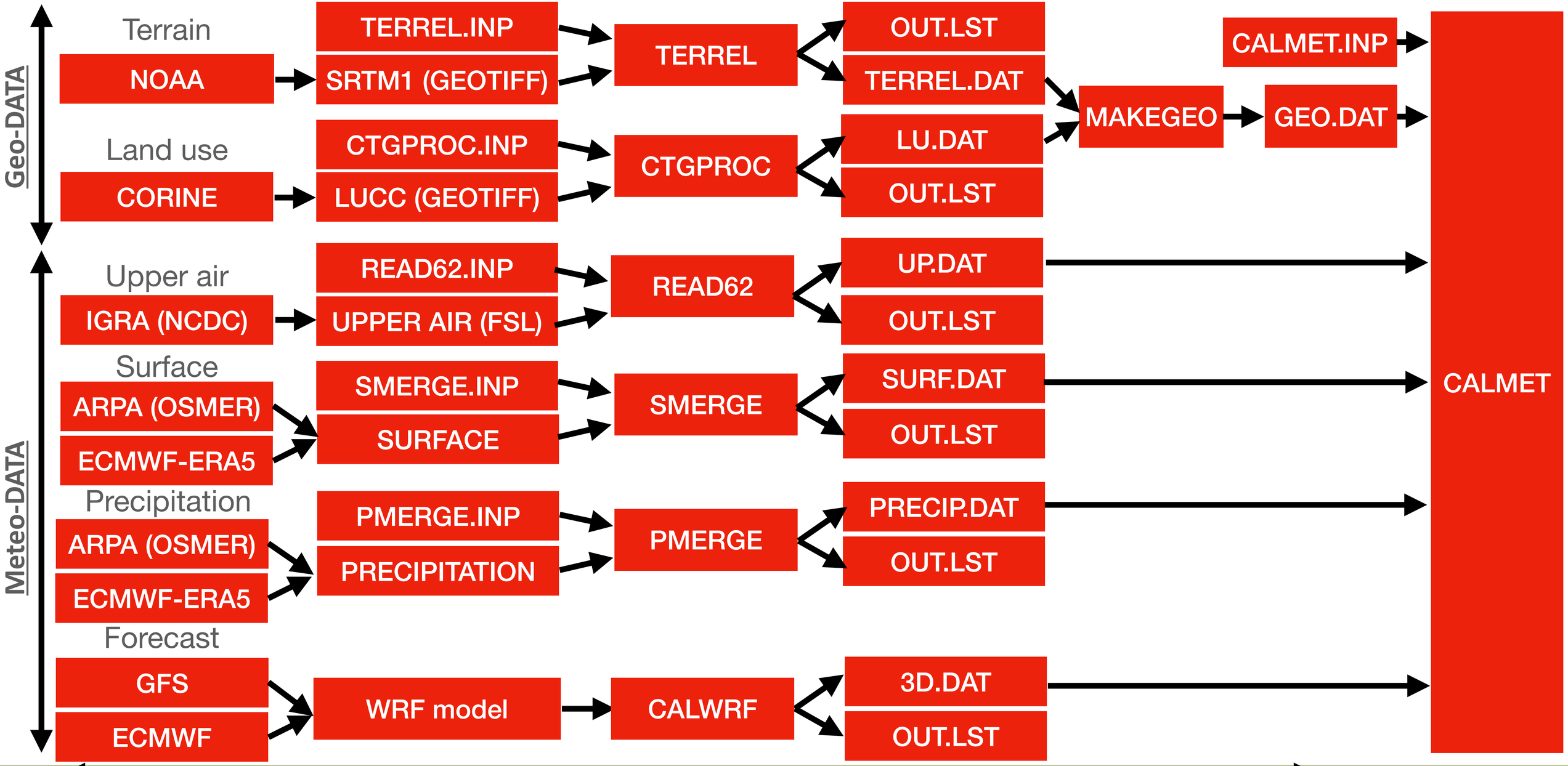
EUROPEAN UNION

CLEANSTONE

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 generated.
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. This step requires the use of different database and different pre-processor tools:



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

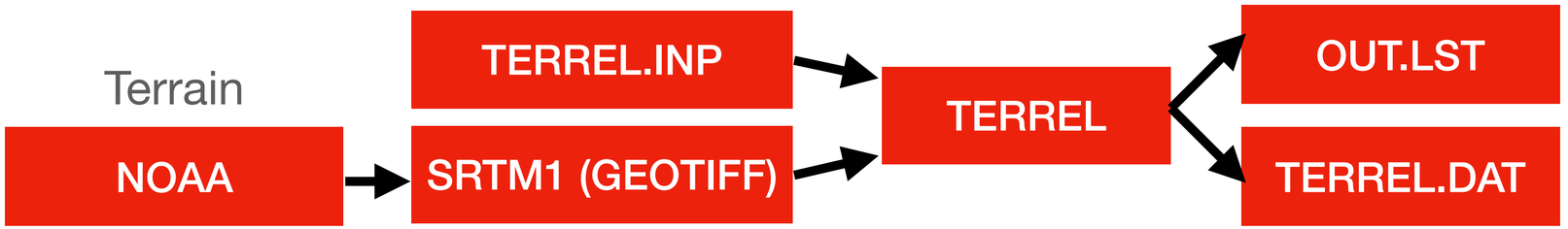
46.1373722 N, 13.50398888888889 E
(46° 8’ 14.54” N, 13°30’ 14.36 E)

- 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>

Terrain elevation data pre-processing workflow:



Terrain database (provided and maintained by USGS):
-GTOPO30 (Global digital elevation model)
-SRTM (Shuttle Radar Topography mission)

The following files can be downloaded from:
-GTOPO30 (GeoTiff format, 30 arc-second = 1km resolution) from earthexplorer.usgs.gov/
-SRTM3 (GeoTiff format, 3 arc-second = 90 m resolution) from earthexplorer.usgs.gov/
-SRTM1 (GeoTiff format, 1 arc-second = 30 m resolution) from earthexplorer.usgs.gov/
-SRTM1 (oil format, 1 arc-second = 30 m resolution) from earthexplorer.usgs.gov/
-SRTM1 (hgt format, 1 arc-second = 30 m resolution) from http://viewfinderpanoramas.org/dem3.html

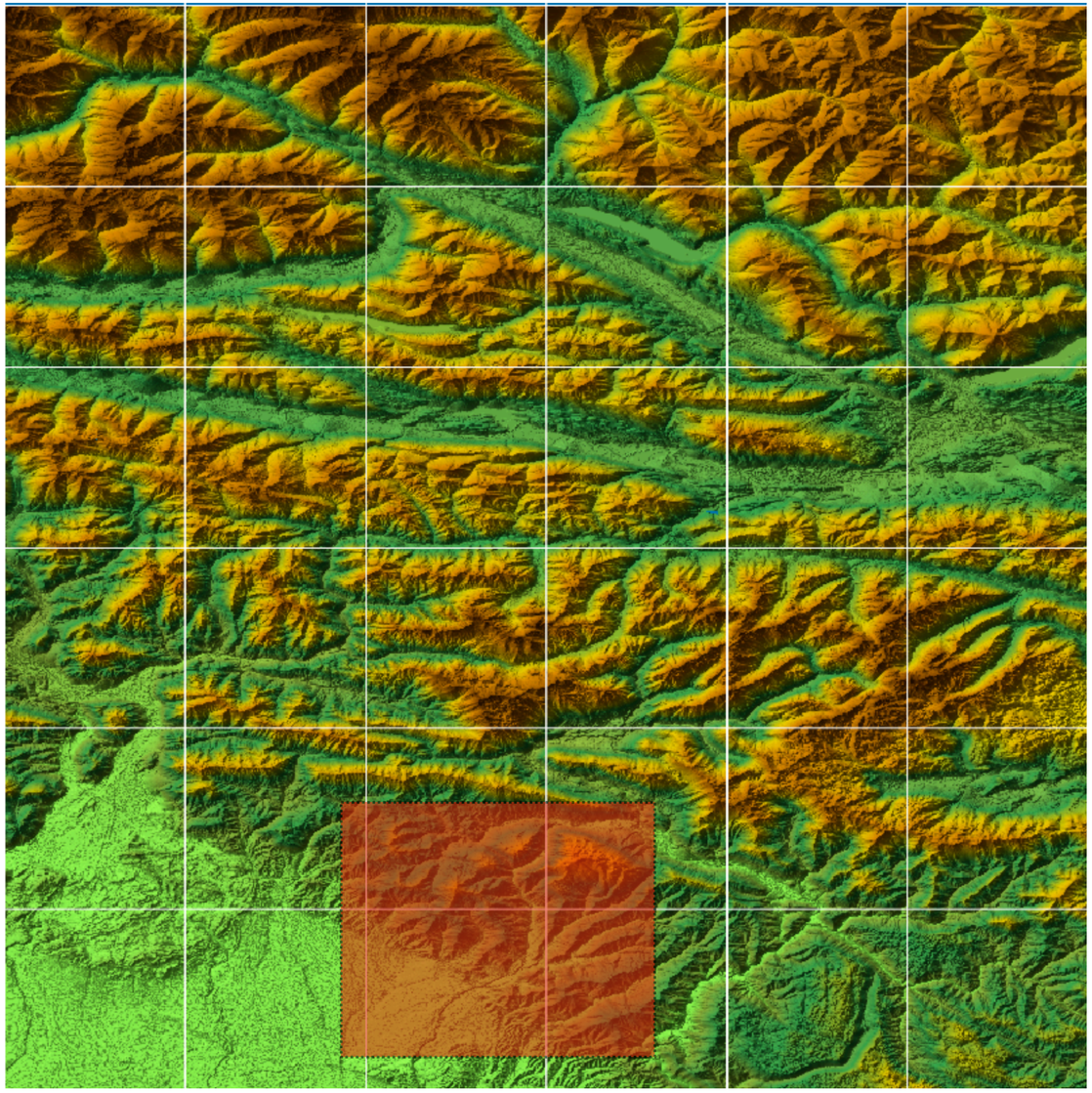
Definition of computational domain:

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

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).



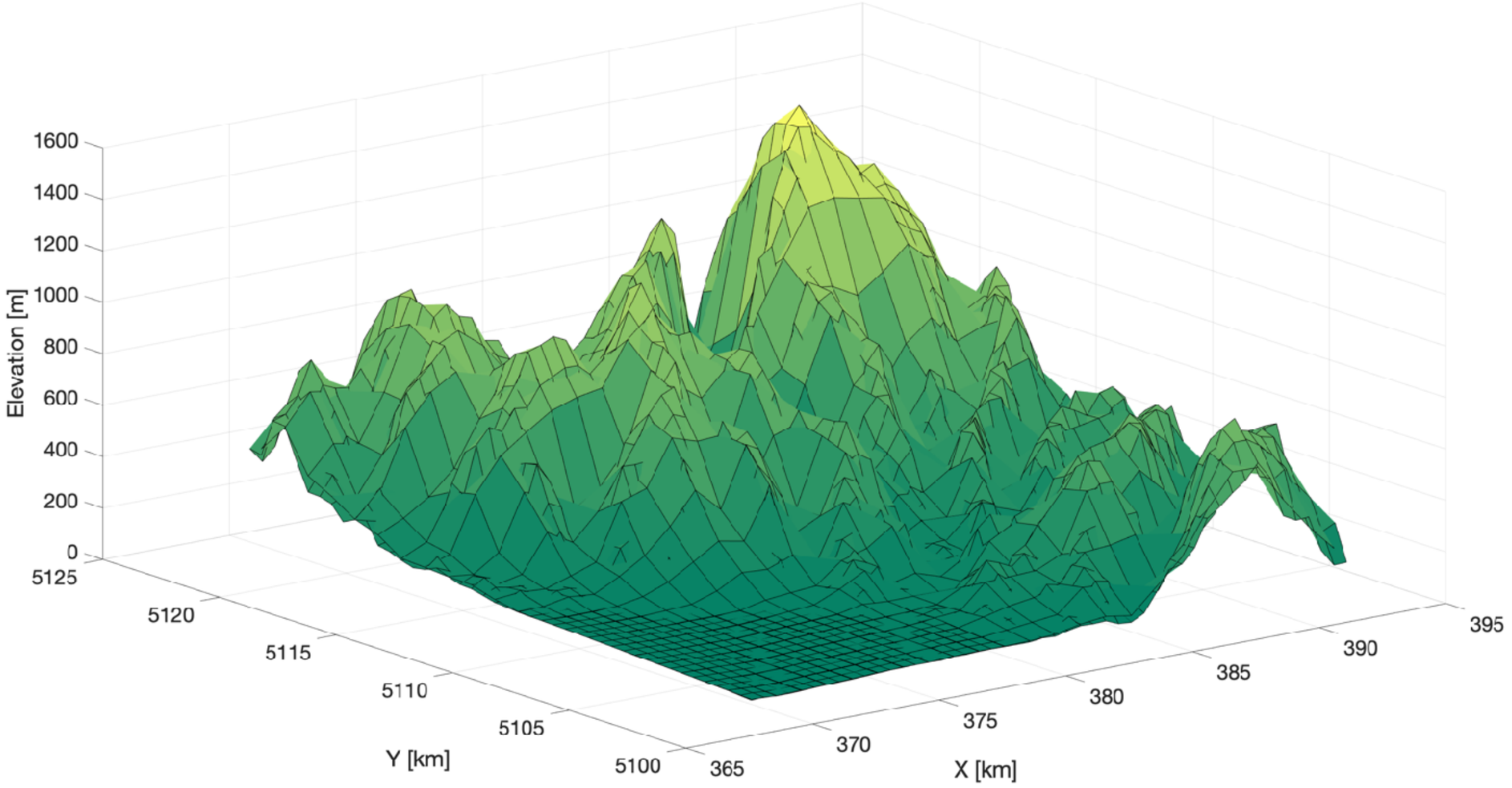
Same computational domain (24 km x 22 km) and we consider three different grid resolution:

- 1 kilometer
- 500 meters
- 250 meters

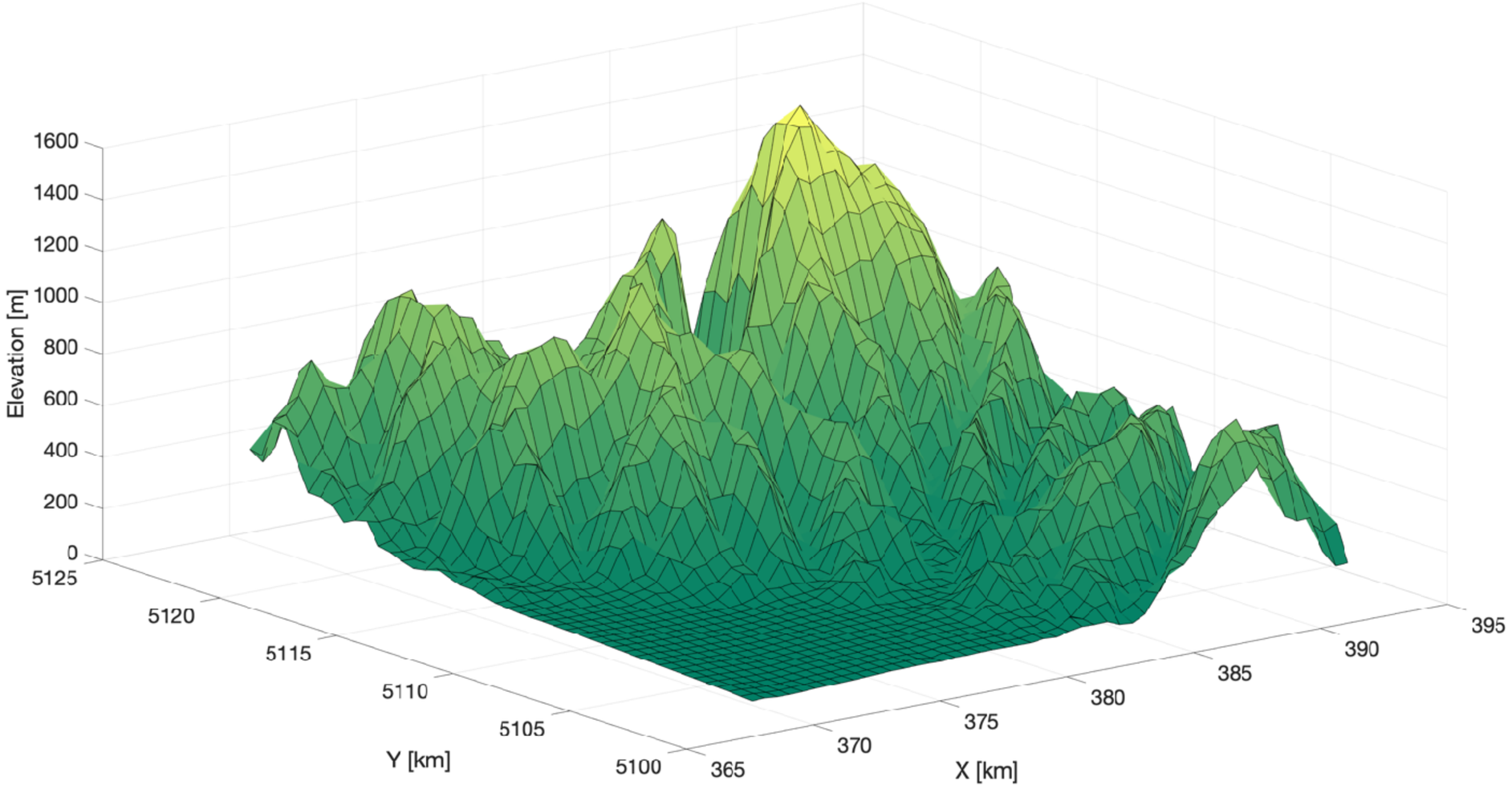
Simulations overview:

NX	NY	DXGRID
24	22	1000 m
48	44	500 m
96	88	250 m

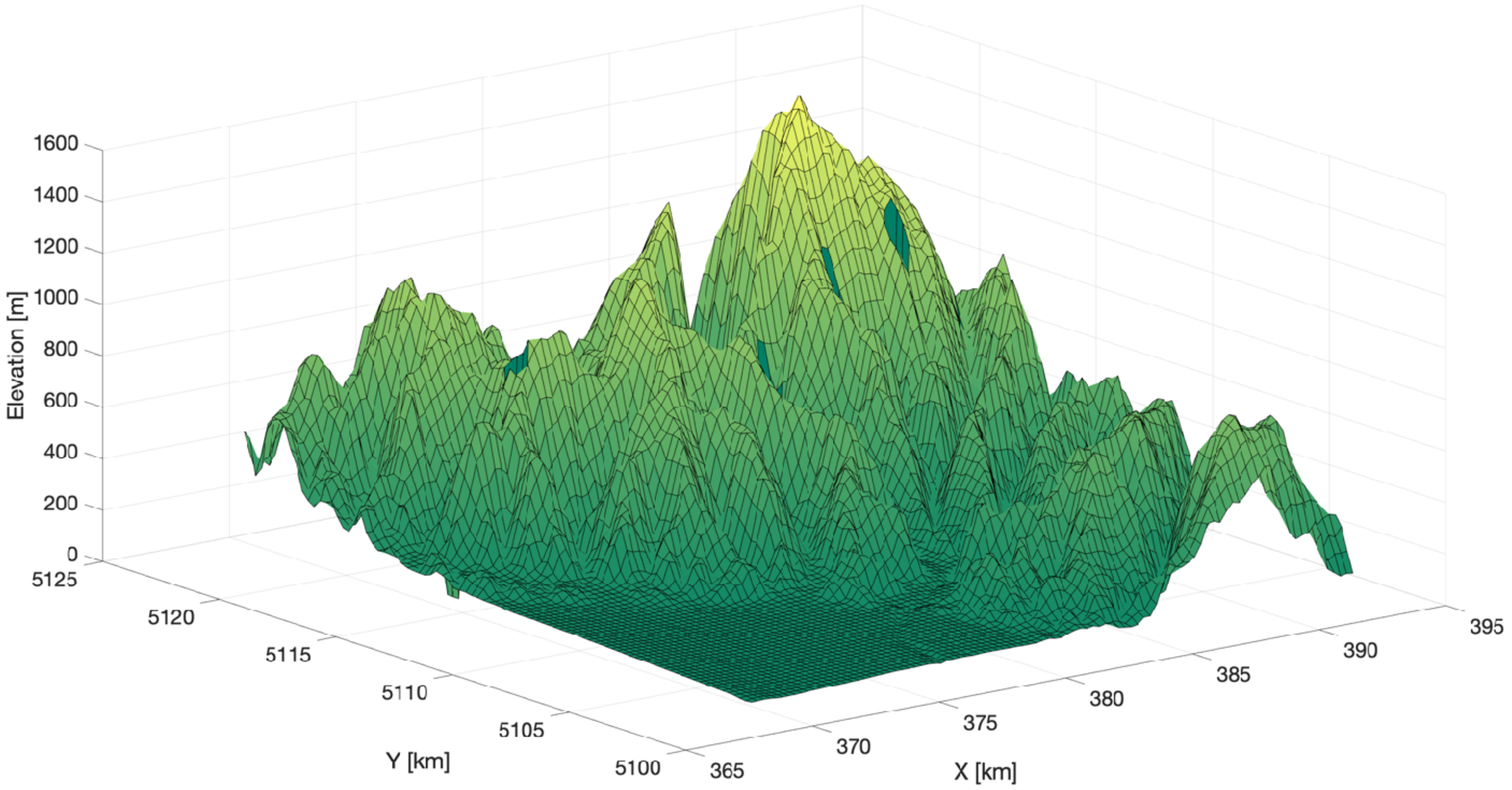
Resulting elevation files (TERREL.DAT) - 1 km resolution (NX x NY = 24 x 22)



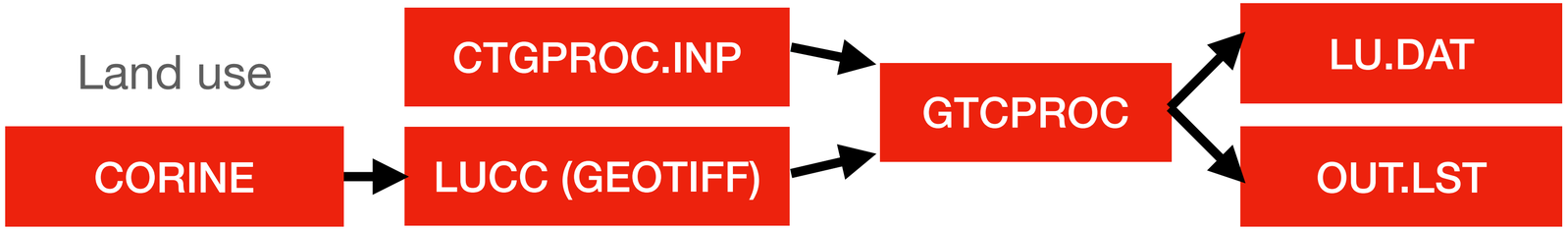
Resulting elevation files (TERREL.DAT) - 500 m resolution (NX x NY = 48 x 44)



Resulting elevation files (TERREL.DAT) - 250 m resolution (NX x NY = 96 x 88)



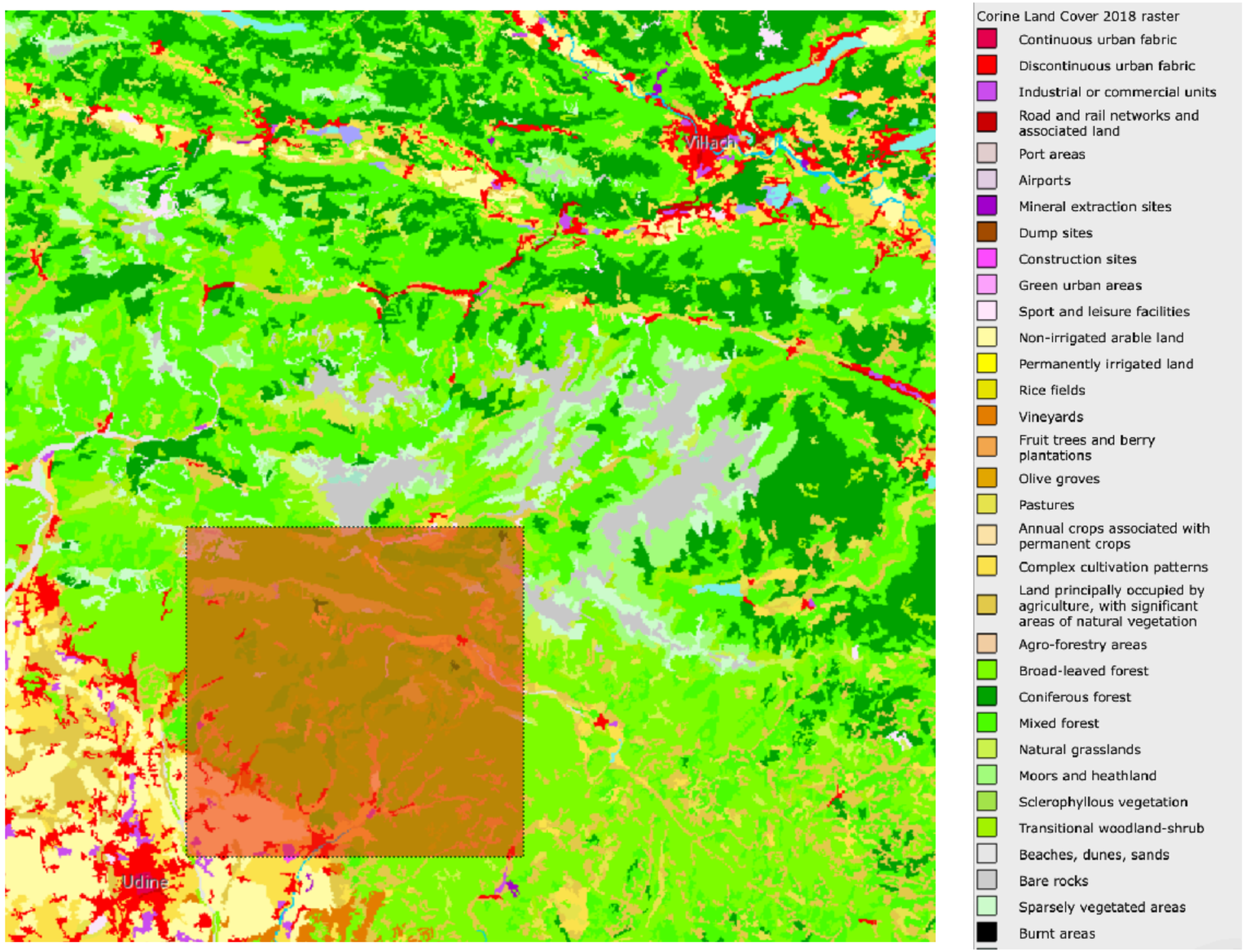
Land use and cover change data pre-processing workflow:



Land use and cover change database:
-LUCC (Provided and maintained by USGS, 1km resolution for Europe)
-CORINE Database (Provided and maintained by European Environment agency, 100m and 30m resolutions)

The following files can be downloaded from:
-USGS Global (GlazaEU format, 1km resolution) from earthexplorer.usgs.gov/
-CORINE (GeoTiff format, 100 m resolution) from https://land.copernicus.eu/pan-european/corine-land-cover
-CORINE (GeoTiff format, 30 m resolution) from https://land.copernicus.eu/pan-european/corine-land-cover

Corine Database:



Corine Land Cover 2018 raster

- Continuous urban fabric
- Discontinuous urban fabric
- Industrial or commercial units
- Road and rail networks and associated land
- Port areas
- Airports
- Mineral extraction sites
- Dump sites
- Construction sites
- Green urban areas
- Sport and leisure facilities
- Non-irrigated arable land
- Permanently irrigated land
- Rice fields
- Vineyards
- Fruit trees and berry plantations
- Olive groves
- Pastures
- Annual crops associated with permanent crops
- Complex cultivation patterns
- Land principally occupied by agriculture, with significant areas of natural vegetation
- Agro-forestry areas
- Broad-leaved forest
- Coniferous forest
- Mixed forest
- Natural grasslands
- Moors and heathland
- Sclerophyllous vegetation
- Transitional woodland-shrub
- Beaches, dunes, sands
- Bare rocks
- Sparsely vegetated areas
- Burnt areas

The use of the database files is not straightforward: CALPUFF, USGS and CORINE use different classification:

- CALPUFF (14 Categories, derived from USGS)
- USGS (38 categories)
- CORINE (level classification)

We can use a table for the conversion between the different database:

CODIFICA		ETICHETTA		RGB
CORINE	USGS	CORINE livello 3	USGS livello 2	CORINE
111	11	Continuous urban fabric	Residential	230-000-077
112	11	Discontinuous urban fabric	Residential	255-000-000
121	15	Industrial or commercial units	Industrial and Commercial Complexes	204-077-242
122	14	Road and rail networks and associated land	Transportation, Communications and Utilities	204-000-000
123	14	Port areas	Transportation, Communications and Utilities	230-204-204
124	14	Airports	Transportation, Communications and Utilities	230-204-230
131	75	Mineral extraction sites	Strip Mines, Quarries, and Gravel Pits	166-000-204
132	17	Dump sites	Other Urban or Built-up Land	166-077-000
133	16	Construction sites	Mixed Urban or Built-up Land	255-077-255
141	16	Green urban areas	Mixed Urban or Built-up Land	255-166-255
142	14	Sport and leisure facilities	Transportation, Communications and Utilities	255-230-255
211	24	Non-irrigated arable land	Transportation, Communications and Utilities	255-255-168
212	-21	Permanently irrigated land	Cropland and Pasture	255-255-000
213	-22	Rice fields	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	230-230-000
221	22	Vineyards	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	230-128-000
222	22	Fruit trees and berry plantations	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	242-166-077
223	22	Olive groves	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	230-166-000
231	21	Pastures	Cropland and Pasture	230-230-077
241	21	Annual crops associated with permanent crops	Cropland and Pasture	255-230-166
242	22	Complex cultivation patterns	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	255-230-077
243	23	Land principally occupied by agriculture, with significant areas of natural vegetation	Confined Feeding Operations	230-204-077
244	22	Agro-forestry areas	Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas	242-204-166
311	41	Broad-leaved forest	Deciduous Forest Land	128-255-000
312	42	Coniferous forest	Evergreen Forest Land	000-166-000
313	43	Mixed forest	Mixed Forest Land	077-255-000
321	82	Natural grasslands	Herbaceous Tundra	204-242-077
322	81	Moors and heathland	Shrub and Brush Tundra	166-255-128
323	81	Sclerophyllous vegetation	Shrub and Brush Tundra	166-230-077
324	85	Transitional woodland-shrub	Mixed Tundra	166-242-000
331	72	Beaches, dunes, sands	Beaches	230-230-230
332	74	Bare rocks	Bare Exposed Rock	204-204-204
333	76	Sparsely vegetated areas	Transitional Areas	204-255-204
334	83	Burnt areas	Bare Ground	000-000-000
335	91	Glaciers and perpetual snow	Perennial Snowfields	166-230-204
411	62	Inland marshes	Nonforested Wetland	166-166-255
412	62	Peat bogs	Nonforested Wetland	077-077-255
421	62	Salt marshes	Nonforested Wetland	204-204-255
422	71	Salines	Dry Salt Flats	230-230-255
423	62	Intertidal flats	Nonforested Wetland	166-166-230
511	51	Water courses	Streams and Canals	000-204-242
512	52	Water bodies	Lakes	128-242-230
521	54	Coastal lagoons	Bays and Estuaries	000-255-166
522	54	Estuaries	Bays and Estuaries	166-255-230
523	55	Sea and ocean	Oceans and Seas	230-242-255
999	999	NODATA		
990	990	UNCLASSIFIED LAND SURFACE		
995	980	UNCLASSIFIED WATER BODIES		230-242-255
990	970	UNCLASSIFIED		

Issues with version v7.0 of CTGPROC.

- Reading of the CORINE database files in CTGPROC does not work.
- LU.DAT (main output) is not generated.
- Source-code (Fortran-77) of CTGPROC cannot be modified since the program is compiled with a commercial compiler with non-standard directives (cannot be compiled with PGI and/or gfortran).

Current Solution:

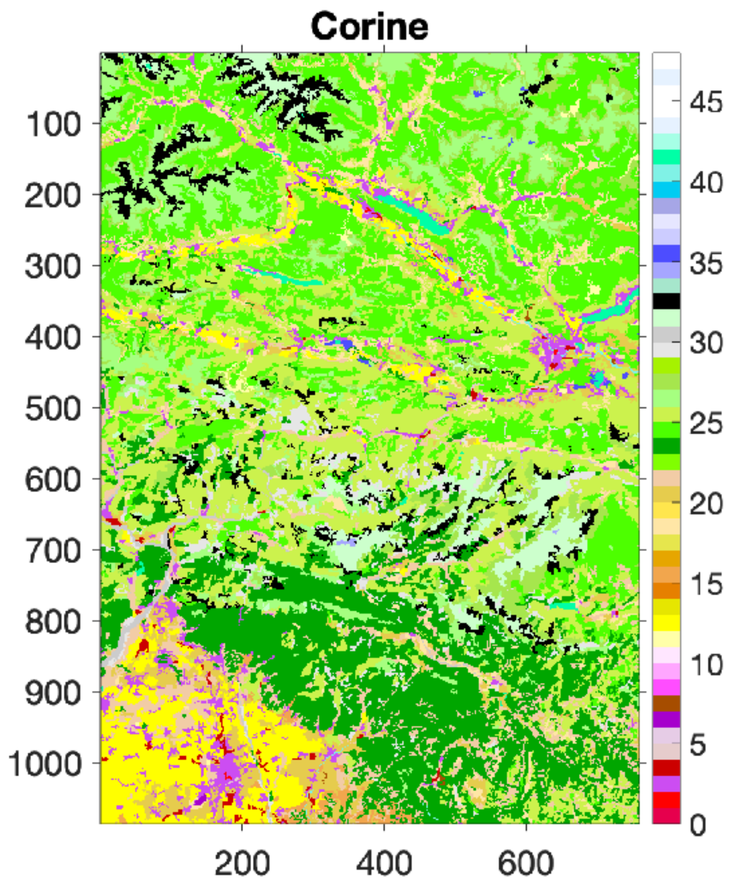
- Using the GIS part of Matlab, the CORINE file (Raster GEOTIFF, 100m) can be read.
- Using Matlab, CORINE is converted in USGS categories and then in CALMET categories.

CALMET CATEGORIES:

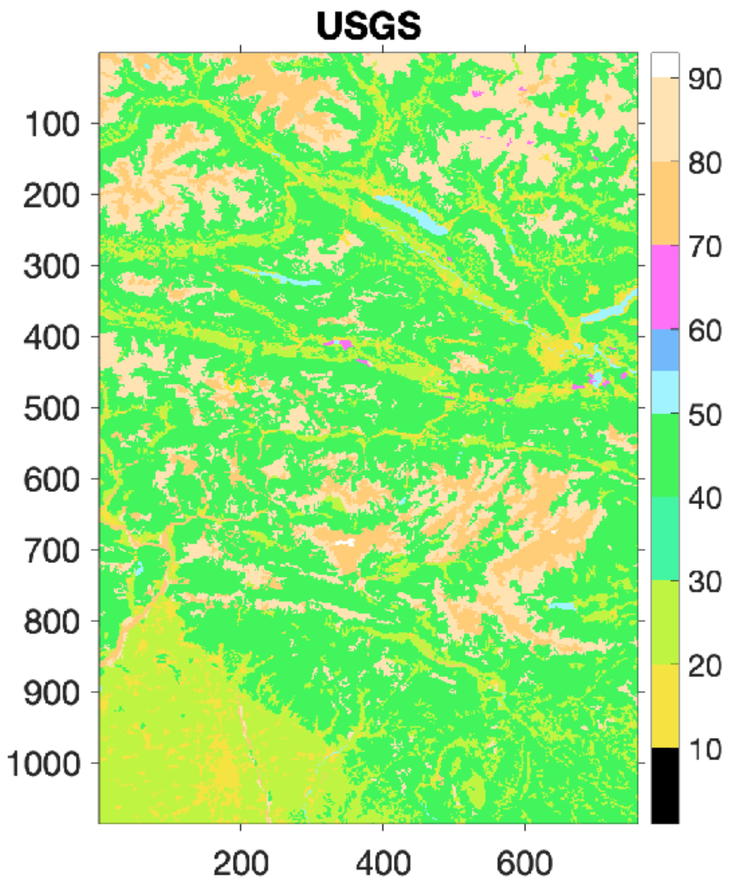
CALMET LAND USE CATEGORY	CALMET LAND USE CODE
Water (Bays, Estuaries, Ocean, Rivers and Lakes)	50-55
Agricultural	20
Urban	10
Wetlands	60
Forest Land	40
Barren Land	70
Rangeland	30
Tundra	80
Perennial Snow and Ice	90

First test (entire FVG region)
Land use and Cover Change after conversion:

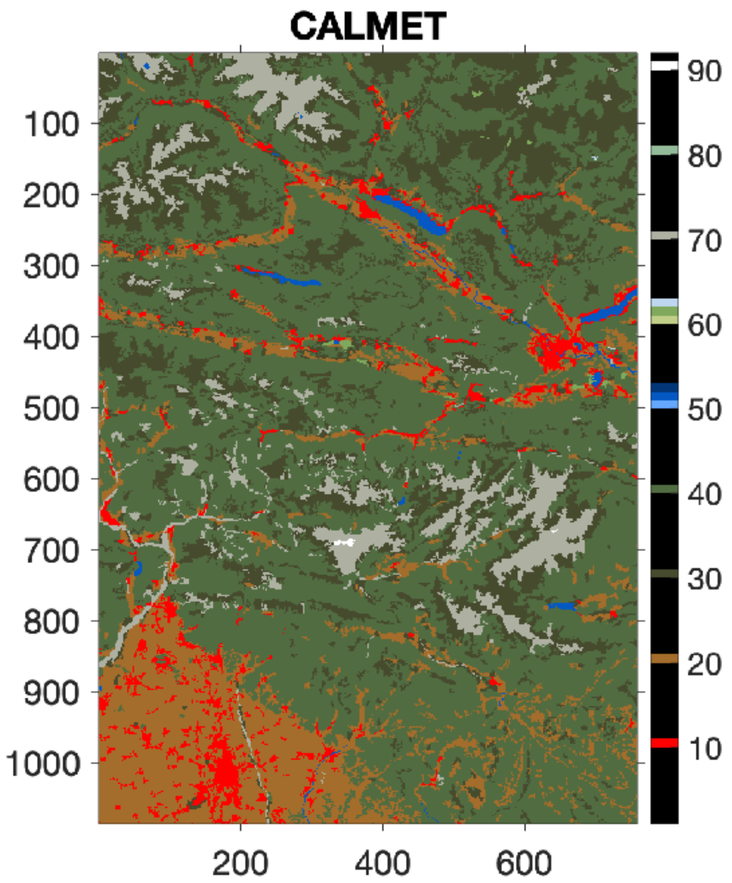
Corine Database (1-999 levels)



USGS Categories (38 categories)

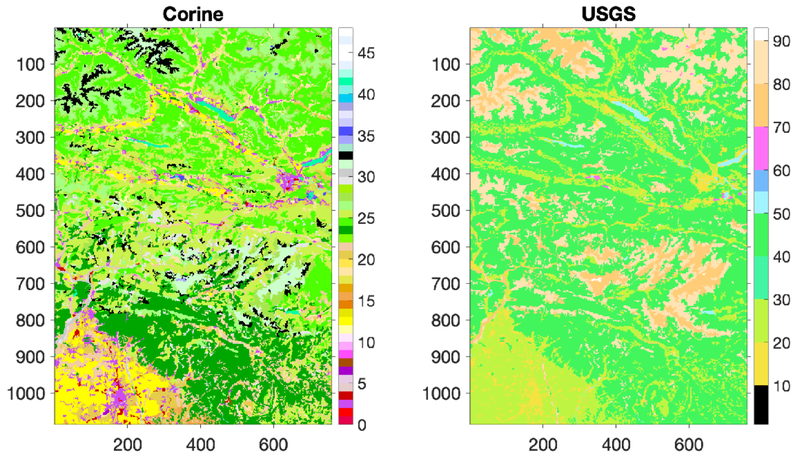


CALMET Categories (14 categories)

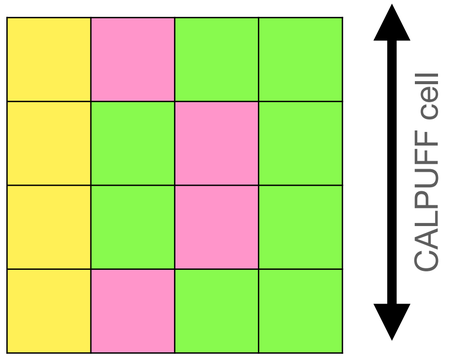


Pipeline of the process:

- Conversion from CORINE to USGS (38 categories)



- Find the fractional value for each CALPUFF Cell



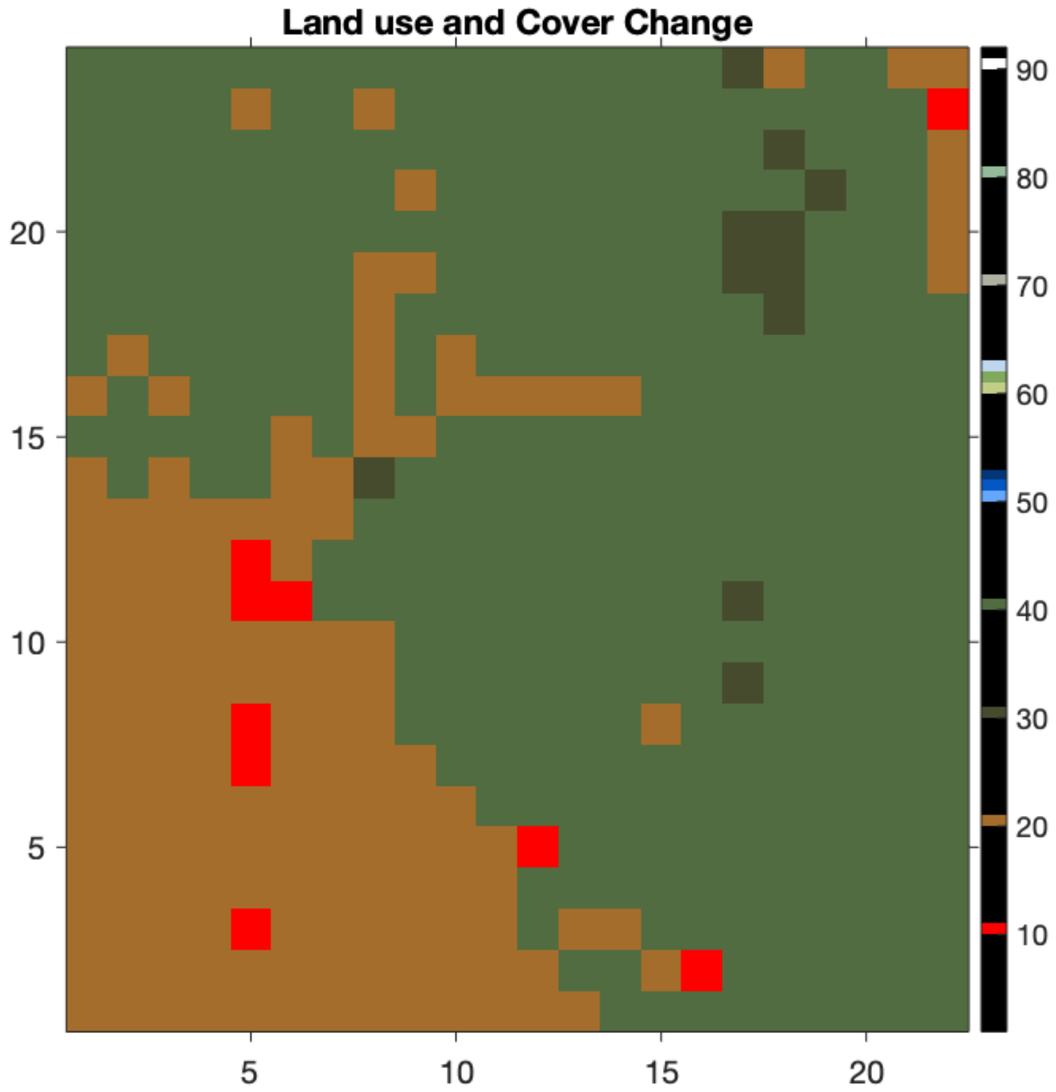
USGS 11 : 25 % (CALMET level 10)
USGS 22 : 25 % (CALMET level 20)
USGS 43 : 50 % (CALMET level 40)

- Generate the fractional LU.dat file :

```
  2
Produced by CTGPROC Version: 7.0.0  Level: 150211
Internal Coordinate Transformations  ---  COORDLIB   Version: 1.99   Level: 070921
FRACTION
UTM
  33N
NAS-C   02-21-2003
     14      14     368.500    5095.500       1.000       1.000    38
KM
                 11    12    13    14    15    16    17    21    22    23    24    31    32    33    41    42    43    51    52    53    54    55    61    62    71    72    73    74    75    76    77    81    82    83    84    85    91    92
   1    1 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 .
   2    1 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 .
   3    1 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 1.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 0.000 .
```

CALMET Categories:

Dominant LAND USE - 1 km resolution (NX x NY = 24 x 22)



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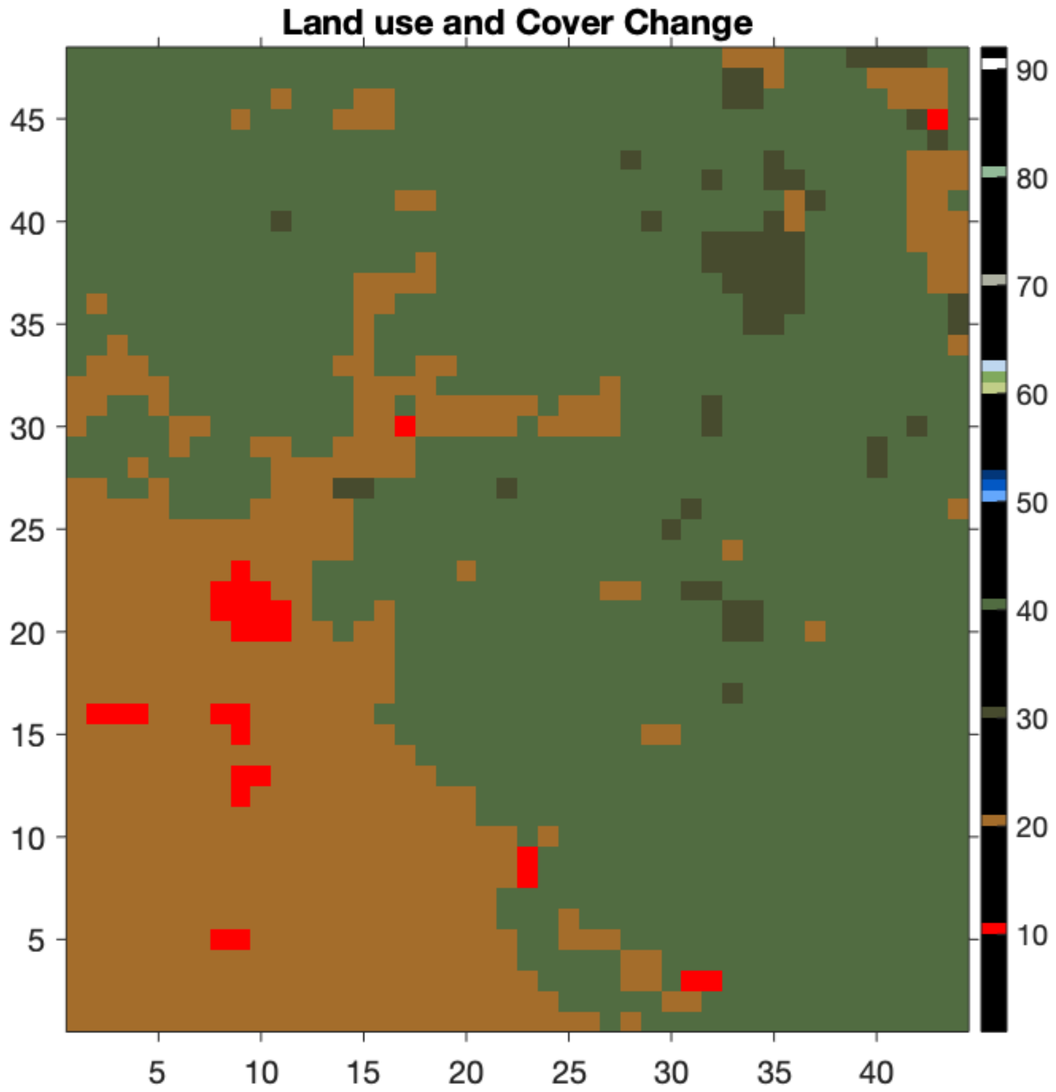
Urban	10
Wetlands	60
Forest Land	40
Barren Land	70
Rangeland	30
Tundra	80
Perennial Snow and Ice	90

Dominant LAND USE- 500 m resolution (NX x NY = 48 x 44)



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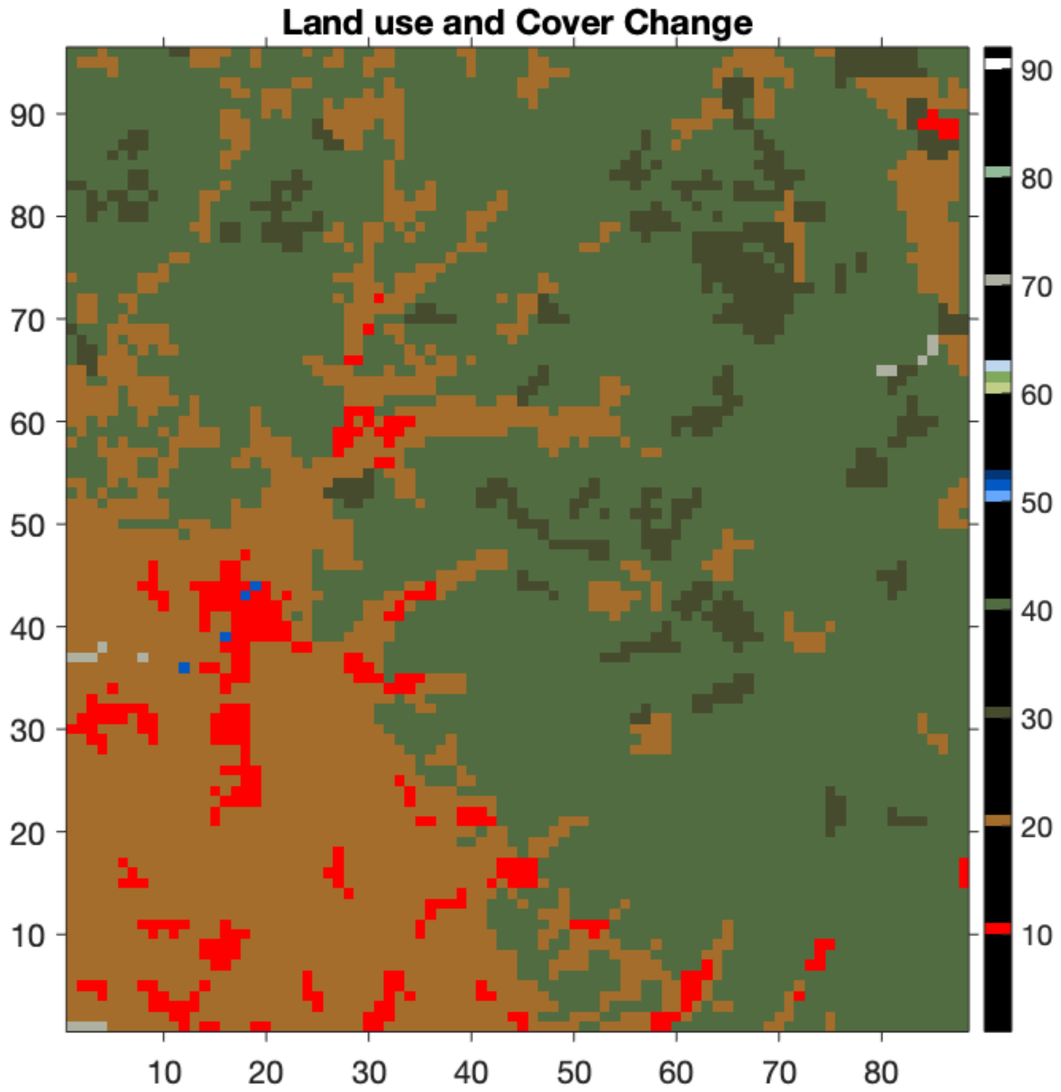
Forest Land	40
Barren Land	70
Rangeland	30
Tundra	80
Perennial Snow and Ice	90

Dominant LAND USE - 250 m resolution (NX x NY = 96 x 88)



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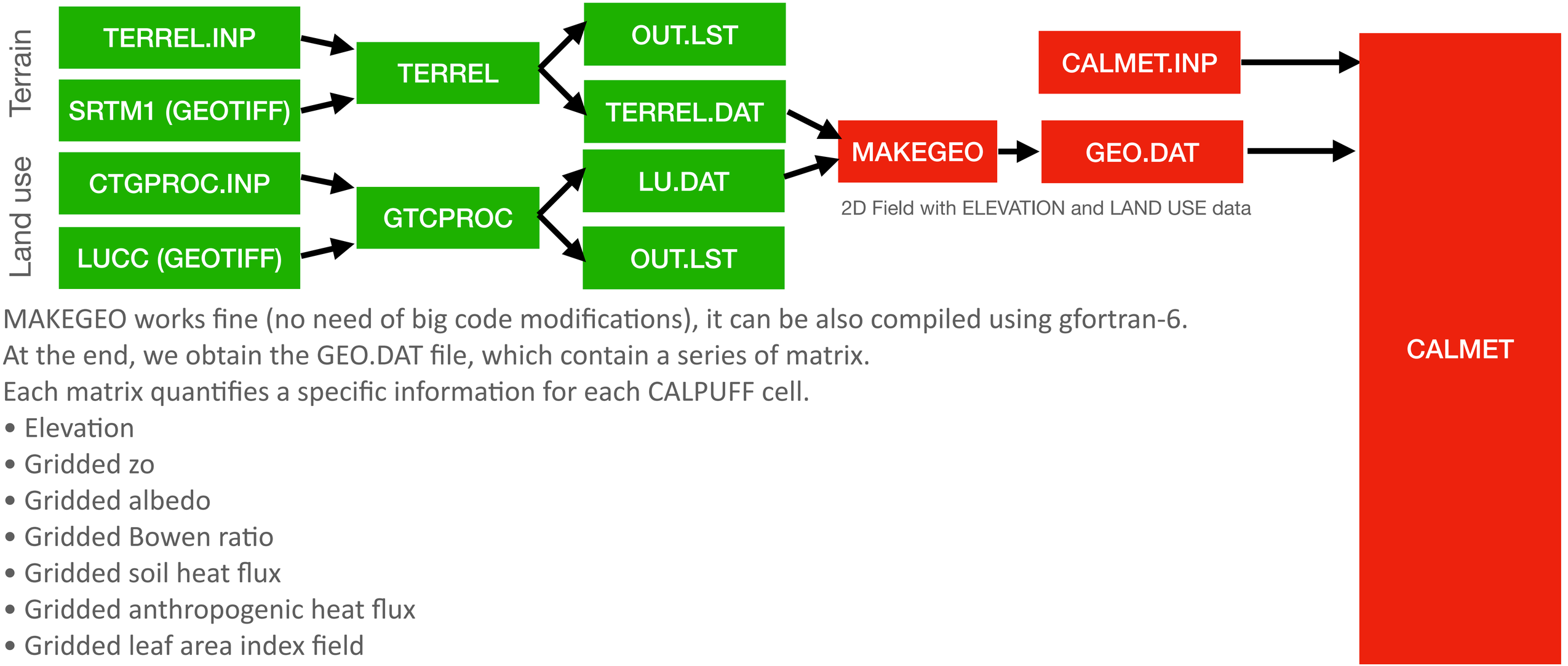
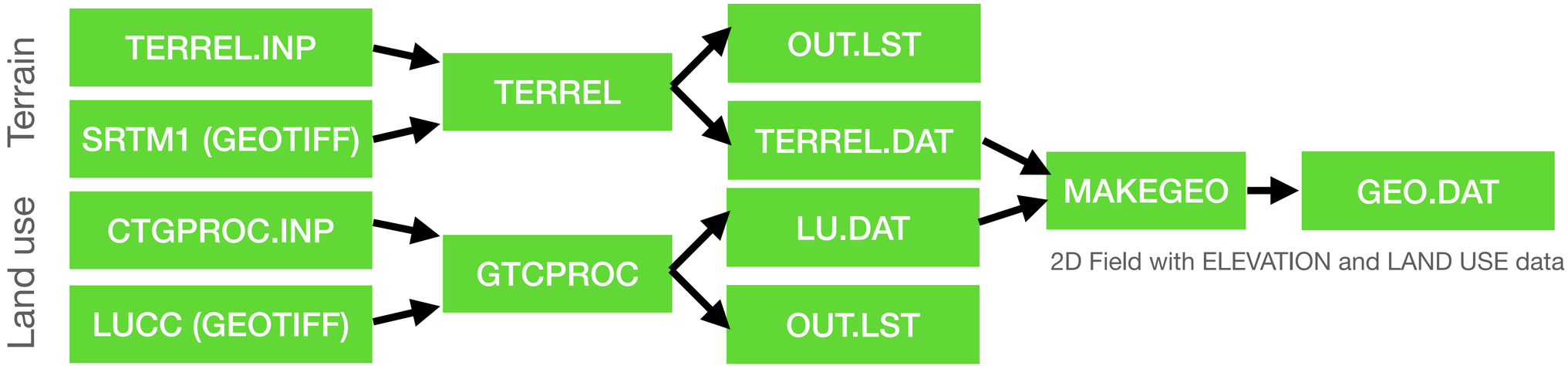
TERREL.DAT (Terrain elevation) and LU.DAT files have been generated.
Next step is to use MAKEGEO and generate the GEO.DAT file.



MAKEGEO works fine (no need of big code modifications), it can be also compiled using gfortran-6.
At the end, we obtain the GEO.DAT file, which contain a series of matrix.
Each matrix quantifies a specific information for each CALPUFF cell.

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

Terrain (TERREL), Land use (LU) have been merged in the GEO.DAT file



The GEO.DAT file is created, this final file is an input for CALMET.
This file includes terrain elevation information and the respective land use (and respective characteristics).

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

The following meteorological files are required by CALMET:

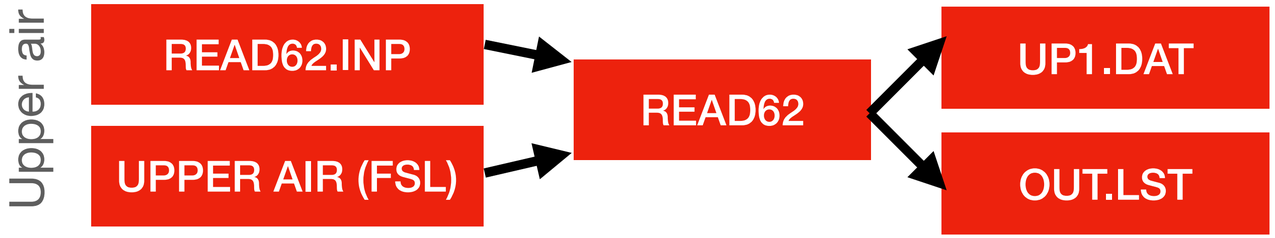
UP.DAT, upper air DATA information.

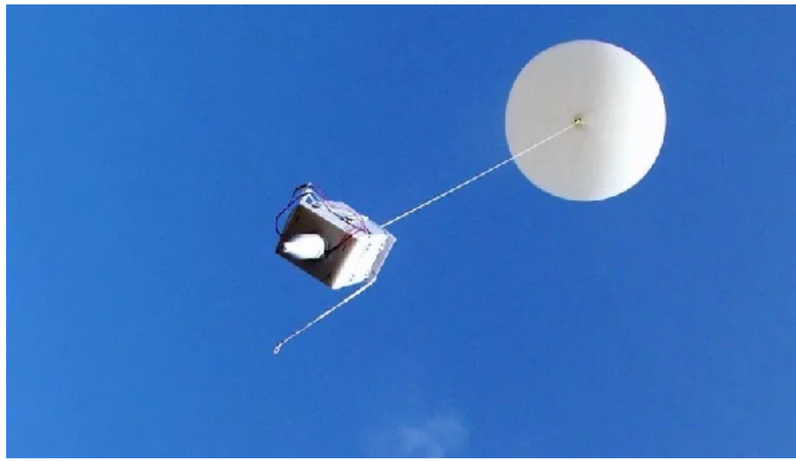
SURF.DAT, meteorological data (temperature, cloud cover, humidity, wind) at the surface of the computational domain (in one or more stations).

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 specified by the client.

Upper air information pre-processing workflow:





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)

Data are collected twice per day, every day of the year.
As a reference year, we select the 2019 (2020 data are affected by the covid-19 pandemic).

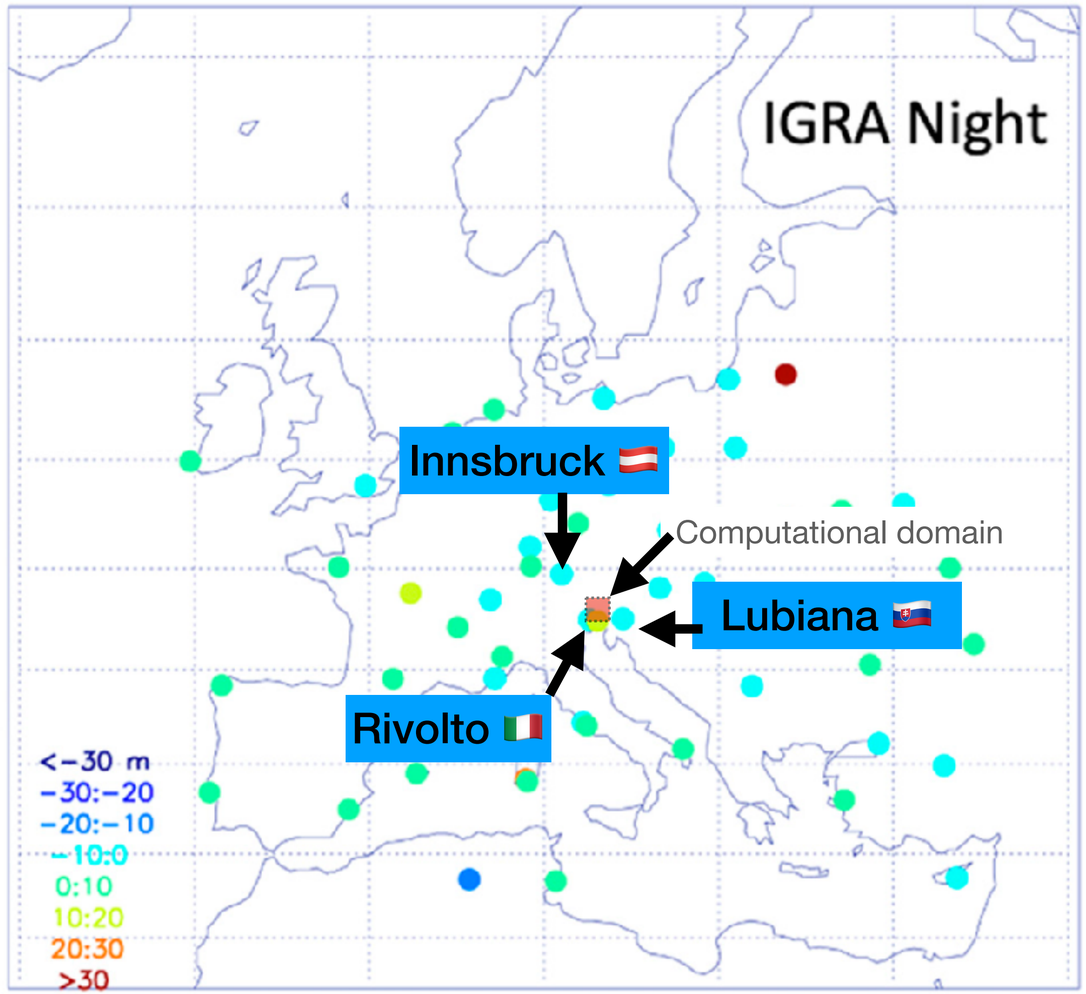
We only use the Rivolto database (closest location), Innsbruck (AT) and Lubiana (SL) airports information are too far from the computational domain.

Input file: Rivolto.dat (new FSL format)
Output file: up.dat

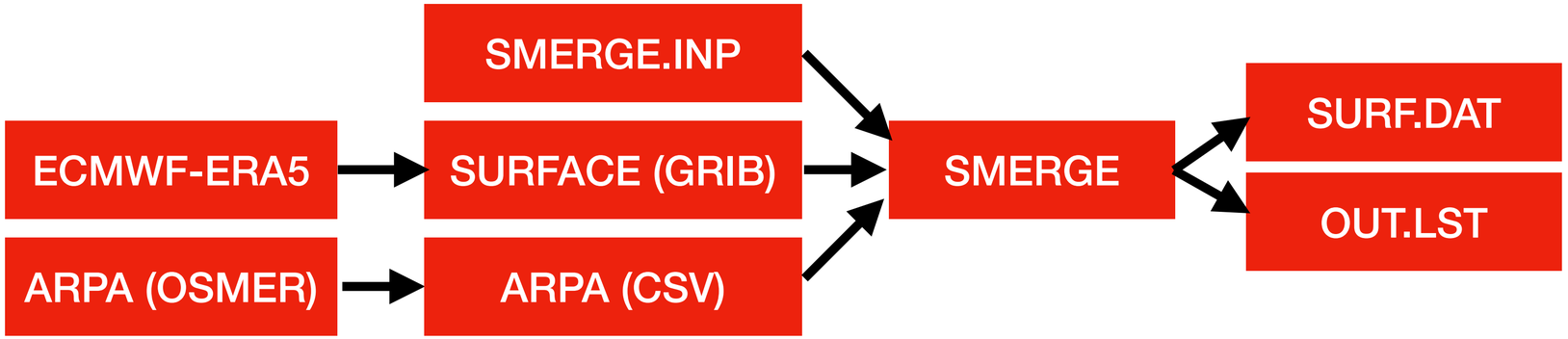
Resulting file (UP.DAT) :

```
UP.DAT          2.1             Hour Start and End Times with Seconds
   1
Produced by READ62 Version: 5.661  Level: 110225
NONE
UTC+0000
  2019    1    0    0 2019  365   23   59   0.    2    2
     T    T    T    T
   6201     16045    2019   1  1  0    0    2019   1  1  0    0  128       8
   1024.0,  52.,274.0, 60,  1.5,      0.1, 248.,279.6,105,  7.7,      0.0, 883.,275.8,240,  5.1,
      0.0,3092.,266.1, 15, 21.6,      0.0,5660.,253.7, 30, 31.4,      0.0,7270.,242.1, 25, 36.5,
   6201     16045    2019   1  1 12    0    2019   1  1 12    0  128       9
   1022.0,  52.,280.0,335,  1.0,   1000.0, 229.,278.2,340,  1.5,    100.0, 861.,273.8,230,  4.1,
      0.0,2780.,273.6,  5, 12.3,      0.0,3097.,271.7, 15, 11.3,      0.0,5680.,252.7,350, 23.1,
      0.0,9250.,224.3,345, 28.3
   6201     16045    2019   1  2  0    0    2019   1  2  0    0  122       9
   1012.0,  52.,276.6, 30,  1.5,    100.1, 150.,278.4, 50,  3.6,     10.0, 782.,273.2, 90,  1.5,
```

For each day of the selected year (2019), we have the vertical profiles of pressure, temperature and wind.



Superficial meteorological data pre-processing workflow (in one or more stations):



Meteorological data at the surface 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, pressure while from the European database we extract information on cover cloud and cloud base height.

Data from NOAA (NCDC) cannot be used. This data are only available for the United States of America and in a new format (not supported anymore by SMERGE).

OSMER Database.

We employ the data registered in the station of Cividale del Friuli 46.08 N and 13.42 E.

This dataset is the most complete and data are registered every hour.

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	-

Data for the entire year 2019 can be downloaded in CSV format.

Cloud cover and cover height are missing.

Merging the information from these two datasets (ARPA and ECMWF), we generate a CSV file that contains the following hourly information at the Cividale location.

- Temperature
- Precipitation (not used in SMERGE)
- Wind direction
- Wind speed
- Relative humidity
- Total cloud cover
- Cloud base height
- Pressure

This file is then read by SMERGE and the SURF.dat file is generated.

```
GENERIC,Version,'2.0',Manually generated,Time as ending hour,,,,,,,
Station,ID,=',16045,Temp,Precip,Pressure,RH,Wdir10m,Wspeed10m,Ccover,Cheight
Month,Day,Year,Hour,DegC,mm,mb,%,%,ms-1,tenths,hundreds_of_feet
1,1,2019,0,1.4,0,1026.6,85,81,5,4,28
1,1,2019,100,1,0,1027,87,346,4,2,62
1,1,2019,200,0.7,0,1026.7,89,350,5,2,58
1,1,2019,300,-0.7,0,1026.5,92,355,6,2,52
1,1,2019,400,-1.5,0,1026.6,92,1,6,1,50
1,1,2019,500,-1.6,0,1027,94,346,6,3,51
1,1,2019,600,-1.9,0,1027.2,94,5,7,3,54
1,1,2019,700,0.4,0,1026.5,92,7,6,5,67
1,1,2019,800,3.3,0,1025.3,85,14,5,5,17
1,1,2019,900,6.5,0,1023.9,70,26,5,5,14
1,1,2019,1000,7.1,0,1022.1,64,20,3,8,14
1,1,2019,1100,7.1,0,1021.3,67,46,4,8,14
1,1,2019,1200,7,0,1020.7,67,66,2,9,21
1,1,2019,1300,7,0,1019.7,67,200,2,9,15
1,1,2019,1400,6.4,0,1019,72,181,1,9,21
```

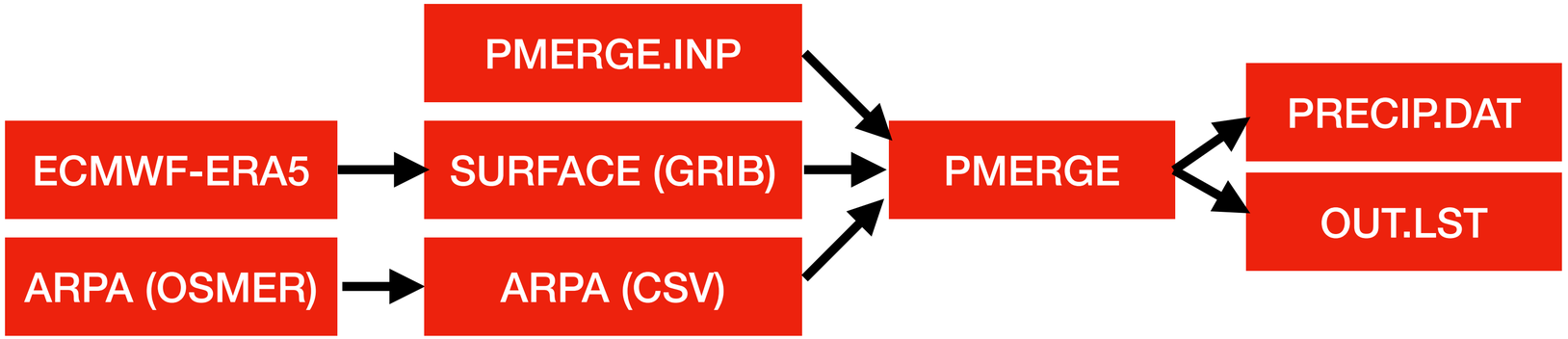
Cividiale_2019.csv

SMERGE

```
SURF.DAT        2.1             Hour Start and End Times with Seconds
   1
Produced by SMERGE Version: 5.7.0  Level: 121203
NONE
UTC-0000
  2019   1   1     0  2019 365  23     0    1
   16045
2019   1   1    0   2019   1   2    0
   18.000   42.000   58    2  277.350   65 1014.100    0
2019   1   2    0   2019   1   3    0
   13.000   51.000   52    2  276.750   67 1014.000    0
2019   1   3    0   2019   1   4    0
   13.000   46.000   50    1  276.350   69 1013.900    0
2019   1   4    0   2019   1   5    0
   12.000   43.000   51    3  276.650   68 1014.200    0
2019   1   5    0   2019   1   6    0
   12.000   43.000   54    3  276.650   67 1014.000    0
2019   1   6    0   2019   1   7    0
    8.000   16.000   67    5  274.750   72 1013.800    0
```

SURF.DAT

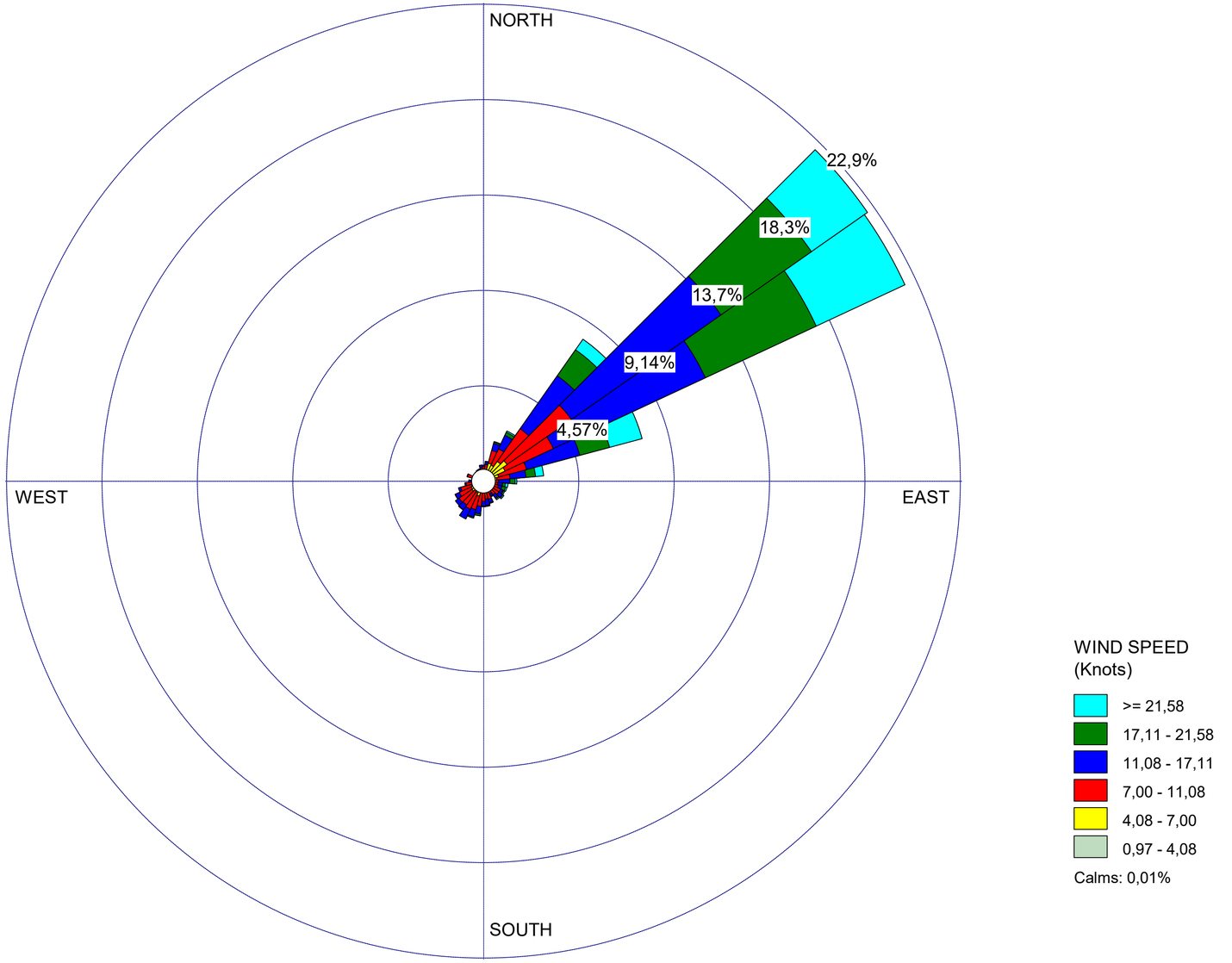
Precipitation data pre-processing workflow (in one or more stations):



PMERGE only supports the TD-3240 format (NCDC) for precipitation recordings.
This file format is not anymore supported by NCDC (and data cannot be accessed).
PMERGE has been rewritten using Matlab and can now use the CSV file previously generated to compute the precipitation data.
The output is the PRECIP.DAT file (compatible with the last version of CALMET).

Let’s take a look at the meteorological data recored in Cividale during 2019.

Wind Rose



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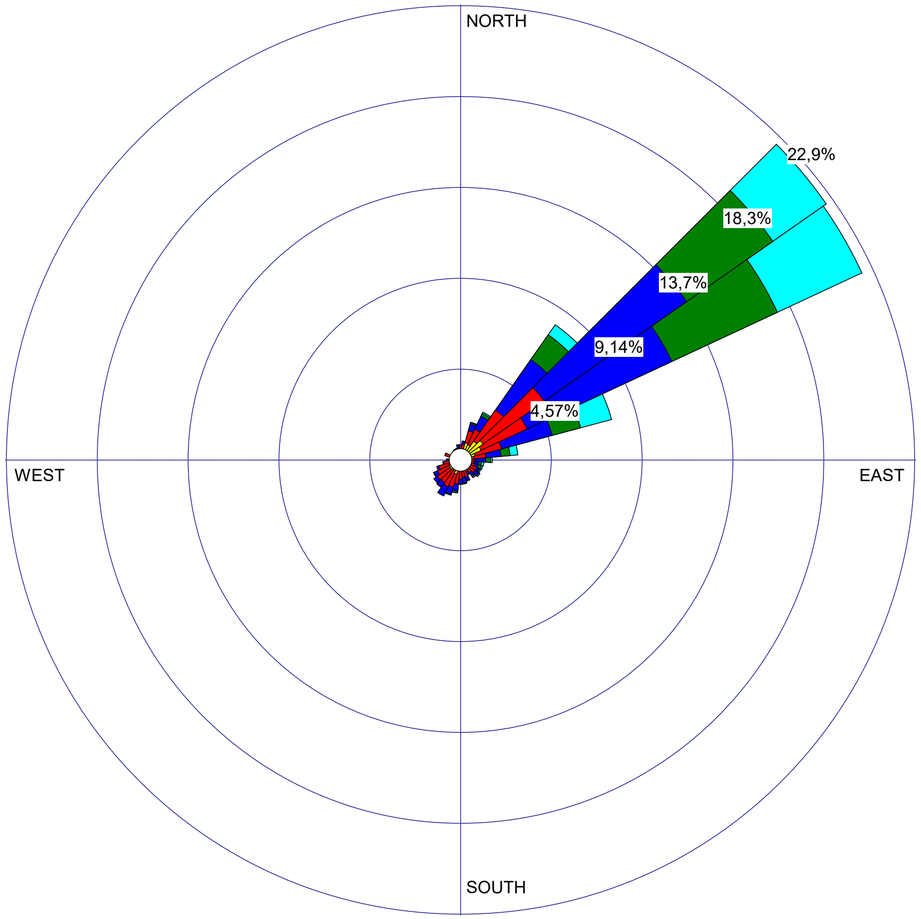
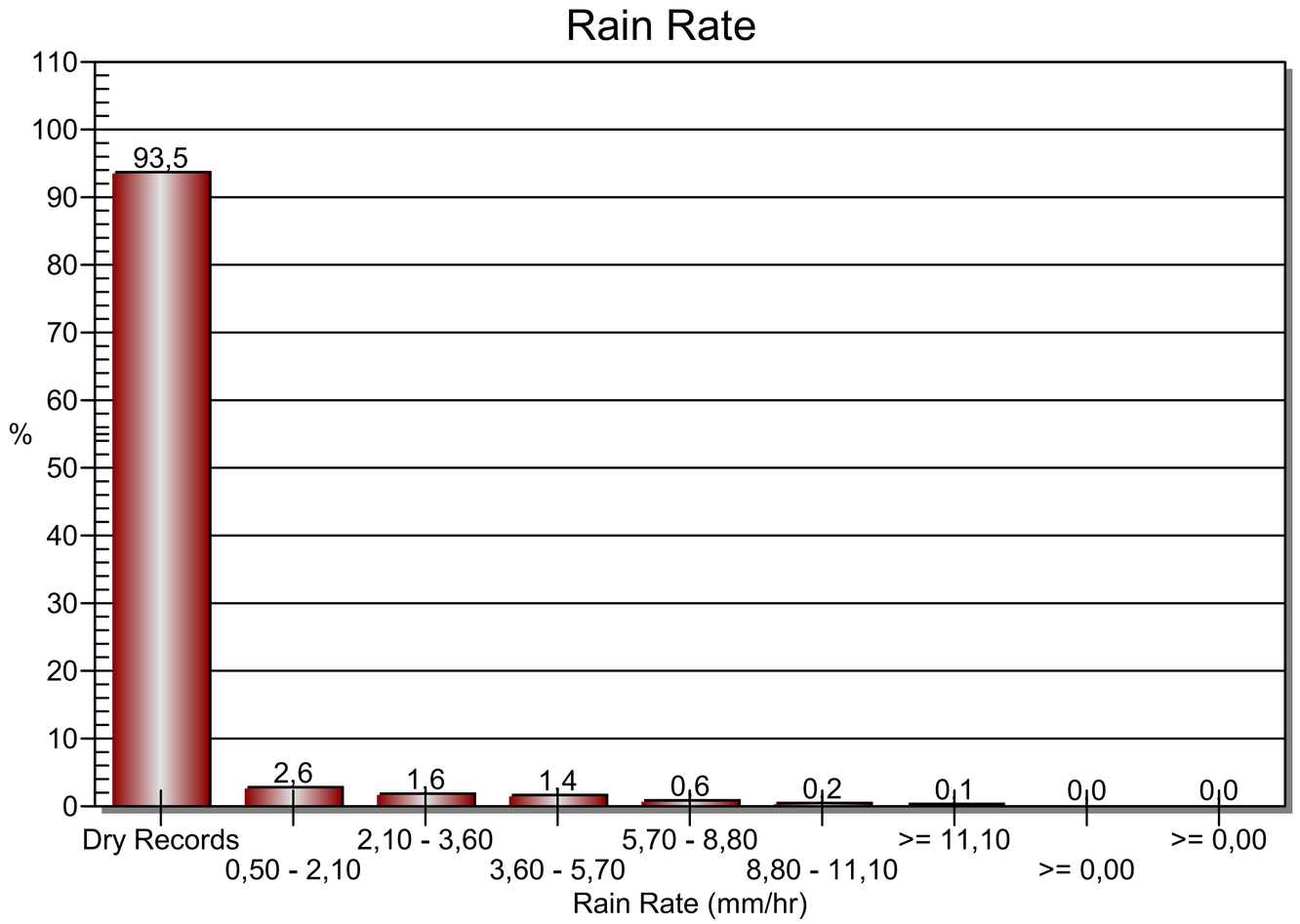


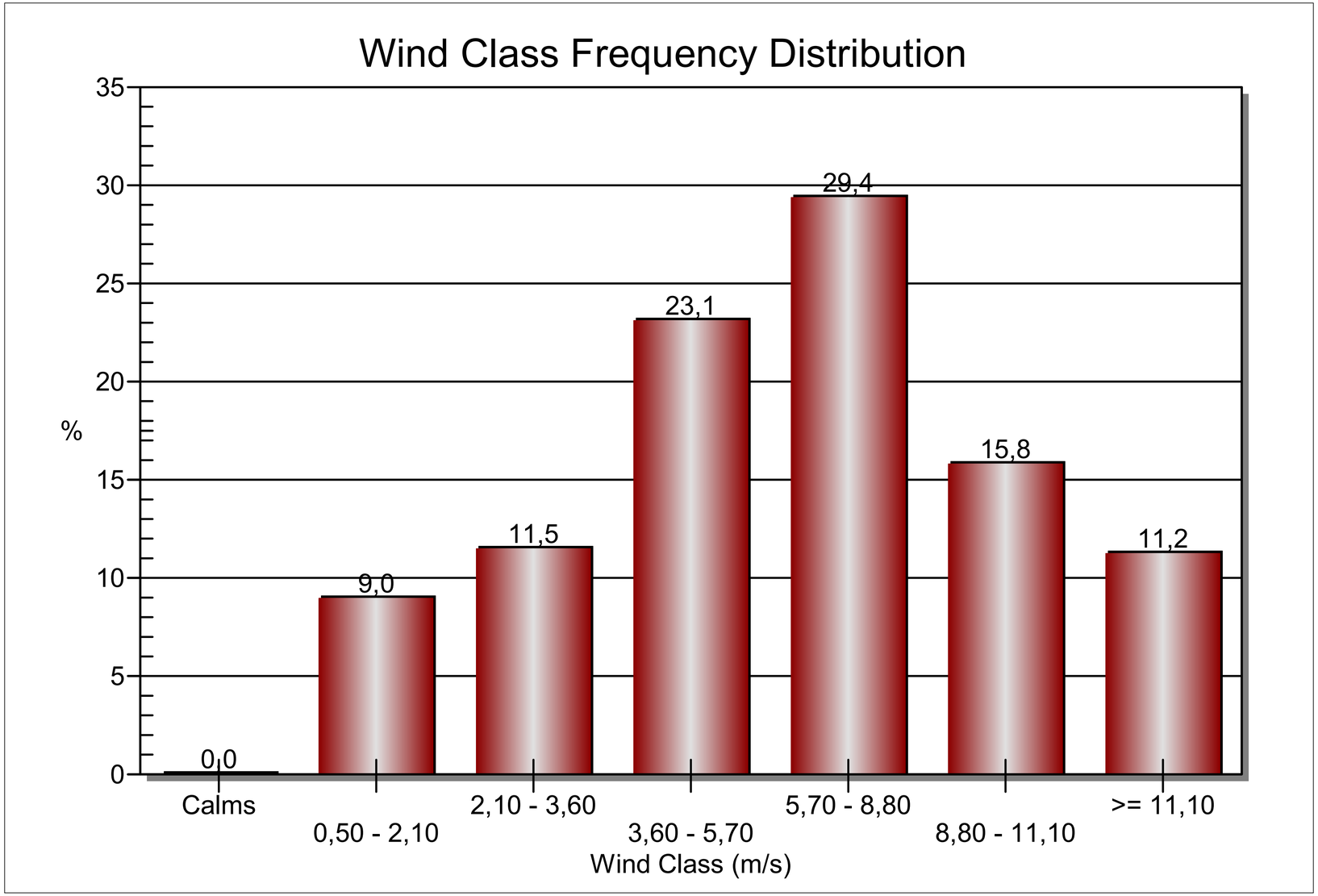
WIND SPEED
(Knots)

- >= 21,58
- 17,11 - 21,58
- 11,08 - 17,11
- 7,00 - 11,08
- 4,08 - 7,00
- 0,97 - 4,08

Calms: 0,01%

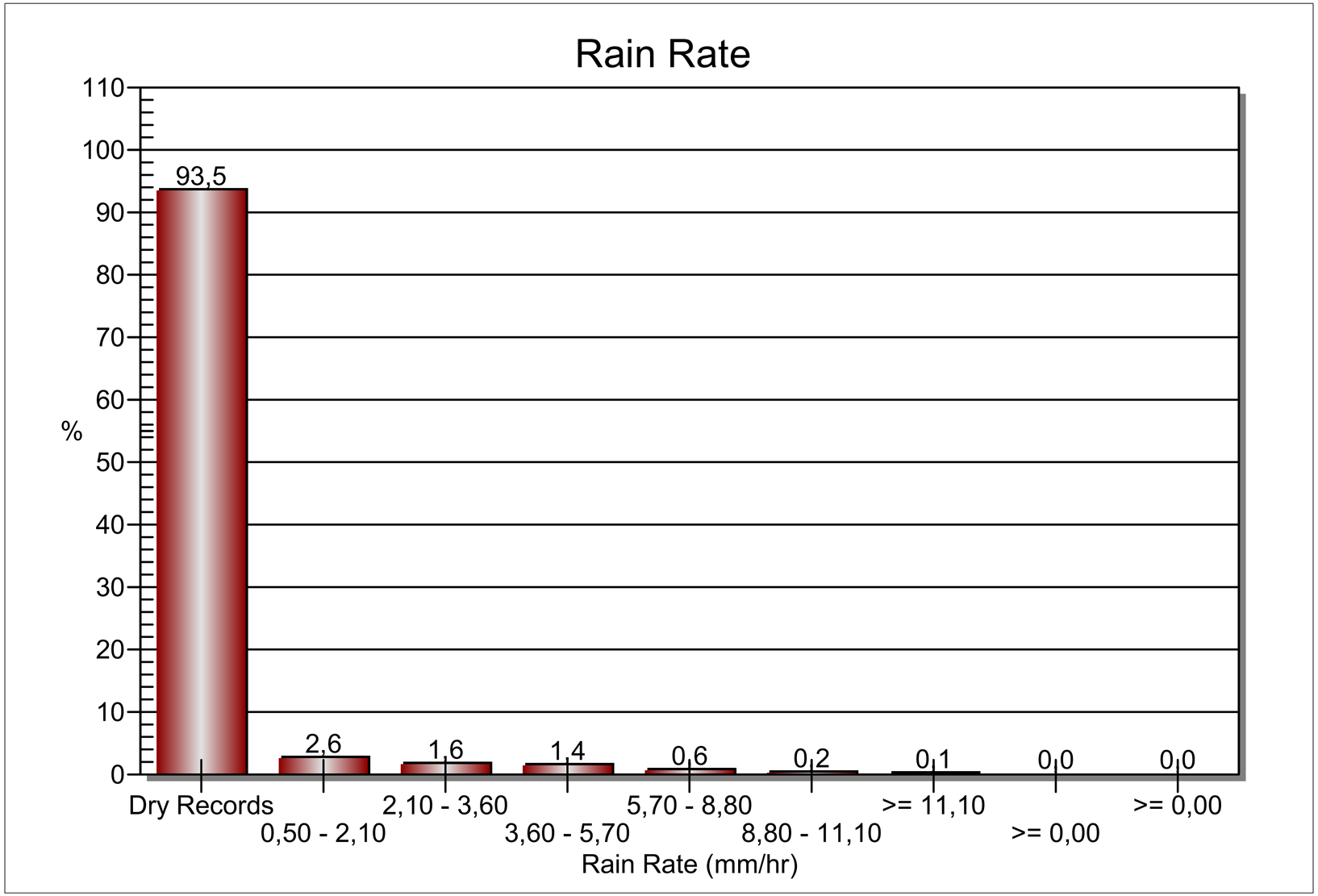


- Wind intensity distribution.



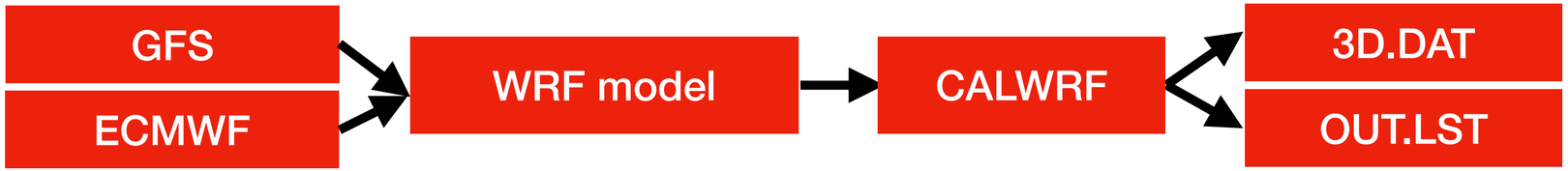
WRPLOT View Freeware 8.0.2 - Lakes Environmental Software

- Rain intensity distribution



WRPLOT View Freeware 8.0.2 - Lakes Environmental Software

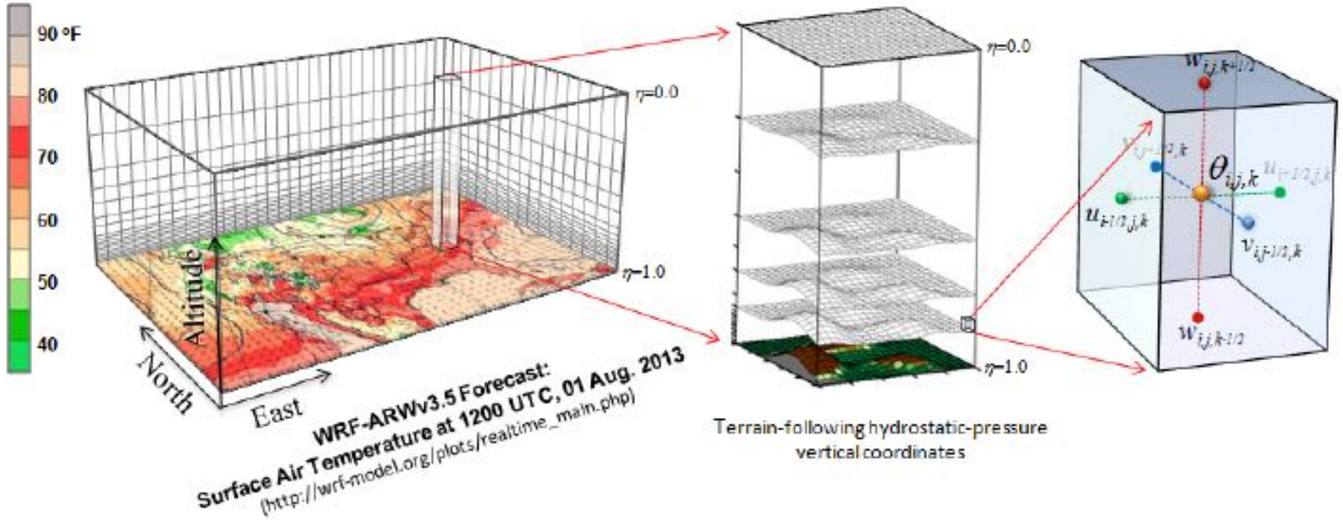
Prognostic meteorological data.



Theoretically we can directly use CALWRF and elaborate the output fields.
However, these fields are not available at high resolution (1, 2 or 4km) and must be generated running the WRF model.

WRF model

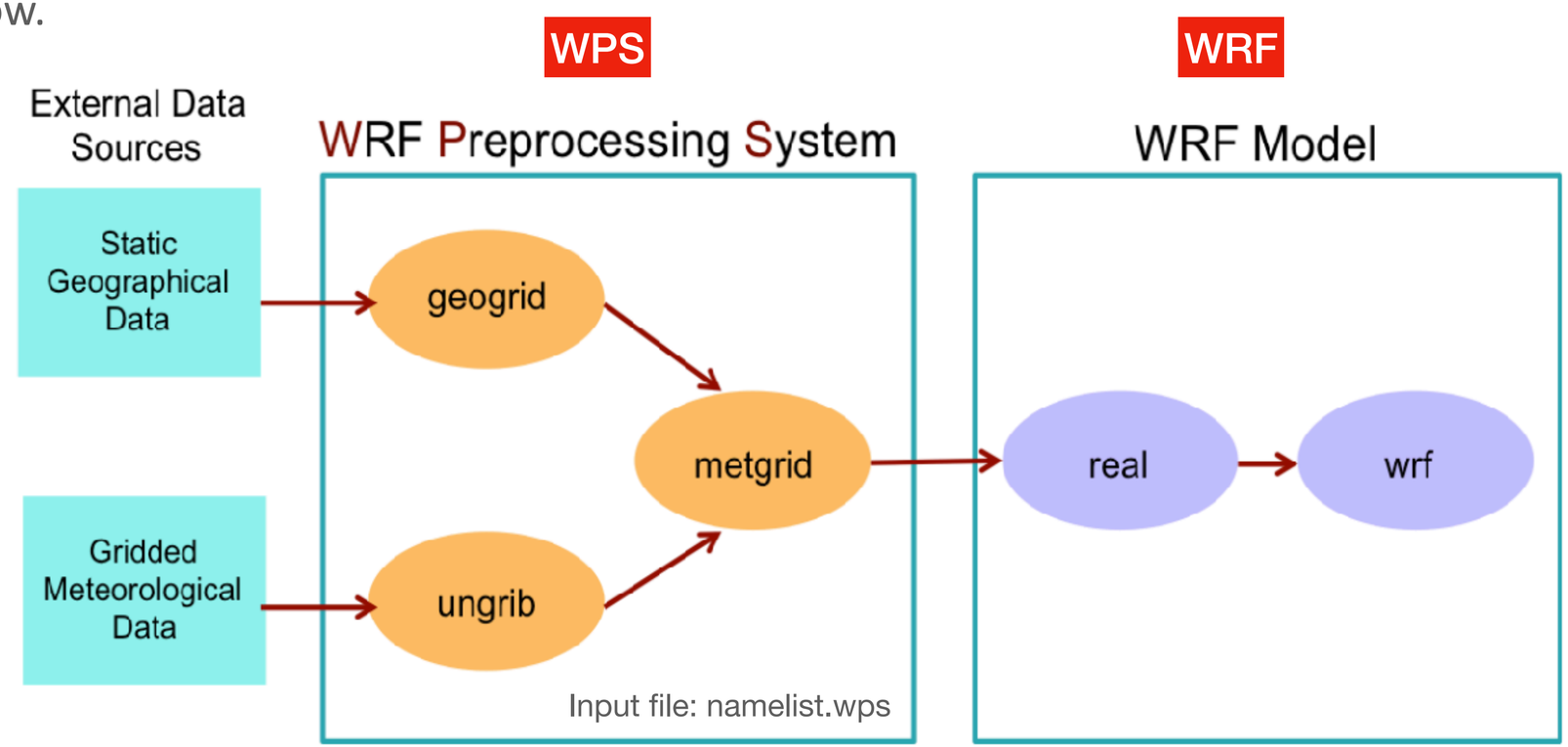
The Weather Research and Forecasting (WRF) Model is a next-generation mesoscale numerical weather prediction system. It is made of a series of pre-processing tools (WPS) and the real weather model (WRF).



Main features:

- Used by a vast community (NCEP, ECMWF).
- Parallel code.
- Support most of the available datasets.

WRF Model Workflow.



The different components do the following tasks:

- Geogrid defines the simulation domain and the geographical data and the land use.
- Ungrib extract the meteorological field from the NCEP or ECMWF.
- Metgrid interpolates the data.
- Real creates the 3-D initial and boundary conditions.
- WRF is the main model that simulates the metereological fields.

Geogrid (Geographical data for initial and boundary conditions)

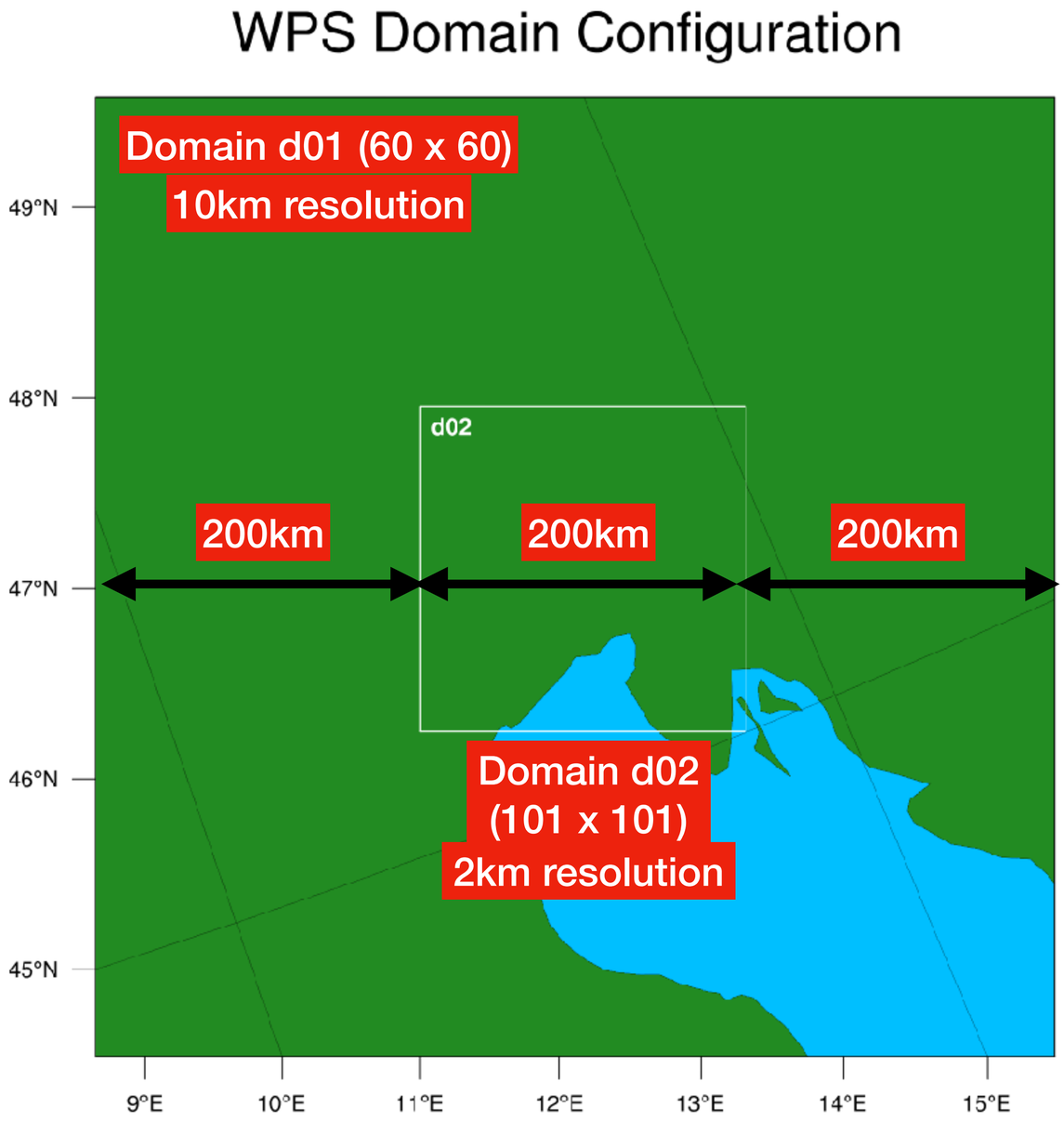
Parameters of the simulation:
Input data from WRF. Considering that meteo files (GFS from NCEP) have resolution of 28 km. We use two nested domains having resolution 10km (d01) and 2km (d02), respectively.

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).

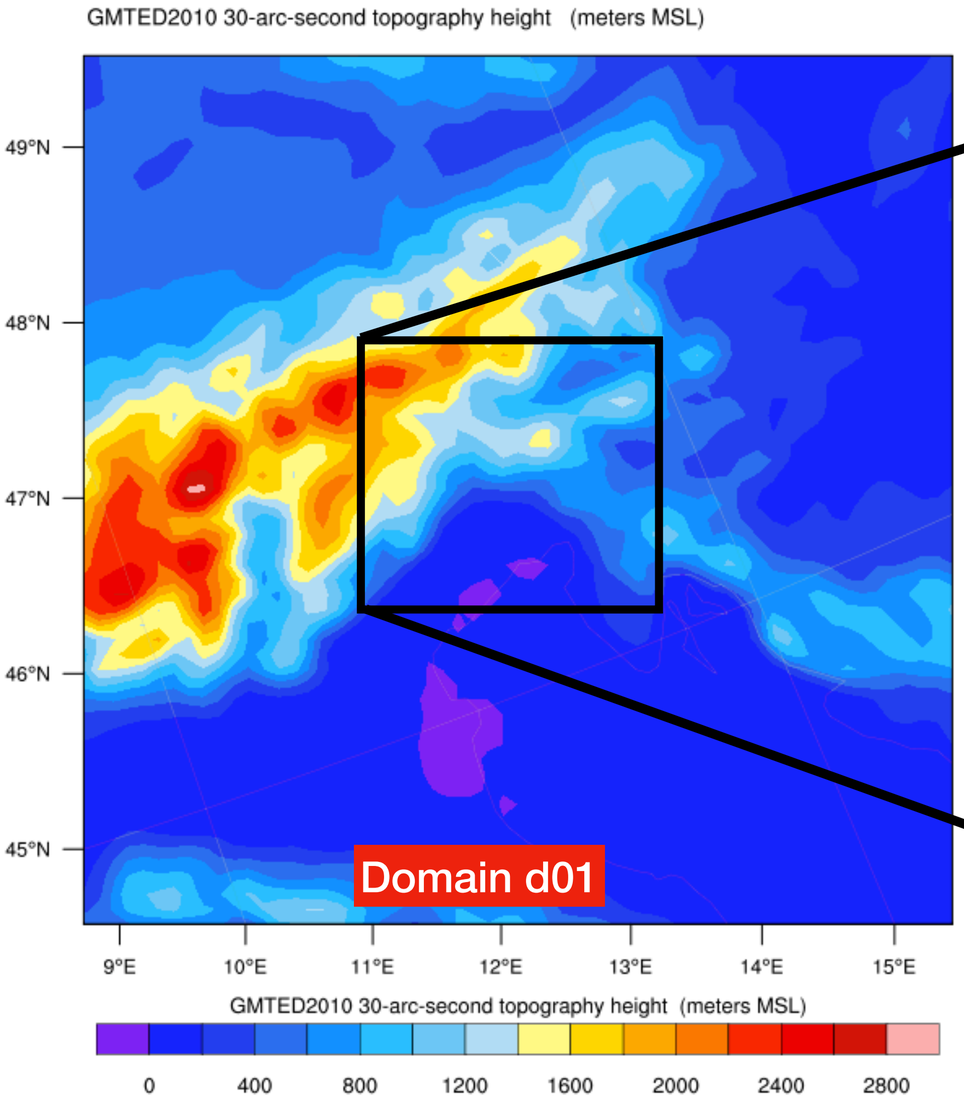
The coarse domain is discretised using 60 x 60 nodes while the central domain is discretised using 101 x 101 nodes. (101 because nodes must be coincident).

After the run, geo_em_d0*.nc files (WPS-intermediate formats) are generated (one for each domain)



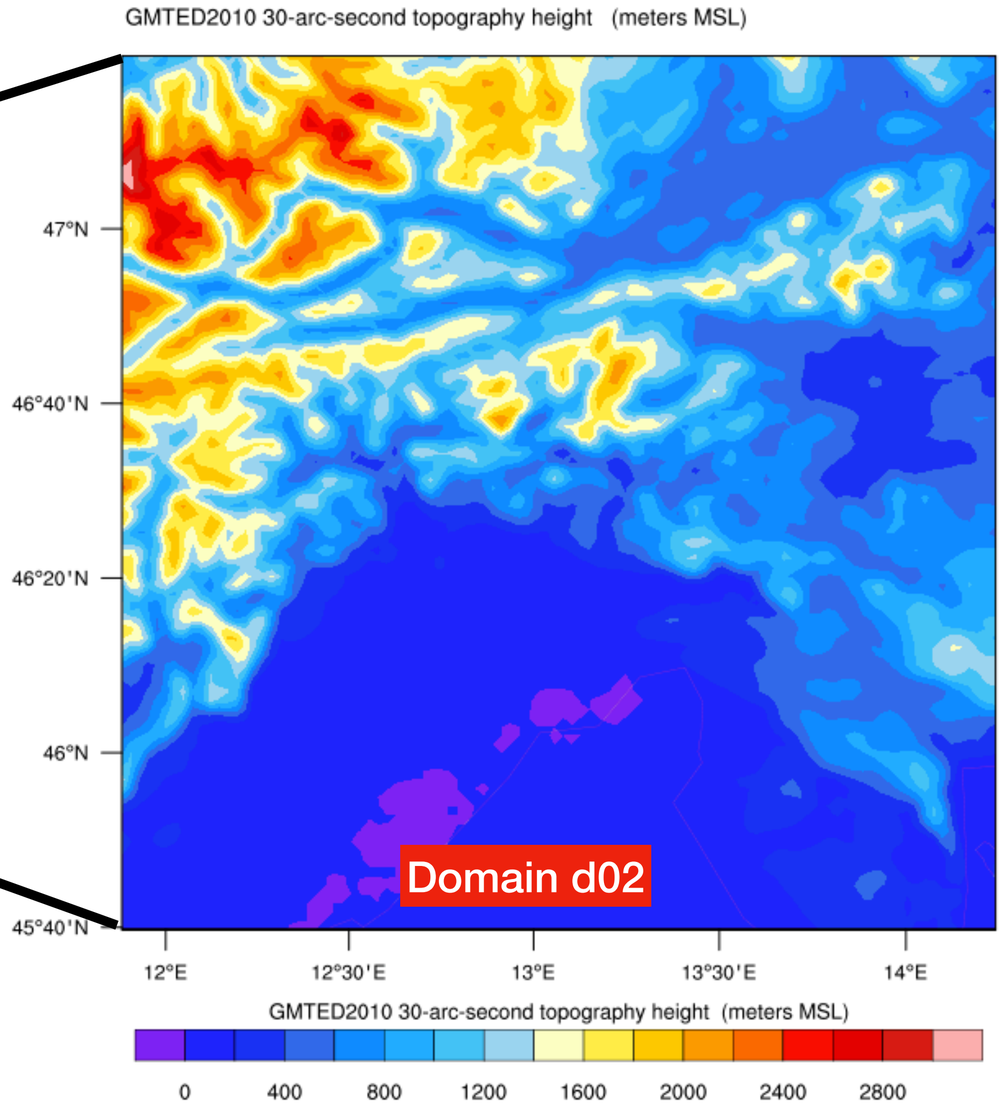
GEOGRID FIELDS

Init: 0000-00-00_00:00:00



GEOGRID FIELDS

Init: 0000-00-00_00:00:00



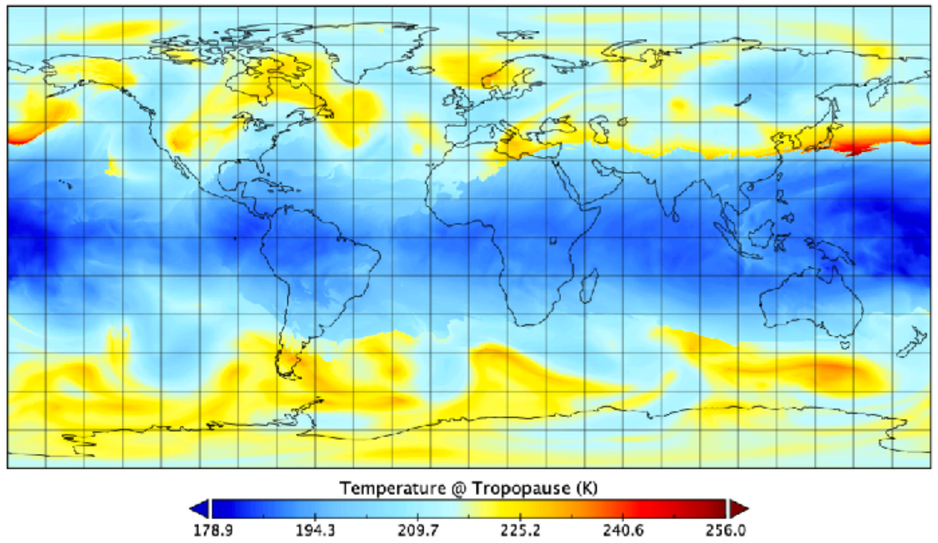
Ungrib (Meteorological data)

Considering the long time span of the simulation (1 year), Sea surface temperature must be also update (SST update). Thus, we need two different types of data:

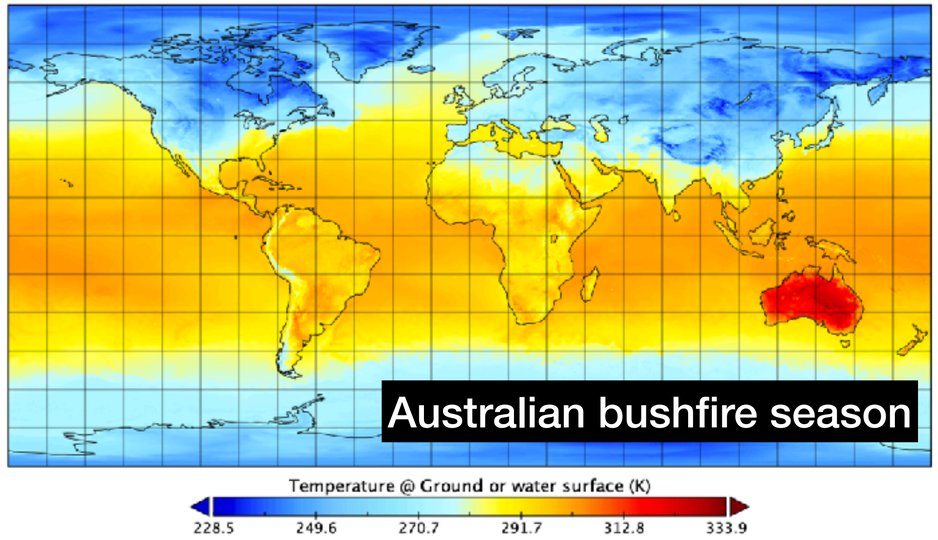
- Global Forecasting system (GFS) data, this are obtained from NCEP and include temperature, wind speed and direction, humidity, etc at different heights.
- Sea Surface Temperature (SST) data, this data are also present in the GFS files but they are not enough detailed (resolution and layers). NCEP SST server is discontinued (old grib format), the ERA5 database (ECMWF) is used.

Both database are in GRIB2 format and can be directly processed by ungrib. For both datasets, data are download with 6 hours time resolution (about 0.5 TB of data).
After ungrib, a “FILE: YYYYY-MM-DD-HH” and a “SST: YYYYY-MM-DD-HH” files (WPS intermediate format) are generated (for every 6 hours). After 12nd of June 2019, there has been a change in the number of levels of GFS files. For files generated after this data, 2 levels are filtered out.

Example of NCEP (GFS) data (2019, Jan, 07):



Example of ERA5 (SST) data (2019, Jan, 07):



GFS: https://rda.ucar.edu/datasets/ds084.1/index.html#!description
SST: https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=overview

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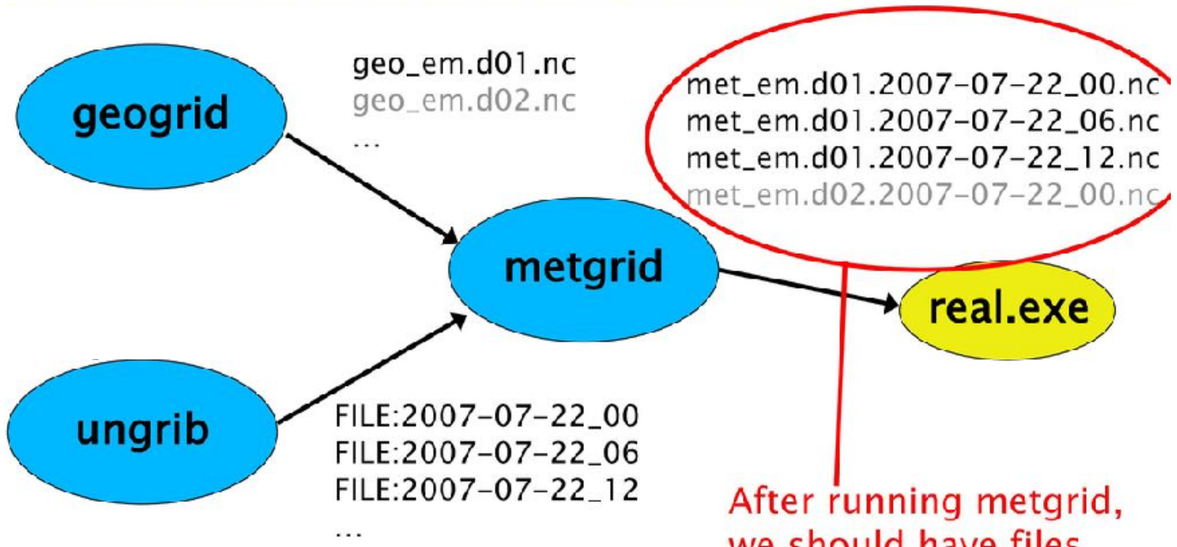
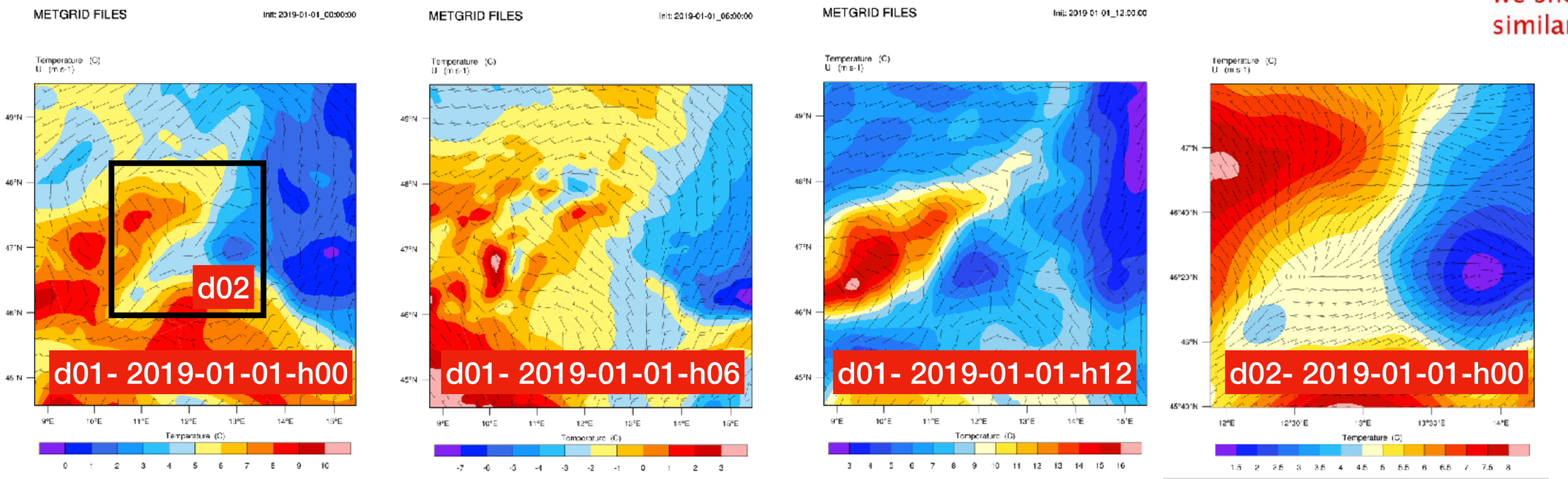
Metgrid (merging of geo and metro files)

The purpose of METGRID is to merge all the data on the model domain. It also check for missing values and other problems with the GRIB2 files. After the run, met_em_* files (WPS intermediate format) are generated, one per time step for the external domain (forcing) and a single file for the small domain. The execution of this program is the last step of the WPS part.



Resulting metgrid files (surface temperature):



Real (interpolation)

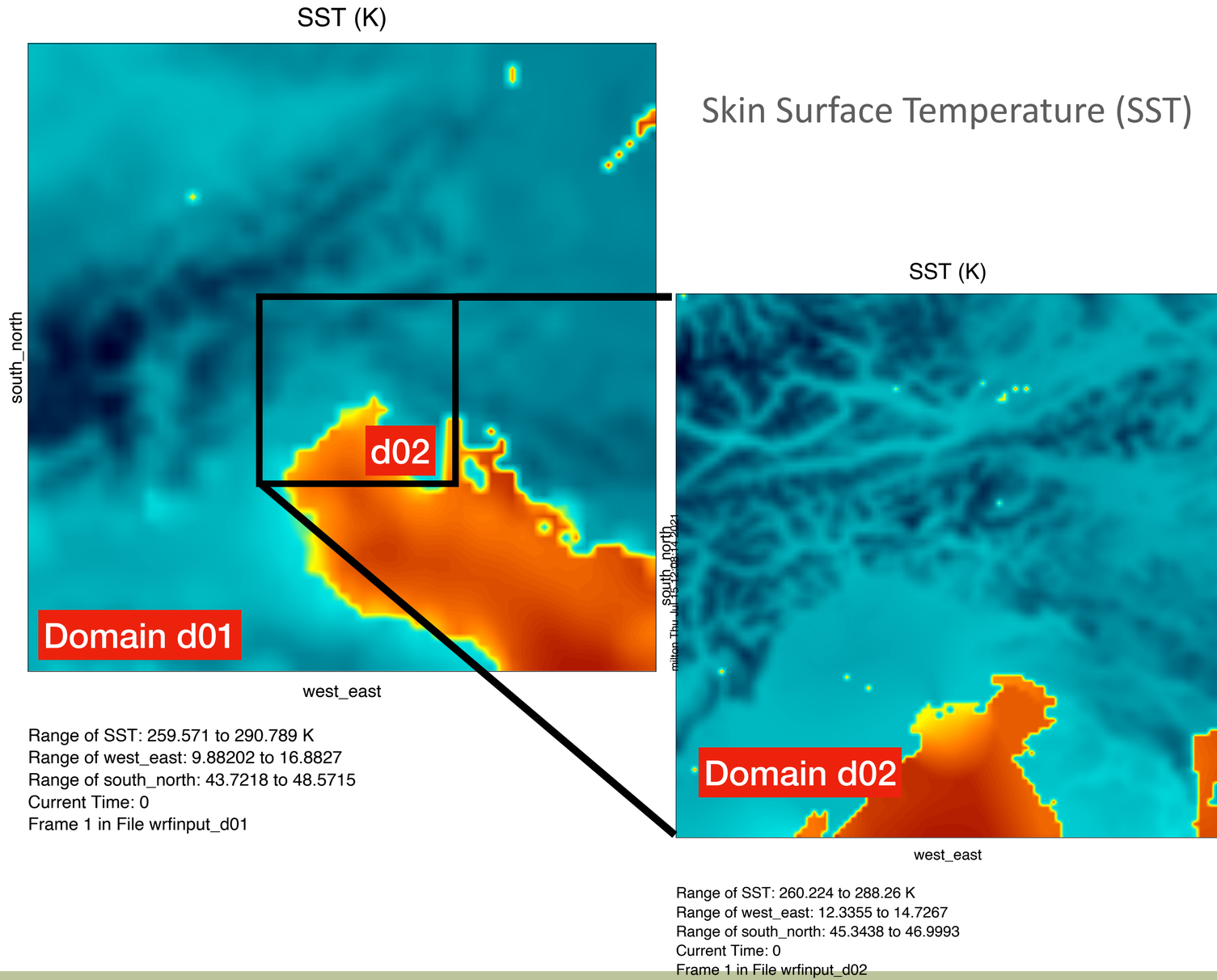
This program vertically interpolates the met_em files generated by metgrid.exe, creates boundary and initial condition files (netCDF format), and does some consistency checks. After running, we obtain the following files:

- wrfinput_d01 (Initial conditions for d02)
- wrfinput_d02 (Initial conditions for d02)
- wrfbdy_d01 (Boundary conditions for d01)

IC files (starting time of simulations): we have the initial conditions for both domains d01 and d02.

BCs files: we have a time-series of boundary conditions (updated every 6 hours) for domain d01. (On d02, boundary conditions are not directly imposed)

Example of initial conditions (wrfinput_d01 and *_d02)



Skin Surface Temperature (SST)

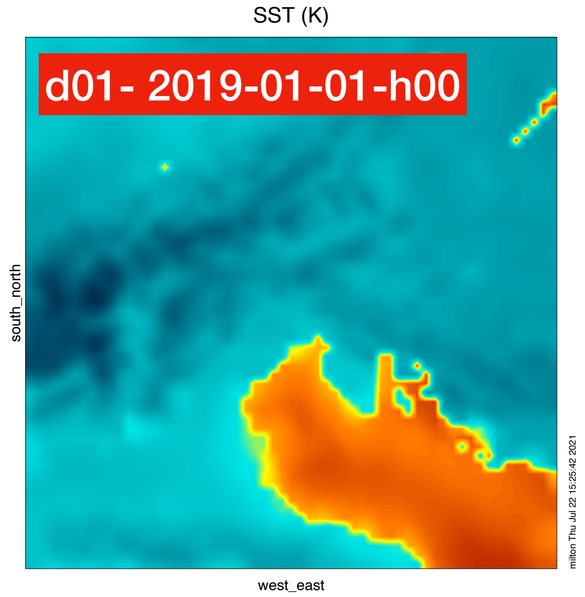
WRF (additional details)

The length of the simulation is almost one year. For better results, SST_update option should be turned on. Surface Temperature is updated during the run of the simulation.

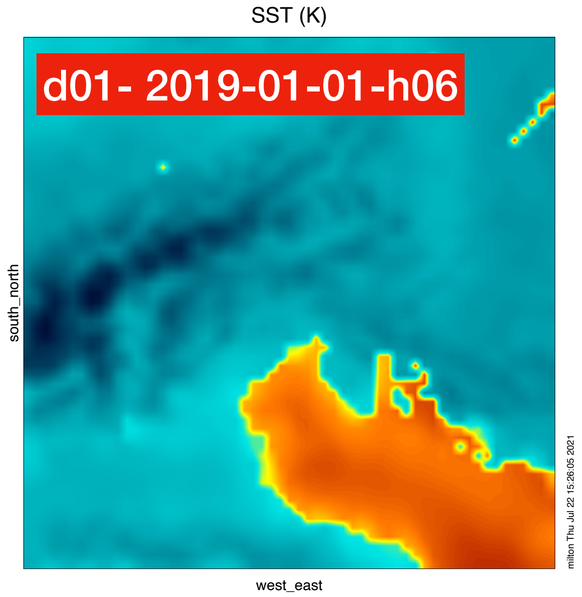
Real.exe generate a series of additional files with the SST info for the two domains:

- wrflowinp_d01
- wrflowinp_d02

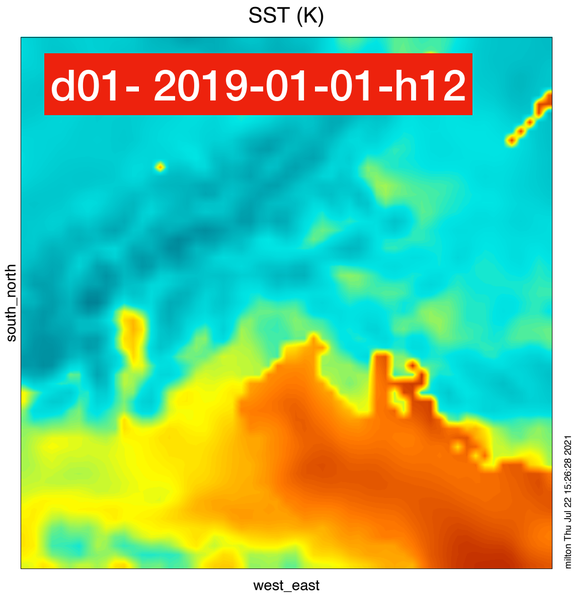
Example of SST info contained in wrflowinp_d01:



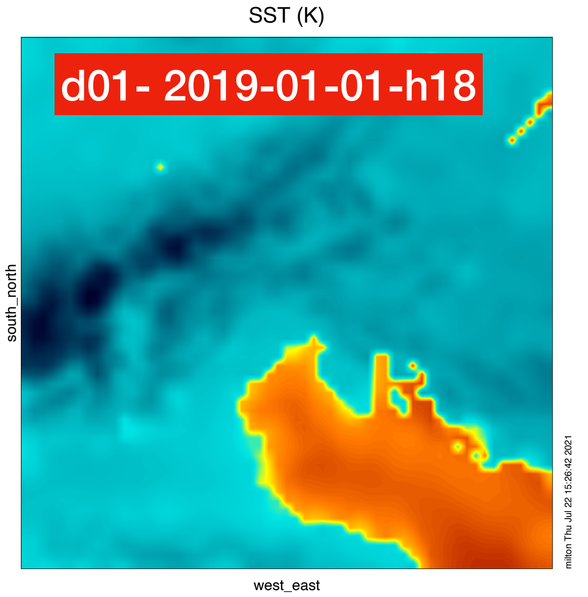
Range of SST: 254.451 to 291.564 K
Range of west_east: 0 to 58
Range of south_north: 0 to 58
Current Time: 0
Frame 1 in File wrflowinp_d01



Range of SST: 254.451 to 291.564 K
Range of west_east: 0 to 58
Range of south_north: 0 to 58
Current Time: 1
Frame 2 in File wrflowinp_d01



Range of SST: 254.451 to 291.564 K
Range of west_east: 0 to 58
Range of south_north: 0 to 58
Current Time: 2
Frame 3 in File wrflowinp_d01



Range of SST: 254.451 to 291.564 K
Range of west_east: 0 to 58
Range of south_north: 0 to 58
Current Time: 3
Frame 4 in File wrflowinp_d01

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 0.5 TB).

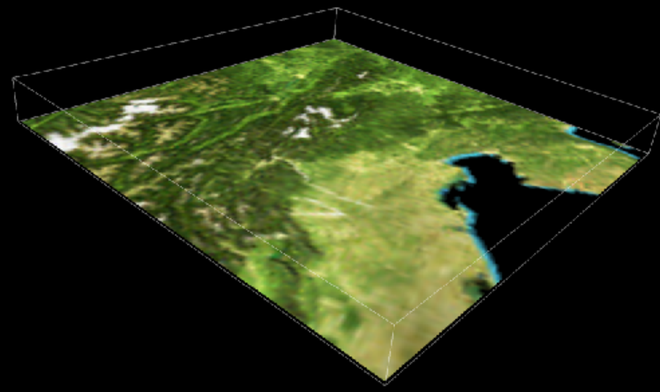
The namelist.input file is used to control the resolve physics (microphysics, long- short-wave radiation, surface later physics, Urban surface, lake/water physics, cumulus Parameterization, etc.).

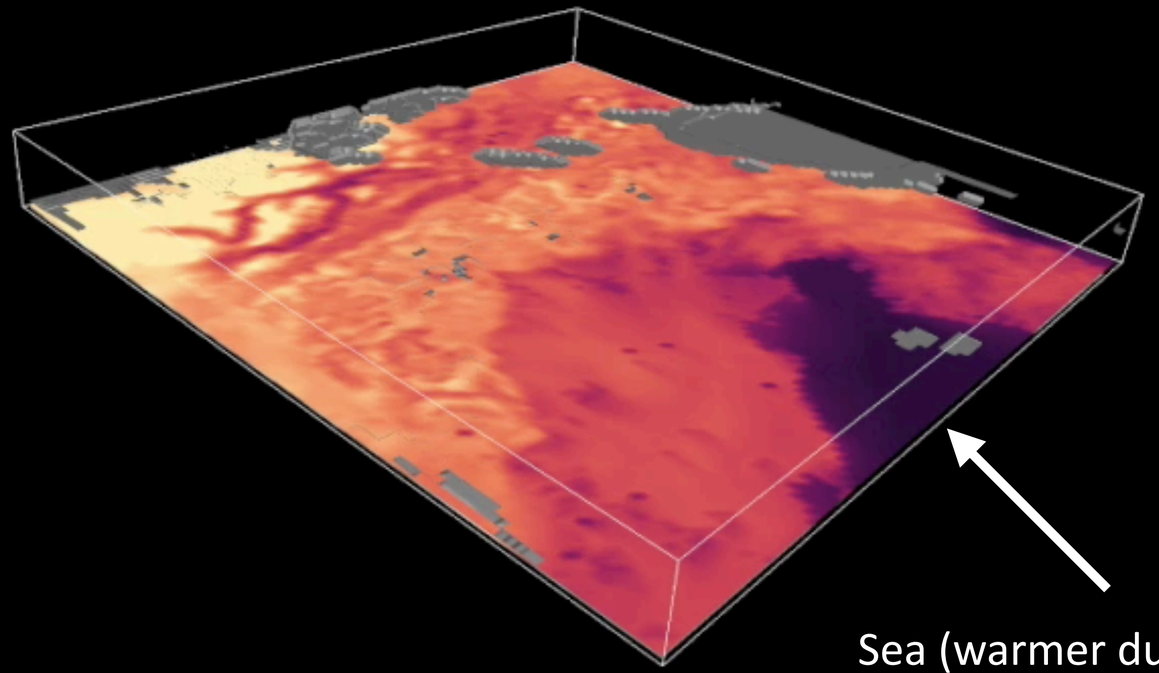
The results can be visualised using ncview (NCAR), Panoply (NASA), Vapor (UCAR) or any other program able to work with NetCDF files.

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)

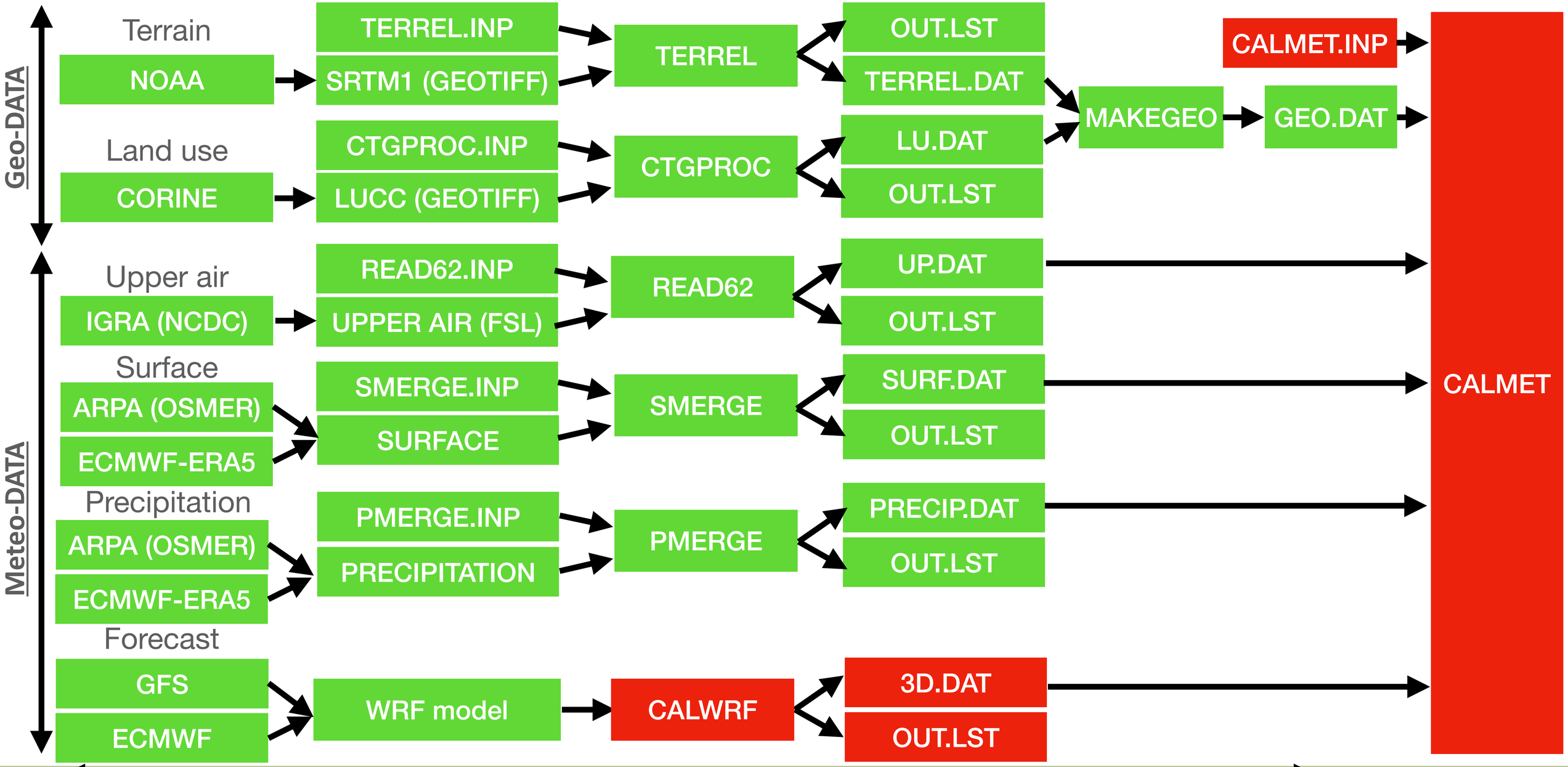
Domain d02





Sea (warmer during winter)

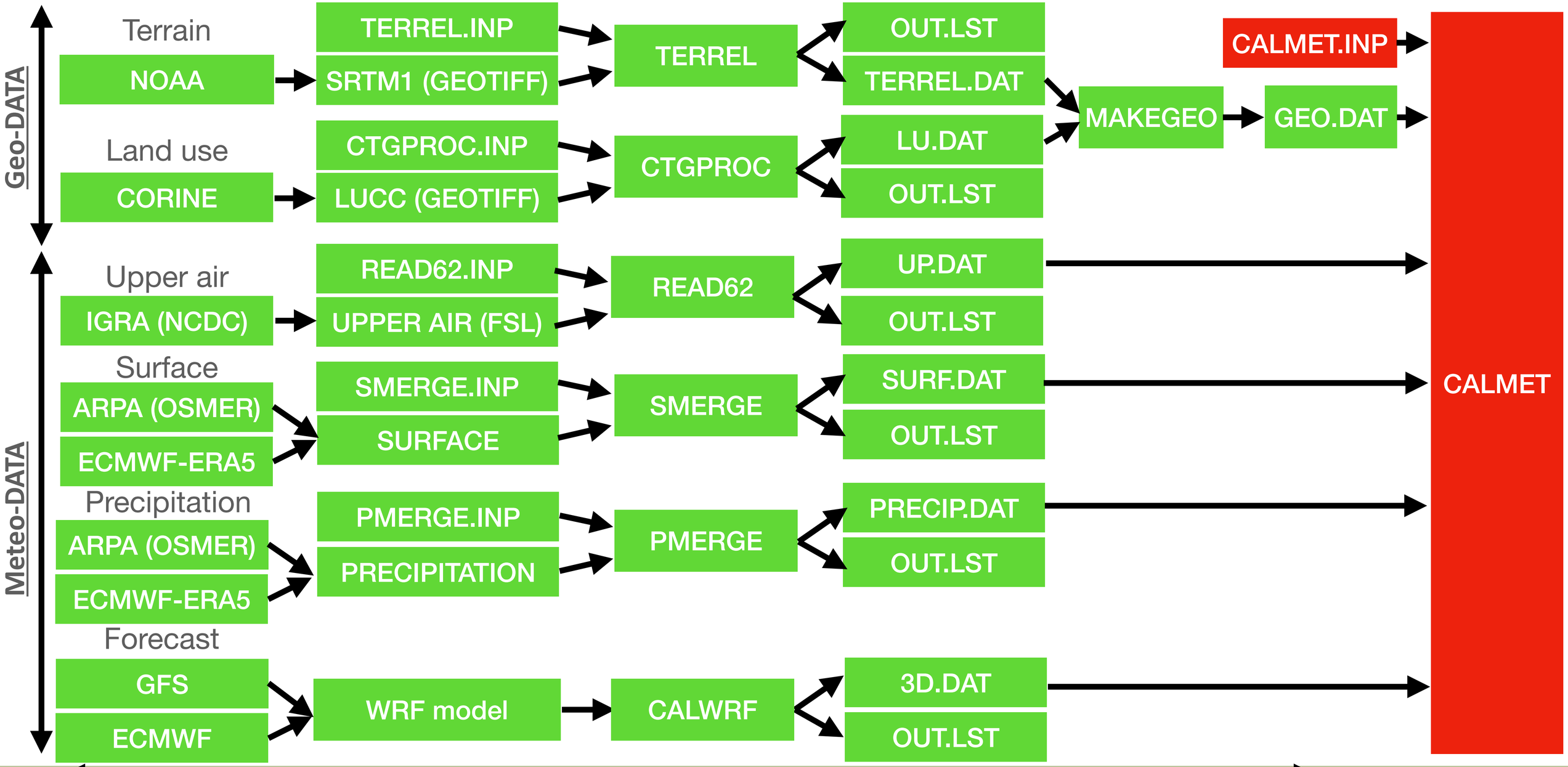
After the WRF run, we are in this situation and we can run CALWRF.



After the run of the WRF model, we have generated the 3D fields in the two domains (d01 and d02). The size of this data is about 0.5 TB:
-0.1 TB, Domain d01 data (365 x 24 = 8760 wrfout files).
-0.4 TB, Domain d02 data (365 x 24 = 8760 wrfout files).
CALWRF can read up to 100 files (code limitation), using the ncrcat com-and we can group the wrfout of each domain per month. At the end, we obtain a WRF file for each month (30/35 GB per file) and we generate a 3D.dat file for each month (input then for CALMET).
After this process, we have 12 files called:
3D_month.dat3 (15/16 GB more or less).

These files will be then one of the input for CALMET.

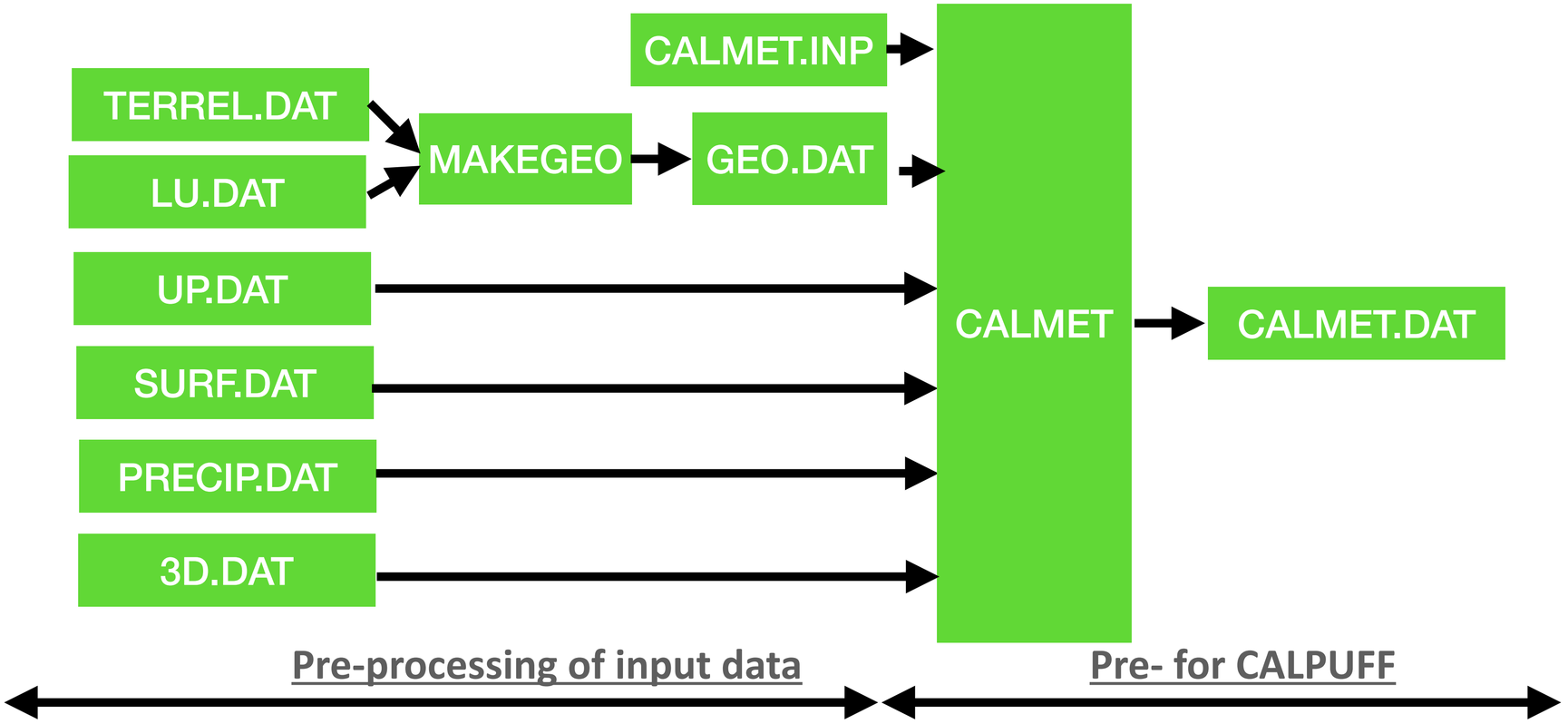
After the WRF run, we are in this situation and we can run CALWRF.



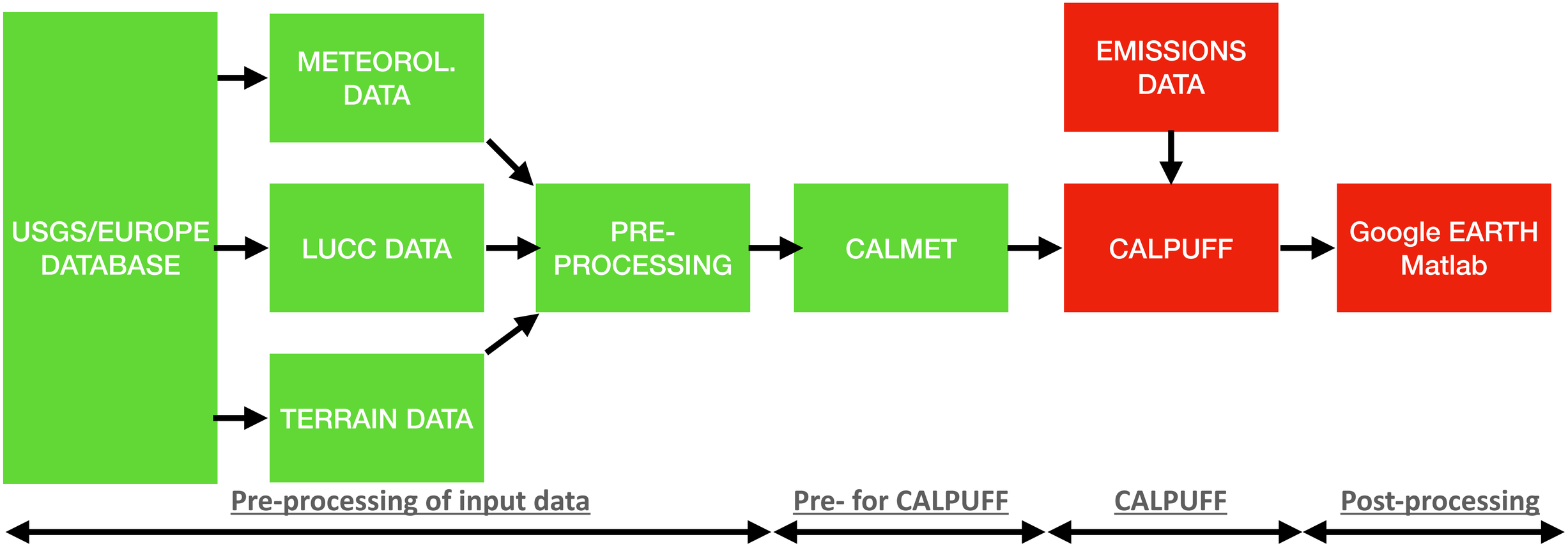
CALMET

Problems with the reading of the 3D.DAT files on UNIX machines have been fixed (compiler options). The program now runs fine on all UNIX machines if compiled with gfortran.

All the data (observations and WRF simulations results) are integrated using CALMET.
In particular, WRF data are used as initial guess for the wind field (IPROG=14). The wind field is then corrected using the CALMET diagnostic module. At the end, we obtain the CALMET.DAT file.



After running CALMET, we are in the following situation:



CALPUFF (emissions)

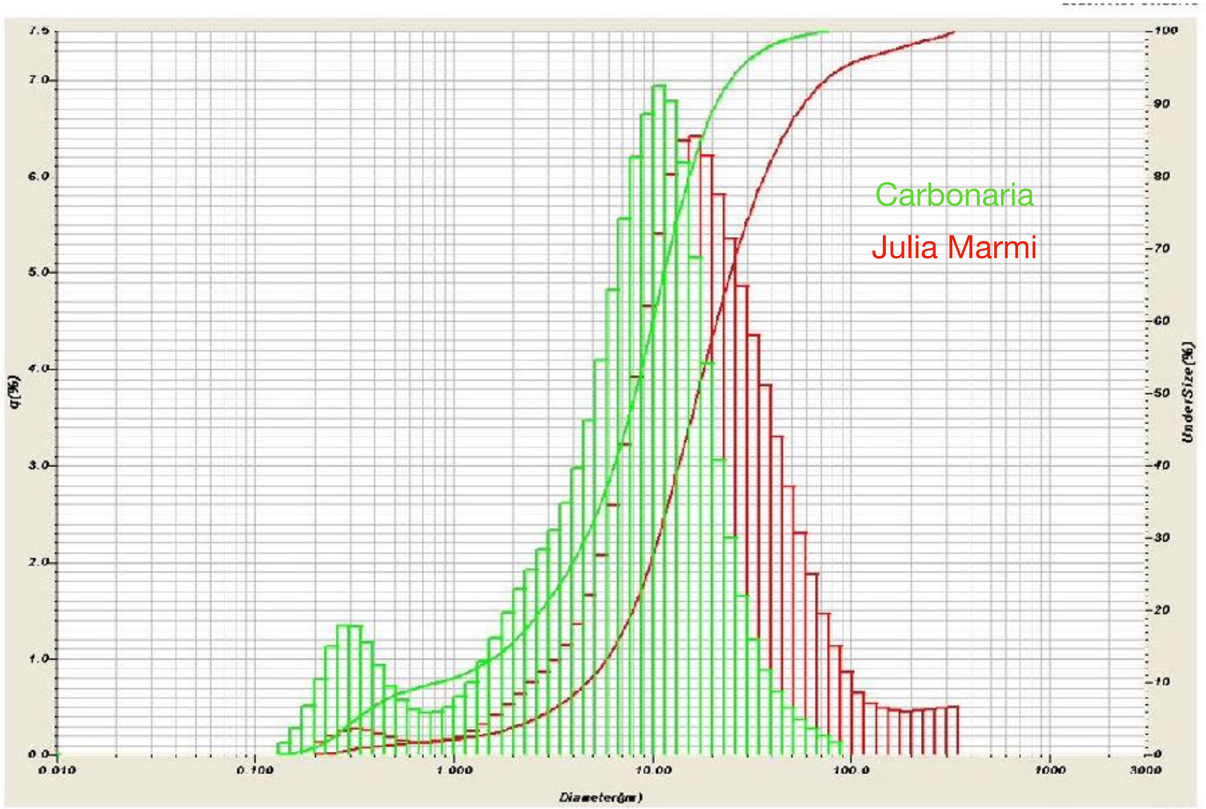
We need to define the emission generated by the extraction activities.

We can consider the following emissions:

- Emissions of pollutants (NOx, SOx, C02) due to vehicles (e.g. trucks).
- Emission of stone powder generated by machining operations on stone.

We focus on the second type of activities.

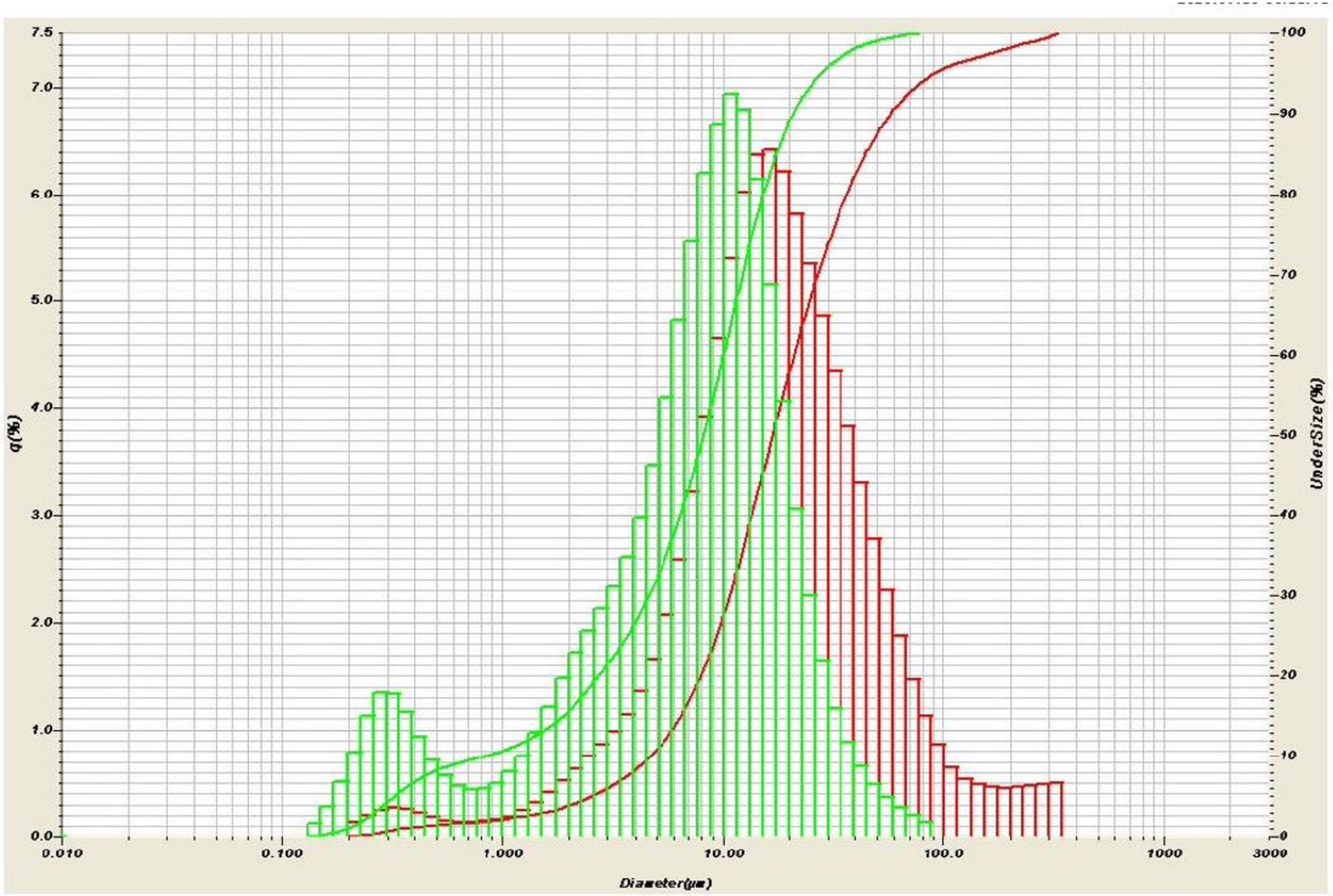
We need to consider the particle size distribution of the powder generated during these activities (obtained from slurries).



We focus on particles smaller than 10 microns, 30 to 100 microns particles deposit within 100m from the source.

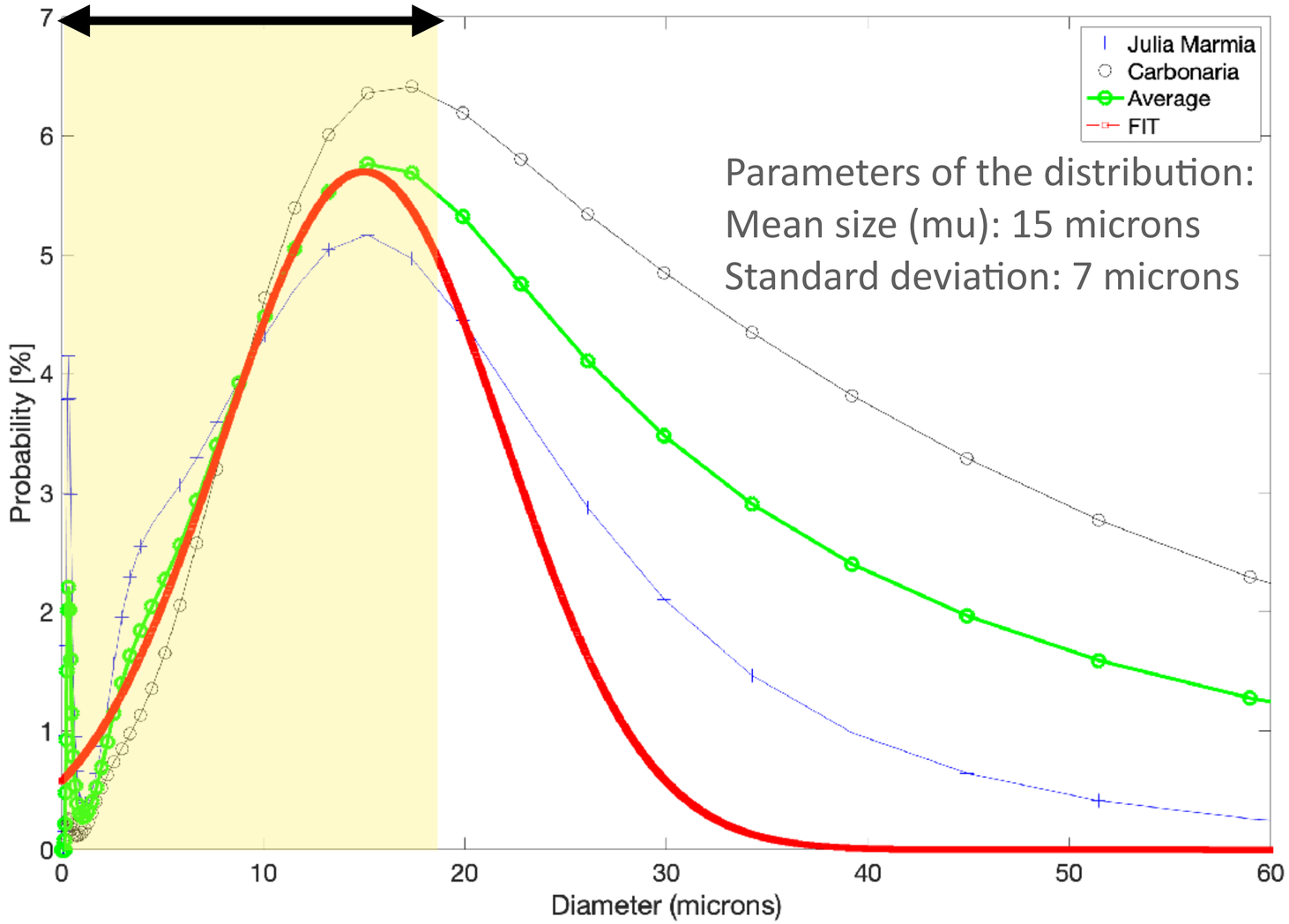
Particles considered
PM 10 (smaller than 10 microns)

Deposit within 100 m from the source



We consider an average distribution and we fit with a Gaussian distribution, we consider the left side only for the fitting. We are not interested in larger particles (which deposit within 100m from the source).

Particles size considered for the fit.



To estimate the emissions, we can consider the correlations proposed by EPA.
In this way, depending on the different operations performed on the quarry, we can estimate the total amount of PM10 released during the working (and non working time).

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

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

Considering that the average amount of stone removed is 4000 ton/year, 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)

The quarries are modelled as 3 point sources emissions (PTEMARB.DAT file).

Emission file (PTEMARB.DAT)

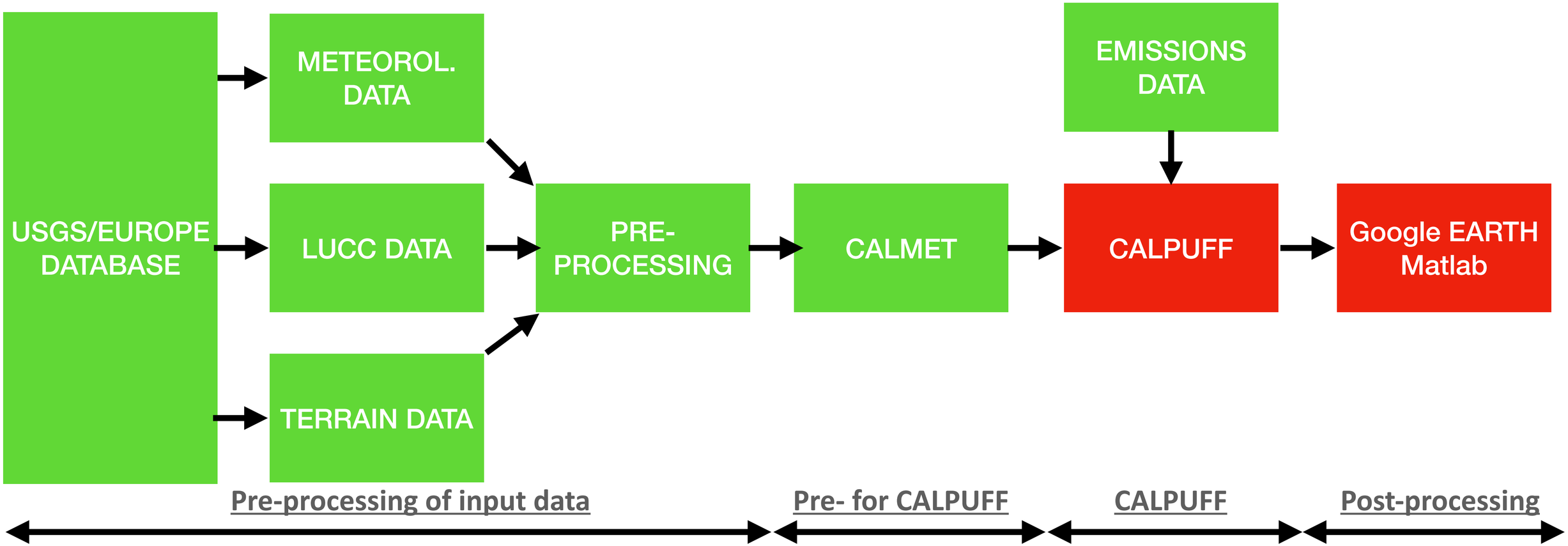
```
PTEMARB.DAT     2.1
   1
Test
UTM
  33N
WGS-84
KM
UTC+0100
2019   1   1     0  2019 365  23  3600
   3   1
'PM10'
30.000
'Noglar'      380.755  5110.794  2.000   20.0   455.0    0.00  1.00    0.00
'Tarpezzo'    384.440  5110.390  2.000   20.0   343.0    0.00  1.00    0.00
'Clastra'     385.006  5109.635  2.000   20.0   343.0    0.00  1.00    0.00
2019   1   0    0   2019   1  23 3600
'Noglar'    286.000  5.000 0.0   0.0    0.060
'Tarpezzo'  286.000  5.000 0.0   0.0    0.060
'Clastra'   286.000  5.000 0.0   0.0    0.060
2019   2   0    0   2019   2  23 3600
'Noglar'    286.000  5.000 0.0   0.0    0.060
'Tarpezzo'  286.000  5.000 0.0   0.0    0.060
'Clastra'   286.000  5.000 0.0   0.0    0.060
2019   3   0    0   2019   3  23 3600
'Noglar'    286.000  5.000 0.0   0.0    0.060
'Tarpezzo'  286.000  5.000 0.0   0.0    0.060
'Clastra'   286.000  5.000 0.0   0.0    0.060
2019   4   0    0   2019   4  23 3600
'Noglar'    286.000  5.000 0.0   0.0    0.060
'Tarpezzo'  286.000  5.000 0.0   0.0    0.060
'Clastra'   286.000  5.000 0.0   0.0    0.060
2019   5   0    0   2019   5  23 3600
'Noglar'    286.000  5.000 0.0   0.0    0.060
'Tarpezzo'  286.000  5.000 0.0   0.0    0.060
'Clastra'   286.000  5.000 0.0   0.0    0.060
2019   6   0    0   2019   6  23 3600
'Noglar'    286.000  5.000 0.0   0.0    0.060
'Tarpezzo'  286.000  5.000 0.0   0.0    0.060
'Clastra'   286.000  5.000 0.0   0.0    0.060
2019   7   0    0   2019   7   7 3600
'Noglar'    286.000  5.000 0.0   0.0    0.060
'Tarpezzo'  286.000  5.000 0.0   0.0    0.060
'Clastra'   286.000  5.000 0.0   0.0    0.060
2019   7   8    0   2019   7  17 3600
'Noglar'    286.000  5.000 0.0   0.0    0.380
'Tarpezzo'  286.000  5.000 0.0   0.0    0.380
```

Info on the quarries (location, elevation, size)

PM10 Emissions during a non-working day.

PM10 Emissions during a working day.

After setting up the emissions we are in the following situation:



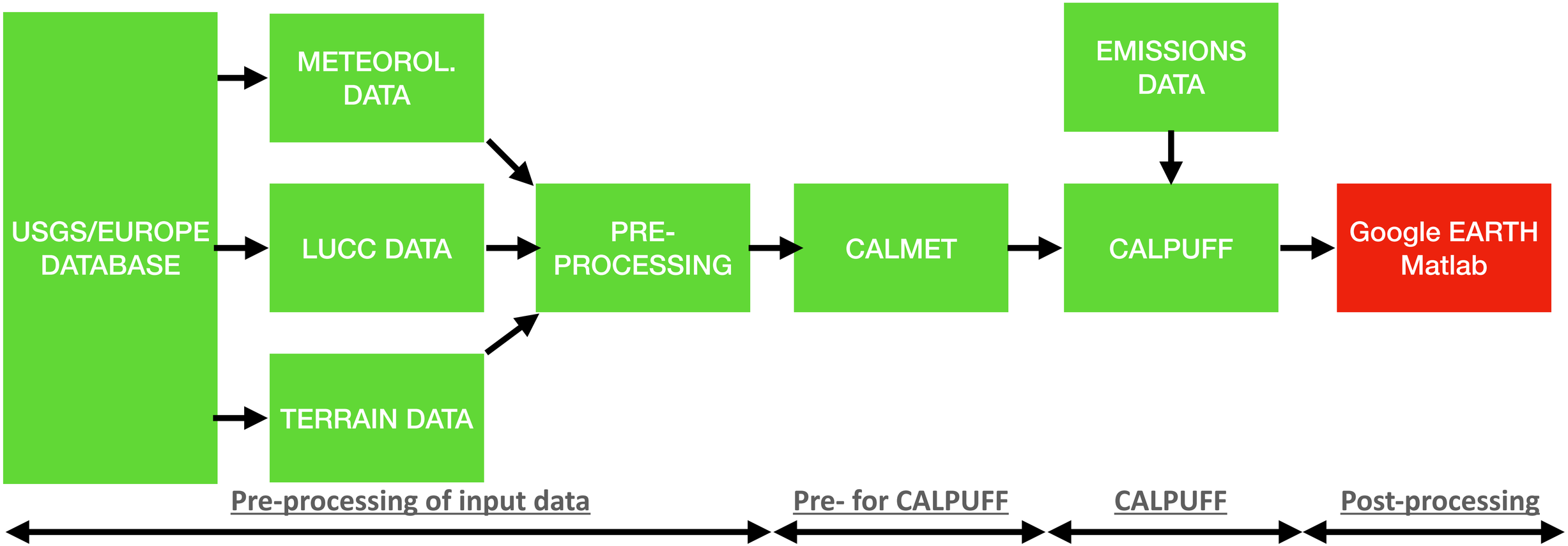
We can now run CALPUFF with the CALMET.DAT and emission file created at the previous steps.
For the setup of CALPUFF, we track only the PM10 species.
The grid is the same in the previous steps:
Nx= 96 and Ny=88, grid resolution= 1km.

After running CALPUFF, we obtain different files:

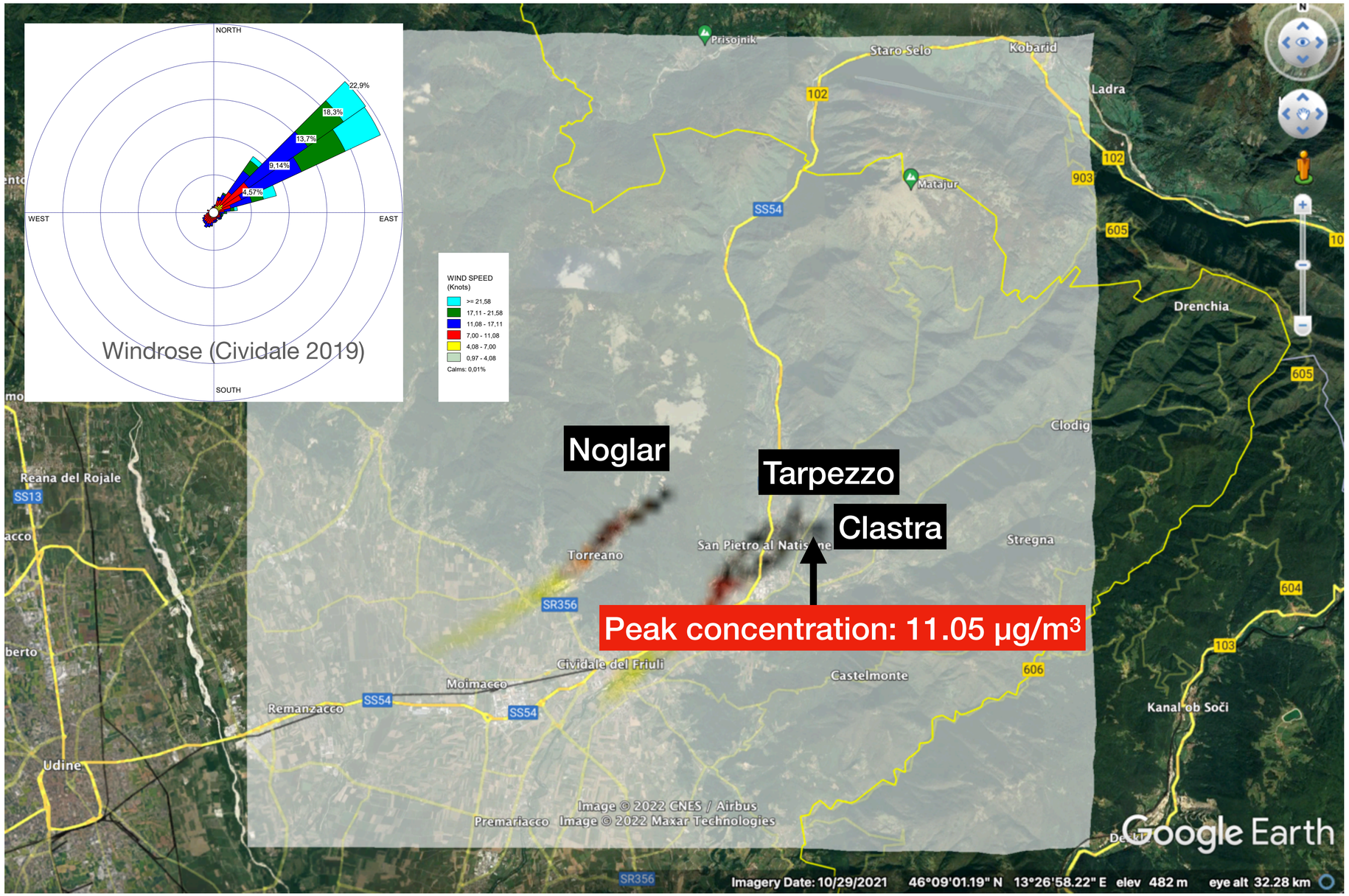
- MASS.BAL, file with the emitted PM10 and the emission and deposition rates.
- CONC.DAT, file with the resulting PM10 concentration (microgram/mc) at the surface level.
- WET.DAT, file that contains the wet deposition fluxes (e.g. due to rain)
- DRY.DAT, file that contains the dry deposition fluxes.

We can take a look at the CONC.DAT file, in this file the concentrations at the surface level at the different grid points are collected. The file is binary, we can read it using Fortran and then post process this file in Matlab so we can visualise the results in Google Earth (TIFF image geo-referenced).

After setting up the emissions we are in the following situation:



Example of the resulting concentration of PM10 obtained from CALPUFF.

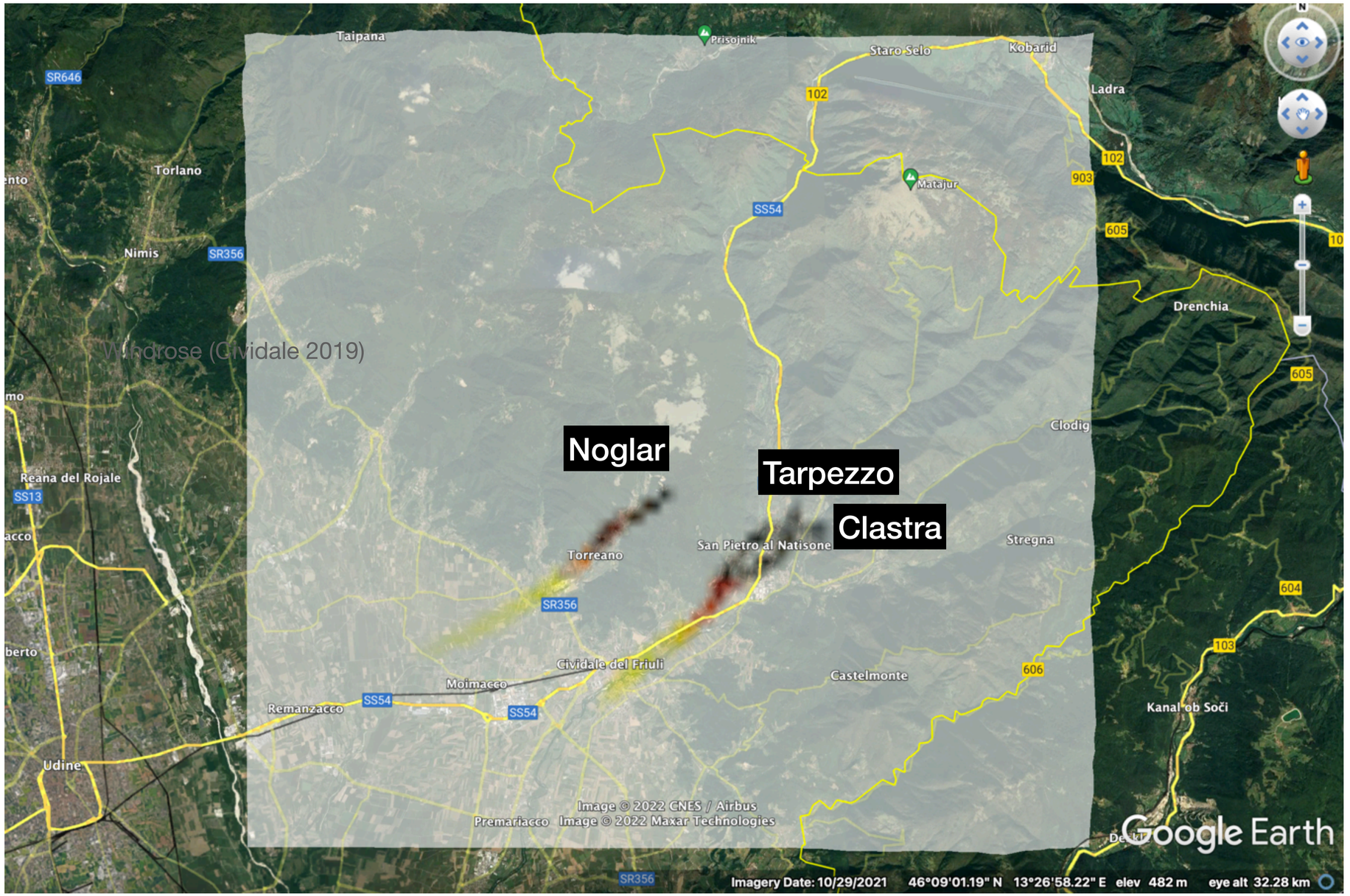


0.1 µg/m³

0.05 µg/m³

0.01 µg/m³

Law limits:
Daily average: 50 µg/m³
(Can be exceeded 35 times during a year)
Annual average: 40 µg/m³

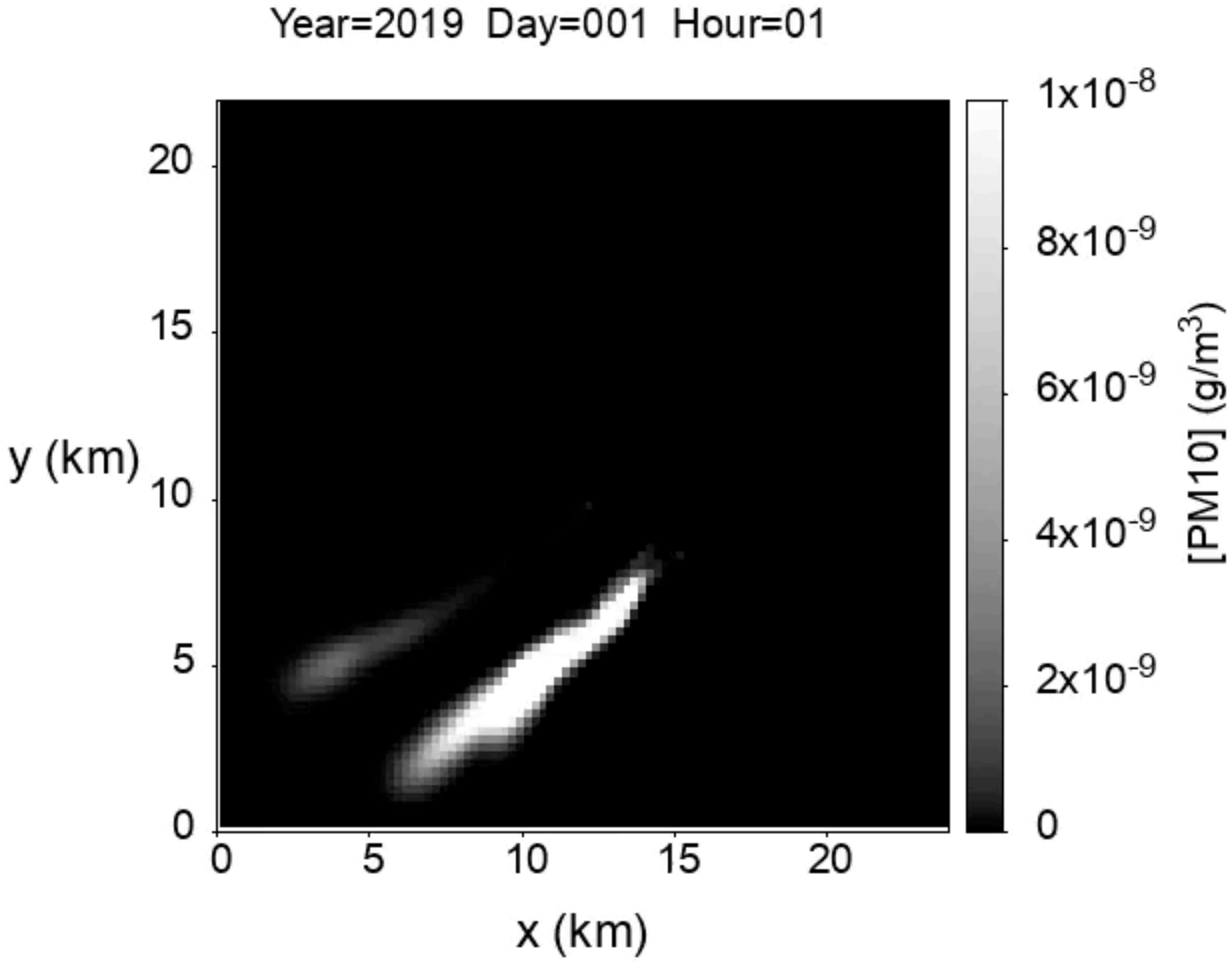


0.1 µg/m³

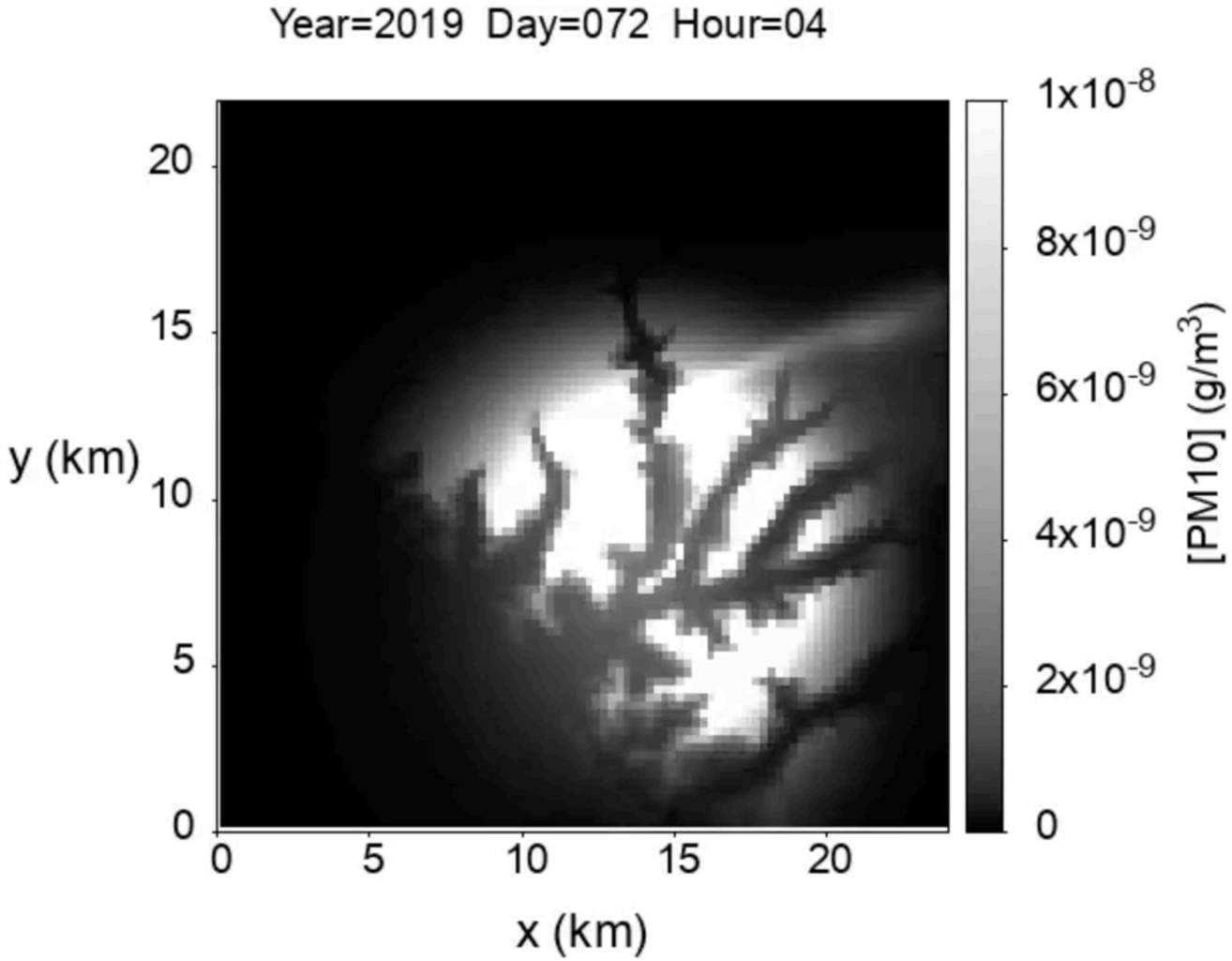
0.05 µg/m³

0.01 µg/m³

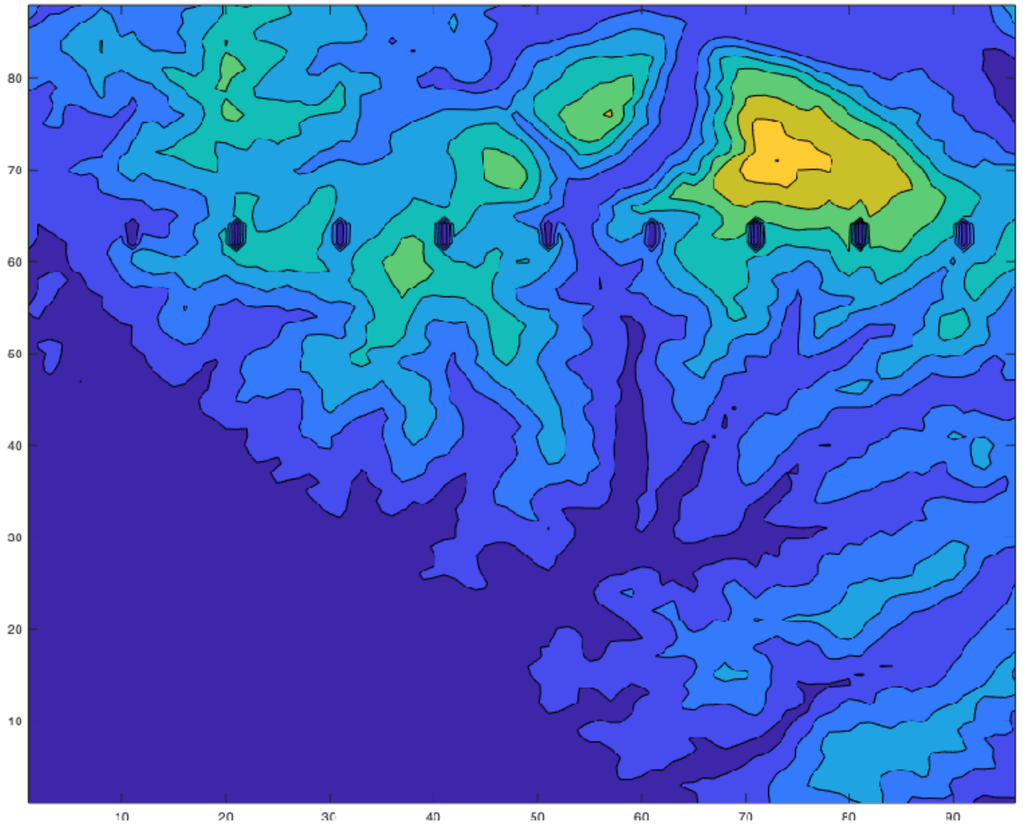
Simulation of year 2019.



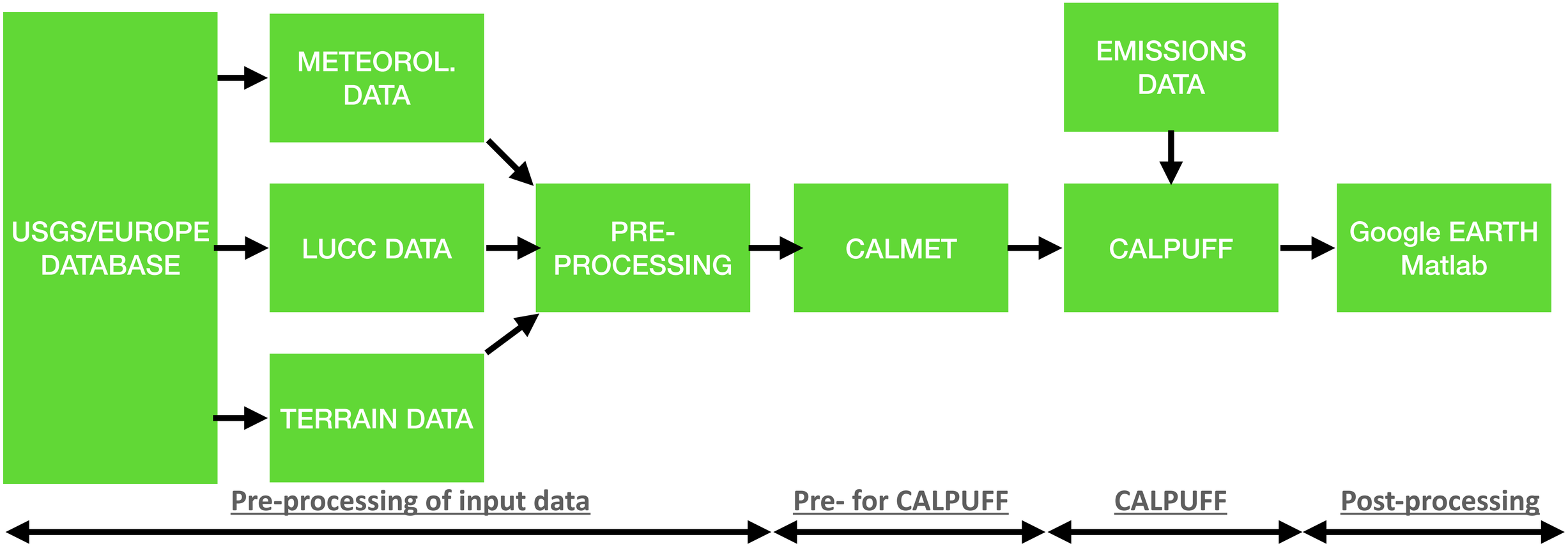
Concentration correlates with the valleys location (when the wind is very low).



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



Current situation (18/02/2022), all tasks completed:



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 (0.5 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.