5. 1961-1990 high resolution precipitation climatologies for Italy

5.1 Update of the Italian precipitation database

5.1.1 Italian precipitation data rescue: providers and first quality checks

The contributions of this PhD project to the development of the precipitation climatologies of Italy were smaller than for temperature. This is because a preliminary version of the *PRISM* model had already been developed at the beginning of this PhD project by a collaboration between the *ISAC-CNR* and the University of Milan. Here we briefly describe the dataset construction, the gridding technique, and present results that are not yet final, because some improvements should be still introduced.

The enlargement of the precipitation database was based on the search and rescue for data from any possible source that collected precipitation data within the 1800-2010 period. As for temperature, there is not an official data provider in Italy. However in this case, there is a main provider, that being *ISPRA* (Institute for Environmental Protection and Research, *SINTAI PLUTER* data set, Dipartimento Tutela Acque Interne e Marine, precipitation and temperature dataset from the Hydrological Annals of the former Italian Hydrological Service, *http://193.206.192.243/storico/index.html*).

The data collection was performed with the support of some quality-check rules. In particular we accepted:

- records with at least 20 years of data in the 1800-2010 period:

  · monthly data: for each year, we considered a year as valid only if its record has all the 12 monthly data, we rejected years made of 11 or less months;

  · daily data: for each month, we considered a month as valid only if its record has all the days, we rejected months with one or more missing days;

- records without negative precipitation data that cannot be further corrected;
- records with basic metadata on geographic location, elevation and data availability.

In the case of two or more stations located very close with the same name, we chose the station with data nearest to the 1961-1990 period and fully-reported metadata.

We obtained precipitation data from a list of data providers, but the majority of the collected data were obtained from the station net of the former Italian Idrographic Service (Sevizio Idrografico del Ministero dei Lavori Pubblici).

The former Italian Idrographic Service commissioned the stations management to regional services as Regional Agencies for the Environment Protection, i.e. *ARPA* (Agenzia Regionale per la Protezione dell'Ambiente). We obtained data from many regional bureau as, e.g., *ARPA* Emilia-Romagna, *ARPA* Veneto, *ARPA* Piemonte, *ARPA* Liguria, *ARPA* Lombardia for the Northern part of Italy and so on.

Our data search consisted (and still consists) of collecting data from regional provider as *ARPA* , *ENEL* and from national organizations, as *ISPRA* or *APAT* (Sistema di raccolta dati Climatologici di Interesse Nazionale, *http://www.scia.sinanet.apat.it/*) which gather precipitation records from various data providers.

Then, we collected data from the Italian Air Force dataset (*AMI*, Aeronautica Militare Italiana, *http://www.meteoam.it/*), from the *UCEA* data-sets (Ufficio Centrale di Ecologia Agraria, *http://www.cra-cma.it/*) and we collected the secular Italian records already used in previous projects or scientific papers as in *Brunetti et al (2006b)*.

We also collected data from foreign providers as *ZAMG* (the *HISTALP* database, *Auer et al., 2007*; *http://www.zamg.ac.at/histalp/*), MeteoSwiss (*http://www.meteoswiss.admin.ch/web/en/ weather.html*), *ARSO* (Agencija Republike Slovenije za okolje, *http://www.arso.gov.si/*), *NCDC-GSOD* (*http://www.ncdc.noaa.gov/oa/about/whatsnew.htm*, National Climatic Data Center, global dataset).

Some other minor sources as monographic books and personal communications have been taken into account.

The total number of stations considered is more than 5,000. It includes, however, a number of duplicates as well as stations that could not be used because their amount of date is too low. The activities on the refinement of the Italian database are still in progress. The number of records that will be considered in the definitive precipitation climatologies can be subjected to changes.

5.1.2 Geographic, elevation, and other metadata checks

As for temperature records, the collected precipitation data were subjected to many quality checks, for details on similar procedures, see Chapter 4.2.2.

As for temperature records, we assigned to each station a longitude, latitude and elevation value which correspond to the grid cell of the *USGS* digital elevation model *(USGS website)* where the station is located. First, we compared the elevation and the coordinates of the corresponding grid cell to the station elevation. Second, by means of Google Earth™ and provider's metadata, we studied the stations with largest elevation or coordinates' discrepancies, re-located the wrong ones and we corrected the coordinates where the correct values could be identified. Third, we deleted the series any time the correct position or elevation could not be identified, as in *Brunetti et al., (2009)*.

The elevation check is particularly important in this case, because our model is driven by local *LR* of precipitation versus elevation; thus an incorrect elevation leads to a wrong assignment and consequently to wrong modelled precipitation values.

The *USGS DEM* is given with a low *RMSE*, 18 m (from a report of USGS of 1996, *USGS website, 1996*), and it leads to an intrinsic error while we evaluate linear regressions versus elevation.

After a first check on coordinates, elevation, and names we obtained a database of more than 5,000 precipitation records for Italy and surroundings regions.

5.1.3 Quality checks on precipitation data and data rescaling to 1961-90

Thanks to the higher precipitation records density and their higher daily and monthly availability than temperature records (often provided only as normals), the quality checks on data were performed before the re-scaling.

We converted daily data into monthly data (we used <u>total monthly precipitation</u> as dependent variable, not the mean precipitation monthly value). Then we compared the monthly normals versus neighbouring station values, we filled their gaps where possible and we chose the stations with the minimum number of missing values as reference stations. Any station that showed large or non-correctable discrepancies was rejected (see *Brunetti et al. (2006b)* and *Brunetti et al. (2009)* for further details).

The re-scaling procedure was performed as in *Brunetti et al. (2009c)*. If the nearest complete station had data in 1961-1990, it was used for re-scaling the station under investigation, or else the closest station with the minimum number of missing data in 1961-1990 and at least 10 years of overlapping with the investigated station was used. In any other case, the station was rejected. In the re-scaling process, we also used the secular homogenized series and the gridded anomalies as for temperature series (see chapter 4.1.5 and Chapter 4.2.3 for further details).

At the end of the re-scaling procedure we got a precipitation dataset of approximately 4,500 1961-1990 records: approximately 3,200 in northern and central Italy and in the alpine region, approximately 1,300 in southern Italy, Sicily and Sardinia.

5.1.4 1961-1990 precipitation dataset used for the Italian climatologies

The precipitation dataset is subjected to on-going further enlargements and quality checks. At this point we have approximately 5,000 precipitation stations. Let us show their geographic distribution.

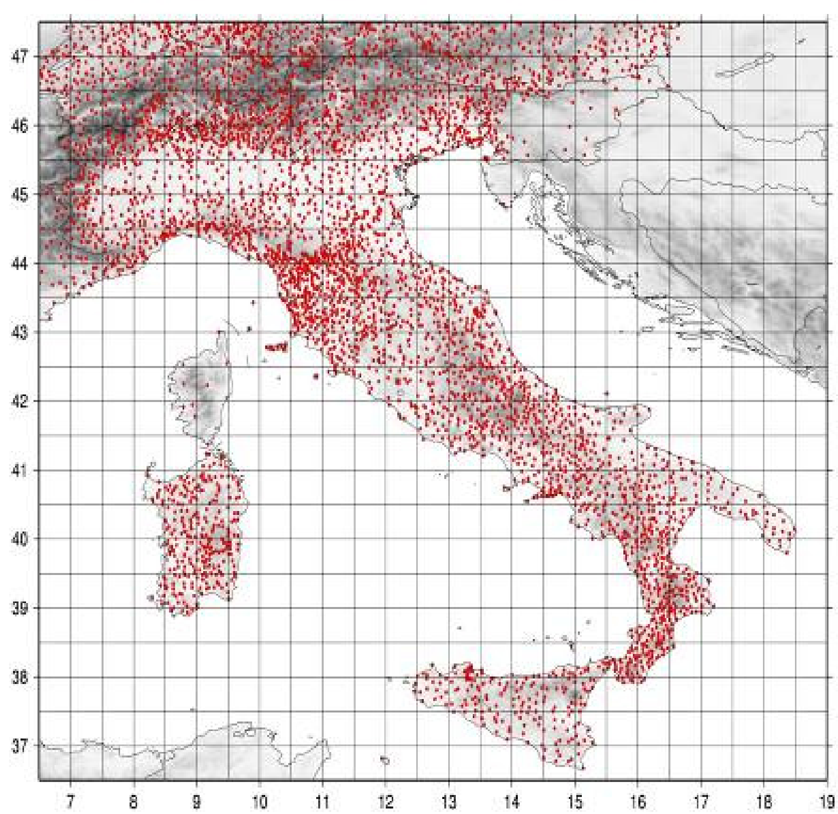

Fig.129 1961-1990 precipitation distribution for Italy and surrounding regions

The precipitation data density is approximately 1/76km². Thus, the mean distance between two stations is approximately 8.3 km. If we compare such values with other precipitation datasets, we find that, except for some small countries in northern Europe (e.g., *Frich et al. (1997)* obtained 1/44km² for Denmark), our density is generally higher than global databases. *New et al. (2002)* obtained a precipitation record density of 1/5,490km² for the Globe. *Daly et al. (2009)* obtained 1/741km² for the conterminous USA. *Tveito et al. (2001)* obtained 1/1,596km². *Goodale et al. (1998)* obtained 1/88km² for Ireland and so on.

The vertical distribution of station records is a critical task because precipitations are strongly influenced by the orography. Even though the update of the secular database introduced new high-elevation stations, their density over 2,500 m is still not completely satisfactory.

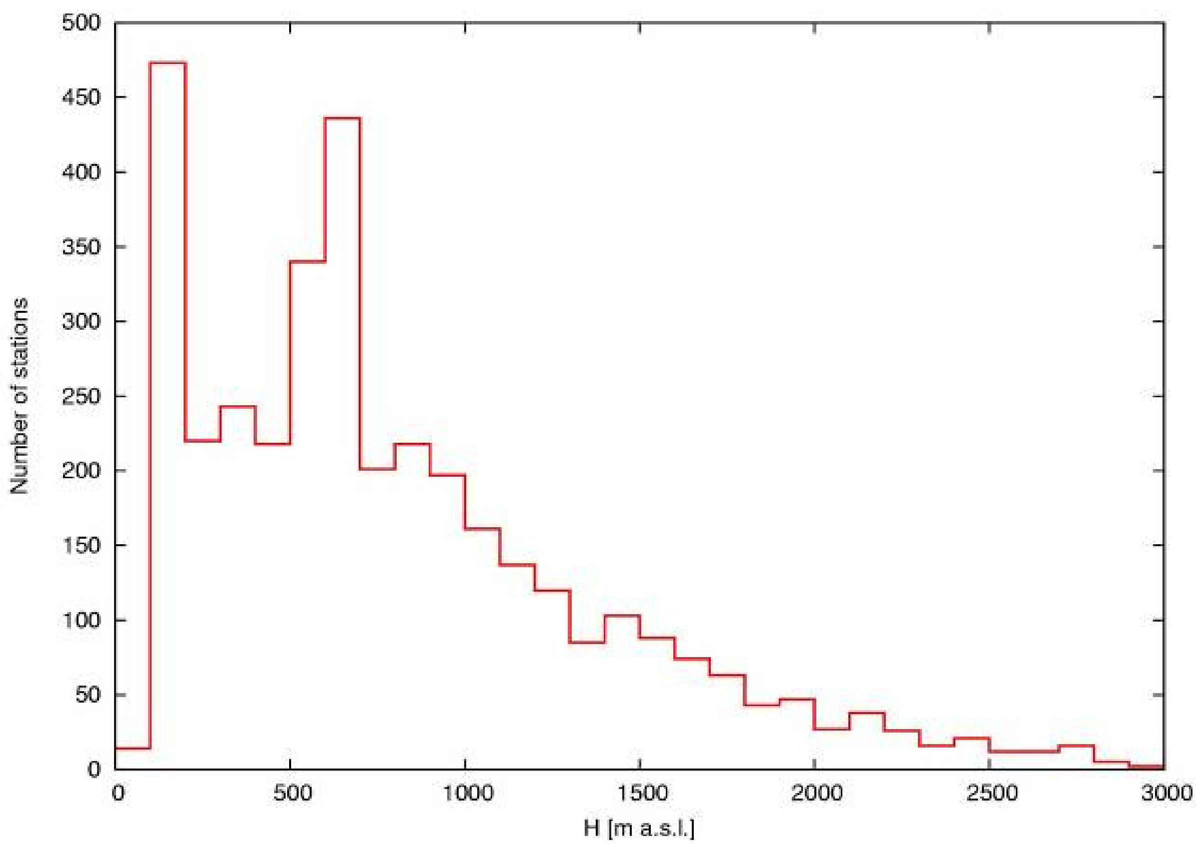

Fig.130 Precipitation station distribution for northern Italy (Brunetti et al., 2009c)

In fig. 130, we can see that, even for northern Italy, i.e. the area with the most high-elevation stations number for Italy, the number of stations over 2,500 m is very low. Thus in the future we plan to collect and digitalize data from the snow plus rain gauges totals that can be found in the Hydrological Service Annals.

5.2 Data analysis and 1961-1990 precipitation models for Italy

5.2.1 *PRISM* model: motivations of the choice

Dealing with precipitation, we based our hypotheses on some assumptions. Precipitation climatologies are strictly linked to physiographical features of the Earth's surface and this allows the integration of the information contained in the meteorological records with the one arising from a hi-res digital elevation model. The link between precipitation and such physiographic variables should be studied at a spatial scale which leads to a good compromise between the smallness of the area and a reasonable number of stations that describes the climatic signal. The leading independent variable should be elevation.

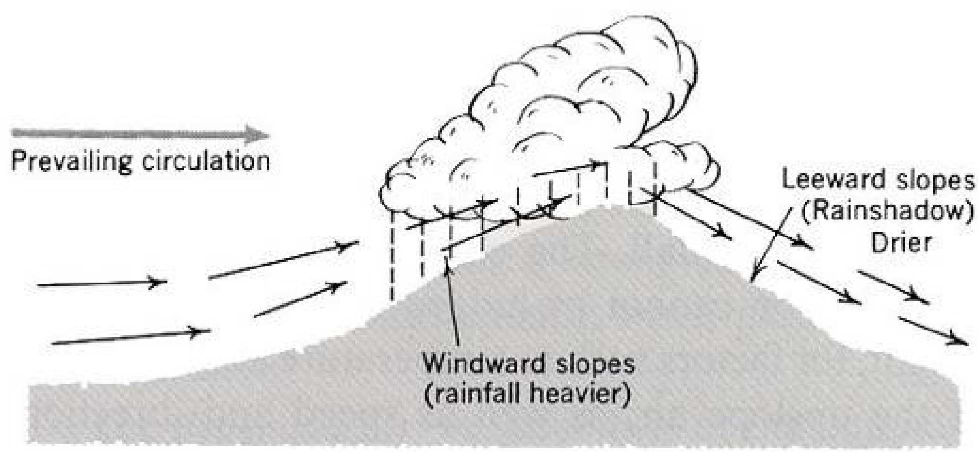

Fig.131 Windward slopes are subjected to heavier rainfalls than leeward slopes (Spinoni et al., 2009)

Furthermore, tall mountain ridges as the Alps and the Apennines greatly modify the atmospheric circulation. The spatial distribution of precipitations is strongly influenced by orography. In fact, see fig. 131, windward slopes are subjected to heavier rainfalls than leeward slopes. Thus, slope steepness and aspect are important predictors for precipitation models.

According to these considerations, we chose a precipitation versus elevation weighted linear regression model; such a model, usually called *PRISM*, makes use of local regressions of the independent variable (i.e. precipitation) versus the first deterministic variable (i.e. elevation) with weights that depend on secondary variables.

As we can see in the next paragraphs, *PRISM* evaluates a *LR* (precipitation vs. elevation) for each grid cell, just considering the surrounding stations or the most topographically similar stations. In particular, the *LR* are *WLR* (weighted linear regressions) because *PRISM* assigns to each cell a precipitation value that depends on the real measured values in the surroundings, used in the assignment with weights that depend on raster variables.

Such a methodology, with slight modifications, was already used by *Daly et al. (1994, 2002, 2006, 2009)* for USA, Puerto Rico, China and Canada and by *Schwarb (2000)* for northern Italy and central Europe. It was proven to be suitable for regions with complex orography. Of course, every *PRISM* application is based on different weights.

5.2.2 Step I: weighted local *LR* (precipitation versus elevation)

• Elevation grid: 5x5 smoothed *DEM* from *USGS GTOPO30*

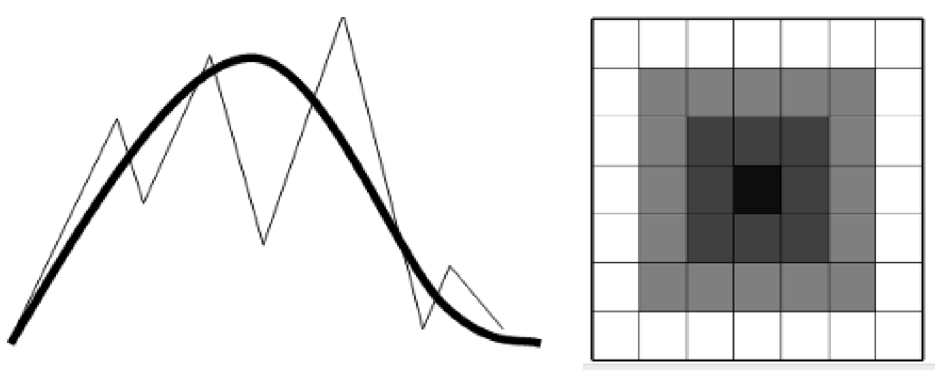

Fig.132-133 A schematic smoothing of a mountain profile and the 5x5 cells area used for smoothing

For the precipitation model, we assigned to each station the elevation value of the nearest *DEM* grid cell and we used these elevation values in *LR* and weights. Thus we preferred a smoothed version of the *DEM*, in order to avoid misleading high discrepancies between the elevation of the grid cells and the elevation of the stations.

We opted for a <u>5 x 5 grid cells scheme to smooth *DEM*</u>, that is:

$$h(x, y) = \frac{\displaystyle\sum_{i=-k}^{k}\sum_{j=-k}^{k}\frac{h(x+i, y+j)}{(1+\max(|i|,|j|))}}{\displaystyle\sum_{i=-k}^{k}\sum_{j=-k}^{k}\frac{1}{(1+\max(|i|,|j))|}} \qquad \textbf{(109)}$$

Where *h(x,y)* is the elevation of a grid cell, *i* and *j* are the pivots related to the surrounding cells (the *DEM* is in a matrix file format); *k* = 2 in this smoothing scheme.

Such a smoothing was weighted. It was not the 25 km² elevation average but the smoothing process which gave the maximum weight to the central grid cell and decreasing (with distance from the central cell) weights to other cells. This smoothing was performed in order to consider a spatial resolution closer to the actual scale at which the interactions of atmospheric circulation with orography occur *(Brunetti et al., 2009c)*. Such a 25 km² scale is more realistic than a 1 km² scale.

In order to grid the precipitation data we used this smoothed elevation raster in the governing equation of the *PRISM* model.

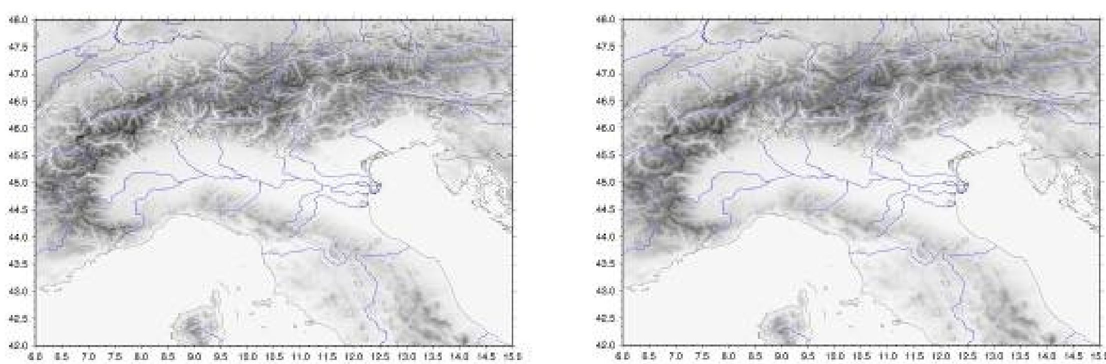

Fig.134-135 Original DEM and 5x5 smoothed DEM for northern and central Italy

• <u>Governing equation: precipitation vs. elevation</u>

The precipitation versus elevation regression is performed considering the closest 15 stations to the grid point and by means of weighted *LR* of precipitation versus elevation.

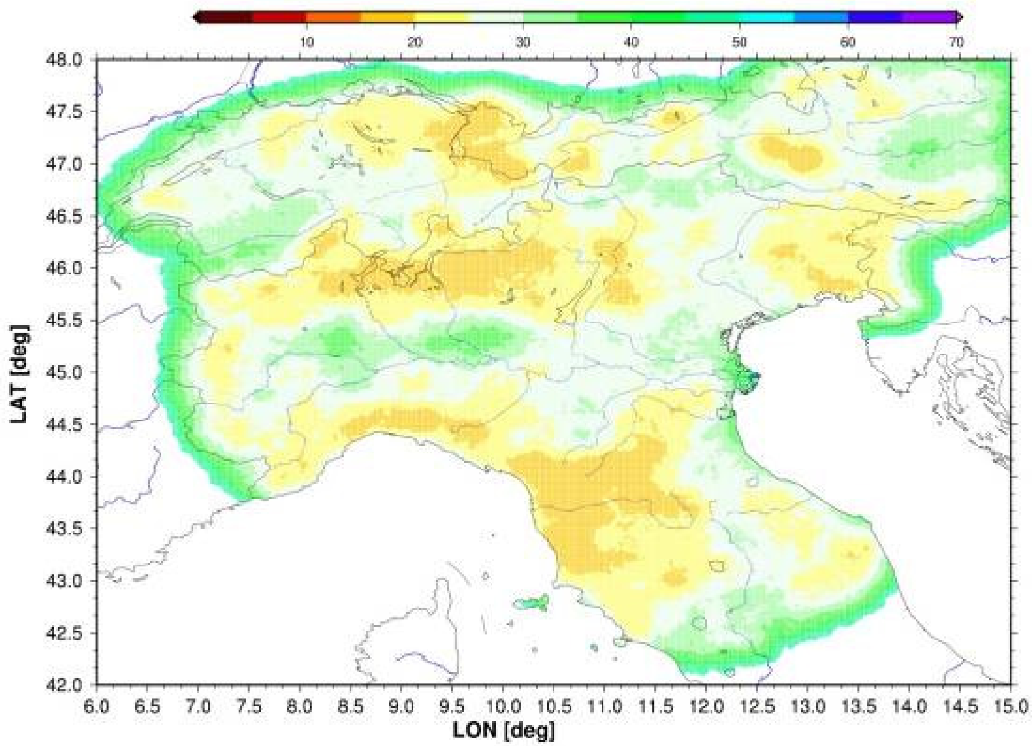

Fig.136 The search distance radius (in km) necessary to find 15 stations in northern and central Italy

First, we set up a search radius of 10 km in order to find 15 surrounding stations, if the number is inferior, we iteratively incremented the search radius by 5 km until 15 stations were found. If 15 stations were not found with a search radius of 50 km, the grid cell was not modelled, but with our dataset this never occurred for Italy. As we see in the next paragraphs, each station was assigned the closest grid cell's 5 x 5 smoothed raster values of sea distance from the coast, aspect, elevation, slope, co-ordinates; such values were used to give weights.

For any grid cell, the precipitation monthly value *p(x,y,)* was calculated as in *Brunetti et al. (2009c)*:

$$p(x, y) = a(x, y) + b(x, y) \cdot h(x, y) \quad \textbf{(109)}$$

Where *h(x,y)* is the grid cell elevation and *a, b* are the local coefficients of the weighted *LR* of precipitation versus elevation. The maximum *h(x,y)* was set up to 2,500 m because the station density over 2,500 m is not sufficient to perform unbiased estimations.

During the weighting procedure, we performed a sort of local jack-knife. We removed the station, out of the 15 selected, that caused the maximum variation in *b(x,y)* (in comparison with the other 14) if this discrepancy was higher than *0.1* mm/m.

Every *i-th* station (out of the 15 nearest ones) was assigned a weight w_i that is the product of the following weighting factors *(Brunetti et al., 2009c)*:

$$w_i = w_i^{rad}(x,y) \cdot w_i^{elev}(x,y) \cdot w_i^{asp}(x,y) \cdot w_i^{slope}(x,y) \cdot w_i^{sea}(x,y) \qquad \textbf{(110)}$$

Where *rad* is referred to the radial weight, *elev* is referred to a further elevation weight, *asp* is referred to the aspect weight, *slope* is referred to the slope weight, *sea* is referred to the sea distance weight.

5.2.3 Step 2: set up of weights

• Elevation weight: raster and formalism

The elevation weight is based on the same 5 x 5 smoothed *DEM* used as principal raster. It is a Gaussian weight that can be written as:

$$w_i^{elev}(x,y) = e^{-\left(\frac{(\Delta h_i(x,y) - \Delta h_{\min})^2}{c_h}\right)} \qquad \textbf{(111)}$$

Where Δh_i is the elevation difference between the *i-th* station and the grid cell under investigation, Δh_{min} is a varying threshold that can be used to better set up the weight, and c_h is a coefficient that regulates the decrease of the weighting factor as:

$$c_h = -\frac{\bar{h}^2}{\ln(0.5)} \qquad \bar{h} = h(x,y) + 100m \qquad \textbf{(112)}$$

Where the coefficient c_h was chosen in order to have a stronger decrease to the foothills and a weaker one at higher elevations.

• Radial weight: raster and formalism

The radial weight is based on the original *USGS GTOPO30 DEM* which provided the geographical coordinates used to calculate the radial distances between stations and grid cells and it is a Gaussian weight that can be written as:

$$w_i^{rad}(x, y) = e^{-\left(\frac{(d_i(x,y))^2}{c_d}\right)} \qquad \textbf{(113)}$$

Where $d_i(x,y)$ is referred to distances between a grid cell with a station and the modelled grid cell and c_d is a coefficient that regulates the decrease of the weighting factor as:

$$c_d = -\frac{\overline{d}^2}{\ln(0.5)} \qquad \overline{d} = 25km \qquad \textbf{(114)}$$

That leads to $w^{rad} = 0.5$ when a station is located at 25 km from the modelled grid cell.

In this case, as for any other weight described in this chapter, x refers to longitude and y to latitude.

• Slope weight: raster and formalism

The slope weight is based on the 5 x 5 smoothed *DEM* used as principal raster and it is a Gaussian weight that can be written as:

$$w_i^{slope}(x, y) = e^{-\left(\frac{(\Delta Sl(x,y))^2}{c_{sl}}\right)} \qquad \textbf{(115)}$$

where ΔSl is referred to slope differences and c_{sl} is a coefficient that regulates the decrease of the weighting factor as:

$$c_{sl} = -\frac{\overline{\Delta Sl}^2}{\ln(0.5)} \qquad \overline{\Delta Sl} = 0.25 \qquad \textbf{(116)}$$

That leads to $w^{slope} = 0.5$ when a grid cell with a station has a slope difference of 250 m/km, in absolute values, from the modelled grid cell.

The slope parameter was calculated as:

$$Sl = \left|\vec{\nabla} z\right| = \left|\left(\frac{\partial z}{\partial x}\cdot\hat{i}\right) + \left(\frac{\partial z}{\partial y}\cdot\hat{j}\right)\right| = \sqrt{\left(\frac{\partial z}{\partial x}\right)^2 + \left(\frac{\partial z}{\partial y}\right)^2} \tag{117}$$

Where z is the elevation of the *5 x 5* smoothed *DEM*.

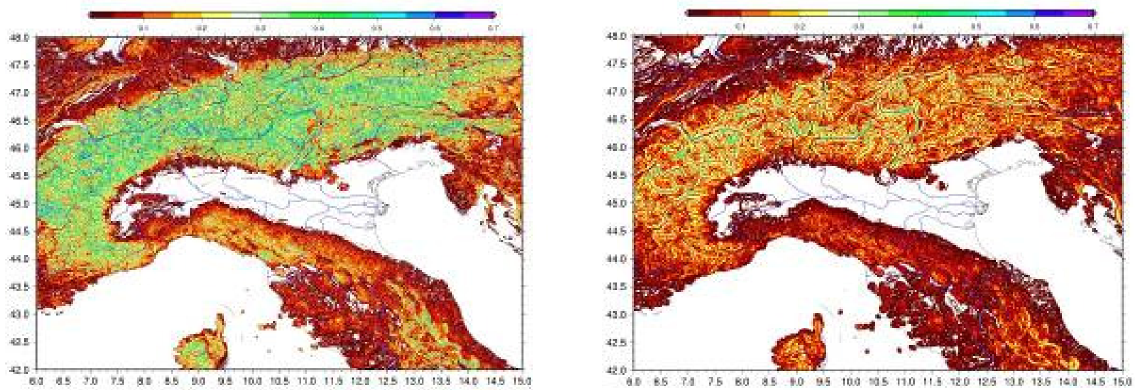

Fig.137-138 Slope raster from original DEM and from 5x5 smoothed DEM for northern and central Italy

• Aspect weight: raster and formalism

The aspect weight is based on the 5 x 5 smoothed *DEM* used as principal raster and it is a Gaussian weight that can be written as:

$$w_i^{asp}(x, y) = e^{-\left(\frac{(\Delta asp(x,y))^2}{c_{asp}}\right)} \tag{118}$$

$$\Delta asp = \begin{cases} \left|asp(x, y) - asp_i\right| & if \quad \Delta asp < 2\pi \\ 2\pi - \left|asp(x, y) - asp_i\right| & if \quad \Delta asp > 2\pi \end{cases} \tag{119}$$

Where *asp(x,y)* is related to the modelled grid cell and asp_i to the grid cells used as weighting station-grid cells, Δasp is referred to aspect differences and c_{asp} is a coefficient that regulates the decrease of the weighting factor as:

$$c_{asp} = -\frac{\overline{\Delta asp}^{2}}{\ln(0.5)} \qquad \overline{\Delta asp} = \pi \tag{120}$$

That leads to $w^{asp} = 0.5$ when a grid cell with a station has an aspect difference of π from the modelled grid cell.

The aspect parameter was calculated as:

$$asp(x,y) = \begin{cases} \arccos\left(\dfrac{\frac{\partial z}{\partial y}}{\left|\vec{\nabla} z\right|}\right) & if \quad \left(\dfrac{\partial z}{\partial y}\right) > 0 \\ 2\pi - \arccos\left(\dfrac{\frac{\partial z}{\partial y}}{\left|\vec{\nabla} z\right|}\right) & if \quad \left(\dfrac{\partial z}{\partial y}\right) < 0 \end{cases} \tag{121}$$

Where *z* is the elevation of the 5 x 5 smoothed *DEM*.

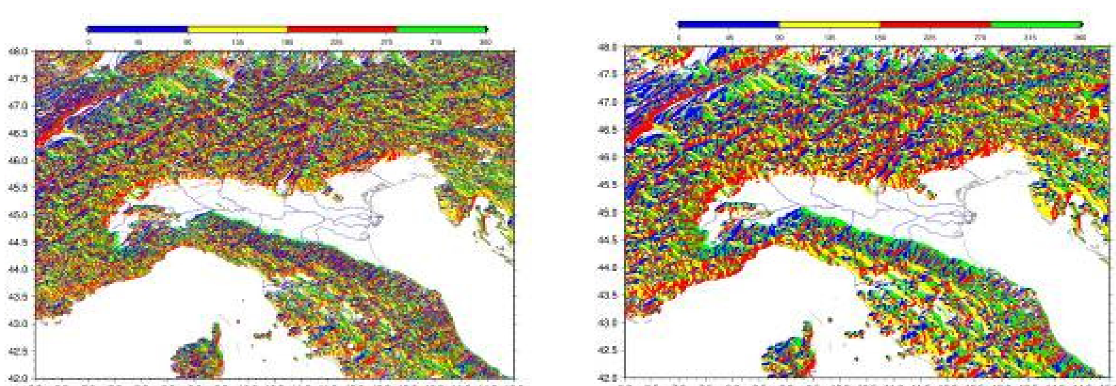

Fig.139-140 Aspect raster from original DEM and from 5x5 smoothed DEM for northern and central Italy

• Sea distance weight: raster and formalism

The sea distance weight is based on the sea distance raster used in temperature models (and described in Chapter 4.3.3) and it is a Gaussian weight that can be written as:

$$w_i^{sea}(x,y) = \begin{cases} e^{-\left(\frac{\Delta sea_i^2(x,y)}{c_{sea}}\right)} & if \quad sea(x,y) < 25km \\ 1 & if \quad sea(x,y) > 25km \end{cases} \qquad \textbf{(122)}$$

Where *Δsea(x,y)* is related to sea distance differences between a grid cell with a station and a modelled grid cell, *sea(x,y)* is the sea distance value of a grid cell (obtained from the sea distance grid described in Chapter 4.3.3), and c_{sea} is a coefficient that regulates the decrease of the weighting factor as:

$$c_{asp} = -\frac{\overline{\Delta sea}^2}{\ln(0.5)} \qquad \overline{\Delta sea} = 10km \qquad \textbf{(123)}$$

That leads to $w^{sea} = 0.5$ when a grid cell with a station has a sea distance difference of *10* km from the modelled grid cell.

• Choice of weights: a study case

In order to better understand the importance of the choice of weights, let us show what happens to 2 contiguous grid points with different slope and aspect values.

Grid point 1

Coordinates: 10.00 °E ; 44.47° N

Smoothed elevation: 1,139 m (Not smoothed elevation: 1,234 m)

Distance from the sea: 43.77 km

Smoothed slope: 0.042 (i.e. 42 m/km)

Smoothed aspect: SE-facing

Grid point 2

Coordinates: 10.00 °E ; 44.48° N

Smoothed elevation: 1,136 m (Not smoothed elevation: 1,187 m)

Distance from the sea: 44.84 km

Smoothed slope: 0.025 (i.e. 25 m/km)

Smoothed aspect: NW-facing

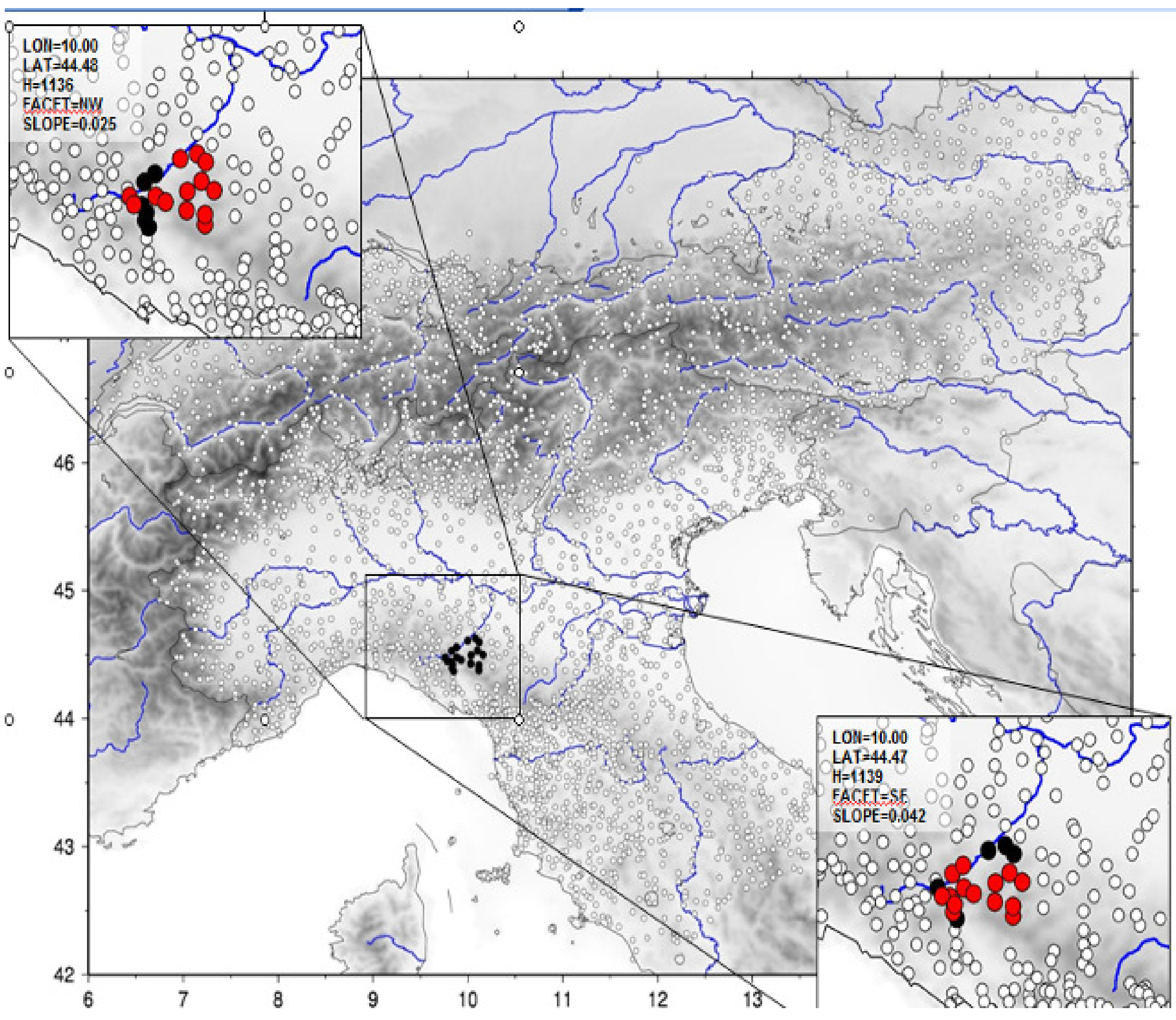

Fig.141 Stations used to model precipitation vs. elevation for Grid Point 1 (right) and Grid Point 2 (left)

The 2 grid points significantly differ only on aspect (facet) and slope values; such discrepancies cause a different choice of the 15 surrounding stations chosen (red dots) to model precipitation versus elevation regression for the grid points themselves by weighting parameters. For Grid Point 1 we can see in fig. 141 that 14 stations are used (one rejected by the local jack-knifing procedure described in chapter 5.2.1). For Grid Point 2, 13 stations are used (2 stations are rejected because they both produce highest variation in the evaluation of $b(x,y)$ coefficient in precipitation vs. elevation *LR*); 9 stations are used for both considered grid points shown in fig. 141. The other 4 (or 5) stations used for the studied cells are used solely by one or another local modelling procedure.

The final results are not very different among themselves, because the precipitation vs. elevation *LR* is the leading modelling part (this reflects a physical behaviour of atmospheric circulation), but the regression equations are different, as we show in fig. 142-143.

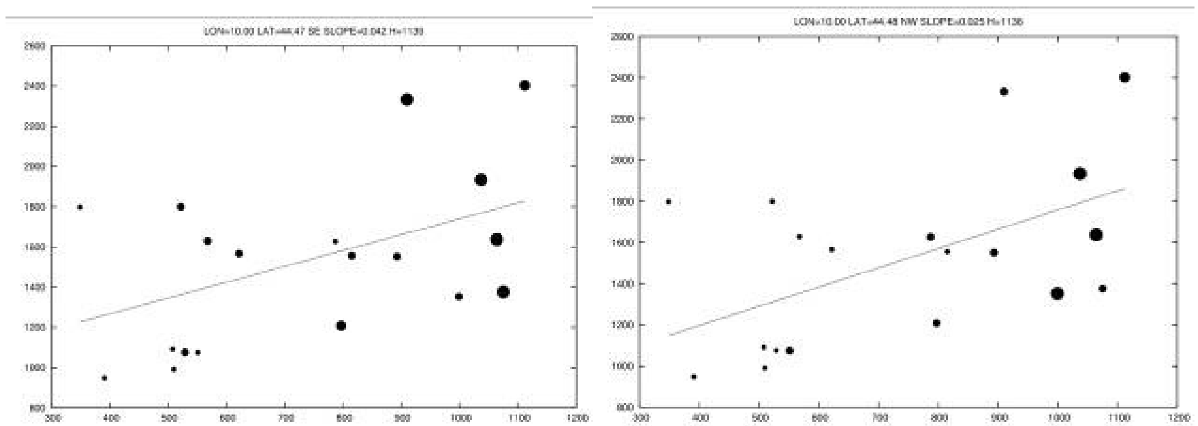

Fig.142-143 Local LR for Grid Point 1 (left) and Grid Point 2 (right)

In this case, for Grid Point 1, whose elevation is 1,139 m, the local *LR* predicts a yearly cumulated precipitation value of 1,843 mm. Whilst for Grid Point 2, whose elevation is 1,136 m, quite identical to Grid Point 1, the local *LR* predicts a yearly cumulated precipitation value of 1,819 mm. The relative difference is approximately 2%, but it can be up to 15-20% in the Alps.

5.2.4 Temporary high-resolution 1961-1990 precipitation maps for Italy

Precipitation climatologies for the whole of Italy are still under construction. We show provisional results because further updates and refinements of the database are planned for the next months and this could lead to better estimations of the precipitation monthly totals for Italy. Because of these considerations, we show the maps of January, July and yearly total 1961-1990 high-resolution precipitation versus elevation climatologies only; even though the temporary model had already been performed on every month (see the next paragraphs for statistical errors monthly parameters).

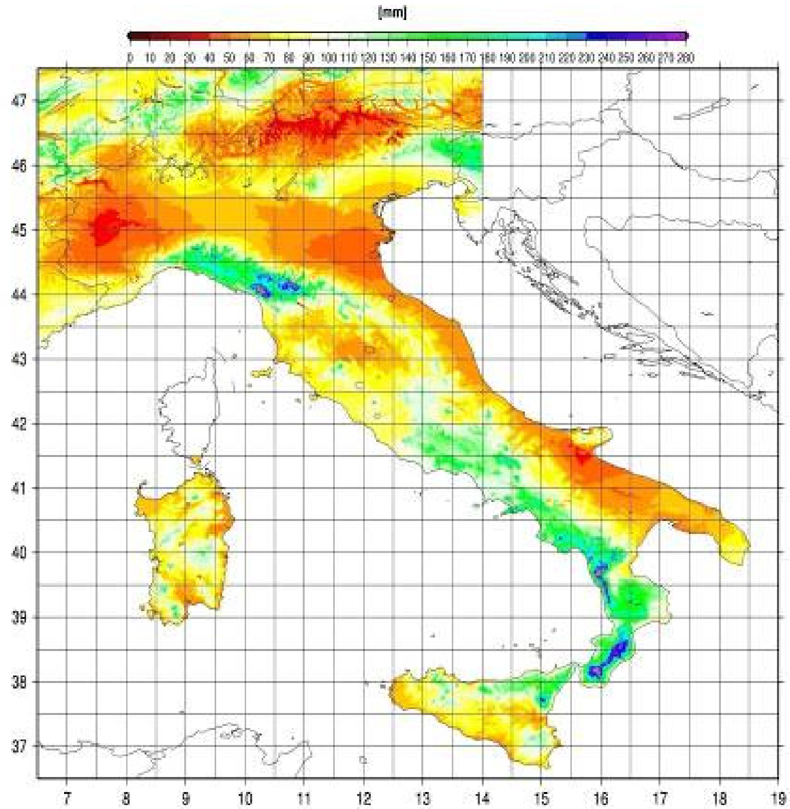

Fig.144 January 1961-1990 total precipitation (in mm) map

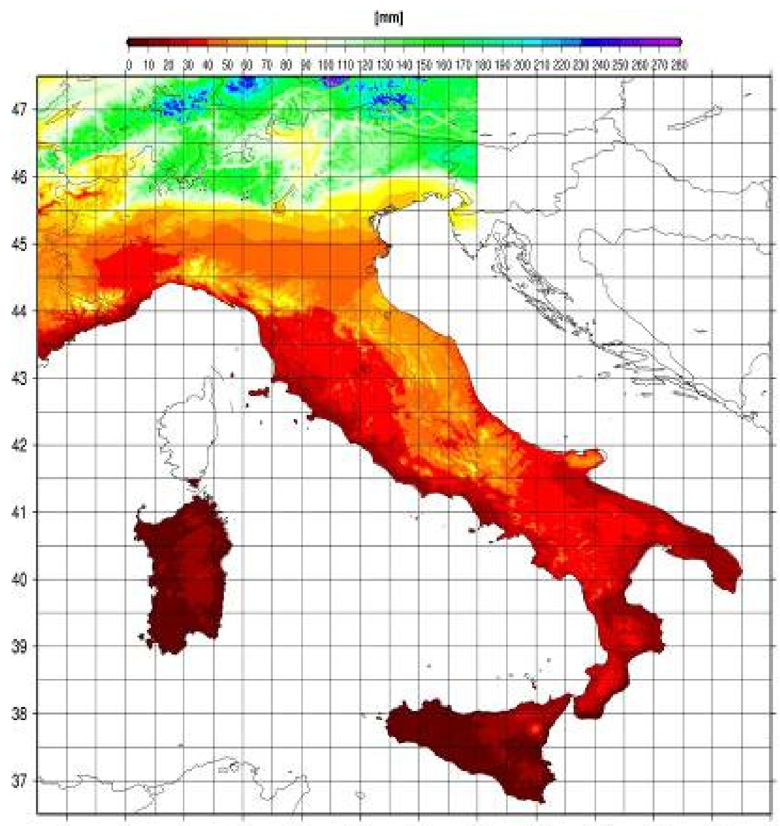

Fig.145 July 1961-1990 total precipitation (in mm) map

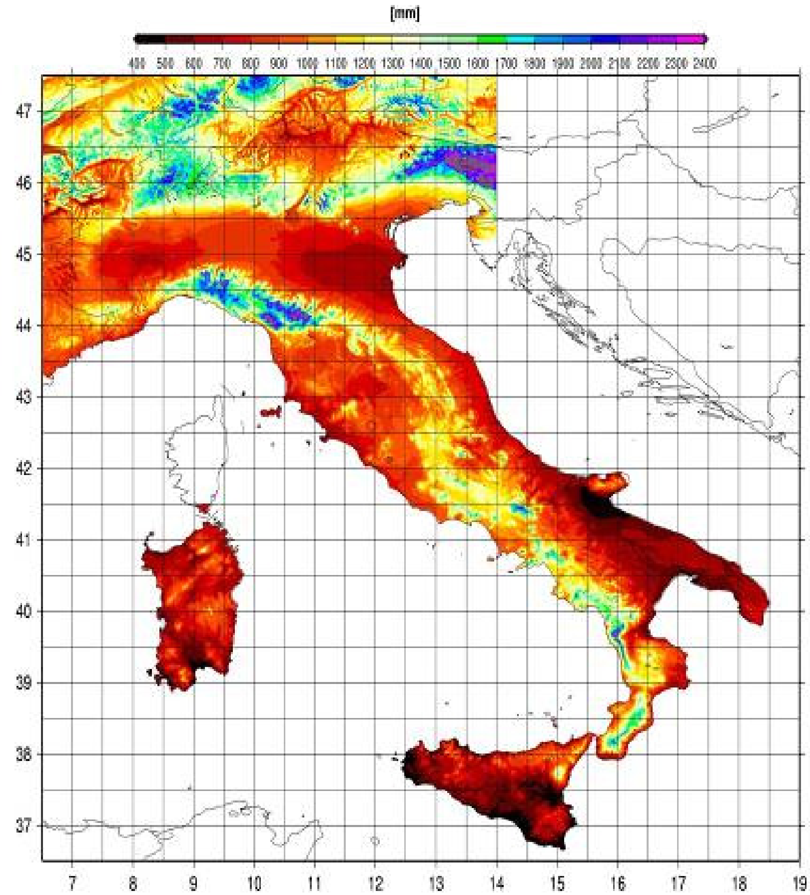

Fig.146 Yearly 1961-1990 total precipitation (in mm) map

As we can see from fig. 146 the maximum yearly total precipitation values for Italy are in the Friuli area and in the Apennines between Liguria and Toscana (more than 2,300 mm/year). Whilst the driest regions are the coasts of Sicily, the southern coasts of Sardinia and the northern part of Puglia (less than 500 mm/year).

5.2.5 Validation of the *PRISM* precipitation models

• Reconstructed vs. observed precipitation values

As "observed values", we mean the 1961-1990 precipitation station data. As "reconstructed data", we mean the precipitation value as predicted by *PRISM* model for the corresponding grid cells.

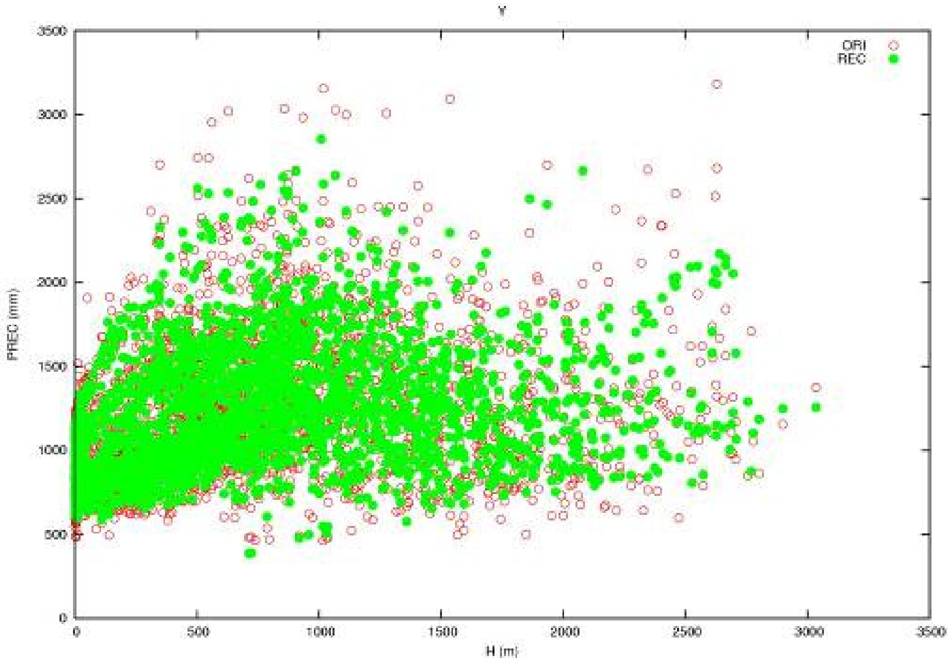

Fig.147 Reconstructed vs. observed yearly total 1961-1990 precipitation values

As we can see in fig. 147, the data modelled by *PRISM* satisfactorily match the observed data in most cases, even if the *LR* shows an intrinsic inaccuracy for high precipitation rates and low precipitation rates at high elevations.

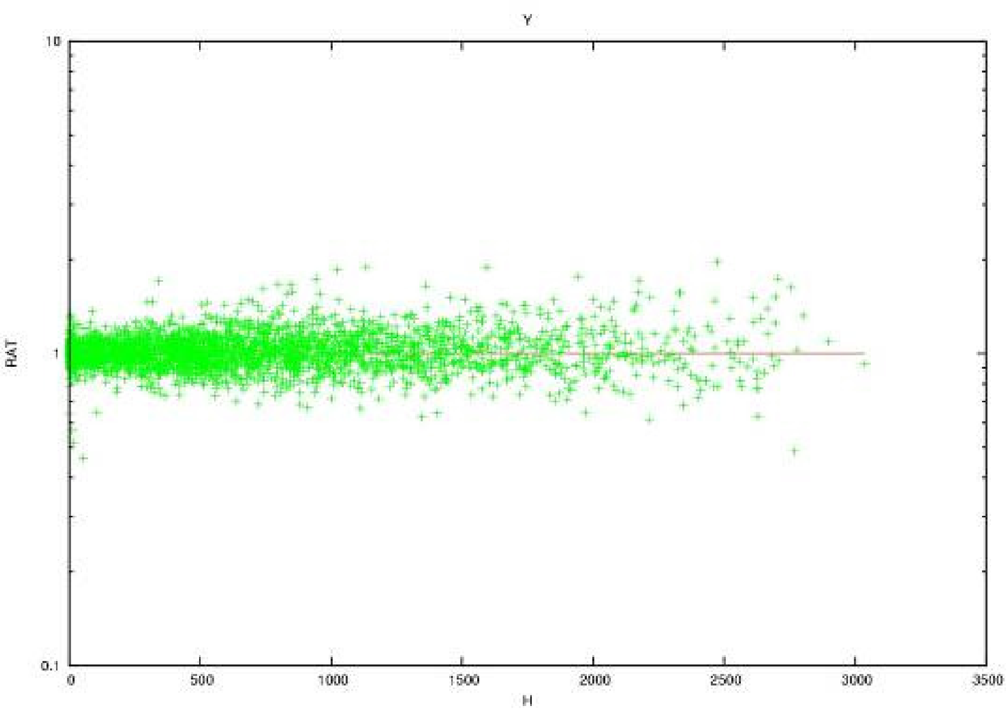

Fig.148 Reconstructed/observed ratio vs. elevation yearly total 1961-1990 precipitation values

In the reconstructed vs. observed precipitation ratio versus elevation (logarithmic scale) plot (see fig. 148), we see that *PRISM* overestimate high-elevation precipitations. This is not only due to the 2,500 m threshold in the *LR* but also because at high elevations, rain often turns into snow (especially in winter) and it can bias the measured values.

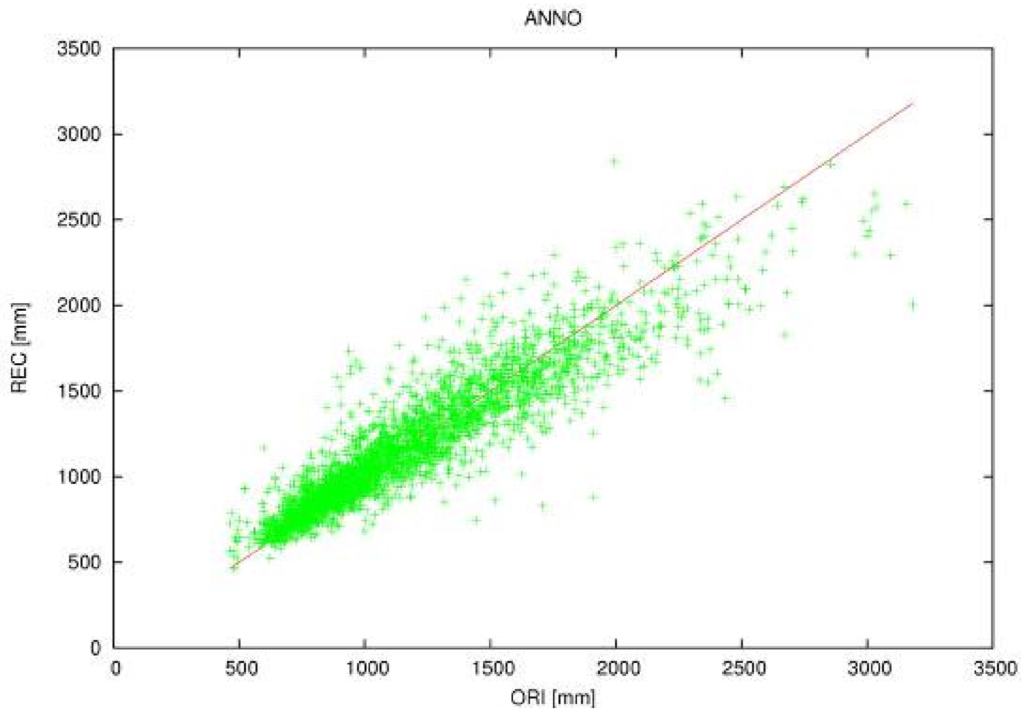

Fig.149 Reconstructed vs. observed yearly total 1961-1990 precipitation values

PRISM satisfactorily predicts precipitation at low and medium rates, but it seems to underestimate the yearly precipitation totals over 2,000 mm.

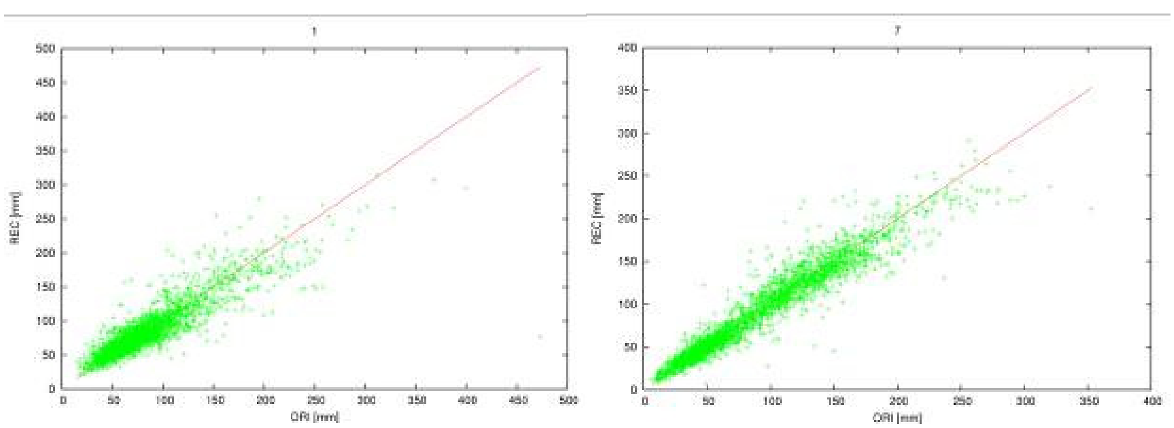

Fig.150-151 Reconstructed vs. observed January (left) and July (right) total 1961-1990 precipitation values

In January, the precipitation totals are better reconstructed than in July.

• Jack-knife validation and statistical parameters (R^2, *ME*, *MAE*, *RMSE*)

In order to calculate the statistical parameters of the precipitation *PRISM* model, we performed a jack-knife validation. We removed one station from the dataset, we reconstructed the precipitation monthly values for the grid cell corresponding to the removed station by means of *PRISM* (whose weights did not depend on the removed data), and then we calculated the statistical parameters for the modelled grid cell. In the end, after the complete jack-knife, we averaged the statistical parameters over the whole dataset as in *Brunetti et al. (2009c)*.

We obtained:

Month	MAE	ME	MAER [%]	MER [%]	RMSE	R^2
1	11.9	0.2	13.9	3.6	17.7	0.91
2	11.0	0.1	13.7	3.4	16.1	0.89
3	11.1	0.0	12.9	3.0	16.2	0.88
4	11.2	0.0	12.5	2.9	16.5	0.92
5	9.8	-0.1	11.1	2.2	15.3	0.95
6	8.7	-0.1	12.1	2.7	13.4	0.97
7	7.7	-0.2	15.2	3.9	12.2	0.97
8	8.7	-0.1	12.4	2.6	13.2	0.97
9	9.1	0.1	11.1	2.3	13.6	0.93
10	11.9	0.3	11.1	2.4	17.1	0.92
11	13.7	0.1	11.7	2.6	20.2	0.91
12	12.6	0.1	13.1	3.1	18.9	0.92
TOT	107.4	0.2	9.9	1.9	155.1	0.93
AVG	10.6	0.0	12.6	2.9	15.9	0.93

Tab. 37 Statistical parameters calculated with a jack-knife procedure for 1961-1990 precipitation climatologies

ME is virtually null for every month, thus the *PRISM* model used for 1961-1990 precipitation climatologies for Italy is unbiased. *MAE* is very low; 5 months out of 12 show a *MAE* less than 10 mm. The total yearly value is 107.4 mm and the average monthly value is 12.6. That is, the relative *MAE* is under 15% in every month except of July; *RMSE* exceeds 20 mm only in November; the explained variance is very high, 97% in summer, approximately 91% in winter and 93% for the yearly total and average values.

5.3 Other precipitation models realized during the PhD project

Within the framework of this PhD project, we contributed to realising other precipitation models for some Italian regions.

• Northern and Central Italy 1961-1990 precipitation models

For northern and central Italy, the precipitation dataset is made of approximately 3,200 1961-1990 records, the model used is a similar to *PRISM* used for the whole Italy. Precipitation climatologies can be found in *Brunetti et al. (2009c)*.

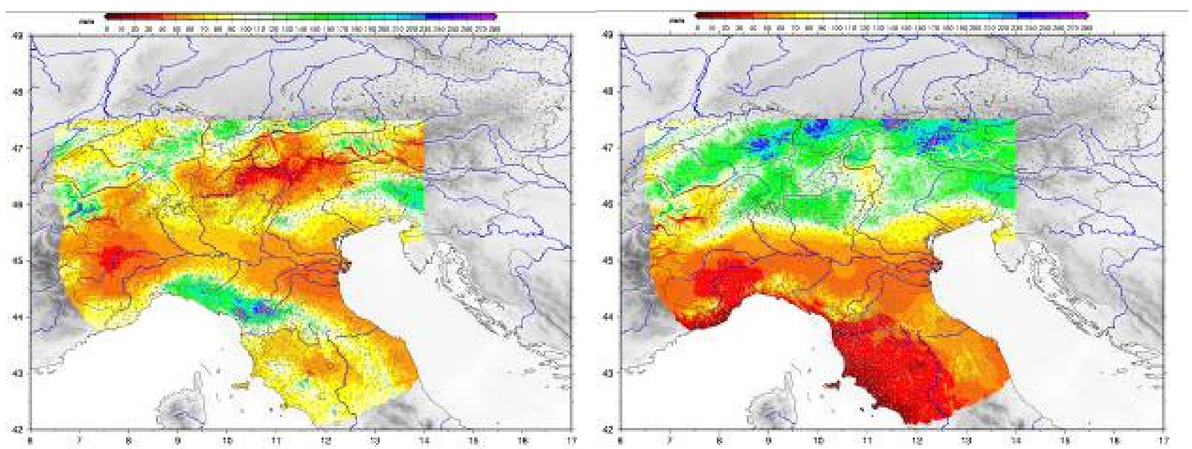

Fig.152-153 January and July 1961-1990 total precipitation (in mm) map for northern and central Italy

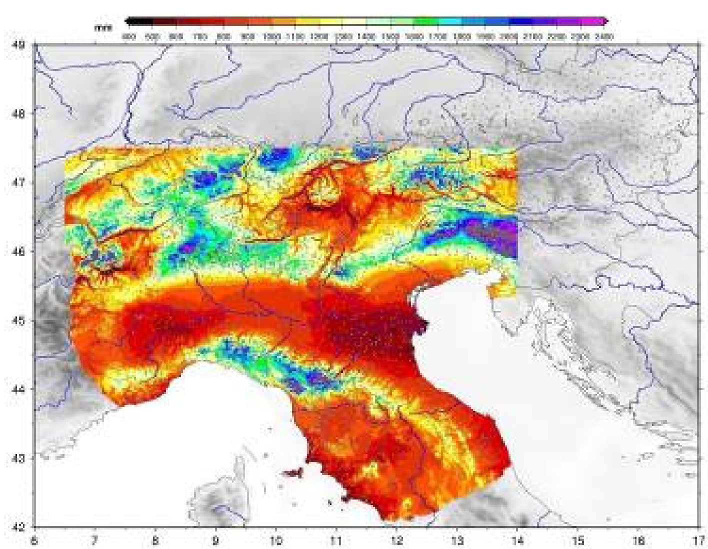

Fig.154 Yearly 1961-1990 total precipitation (in mm) map for northern and central Italy

If we compare the statistical parameters, we find that the average monthly *MAER* value is 12.2%, slightly higher than *MAER* for the whole of Italy, whilst R^2 is slightly lower for northern and central Italy only (92% versus 93%).

• North-Eastern Italy 1961-1990 precipitation models

For north-eastern Italy, the model used is similar to the *PRISM* used for the whole of Italy. The precipitation climatologies can be found in *Brunetti et al. (2010)*.

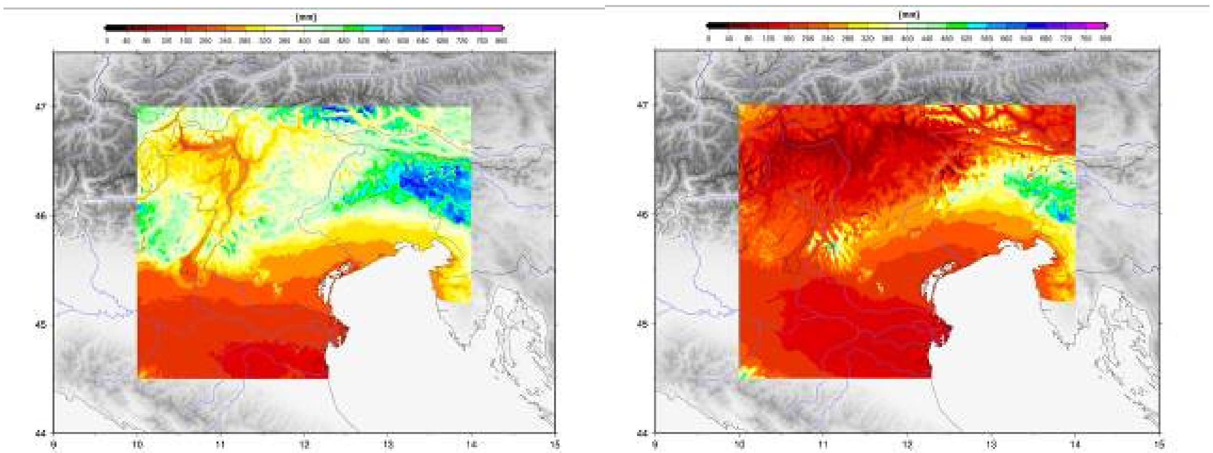

Fig.155-156 Winter and Summer 1961-1990 total precipitation (in mm) map for north-eastern Italy

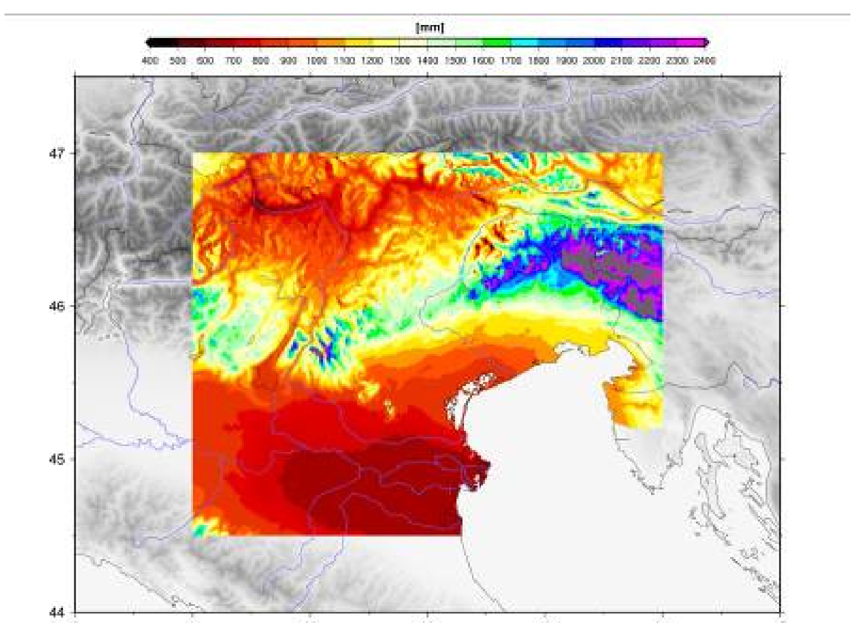

Fig.157 Yearly 1961-1990 total precipitation (in mm) map for north-eastern