# GRASS UTILIZATION TO REALIZE SPATIAL DISTRIBUTION OF CROPS WATER REQUIREMENTS IN AN ALPINE VALLEY

Valentina PORTOLAN (*), Marco CIAMPA (**)

(*) Vimercate (MI), 039−6851367, valentina.portolan@libero.it
(**) ISMAA − Unità di Agrometeorologia, via Mach 2, S.Michele a/A, (TN), 0461−615376, ciampa@ismaa.it

**Abstract**

Aiming at an estimation of crop daily water requirements, a spatial interpolation of temperature, potential evapotranspiration (PET) and precipitation has been performed in **GRASS** frame. The study as been carried out using meteorological data obtained from 12 stations and 5 rain gauges in an alpine valley for the period 1994−1998. The spatial interpolation method yielding the least mean error for daily temperatures (about 1°C) is the inverse−squared−distance, performed after a homogenization of values, all carried at a standard level of 0 m, making use of a second degree equation for modelling the vertical profile. For the interpolation of precipitation, the inverse−squared−distance method wase implemented with a mean error for the rainy days of about 30−60%. The computation of mean errors was carried out by means of crossvalidation. The implementation of Hargreaves' equation in **GRASS** provided the spatial distribution of daily PET. The result of interpolation were used for a agricultural model: the computation of crop daily water requirements.

## 1. The area of investigation

The study was carried out on the Non Valley, a 476 km$^2$ wide mountainous area in Trentino, Italy. The valley is the best known apple growing area in Italy. It is a wide valley, N − S oriented, run through by the Noce River, a right tributary of Adige. The valley itself displays a big span of elevations, going from the valley bottom of its lower part (about 250 m) to the summits of the mountains surrounding the upper part, with peaks reaching 2600 m. A geographical representation of the area is given in fig. 1. In the **GRASS** implementation the territory was represented by means of a digital elevation model (DEM) by a 10 m square regular grid.

## 2. The meteorological data set

All data came from the following networks of meteorological stations (see fig. 2):

1. temperature: both max and min daily values were taken into account from 12 stations scattered in the area, for a 4 year period (1995 − '98);
2. rainfalls: the same 12 stations were used, plus 5 more farm raingauges, for the same 4 year period 1995 − '98.

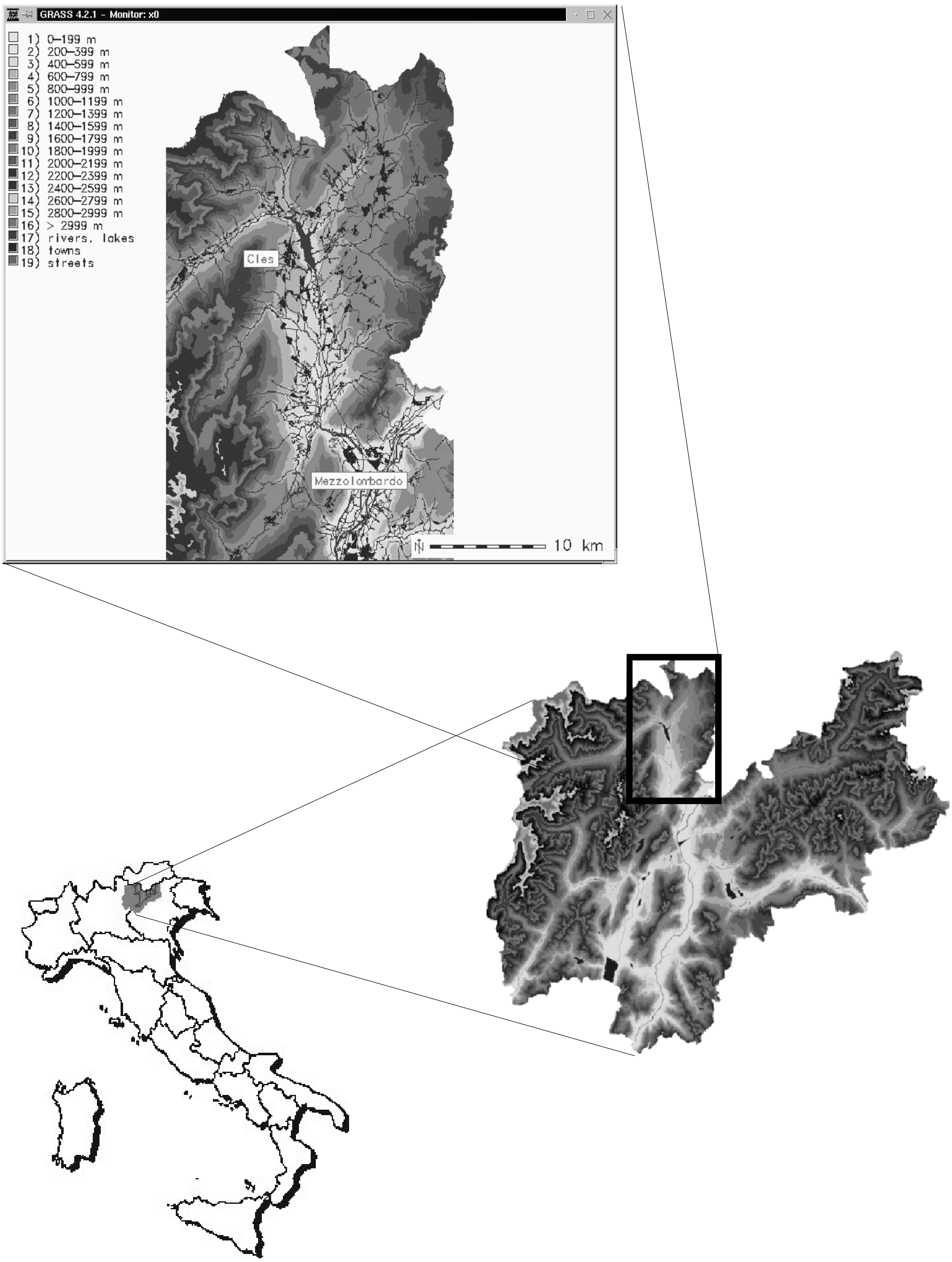


*Figure 1: A geographical representation of the area.*

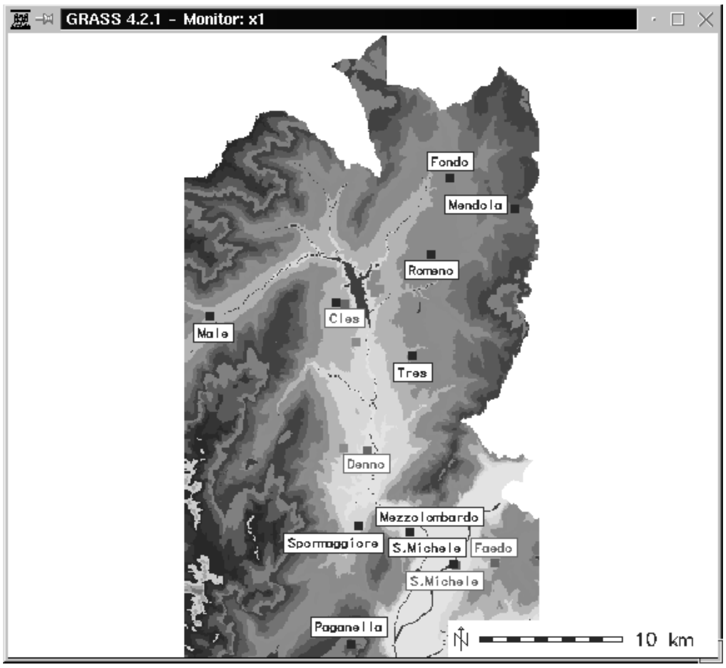


*Figure 2: Locations of meteorological stations and farm raingauges.*

**3. Interpolation procedures**

A spatial interpolation was applied to the following parameters:

1. maximum and minimum daily temperature;
2. daily precipitation amount;
3. daily potential evapotranspiration;

**3.1 Interpolation of temperatures**

Among all the meteorological parameters taken into account here, temperature displays the highest variability with elevation, even if such a behaviour is not a constant in time and space. The need for dealing with comparable values requires a previous homogenization at a standard elevation, e.g. the sea level as suggested by Dodson, Marks, 1997. Such operation requires the definition of a function for modelling the vertical gradient of the 2 m temperature. The function has to represent a general trend for the vertical structure of 2 m temperature, valid for the whole area (Colombo, 2000).

A good approach has seemed the definition of a unique interpolating curve, expressing a hypothetical vertical trend. In order to model the ground thermal profile, a second degree equation was chosen to fit the measured values, applied to every daily max and min temperatures (Conrad, Pollak, 1950; Robenson, 1995; Pielke 1997). In general, temperature profiles tend to be inverted in winter, due to thermal inversion in the lower areas, located in the valley bottom; in those cases the second degree function performs appreciably better in comparison with a simple linear model; the latter is, on the contrary, very close to the first order function under different conditions, namely when no inversion takes place, and particularly for daily maximum values and in summertime.

For every day in the period and for both minimum and maximum temperatures, a fitting function was found and used for tracing values down to a fictitious standard level of 0 m. Having performed this homogenization of the measured values, the spatial interpolation of the values can be implemented in order to generate an array of fictitious values at the "standard" sea level on the area.

The best performing spatial interpolation methodology proved to be the inverse−squared−distance weighted average (IDW), suitable for its simplicity and low computation charge (Maracchi, Pieri, 1993; Colombo, 2000).

Briefly, the spatial interpolation procedure for minimum and maximum daily temperatures can be resumed like this (fig. 3):

1. fitting of the interpolating second order function to the vertical displacement of values in a Temp. − Height graph;
2. estimation of fictitious temperatures for every measurement point at the "standard" level of 0 m, by applying the interpolating second order curve (item 1) for the lapse rate;
3. spatial interpolation of temperatures estimated at the sea level, by means of a inverse−squared IDW method;
4. inverse application of the experimental vertical profile function for estimating interpolated temperatures for every grid point at the true elevation, according to the DEM.

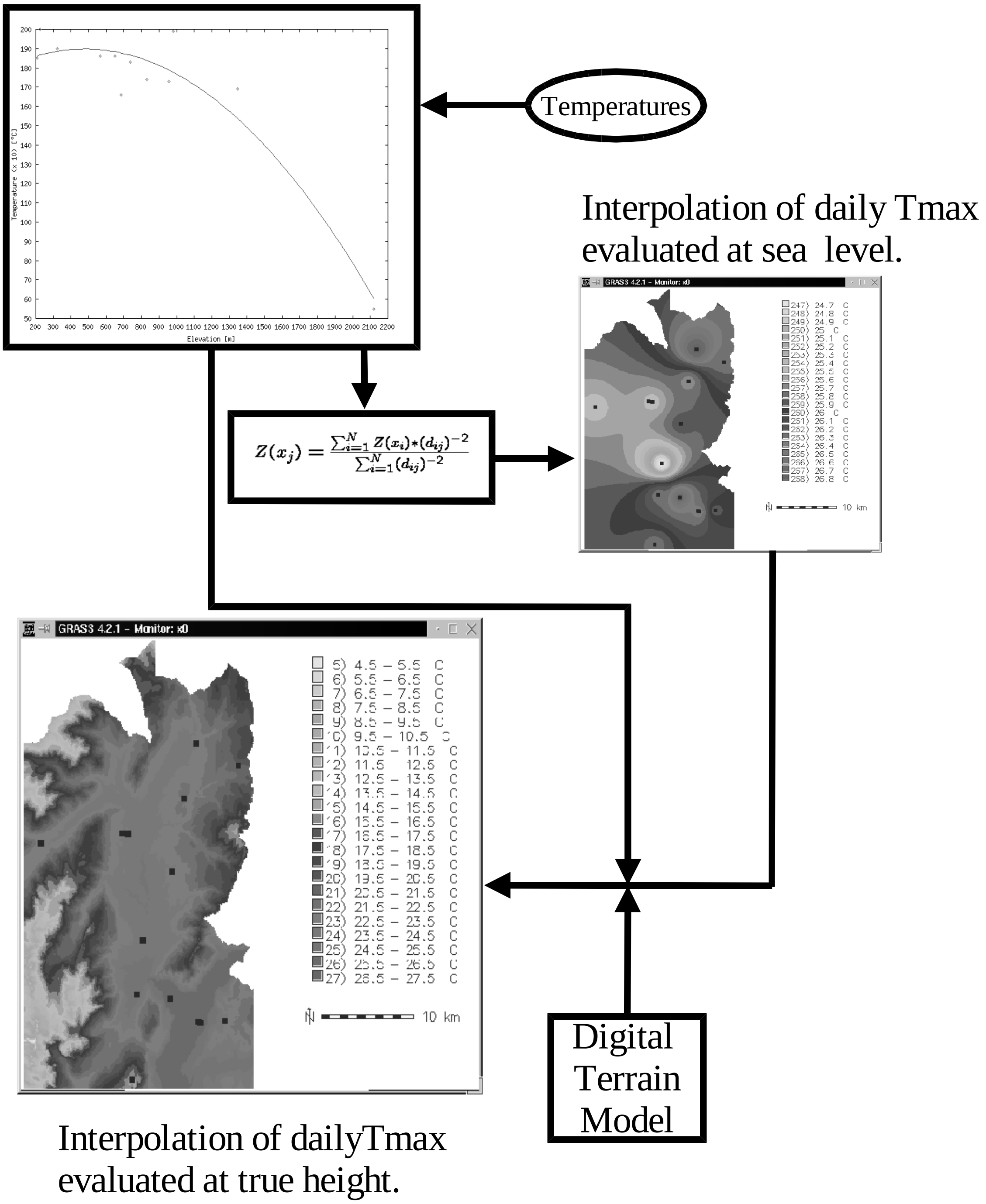


*Figure 3: Spatial interpolation procedure for maximum and minimum daily temperatures.*

### 3.2 Interpolation of precipitation

An enhancement of rainfall with height was not detectable in the data set at the daily scale (Portolan, 2000); in the area under consideration the horizontal variability was found to outweigh the vertical one; this was also due to the displacement of stations on both sides of the valley, introducing inhomogeneities when inferring trends in the precipitation amounts with elevation; at the daily scale, topographic enhancement of precipitation introduces a big variability concealing the general trend of increase of rainfall amounts with elevation. Hence, the spatial interpolation of rainfall was carried out on the rough daily data with no homogenization. Again, the inverse−squared−distance method was implemented to interpolated precipitation.

### 3.3 Interpolation of evapotranspiration

Daily potential evapotranspiration values have been calculated by implementation of the Hargreaves' formula (Battista et al., 1994). This equation allows an estimation of PET on a daily basis with the simple knowledge of minimum and maximum temperature and extra−atmospheric radiation; in this formula the daily range accounts for an indirect estimation of the radiative daily balance. Values of wind speed and sunshine duration were not suitable for use, since an implementation of interpolation procedures of these parameters would have turned out rather unreliable and, above all, the physical measurements would have been too few for an interpolation over a wide area and would not have provided a sound basis for cross−validation. For every grid point and for every day, temperature data were known after spatial interpolation, while solar radiation was calculated from the astronomical position of Earth.

## 4. Evaluation of interpolation errors

Several methods are suitable for estimating interpolation errors. Among these, cross−validation (Tomczac, 1998) is perhaps the best known and employed. By this method the root−mean−square−errors (RMSE) have been evaluated for every interpolation operation, computing RMSE for the 365 days of the years 1995 and 1998.

### 4.1 Temperature

For minimum and maximum temperatures, the smallest RMSE span from 0.3 to 0.7 °C, the highest between 1.6 to 3.9 °C (T max) and between 1.3 and 2.5 °C (T min). These extremes express the RMSE produced by interpolating values at a station site, without taking into account the true measurement at that station; for every simulation a set of n RMSE is calculated, where n is the number of stations considered. On a monthly basis (tab. 4), the RMSE for both maximum and minimum values is about 1 °C (Colombo, 2000).

The linear correlation coefficient is a good indicator of the link between the value estimated by the interpolation and the true value at the measured points. For minimum and maximum daily temperature the linear correlation coefficient was 0.99 (Colombo, 2000). Tracing the scatterplots of the bias (predicted value minus observed value), Colombo found the residual errors to be independent of the entity of the observed values.

| Month | Tmax[°C] | | Tmin [°C] | |
|---|---|---|---|---|
| | Media | DS | Media | DS |
| 1 | 1,3 | 0,6 | 1,0 | 0,4 |
| 2 | 1,2 | 0,3 | 1,3 | 0,4 |
| 3 | 0,9 | 0,4 | 1,1 | 0,3 |
| 4 | 1,0 | 0,4 | 0,8 | 0,3 |
| 5 | 1,0 | 0,2 | 0,9 | 0,3 |
| 6 | 1,0 | 0,3 | 0,9 | 0,2 |
| 7 | 1,0 | 0,3 | 0,9 | 0,3 |
| 8 | 1,2 | 0,2 | 0,9 | 0,3 |
| 9 | 1,2 | 0,6 | 0,8 | 0,2 |
| 10 | 1,2 | 0,8 | 0,9 | 0,3 |
| 11 | 1,0 | 0,2 | 1,0 | 0,3 |
| 12 | 1,1 | 0,3 | 1,3 | 0,3 |

*Table 4: Monthly mean of daily RMSE for temperatures.*

**4.2 Precipitation**

The cross−validation procedures for daily rainfalls was implemented only for the rainy days of the vegetative season (May to September) of the year 1995. A wide range of values was found for this check, with daily RMSE values ranging from 0.1 mm to 13 mm, with an average of 2.6 mm (tab. 6); values expressed in percentages fall between 30% and 60% (fig. 5).

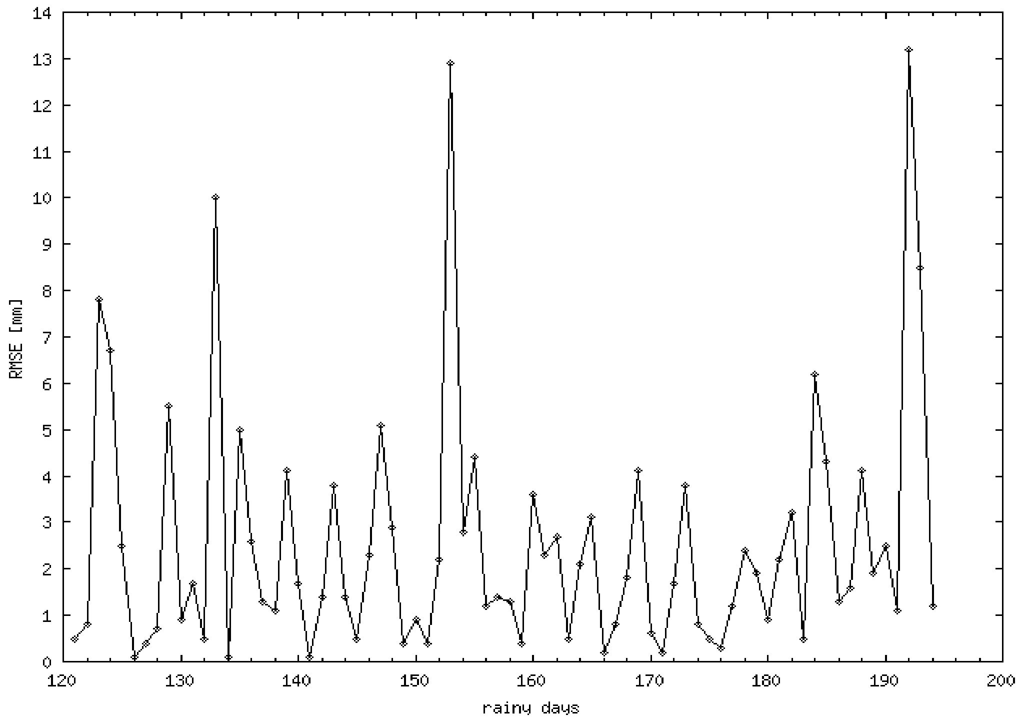


*Figure 5: Annual trend of the daily RMSE of precipitation.*

| Month | Mean | Dev.Std |
|---|---|---|
| 5 | 2.7 | 5.3 |
| 6 | 2.2 | 3.1 |
| 7 | 2.6 | 5.1 |
| 8 | 1.6 | 2.5 |
| 9 | 4.2 | 9.2 |

*Table 6: Montly mean of daily RMSE for precipitation.*

The linear correlation coefficient evaluated for daily precipitations is 0.79 (fig. 7). From the scatterplots a trend can be appreciated to an overestimation of the light rainfalls and an underestimation the heaviest ones, fig. 8 (Portolan, 2000).

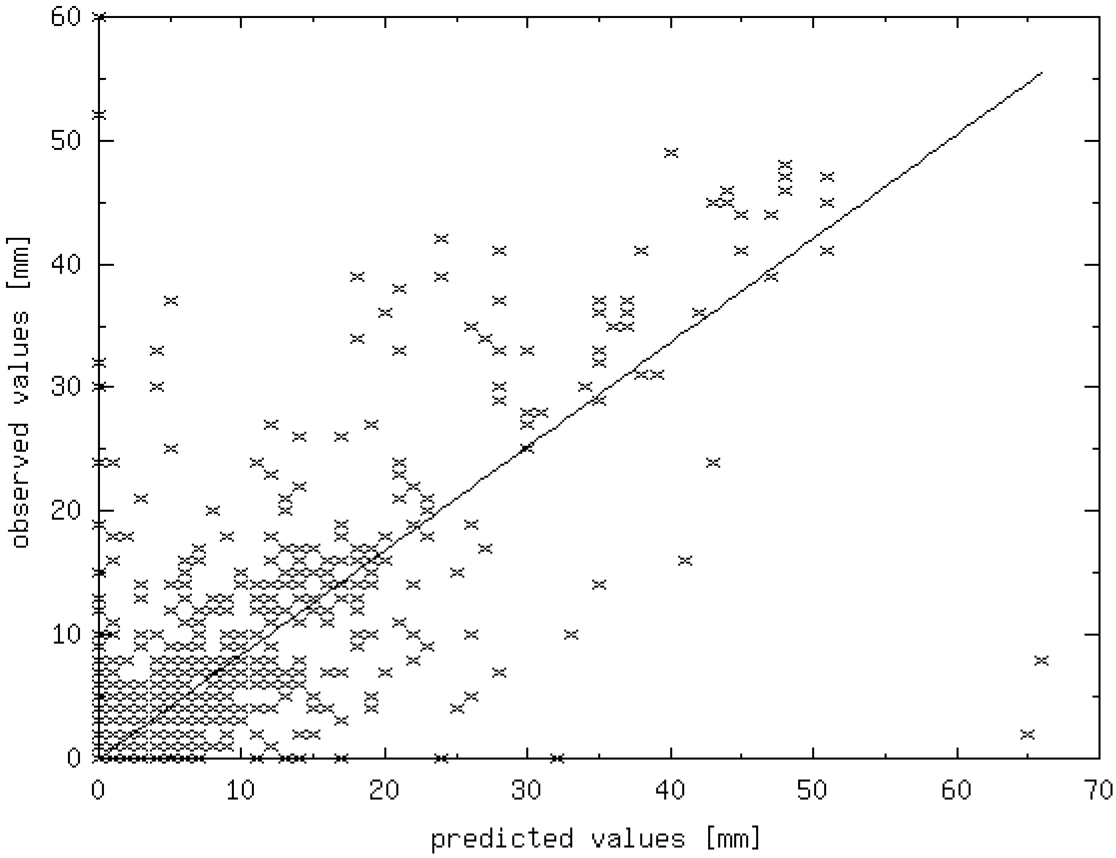


*Figure 7: Scatterplots of observed values vs. predicted values (precipitation).*

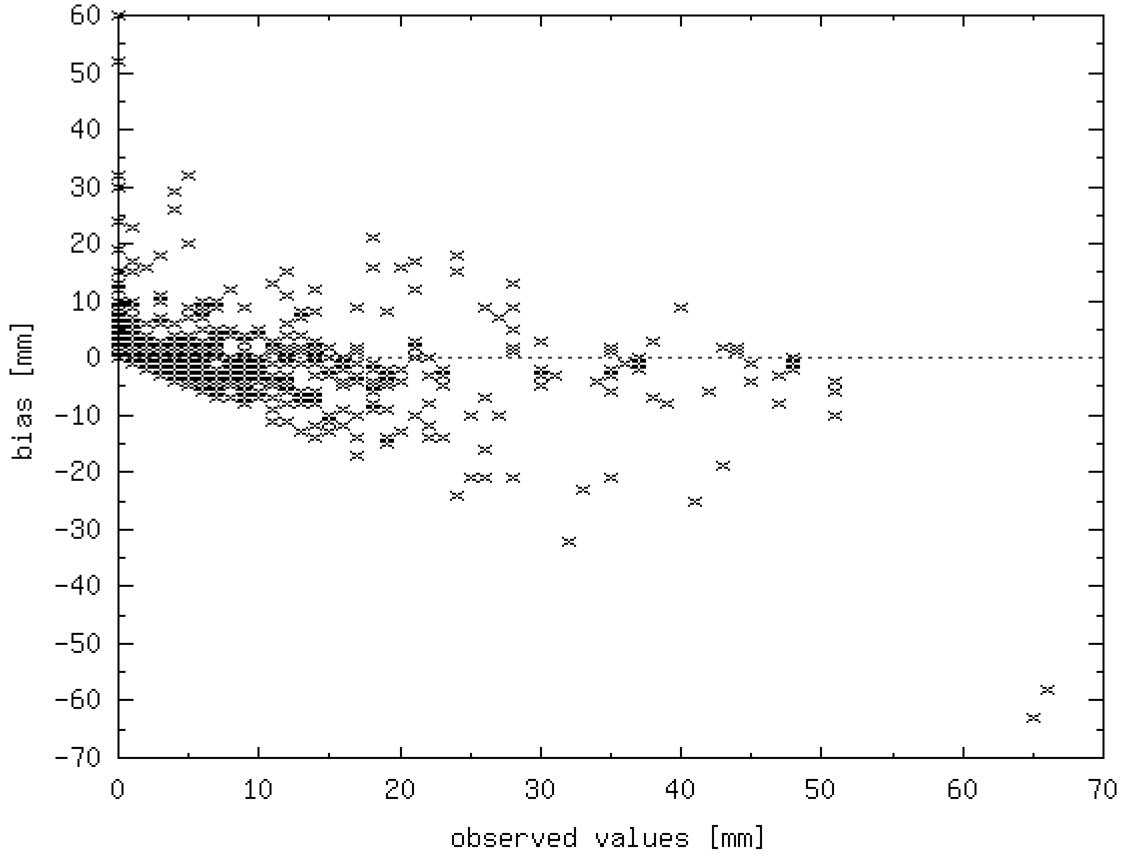


*Figure 8: Scatterplots of the bias vs. observed values (precipitation).*

**4.3 Potential evapotranspiration**

The errors in the PET rates evaluation have been calculated by means of the error propagation in the Hargreaves' formula (Taylor, 1993). Errors originate in the estimation of maximum and minimum temperature, since solar radiation is not evaluated by means of interpolation techniques, but only with topographical information taken from the DEM. Daily RMSE for PET are estimated between 0.2 and 1.3 mm, with an average value of only 0.6 mm (tab. 9); these values, expressed as percentages, span between 10% and 20% (fig. 10); these low figures are in most of the cases less than the error of the estimation of the true potential evapotranspiration by the formula of Hargreaves' itself; the interpolation of PET can then be considered fully satisfactory.

| Month | Mean | Dev.Std |
|---|---|---|
| 5 | 0.6 | 0.2 |
| 6 | 0.7 | 0.2 |
| 7 | 0.6 | 0.1 |
| 8 | 0.6 | 0.2 |
| 9 | 0.5 | 0.2 |

*Table 9: Montly mean of daily RMSE for PET.*

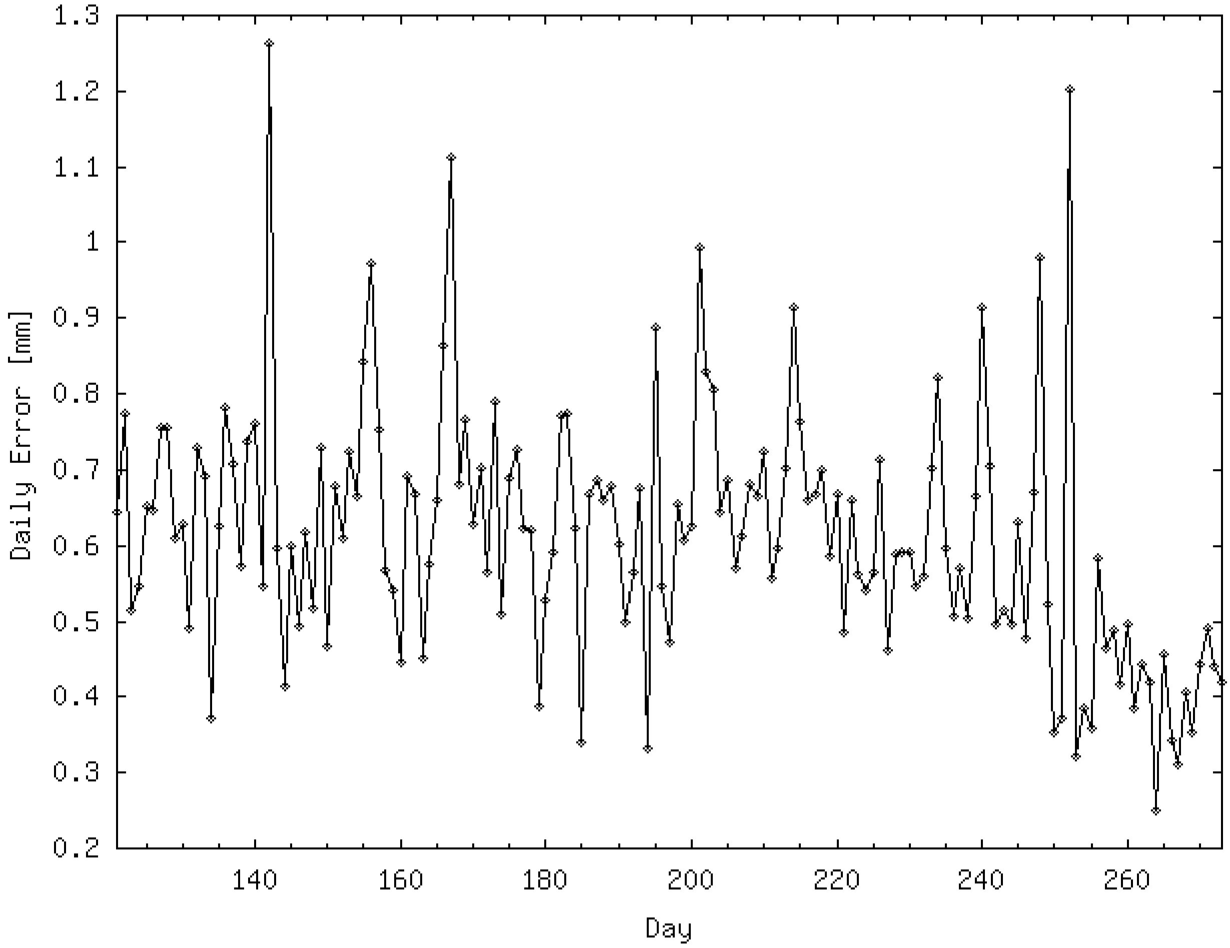


*Figure 10: Annual trend of the daily RMSE for PET.*

**5. Agrometeorological application: IRRIGRASS**

A water balance model (IRRIGRASS) was developed for automatic calculation of water balance at a farm−scale. The balance of soil is carried out by means of estimation of rainfalls, PET, and soil properties. Actual evapotranspiration is calculated according to a crop coefficient provided by every final user of the application, according to the cultural phenological phase; soil textural data are requested to the user, too. Rainfalls and PET values are interpolated at every grid point by **GRASS**, as described above.

The estimation of the water deficit of a soil is done by the water balance equation, with respect to the textural features of the soil, the main tillage practices, the meteorological conditions and the amounts of water given out during the irrigation intervention.

$$ADT[t] = ADT[t-1]+P+Ir-ETe$$

- ADT[t]: daily total available water (t);
- ADT{t−1]: daily total available water;
- P: daily rainfall;
- Ir: daily irrigation amount (t);
- ETe: daily actual evapotranspiration;
- t: day.

IRRIGRASS requires as input data (fig. 11):

1. soil texture;
2. potential evapotranspiration;
3. rainfall amounts;
4. water amount supplied with irrigation;
5. type of crop and length of the main phenological phases;
6. type of irrigation plant.

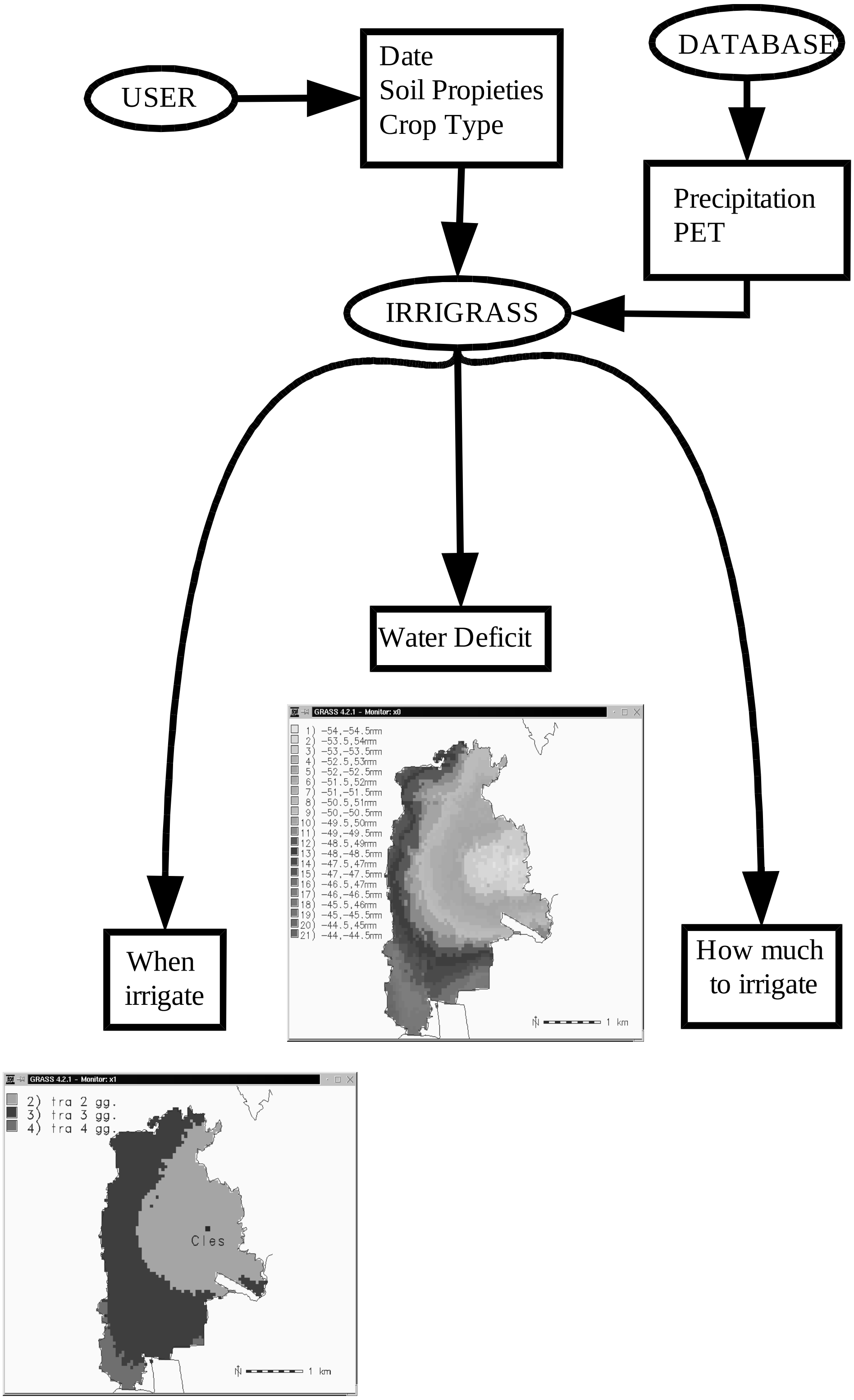


*Figure 11: General diagram of IRRIGRASS.*

The user is required to supply information about textural features of the soil when a sub−area is selected from the whole. The information about the amount of water given out and about the features of the irrigation plant are supplied by the user as well. Actual evapotranspiration is given, as usual, by the application of a crop coefficient to the PET value; such coefficient is dependent on the phenological phase (FAO, 1990).

IRRIGRASS performs a balance based on daily steps, in which precipitation and effettive evapotraspiration (ETe) are estimated for the area concerned by the irrigation. The deficit is estimated daily from the last irrigation, or otherwise a starting value for the deficit is input by the user; this is useful above all for drop irrigation facilities, where the field capacity is seldom attained after irrigation.

Finally, the end product of IRRIGRASS is a map of the moisture state of the soil for the day defined by the user. If the balance suggests an irrigation intervention, IRRIGRASS prompts the user with the amount of water to be supplied; otherwise, a map is visualised expressing the expected date for an irrigation in the area, provided that the evapotranspiration rate is maintained as the mean value of the last 15 days and no rainfall occurs.

The error in the evaluation of the water deficit has been estimated by means of the error propagation technique, applied to the estimation of the parameters involved in the formulae; the result was in the range of 2 − 4 mm $d^{-1}$ (tab. 12).

| | Cles | | Denno | | Poz−Cadin | | Tuenno | |
|---|---|---|---|---|---|---|---|---|
| Month | Ea | Er | Ea | Er | Ea | Er | Ea | Er |
| 5 | 1.8 | 0.3 | 1.8 | 0.3 | 1.8 | 0.3 | 1.8 | 0.3 |
| 6 | 1.7 | 0.4 | 1.7 | 0.3 | 1.7 | 0.3 | 1.7 | 0.4 |
| 7 | 2.2 | 0.4 | 2.2 | 0.4 | 2.2 | 0.4 | 2.2 | 0.4 |
| 8 | 1.4 | 0.3 | 1.4 | 0.4 | 1.4 | 0.3 | 1.4 | 0.3 |
| 9 | 2.8 | 0.6 | 2.8 | 0.4 | 2.8 | 0.5 | 2.8 | 0.5 |

*Table 12: Montly average of daily errors of water deficit estimation (Ea = absolute error [mm], Er = relative error).*

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