Parametrization of the Richardson weather generator within the European Union

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ABSTRACT

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The Richardson model for the mathematic generation of daily weather data was parametrized. Thirty years' time series of the 355 main meteorological stations in the European Union formed the database. Model parameters were derived from both observed weather station data and interpolated weather data on nodes of a 50 km x 50 km grid. Comparative analyses were made. The monthly statistics of generated weather are similar to those of observed weather for both temperature and radiation, but not for rainfall. One had better derive parameters from interpolated weather than interpolate parameters derived from observed weather. The geographical distribution of parameter values was determined.

Keywords: meteorology, weather data

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Preface

This report, prepared by the DLO Winand Staring Centre in Wageningen, the Netherlands, describes the procedure generating daily weather data and evaluates two alternative procedures for the generation of weather data on a 50 km x 50 km grid.

The study was carried out during 1994-1995 as amendment to a contract study to develop a Crop Growth Monitoring System (CGMS) for the Joint Research Centre (JRC-Ispra Site) of the Commission of the European Communities. In CGMS agrometeorological models are applied for yield forecasting purposes. This is done in the framework of the MARS Project (Monitoring Agriculture with Remote Sensing), carried out by the Agricultural Information Systems Unit of the Institute for Remote Sensing Applications of JRC, in support to the Statistical Office of the EU (EUROSTAT) and to the Directorate General for Agriculture of the EU (DGVI).

The development and validation study in this report made use of historic daily meteorological data over a period of thirty years. These were selected from the meteo data base of the MARS project. These weather data were provided originally by the National Meteorological Offices of all EC and adjacent countries. Most other geographic data come from CORINE. Derived data came from the Computer Laboratory for Agricultural Statistics (MARS/ISA).

The authors are indebted to Jandirk Bulens, Gert Jan Reinds, Reimund Rotter and Tamme van der Wal for their support and comments. Many thanks are also due to Paul Vossen, Iwan Supit and Hugo de Groof (JRC) for their kind support and counsel.

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Summary

For scenario studies of crop growth or other weather driven ecological processes, e.g in the context of climate change or of risk analysis, weather series are required that are statistically identical to observed weather series. Preferably the synthetic weather series should be available on a grid base.

Such series could be made available for this study in the framework of the development of the Crop Growth Monitoring System (CGMS) for the MARS project of the Joint Research Centre (JRC). Therefore, three conditions had to be fulfilled: (1) a large meteorological database of the 355 main meteorological stations in the European Union; (2) the techniques to interpolate this data spatially on a 50 km x 50 km grid base; and (3) a weather generator that can generate such synthetic weather series, which was evaluated positively in other crop growth studies.

The results of this study are that both the weather generator and the database of parameter values on a grid base are available, called the EURO WEATHER GENERATOR.

Conclusions
Comparing average monthly statistics based on observed weather (first order) with those based on generated weather (second order) shows that for both temperature and radiation the first and second order approach yield similar results. The exception was the amount of precipitation. Using multiple runs the second order weather series could be either too high or too low, especially in summer. This was caused by the high variablility of the generated amount of rainfall. This should be kept in mind when using generated weather for crop growth models, since such models are sensitive to the amount of water available for the crop.

The parameters of the statistical functions for temperature, radiation, and precipitation show a realistic distribution over countries of the European Union, and can be interpreted using elementary knowledge of the weather in this area.

Two approaches of spatial interpolation were considered to obtain the parameter values at a grid base: (1) the interpolation of the weather series to a grid base, and subsequent estimation of the parameters, or (2) estimation of the parameters for the stations, and subsequent spatial interpolation of the parameters. The first method was preferred in this study, for two reasons: (1) the method for spatial interpolation of the meteorological variables developed at the Winand Staring Centre is thoroughly tested and evaluated, and (2) a simple spatial interpolation of parameters is less accurate, as it does not take into account geographical information.

1 Introduction

The availability of daily weather data is of great importance in many studies, e.g. in the development of crop models or for climate change studies. If no direct measurements are available, then synthetic time series may be used, generated by statistical models, such that the generated weather series is statistically identical to the observed series. To evaluate spatial responses these times series should preferably be available on a grid base.

Within the context of the MARS project, synthetic time series when used as approximations of the near future weather in rest of the current year, can be very helpful for simulating crop growth or soil water balances, to provide a basis for near future yield forecasting.

The aim of this study is to make both the weather generator and the database of parameter values on a grid base available. These results will find direct use in the development and the testing of crop models on computer platforms without requiring direct access to a central meteorological data base. It will be called: the EURO WEATHER GENERATOR, geared to the requirements of its possible implementation within CGMS in the framework of the MARS project (Supit et al., 1995).

For the estimation of the parameter values for a synthetic weather generator on a grid base over the countries of the European Union three conditions must be met:

1 A large meteorological database is maintained containing 20 to 30 years of daily measurements of the weather variables: minimum and maximum temperature; radiation; precipitation, vapour pressure and wind speed of 355 main meteorological stations in the European Union. This database is part of CGMS and will be referred to in this report as 'DBMETEO' (Van der Drift et al., 1992; Reinds 1991, 1992).
2 In previous studies, techniques and algorithms were developed to interpolate the daily observed values spatially on a 50 km x 50 km grid base (Van der Voet et al., 1994).
3 A synthetic weather generator, called WTHGEN developed by Richardson (1981, 1982, 1984; Richardson and Wright 1984), was available.

These conditions could be met at the DLO Winand Staring Centre when the Crop Growth Monitoring System of the Joint Research Centre was developed in the framework of the MARS project.

Based on DBMETEO it is possible: (1) to estimate the parameter values required to generate synthetic weather series for each of the main meteorological stations (see Figure 1); and (2) to estimate the parameters values at a grid base after spatial interpolation of the weather variables (see Figure 2).

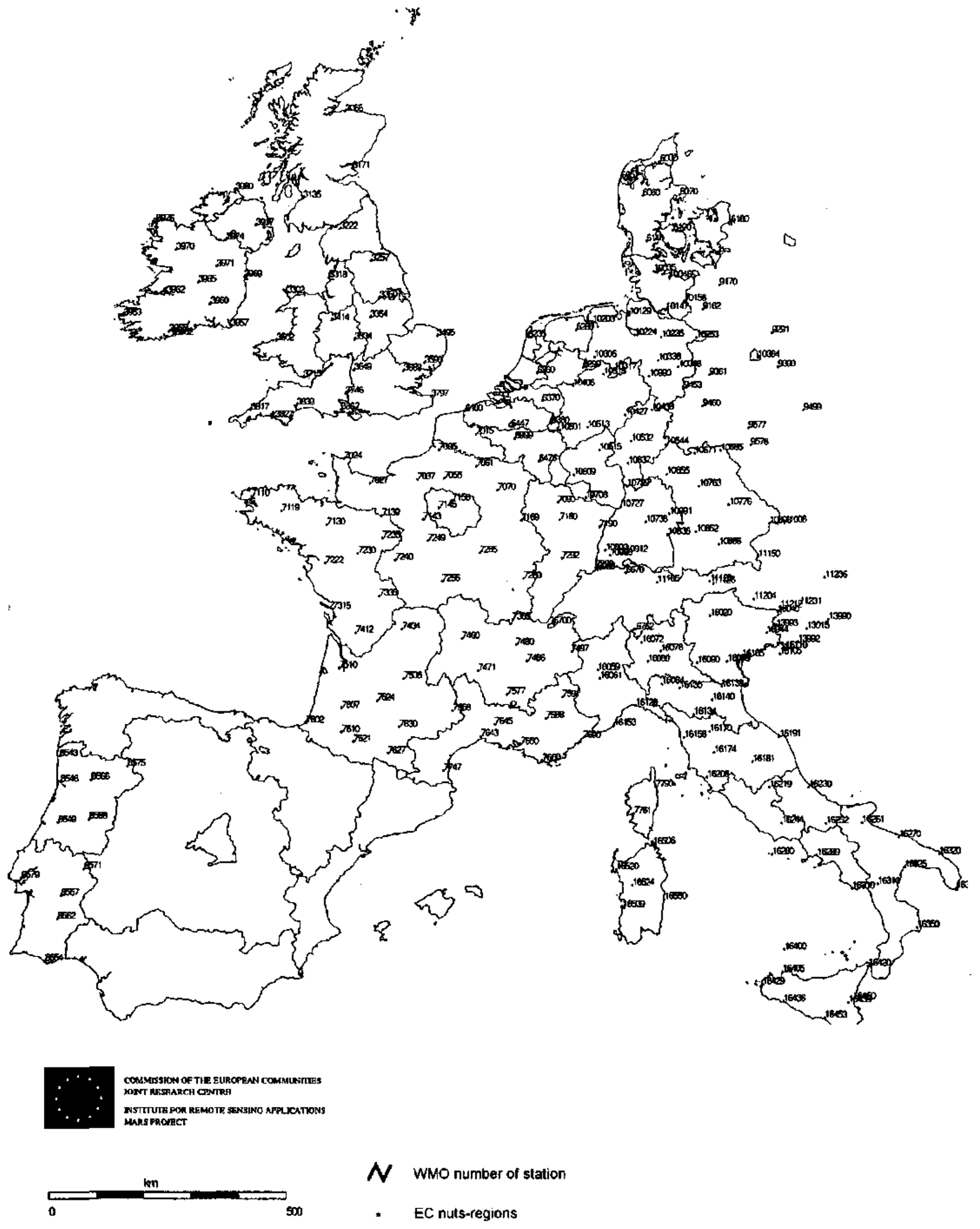

Fig. 1 Stations for generating daily synthetic weather

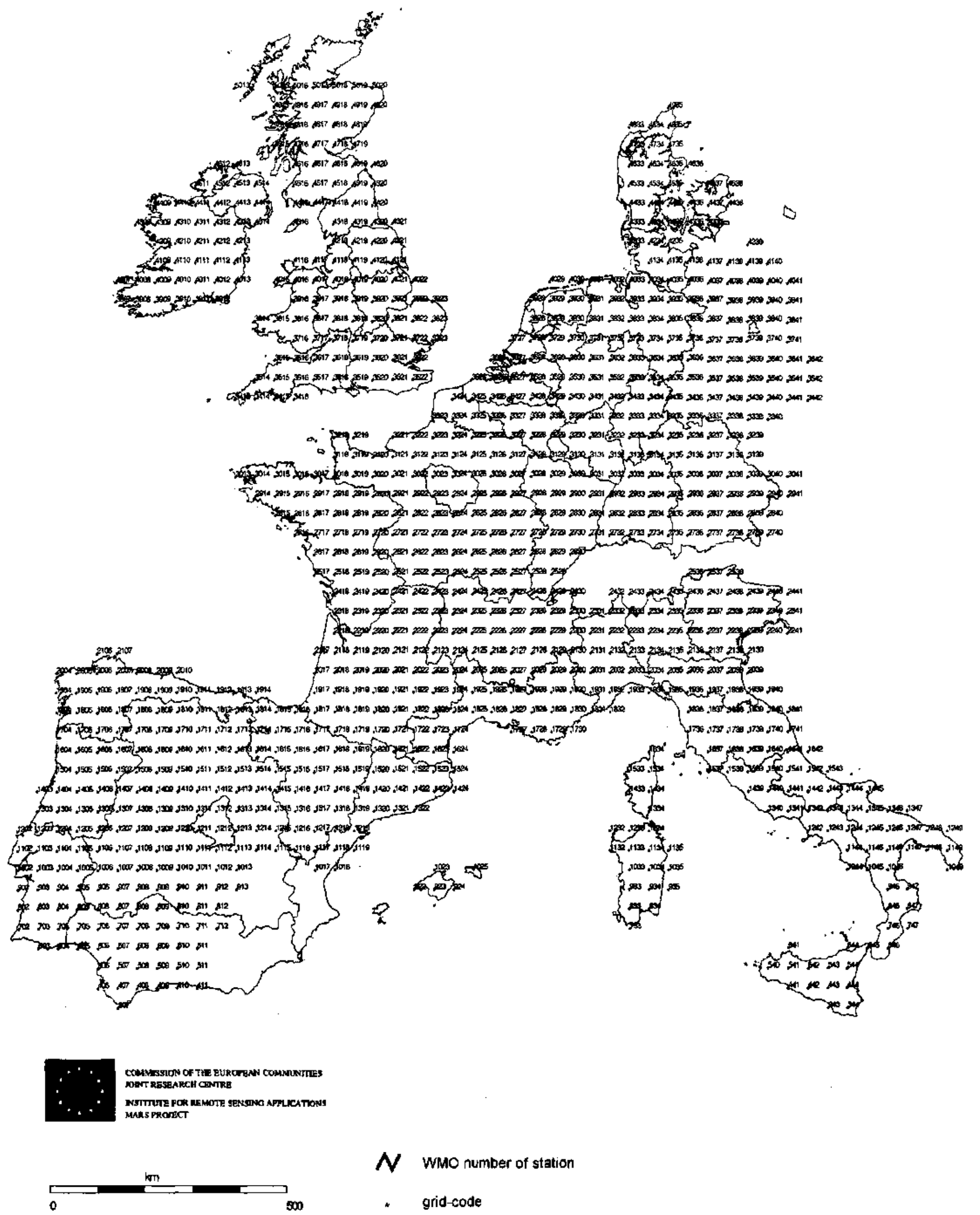

Fig. 2 Generating daily synthetic weather on a grid base. Centres of 50 km x 50 km cells with derived parameter values

The software modules developed in this study allow the creation of synthetic weather data by firstly analyzing historic time series of 20 to 30 years daily measured weather data and secondly to derive the parameter sets per weather measurement point. These latter points may have observed or interpolated weather data. The weather variables concerned include minimum and maximum temperature, radiation, precipitation and wind speed.

In the approach used in WTHGEN, the seasonal variation of temperature and radiation is described by a cosine function. Cross- and auto-correlation between radiation and temperature, both with a zero and a one-day lag, are taken into account for the generation of consistent time series. The occurrence of precipitation depends on precipitation of the previous day, whereas the amount of precipitation is described with a Gamma distribution. For wind speed also a Gamma distribution is assumed. The daily vapour pressure of the synthetic weather is a function of minimum temperature only, using an empirical function.

DBMETEO allows determination of the mean, amplitude and phase of the cosine function describing temperature and radiation. For the occurrence and amount of rain, and for wind speed, monthly parameter values are derived from the data base. Using the expertise on GIS techniques available at the Winand Staring Centre, the weather series can be interpolated to a 50 km x 50 km grid throughout the countries of the European Union. Subsequently, the parameter values can be estimated based on this interpolated weather.

There are many models presented in the literature that describe meteorological variables and their correlations statistically, so that these functions can be used to generate synthetic weather series. However, a thorough comparison either of the available models or on the appropriateness of the basic assumptions of WTHGEN for the European weather, is beyond the scope of this study. WTHGEN was chosen because it was available, thoroughly tested by the author and others (Geng et al., 1985a, 1985b, 1986), and successfully applied and evaluated in crop growth studies (e.g. Racsko and Szeidl, 1991; Buydens, 1992).

In chapter 2 of this report the theory and concepts of two major components of the present study are explained, generation and interpolation. In chapter 3 the results of the weather analysis and weather generation are discussed, and comparisons between alternative calculation procedures are made, followed by conclusions. The practical aspects of using the software are described in the Annexes, preceded by a Guide to the Annexes.

2 Theory

2.1 Model

WTHGEN is based on three assumptions considering the characteristics of temperature and radiation. (1) the systematic part of minimum and maximum temperature, and radiation, as well as for the coefficient of variation of these variables can be characterized by single harmonic functions; (2) the phase of these harmonic functions is spatially constant, i.e. they vary little between stations (day number 175 for both radiation harmonics, and day number 200 for the four temperature harmonics); and (3) the correlations, as well as the one-day lagged correlations between these variables, are spatially constant.

In short, the Richardson model (Richardson, 1981, 1982, 1984; Richardson and Wright, 1984; Supit, 1986) considers the occurrence and amount of precipitation independent of temperature and radiation. Minimum and maximum temperature, and radiation are considered to be cross- and serially correlated, with a one-day lag. For dry and wet weather series harmonic functions are fitted for maximum and minimum temperature and total solar radiation. The occurrence of precipitation is assumed to be dependent only on the occurrence of precipitation on the previous day. The amount of precipitation as well as the wind speed, is assumed to be Gamma distributed. This distribution predicts low values to occur more often than high values.

2.1.1 Temperature and radiation

The systematic part of daily maximum and minimum temperature, and radiation is modelled by a harmonic function. This function takes the following form:

$$\bar{X}_{i,j} = a_j + b_j \cdot \cos(2 \cdot \pi \cdot \frac{i - c_j}{365}) \qquad (1)$$

I = day number
j = weather variable 1: maximum temperature, 2: minimum temperature, 3: solar radiation
$\bar{X}_{i,j}$ = average value of variable j at day i
a_j = yearly average
b_j = amplitude
c_j = position of maximum

See Figure 3 for a graphical presentation of the harmonic function (Eqn 3).

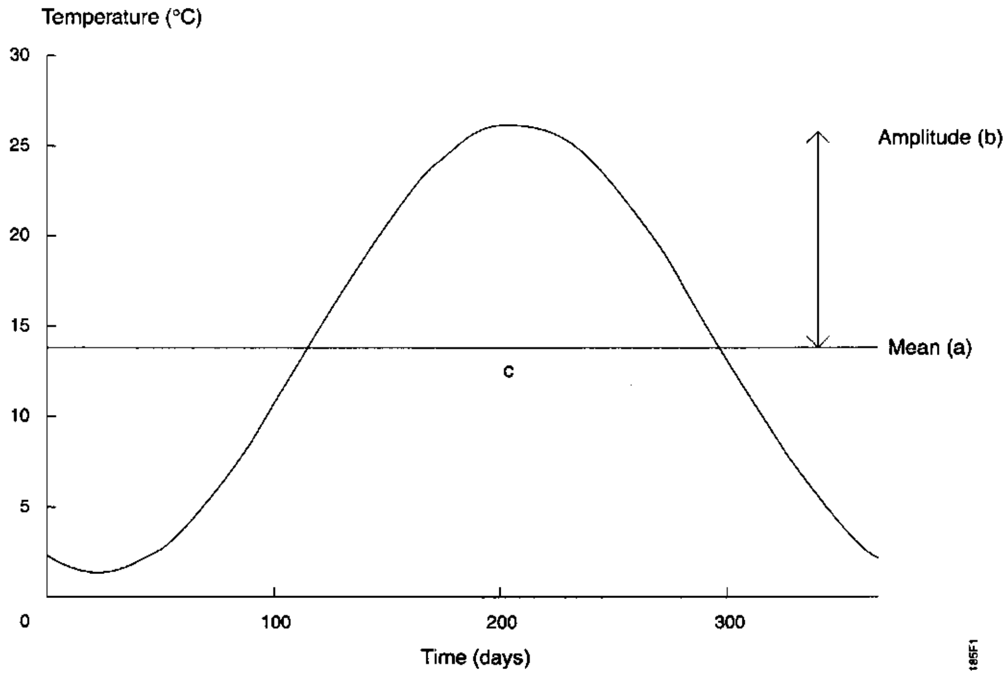

Fig. 3 Graphical presentation of harmonic function for temperature (Eqn 1)

The day on which temperature and radiation on average reach their maximum is about the same for all stations considered. Therefore c_j is fixed at 29 July (day number 210) for minimum temperature, 24 July (day number 205) for maximum temperature, and 26 June (day number 177) for radiation.

Actual values of variable j can be generated according to:

$$X_{i,j} = \bar{X}_{i,j} \cdot (1 + d_j \cdot CV_j) \qquad (2)$$

$\bar{X}_{i,j}$ = actual value of variable j at day i
d_j = residual component of variable j
CV_j = coefficient of variation of variable j

The residual component contains serially- and cross correlation. Matalas (1967) derives for a multivariate weakly stationary process (i.e. a process with constant mean and auto-covariance only dependent on the lag (Chatfield, 1989):

$$d_{i,j} = A \cdot d_{i-1,j} + B \cdot \varepsilon \qquad (3)$$

ε = standard normal distributed random component
A, B = matrices:
A = $M_1 \cdot M_0^{-1}$
$B \cdot B^T$ = $M_0 - M_1 \cdot M_0^{-1} \cdot M_1^T$
M_0 = variance/covariance matrix
M_1 = matrix with lag-one serial- and cross correlation coefficients

Richardson (1982) found that seasonal and spatial variation in the correlation coefficients is small. Therefore, for all stations constant values for M_0 and M_1, and consequently for the vector with residuals, d, are used. For M_0 and M_1 the following values were derived (Richardson, 1982):

$$M_0 = \begin{matrix} 1 & 0.633 & 0.186 \\ 0.633 & 1 & -0.193 \\ 0.186 & -0.193 & 1 \end{matrix} \tag{4}$$

$$M_1 = \begin{matrix} 0.621 & 0.445 & 0.087 \\ 0.563 & 0.674 & -0.100 \\ 0.015 & -0.019 & 0.251 \end{matrix} \tag{5}$$

In this study the parameters a and b were estimated for minimum and maximum temperature, and radiation, (T_{min}, T_{max}, Rad) as well as for the coefficient of variation of these variables (CV_{Tmin}, CV_{Tmax}, CV_{Rad}).

2.1.2 Precipitation

The occurrence of rainfall is modelled by a first order, two state Markov process. A day with precipitation is considered wet, and is a dry day otherwise. A first order Markov process considers the state at day *i* dependent on day *i-1* only. Thus, it is necessary to estimate two conditional probabilities: the probability that day *i* is wet day given the fact that day *i-1* was wet, $P(W|W)$, and the probability that day *i* is wet given the fact that day *i-1* was dry, $P(W|D)$. Then the complementary probabilities are fixed. These conditional probabilities are estimated monthly for each year, and then monthly averages are calculated over all years as well as for wet and dry years.

When a day is determined to be wet, the amount of precipitation is generated, based on the two parameter Gamma distribution. This distribution takes the following form:

$$P(X) = \frac{X^{\alpha-1} \cdot e^{(-X/\beta)}}{\beta^{\alpha} \cdot \Gamma(\alpha)} \tag{6}$$

$P(X)$ = probability of occurrence of X
α = shape parameter of Gamma distribution
β = scale parameter of Gamma distribution
$\Gamma(\alpha)$ = Gamma function:

$$\Gamma(\alpha) = \int_0^{\infty} t^{\alpha-1} \cdot e^{-t} dt \tag{7}$$

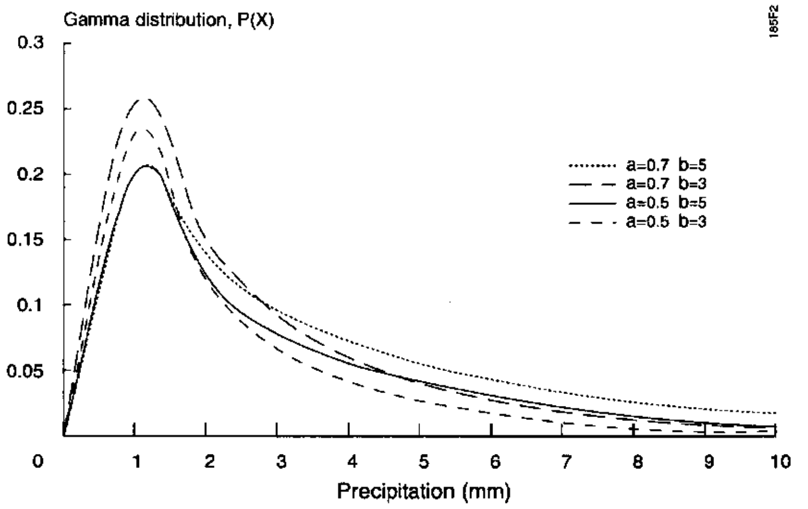

Fig. 4 Graphical presentation of Gamma distribution for precipitation (Eqn 6)

See Figure 4 for a graphical presentation of the Gamma function (Eqn 6).

The value of ß determines the height of the peak: a high value of ß increases the probability of a low amount of rain on a wet day, but reduces the probability of a high amount of rain on a wet day. The value of α determines mainly the thickness of the tail: a high value of α increases the probability of a high amount of rain on wet days. The parameters α and ß are as follows related to the parametric mean (μ) and variance (σ^2) of the Normal distribution: $\mu = \alpha \cdot \beta$, and $\sigma^2 = \alpha \cdot \beta^2$. Thus, both α and ß affect the mean and the variance of the distribution. However, ß affects the variance, and thereby the occurrence of extreme low and extreme high values, more strongly than α.

The parameters for the Gamma distribution are estimated monthly for each year. The monthly averages over all years, and for wet and dry years can be used to generate amounts of rainfall. This makes the estimation for α with maximum likelihood and method of moments not stable if α is less than one. Therefore approximate maximum likelihood solutions as suggested by Greenwood and Durand (in Supit, 1986) are used:

$$\alpha = (0.5000876 + 0.1648852 \cdot Y - 0.0544274 \cdot Y^2) / Y \qquad 0 < Y < 0.5772$$

$$\alpha = (8.898929 + 9.059950 \cdot Y + 0.9775373 \cdot Y^2) / (17.79728 + 11.968477 \cdot Y + Y^2) \cdot Y \qquad 0.5772 < Y < 17$$

$$\beta = \bar{X} / \alpha$$

$$Y = \ln(\bar{X}/G)$$

$\bar{X}$ = arithmetic mean

G = geometric mean

2.1.3 Wind speed

Richardson (1984) suggests to use the Gamma distribution to describe wind speed. The Gamma distribution yields good fits, except when wind speed is extremely variable and high wind speed (>10 m/s) occurs regularly, a Weibull distribution is a better description. The Weibull distribution is recommended for stations in tropical zones where frequently hurricanes occur. Therefore in this study the Gamma distribution is used for the generation of wind speed at all stations. This makes it possible to use the above mentioned method for estimating the Gamma distribution for wind speed. Monthly values of α and ß are estimated. Further neither serial- nor cross correlation between wind speed and other meteorological variables is assumed.

2.1.4 Humidity

Dewpoint temperature models are not available, however, saturated vapour pressure can be calculated using minimum daily temperature. This value is usually measured at 06:00 UTH and a 100% humidity can be assumed at this moment of the day. The relation between minimum temperature and saturated vapour pressure given by Goudriaan (1977) can be used:

$$e_s = 6.11 \cdot e^{17.47 \cdot \frac{T_{min}}{T_{min} + 239}} \qquad (8)$$

e_s = saturated vapour pressure [mbar]
T_{min} = minimum day temperature [°C]

2.2 Spatial interpolation

To determine the parameter values for the weather generator on a 50 km x 50 km grid base throughout the countries of the European Union, the weather series needs to be interpolated spatially. Two methods of spatial interpolation can be thought of to obtain the parameter values on a grid base: (1) by interpolation of the observed weather series of the meteorological stations, and subsequently estimating the parameters for each grid, or (2) by estimating these parameters for the meteorological stations, and subsequently interpolation of these parameter values to a grid base.

The first method is used in this study for all the parameters, because the technique of spatial interpolation of observed weather was developed at the DLO Winand Staring Centre in earlier studies (Van der Voet et al., 1994). The second approach was tested for a few parameters only, to evaluate whether both techniques yield similar results.

Both approaches use the DBMETEO station data for the period 1960 to 1989. Section 3.3 compares the results of both methods.

2.2.1 Spatial interpolation of the weather

The interpolation was performed using the best possible station configuration for each grid and for each year, based on the algorithm developed by Van der Voet et al. (1994). The procedure has been designed for the specific purpose of estimating weather data on a 50 km x 50 km grid over the E.C. for use as input data for a crop growth simulation model. The study made use of historic daily meteorological data over a period of five years for 275 stations.

The estimation differs for the various variables. The stations to be used for the estimation of weather on a location are selected from the list of European weather stations, available within DBMETEO (Reinds, 1991).

Rainfall is estimated by using the data of a single station that is most similar to *the centre of the grid cell.* The following criteria are used to select the most similar single station as compared to the location:
— proximity;
— similarity in terms of:
- altitude;
- distance to the coast;
- the position relative to climatic barriers.

The use of more than one station to estimate rainfall by interpolation may improve the mean prediction error of the estimate of the amount of rainfall. However, the averaging effect will overestimate the number of wet days considerably. The temporal distribution of rainfall has a strong influence on the availability of soil water for a crop through its effect on evaporation and percolation. Therefor it was decided to use the rainfall data of only one weather station, in order to achieve a realistic representation of the number of rainy days for the grid cell.

The other variables (on radiation, temperature, windspeed and humidity) are estimated by means of averaging the data of the optimum set of stations, surrounding the centre of the grid cell. The averaging is carried out without weighting for distance. For the interpolation of other weather variables one or more similar stations can be selected. The selection criteria for this set of stations are an extension of the criteria to identify the most similar single station. Besides the already mentioned criteria the following criteria are used:

— the degree to which the selected stations are surrounding the location;
— the use of at most four stations;
— the number of stations in a set.

For the meteo variables minimum temperature, maximum temperature and humidity, the values of the stations to be used for interpolation are corrected for differences in altitude between these stations and the average altitude of the grid cell. Before interpolation all values are adjusted to the average altitude of the grid cell. For every 100 m of increase in altitude a decrease in temperature of 0.6 °C and a decrease in vapour pressure of 2.5% are assumed.

The estimation procedure is universally valid and is applicable to any arbitrary location situated in the area covered by a network of meteo stations. The centre of a grid cell is such an arbitrary location.

For every year only those stations are accepted which have less than 50% missing values for radiation, minimum and maximum temperature, wind speed and rainfall. In every year at least one station should fit the above criteria, otherwise the observations of that year are skipped in the analysis of the grid point. Furthermore, there is the restriction that for interpolation from stations to adjacent grids the maximum distance between the centre of a grid and the station is 400 km. The weather parameters are determined if at least 20 years with observations are found meeting these criteria. Consequently, the following regions are excluded: the South East of Spain, Greece, and the North of Scotland, because these regions do not meet the criteria mentioned above.

2.2.2 Spatial interpolation of the parameters

First, parameter values for the stations were estimated. A triangular network was set up, using the locations of the stations as the nodes. Isolines were constructed by linking a series of points located at the triangle edges between the stations. The location of these points, where an isoline crosses a triangle edge, is determined by linear interpolation of the station values of the parameter considered. No smoothing was applied, resulting in mathematically correct, but rather angular isolines.

3 Results and conclusions

In short, the program WANAL (Weather ANALyser) derives parameter values for the models described above, and writes the results to a parameter file. Subsequently, the program WTHGEN (WeaTHer GENerator) may read this parameter file and generate several years of synthetic weather. WANAL could be used directly to estimate parameter values for each of the stations. To find these parameter values on a grid base, WANAL was adjusted and called WANALGR. The annexes contain the technical information on the programmes developed in this study, and how they can be used, including examples files for input.

3.1 Observed and generated weather. An example: Nurnberg

The accuracy was tested of both the estimated parameter values from the observed weather series, and the weather generated based on these parameters. The generated weather was analyzed again. The first order parameter values and weather, i.e. based on observed weather, was compared to the second order parameter values and weather, i.e. based on the generated series. Such a comparison has been performed for the meteorological station Nurnberg (longitude: 11.04, latitude: 49.30, altitude: 319 m) based on 34 years of daily observations.

Figure 5 shows the harmonic functions for temperature based on both first and second order parameter values. It can be seen that for the daily maximum temperature the results are similar, both for dry and wet temperature series. For the daily minimum temperature the second order amplitude is less than the first order amplitude.

Figure 6 shows similar results for radiation. It appears that for radiation the first and second order parameter values are similar. This holds true for radiation series of both dry and wet weather conditions.

Figure 7 presents the results for parameters determining the occurrence of rainfall. The second order values of P(W|W) appear to be too low in spring and autumn compared to the first order values. The first and second order values of P(W|D) are quite similar.

Figure 8 presents the results for the parameters determining the amount of rainfall on wet days. The second order α's appear to be too high, and the second order β's to low, compared to their first order counterparts.

Figure 9 shows the monthly statistics of the first and second order weather series of temperature and radiation for 'overall' weather, i.e. not the dry or wet weather series. It can be seen that for these weather variables the mean monthly values over 34 years are quite similar.

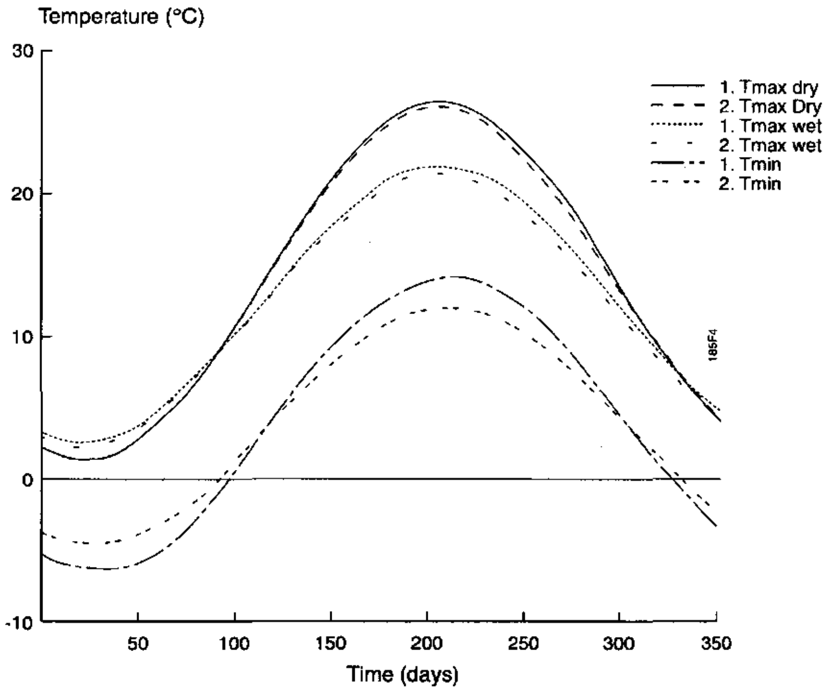

Fig. 5 Harmonic function of temperature at Nurnberg of first order (full lines) and second order (dotted lines) weather series

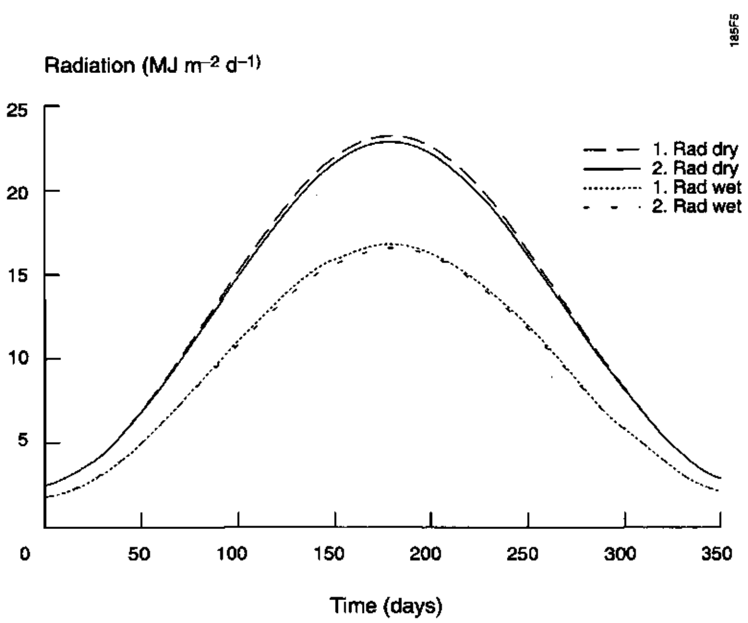

Fig. 6 Harmonic function of radiation at Nurnberg of first order (full lines) and second order (dotted lines) weather series

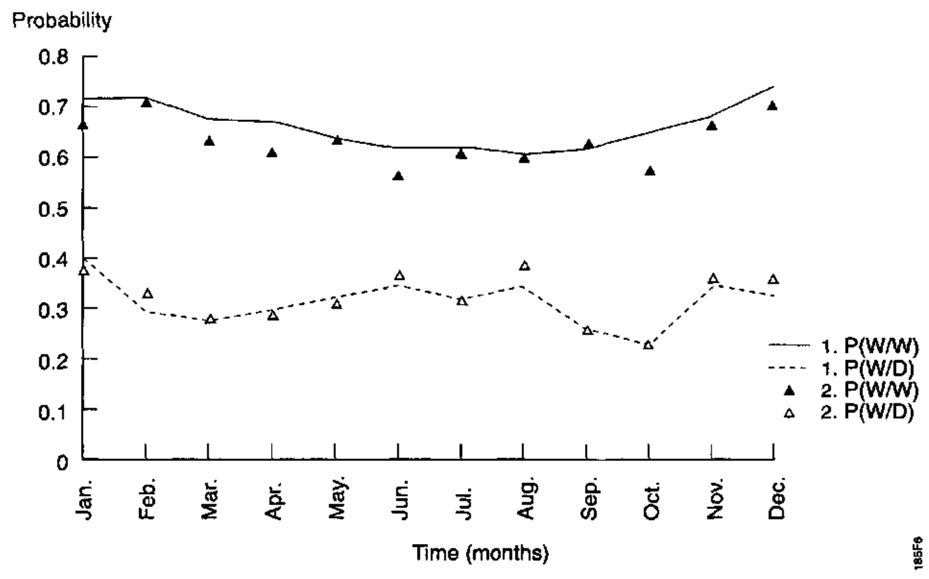

Fig. 7 Probability of occurrence of rainfall at Nurnberg of first order (line) and second order (symbols) weather series

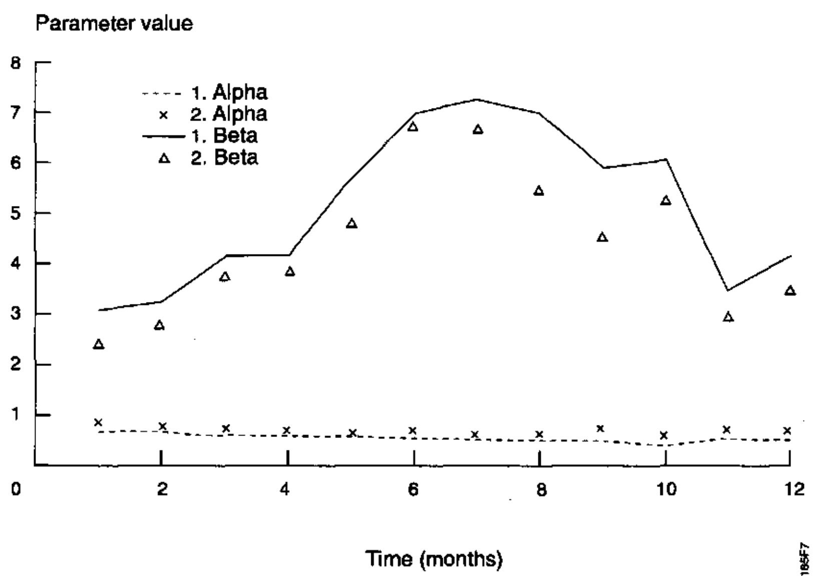

Fig. 8 Shape (α) and scale (β) parameters for the amount of rainfall at Nurnberg of first order (line) and second order (symbols) weather series

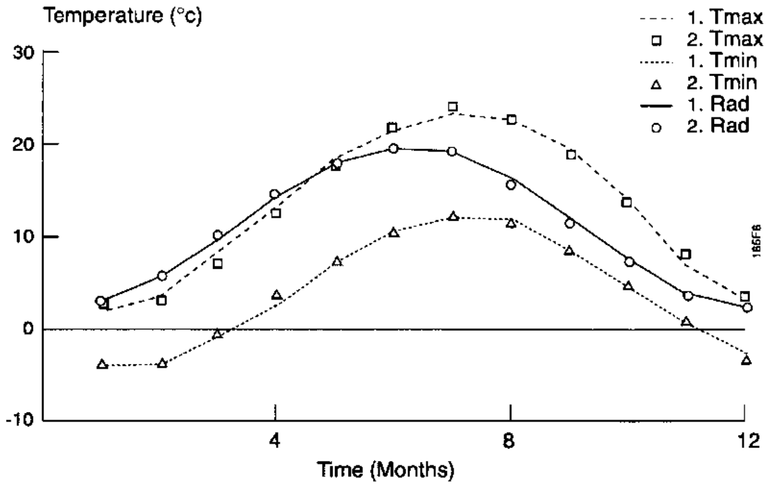

Fig. 9 Monthly statistics for temperature and radiation at Nurnberg of first order (line) and second order (symbols) weather series

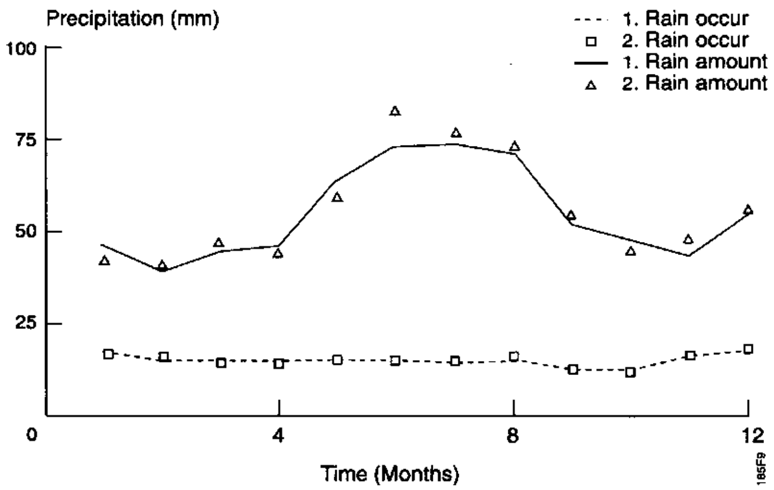

Fig. 10 Monthly statistics for precipitation at Nurnberg of first order (line) and second order (symbols) weather series

Figure 10 shows that for precipitation too much rain is generated on average during the summer months. However, the number of wet days per month are on average correct.

Based on this comparison between first and second order weather series it can be concluded that on average both series are similar. The exception was the amount of precipitation. Using multiple runs the second order weather series could be either too high or too low, especially in summer. This was caused by the high variablility of the generated amount of rainfall. This was caused by the high variablility of the generated amount of rainfall. The standard deviation of the monthly averages was 2.23 in Januari and 6.09 in July. Which is up to 15 times the standard deviation of the other weather variables. This should be kept in mind when using generated weather for crop growth models, because such models are sensitive to the amount of water available to the crop.

The parameter values on which these graphs are based are presented in Tables 1 and 2.

The table contains three sets of monthly values of gamma-distributed parameters, followed by one set of annual values for harmonic cosine-functions. The gamma-distributed parameter for precipitation and windspeed are given for three types of weather: dry, wet and normal or overall weather. The parameters needed to describe the annual course of temperature and radiation are their yearly average and amplitude, and their coefficients of variation. For maximum temperature and radiation different parameter values are distinguished for dry and wet days, for minimum temperature there is one parameter value for both weather types. The yearly mean temperatures in the parameter file are given in Kelvins.

3.2 Distribution of parameter values over the EU on a grid base

The spatial ditribution of the parameters that are used for the generation of weather data series can be presented in the form of maps, covering eleven countries of the European Union, showing isolines of parameter values. These parameter values are derived by analysis of 30 years interpolated weather data on the 50 km x 50 km grid.

3.2.1 Temperature

The temperature related parameters needed for the generation of daily synthetic weather include the annual means of minimum and maximum temperature and their annual amplitude.

From Figures 11, 12 and 13, the following conclusions can be drawn:

- There is a latitudinal gradient for the yearly average temperature, with low values in the north and high values in the south. This is the case for the maximum temperature under both dry and wet conditions, and the minimum temperature.
- The isolines of the yearly average temperature are strongly affected by altitude: the higher the altitude, the lower the yearly average temperature. Again for maximum temperature, both dry and wet conditions, and for minimum temperature.
- The effect of altitude appears to be more prominent on the yearly average values of the minimum temperature compared to those of the maximum temperature.

Figures 14, 15 and 16 show that:

- The isolines of the amplitudes of both the maximum and the minimum temperature show a strong longitudinal trend. The lower values of the amplitudes are found in the west of Europe, representing the oceanic climate, whilst the higher values are found in the east, representing the land climate. Again there is an altitudinal effect, with lower values in the Alps and the Pyrenees, compared to their surroundings.
- The values of the isolines of the amplitude of the maximum temperature are somewhat lower under wet conditions than under the dry conditions.

3.2.2 Radiation

Figures 17 and 18 show that:

- The yearly average of the radiation shows a latitudinal trend, with low values in the north and high values in the south. The values of these isolines are strongly influenced by wet or dry conditions, with the higher values under dry condition compared to wet conditions. Furthermore, the latitudinal trend is somewhat affected by altitude.

Figures 19 and 20 show that:

- The amplitude of radiation is fairly constant throughout Europe: the total range varies approximately 2 MJ m^{-2} d^{-1} under both dry and wet conditions. The difference in amplitude between dry and wet conditions is of the same magnitude.

3.2.3 Precipitation

Figures 21 and 22 show that:

- The values of the shape parameter (α) values of rainfall varies little over the year (see also Figure 7). Moreover, the values of α are rather evenly distributed throughout Europe. This indicates that the Gamma distribution can be used to describe the amount of rain throughout Europe.

Figures 23 and 24 show that:
- The values of the scale parameter (ß) do vary strongly over the year and over Europe (see also Figure 7). Furthermore, a clear altitudinal effect can be seen, with increasing values of ß with increasing altitude. This indicates an increasing probability of low amounts of rain with increasing altitude.

3.3 Spatial interpolation of weather or of weather parameters?

In the foregoing, the results of the spatial distribution of the parameters is presented after spatial interpolation of the meteorological variables to a 50 km x 50 km grid. Another approach to arrive at the spatial distribution of the parameters, is to interpolate the parameters spatially after they have been estimated for the meteorological stations.

As an example of the latter approach, Figure 25 presents both the station values and the isolines, of the yearly average of maximum temperature. Figure 26 presents this information for the scale parameter (ß) of rain in July. Comparing Figures 25 with Figure 11, and Figure 26 with 24, shows that the interpolation of parameters is less realistic than the interpolation of the weather. This is because the interpolation of the weather uses geographical information, which is not used for the interpolation of the parameters. Thus, the latter approach may be improved by considering this information too.

Table 1 Example set of first order parameter values required for WTHGEN for the location Nurnberg, Germany

*** INPUT CARDS FOR THE WEATHER GENERATOR ARE AS FOLLOWS--(Dry, Wet, Overall)
*

*********	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
P(W/W)	0.687	0.664	0.639	0.635	0.596	0.554	0.584	0.575	0.533	0.555	0.645	0.658
P(W/D)	0.358	0.265	0.263	0.246	0.277	0.310	0.252	0.294	0.214	0.185	0.288	0.273
ALPHA	0.787	0.815	0.771	0.782	0.782	0.786	0.713	0.709	0.798	0.677	0.750	0.791
BETA	2.584	2.339	3.005	3.143	4.110	4.945	5.292	5.275	3.582	3.993	2.957	2.793
ALPWI	1.321	2.904	2.899	2.403	3.295	3.967	3.732	3.849	1.776	2.056	2.031	1.887
BETWI	1.366	0.618	0.686	0.784	0.570	0.425	0.428	0.394	0.740	0.701	0.840	0.904
P(W/W)	0.756	0.782	0.728	0.705	0.682	0.674	0.644	0.627	0.673	0.710	0.714	0.782
P(W/D)	0.490	0.368	0.317	0.388	0.414	0.398	0.407	0.391	0.302	0.294	0.429	0.395
ALPHA	0.865	0.848	0.729	0.761	0.732	0.689	0.727	0.701	0.694	0.634	0.790	0.722
BETA	3.599	4.001	5.486	5.043	7.053	8.616	8.385	8.075	7.368	7.372	4.082	5.085
ALPWI	1.996	3.218	3.266	3.443	2.857	3.540	4.272	2.908	2.493	1.878	2.639	2.540
BETWI	1.146	0.649	0.627	0.596	0.614	0.498	0.394	0.509	0.646	0.912	0.750	0.845
P(W/W)	0.720	0.723	0.678	0.671	0.641	0.619	0.619	0.606	0.616	0.647	0.681	0.734
P(W/D)	0.403	0.297	0.281	0.298	0.326	0.346	0.318	0.340	0.252	0.228	0.340	0.325
ALPHA	0.799	0.790	0.722	0.750	0.733	0.713	0.702	0.690	0.703	0.630	0.755	0.724
BETA	3.178	3.348	4.237	4.242	5.787	7.010	7.323	7.050	5.992	6.166	3.623	4.301
ALPWI	1.505	2.980	3.027	2.757	3.076	3.747	3.973	3.283	2.034	1.944	2.235	2.130
BETWI	1.332	0.643	0.664	0.710	0.593	0.459	0.413	0.456	0.720	0.807	0.817	0.911

MEAN	AMPL	PARAM	TYPE	COS-FUNCTION
286.958435	12.452914	MAX.TEMP.	DRY	MEAN
0.015172	0.001993	" "	"	C.V.
285.408875	9.596373	" "	WET	MEAN
0.014748	0.001386	" "	"	C.V.
277.091888	8.240531	MIN.TEMP.		MEAN
0.014832	-0.005036	" "		C.V.
12.707228	10.173055	RADIATION	DRY	MEAN
0.318670	-0.084344	" "	"	C.V.
9.143993	7.310217	" "	WET	MEAN
0.336891	-0.003807	" "	"	C.V.

Table 2 Example set of second order parameter values required for WTHGEN for the location Nurnberg, Germany

*** INPUT CARDS FOR THE WEATHER GENERATOR ARE AS FOLLOWS--(Dry, Wet, Overall)
*

*********	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.
P(W/W)	0.629	0.675	0.599	0.539	0.590	0.550	0.483	0.534	0.539	0.540	0.597	0.681
P(W/D)	0.349	0.300	0.244	0.248	0.248	0.313	0.283	0.356	0.229	0.178	0.310	0.327
ALPHA	0.998	0.964	0.908	0.916	0.903	0.867	0.803	0.859	0.998	0.869	0.998	0.992
BETA	2.309	2.360	3.112	2.748	3.825	5.524	5.486	4.312	3.464	3.304	2.482	2.521
ALPWI	2.000	3.262	3.259	3.133	3.303	3.663	3.974	3.642	2.360	2.351	2.373	2.245
BETWI	1.000	0.605	0.638	0.621	0.549	0.468	0.420	0.415	0.665	0.696	0.752	0.853
P(W/W)	0.733	0.745	0.664	0.671	0.674	0.582	0.684	0.640	0.699	0.597	0.710	0.721
P(W/D)	0.444	0.387	0.328	0.345	0.391	0.442	0.356	0.418	0.299	0.280	0.418	0.396
ALPHA	0.998	0.924	0.894	0.861	0.820	0.879	0.846	0.870	0.880	0.762	0.939	0.838
BETA	2.829	3.298	4.301	4.597	5.571	7.661	7.271	6.145	5.633	6.597	3.597	4.553
ALPWI	1.720	2.993	3.168	2.729	2.709	3.974	4.192	3.240	2.385	2.129	2.619	2.119
BETWI	1.147	0.625	0.619	0.698	0.690	0.426	0.386	0.457	0.655	0.779	0.740	0.899
P(W/W)	0.675	0.713	0.636	0.616	0.638	0.567	0.608	0.598	0.630	0.573	0.664	0.703
P(W/D)	0.379	0.334	0.282	0.291	0.311	0.367	0.316	0.388	0.257	0.225	0.360	0.358
ALPHA	0.998	0.928	0.886	0.855	0.842	0.857	0.816	0.849	0.928	0.769	0.958	0.876
BETA	2.540	2.894	3.838	3.939	4.877	6.786	6.736	5.546	4.648	5.378	3.151	3.660
ALPWI	1.882	3.123	3.205	2.915	2.973	3.802	4.083	3.404	2.371	2.234	2.488	2.180
BETWI	1.057	0.617	0.630	0.660	0.620	0.448	0.402	0.439	0.661	0.737	0.750	0.876

MEAN	AMPL.	PARAM	TYPE	COS -FUNCTION
286.814331	12.277670	MAX. TEMP.	DRY	MEAN
0.014472	0.002244	" "	"	C.V.
285.201477	9.381936	" "	WET	MEAN
0.013853	0.001079	" "	"	C.V.
276.935028	8.247754	MIN.	TEMP.	MEAN
0.013845	-0.004359	" "		C.V.
12.596684	10.094308	RADIATION	DRY	MEAN
0.300992	-0.074619	" "	"	C.V.
9.185519	7.359762	" "	WET	MEAN
0.320408	-0.004144	" "	"	C.V.

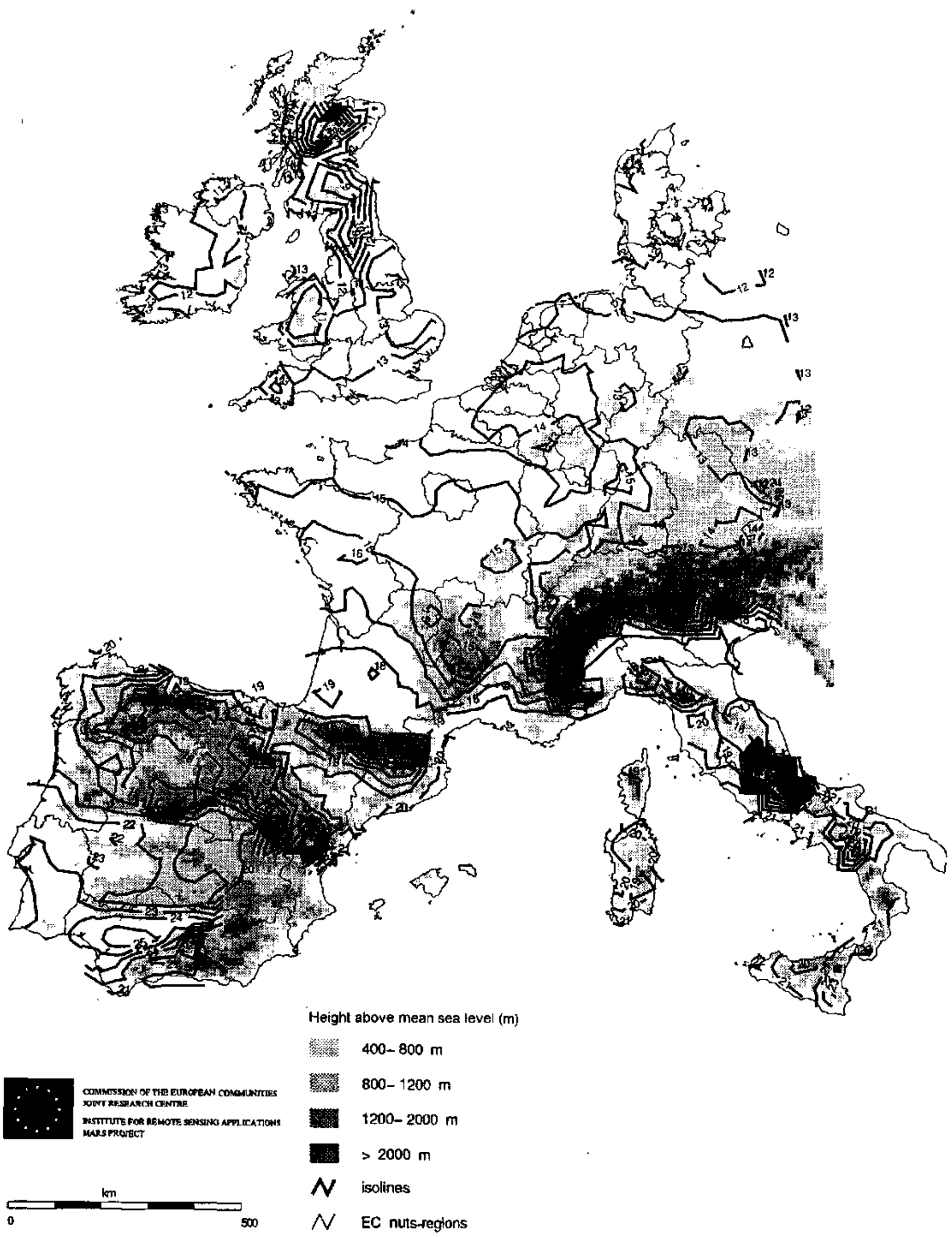

Fig. 11 Yearly average of maximum temperature - dry conditions [°C]

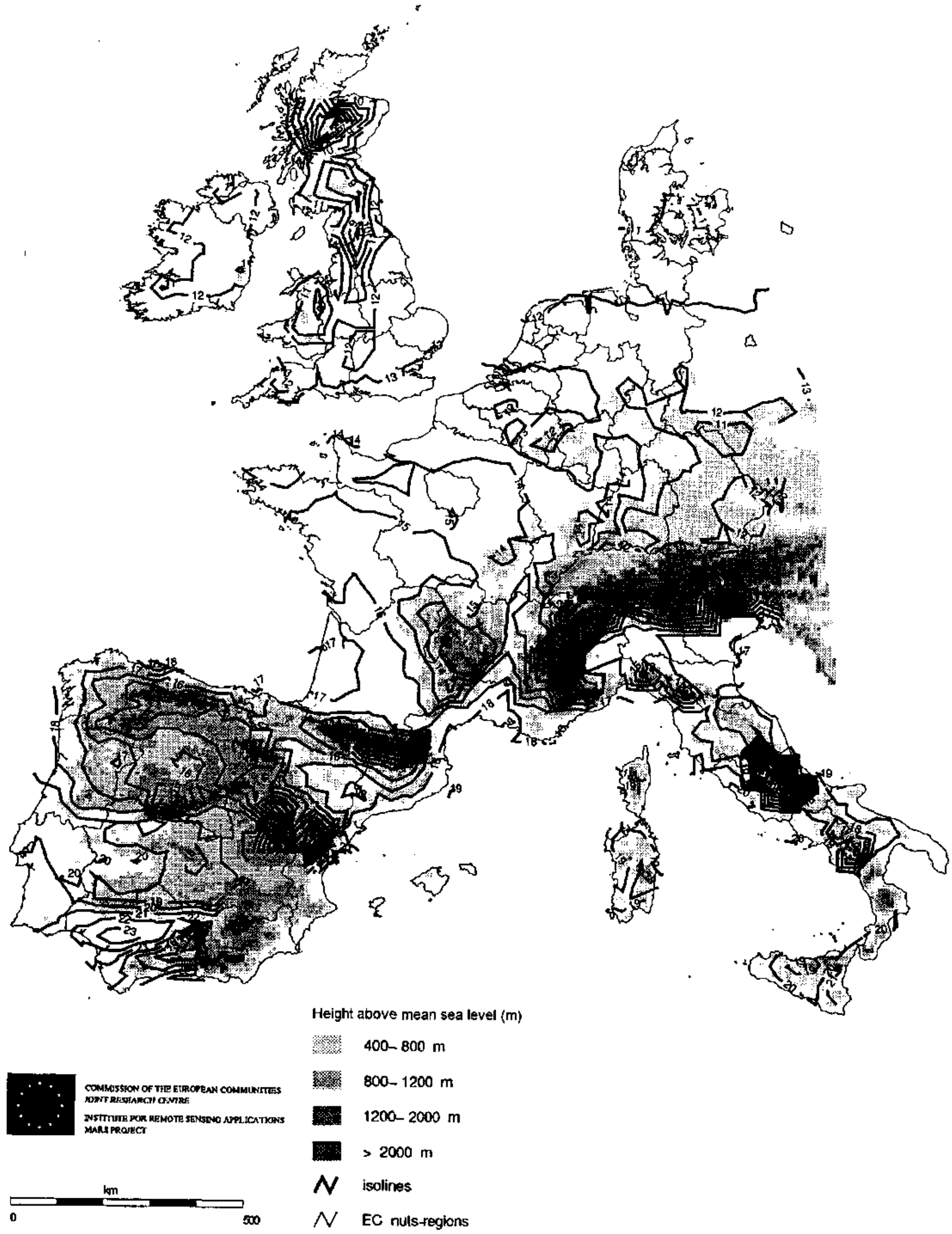

Fig. 12 Yearly average of maximum temperature - wet conditions [°C]

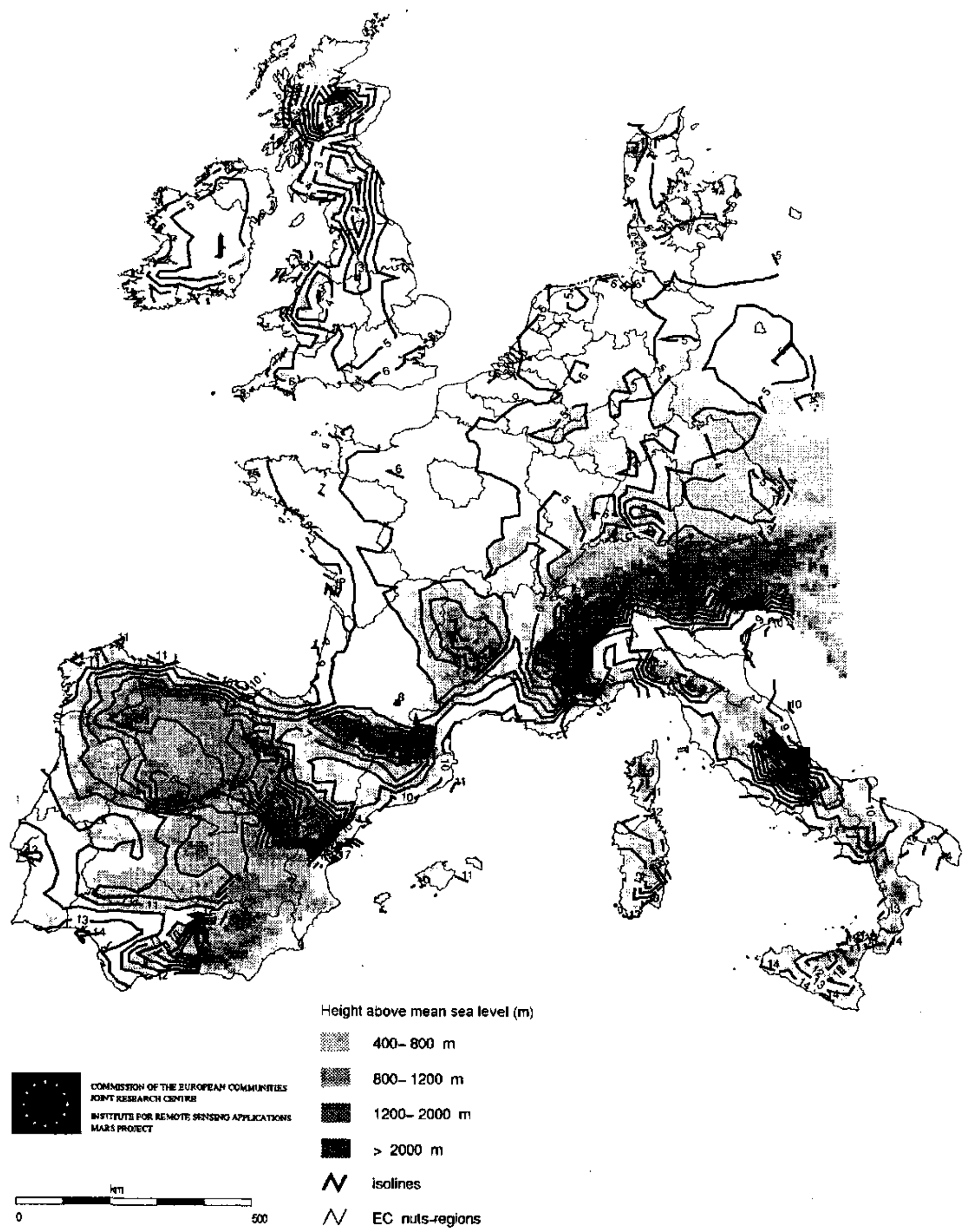

Fig. 13 Yearly average of minimum temperature - normal conditions [°C]

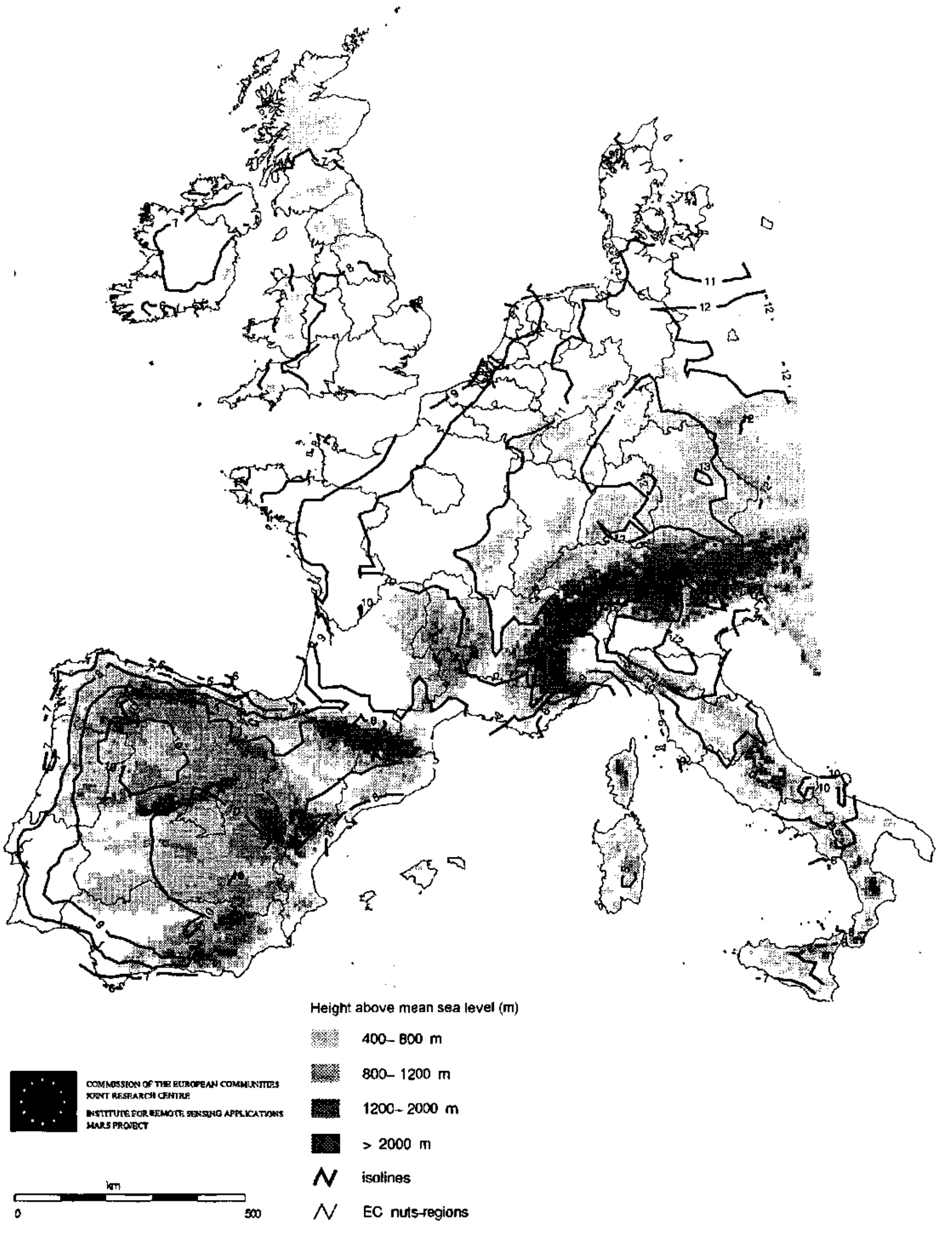

Fig. 14 Amplitude of maximum temperature - dry conditions [°C]

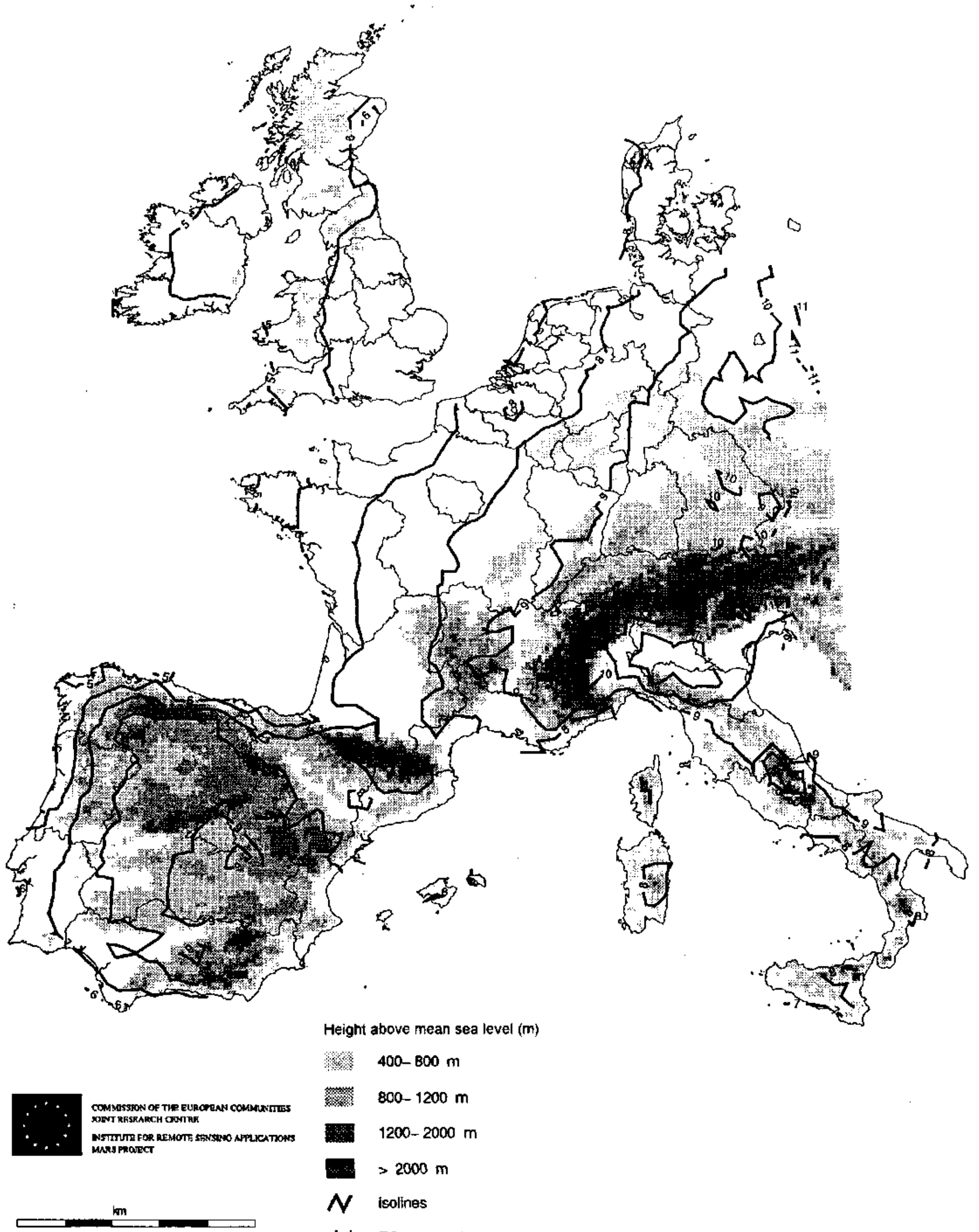

Fig. 15 Amplitude of maximum temperature - wet conditions [°C]

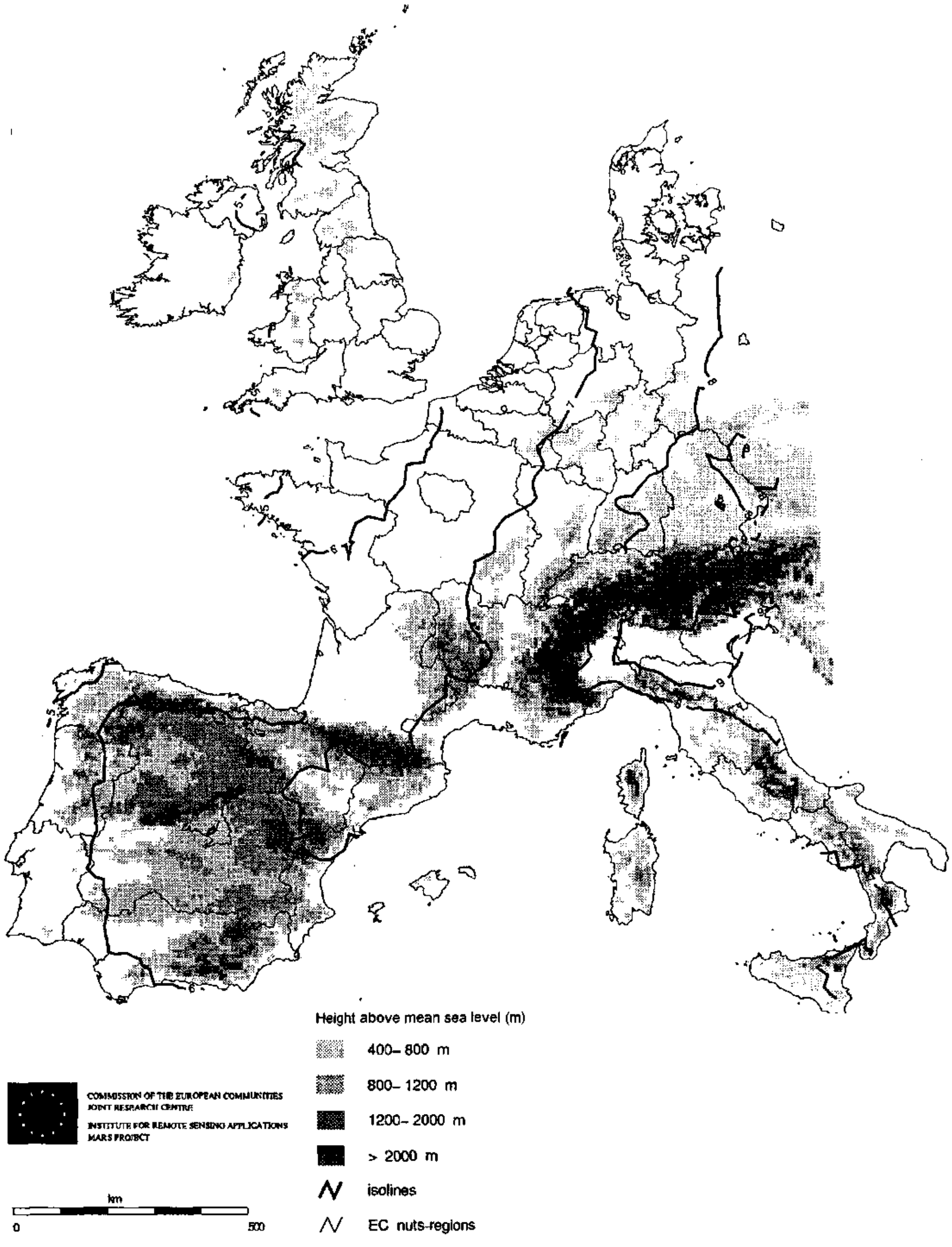

Fig. 16 Amplitude of minimum temperature - normal conditions [°C]

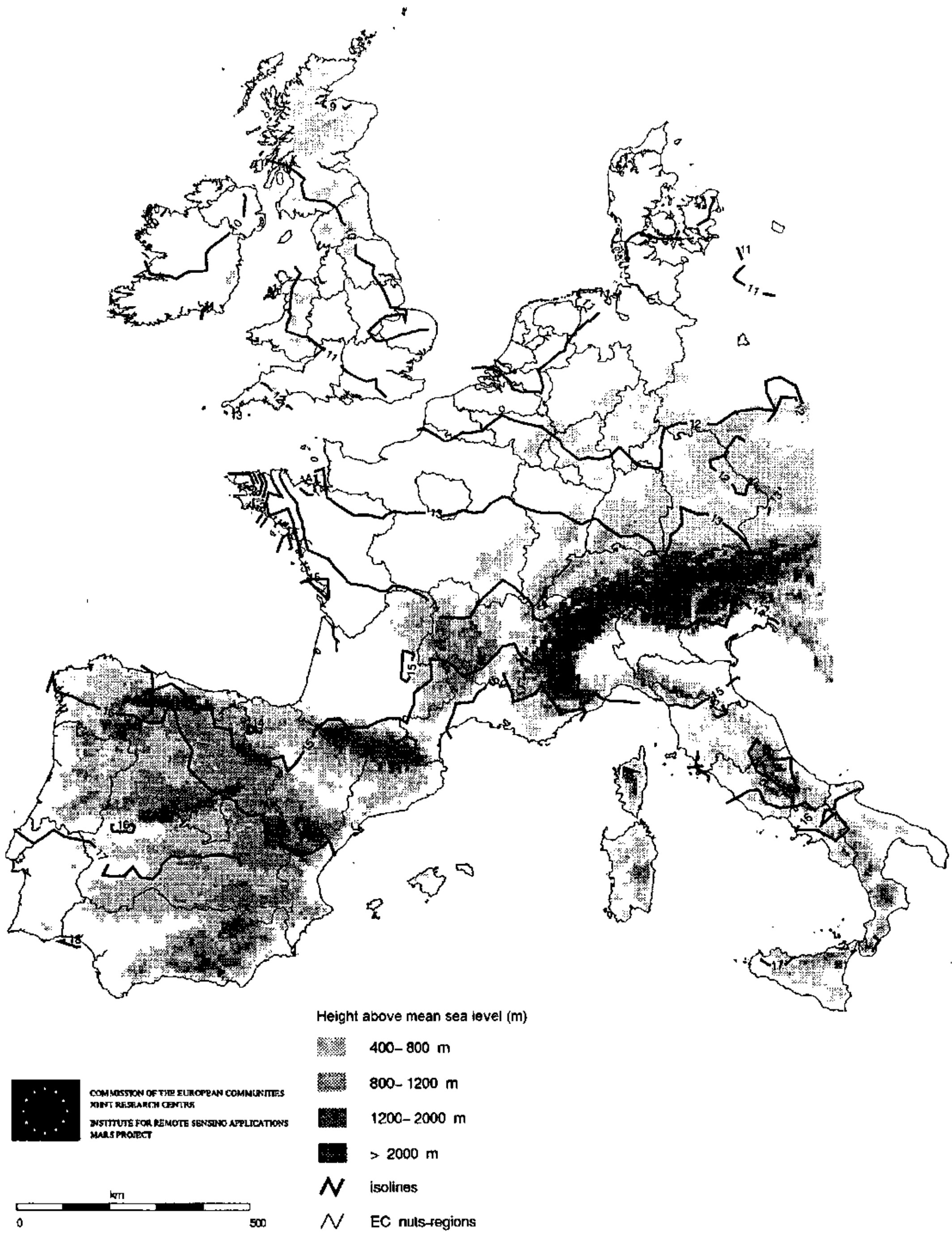

Fig. 17 Yearly average of radiation - dry conditions [MJ $m^{-2}d^{-1}$]

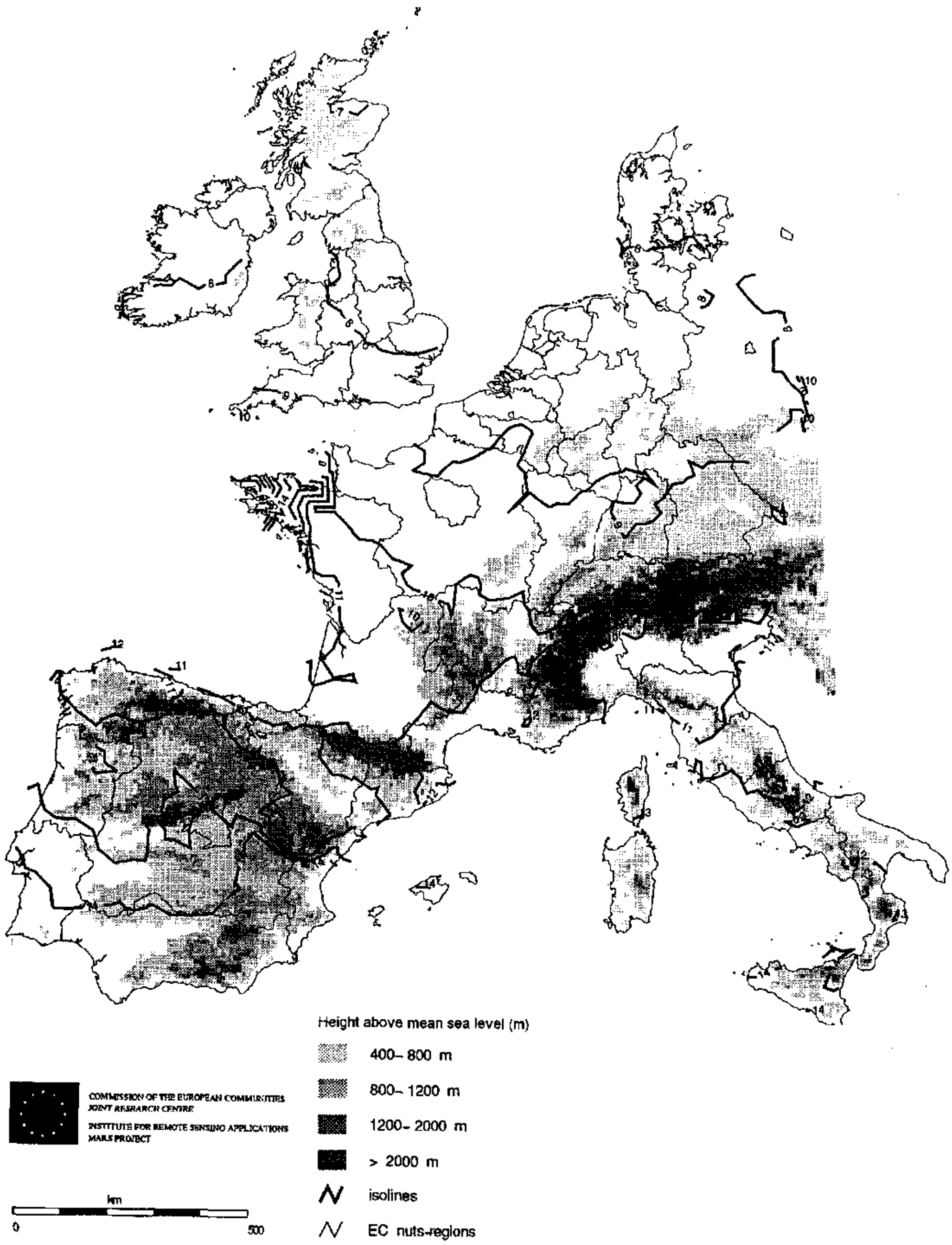

Fig. 18 Yearly average of radiation - wet conditions [MJ $m^{-2}d^{-1}$]

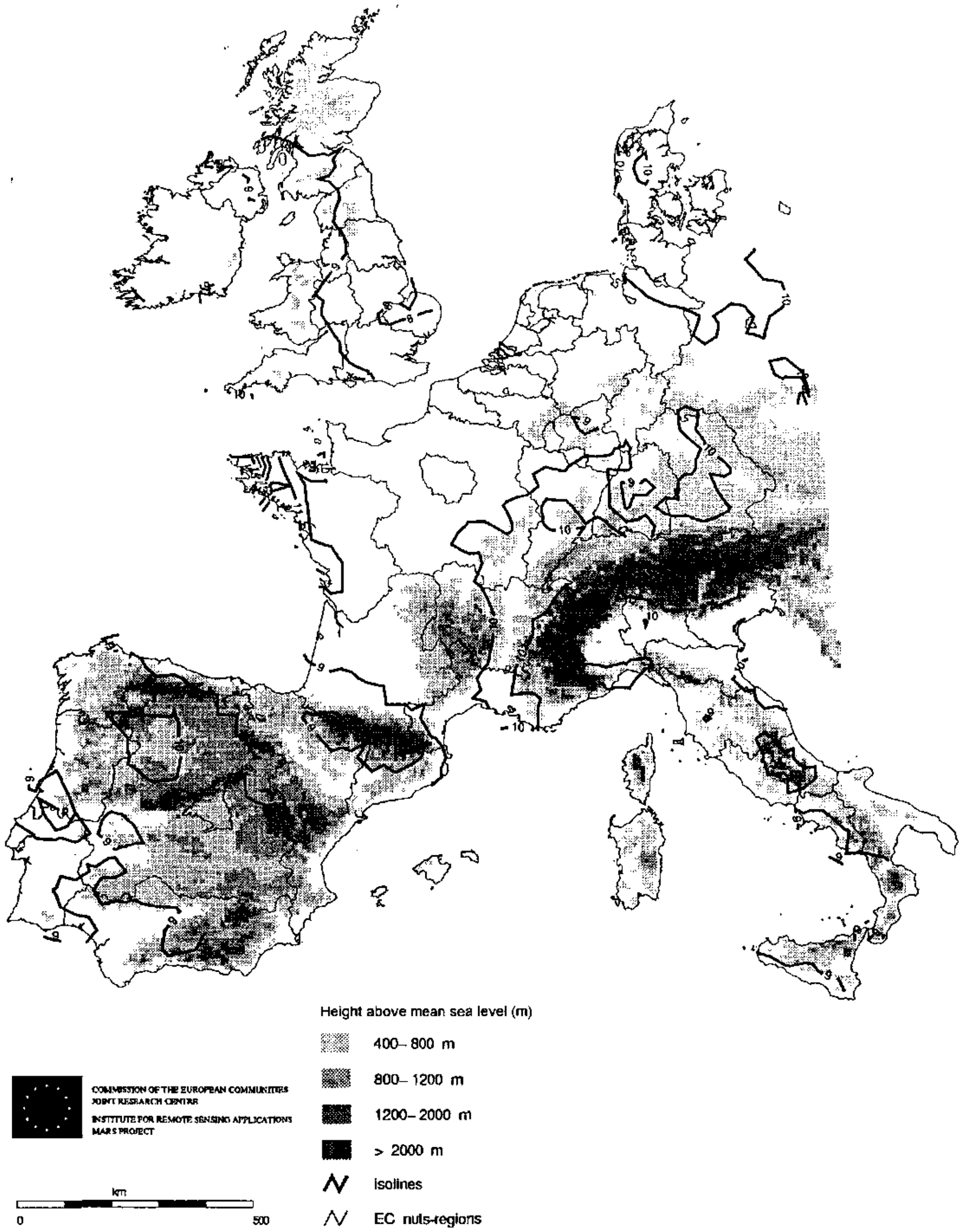

Fig. 19 Amplitude of radiation - dry conditions $[MJ\ m^{-2}d^{-1}]$

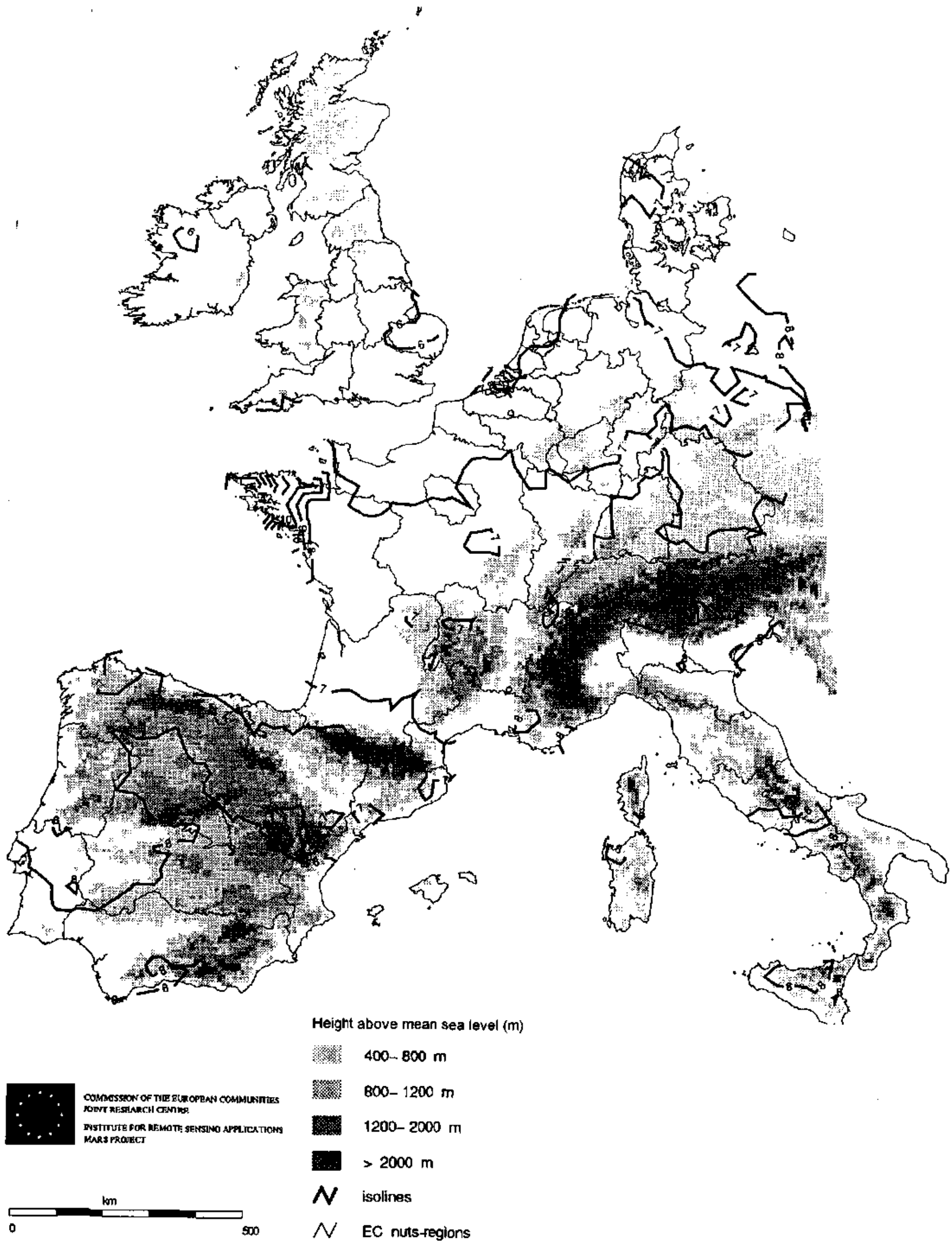

Fig. 20 Amplitude of radiation - wet conditions [MJ $m^{-2}d^{-1}$]

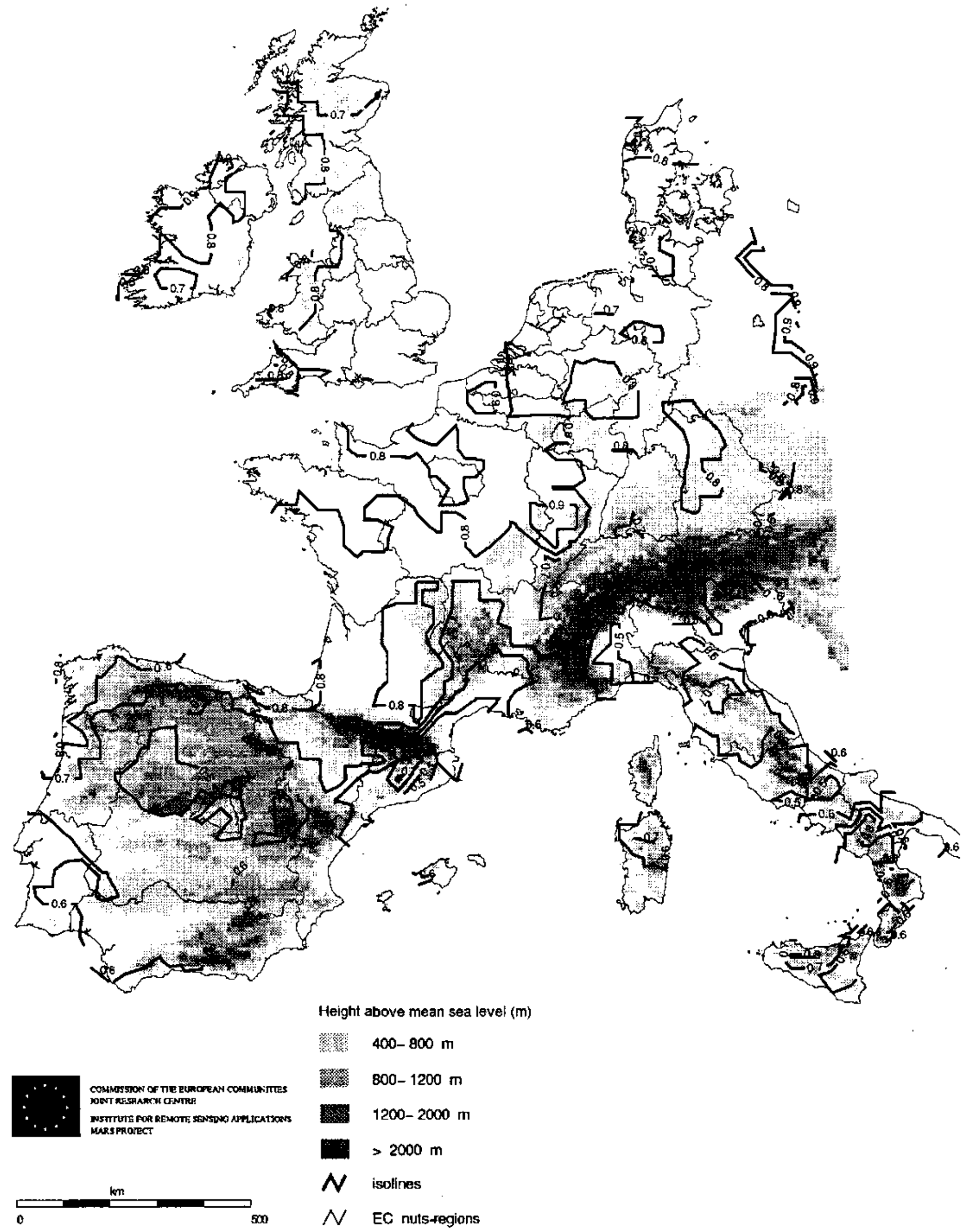

Fig. 21 Shape parameter of rain in January - normal conditions

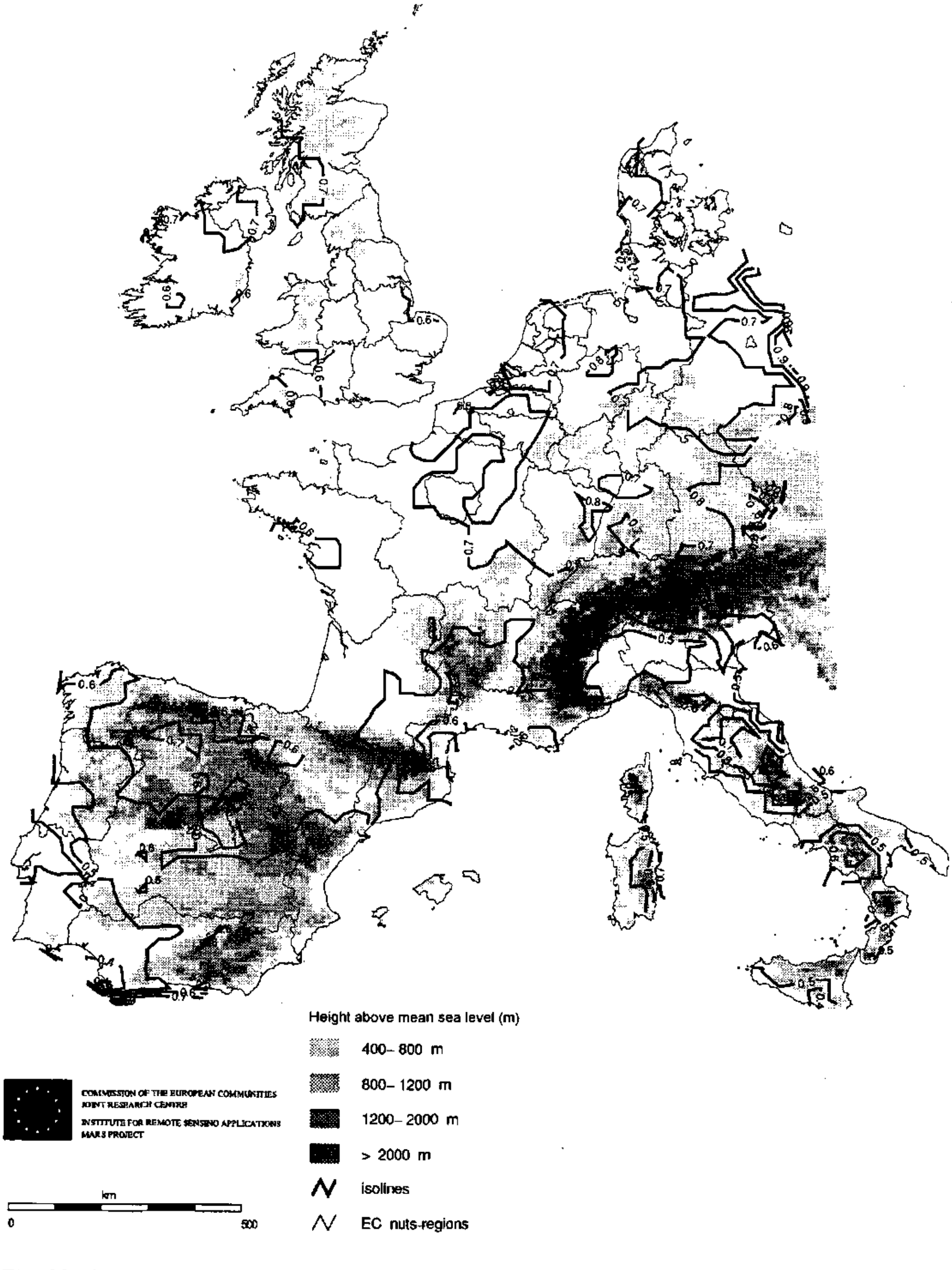

Fig. 22 Shape parameter of rain in July - normal conditions

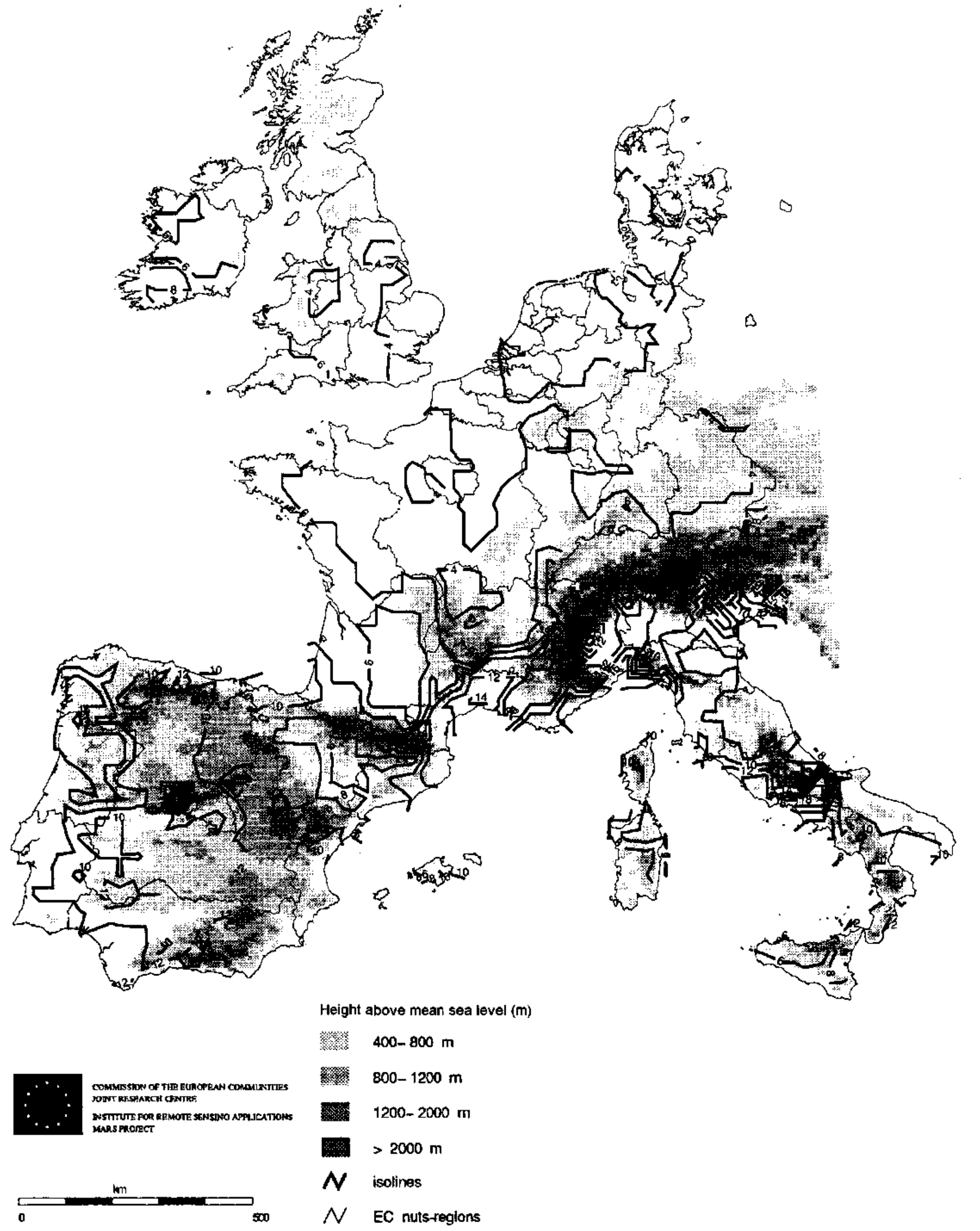

Fig. 23 Scale parameter of rain in January - normal conditions

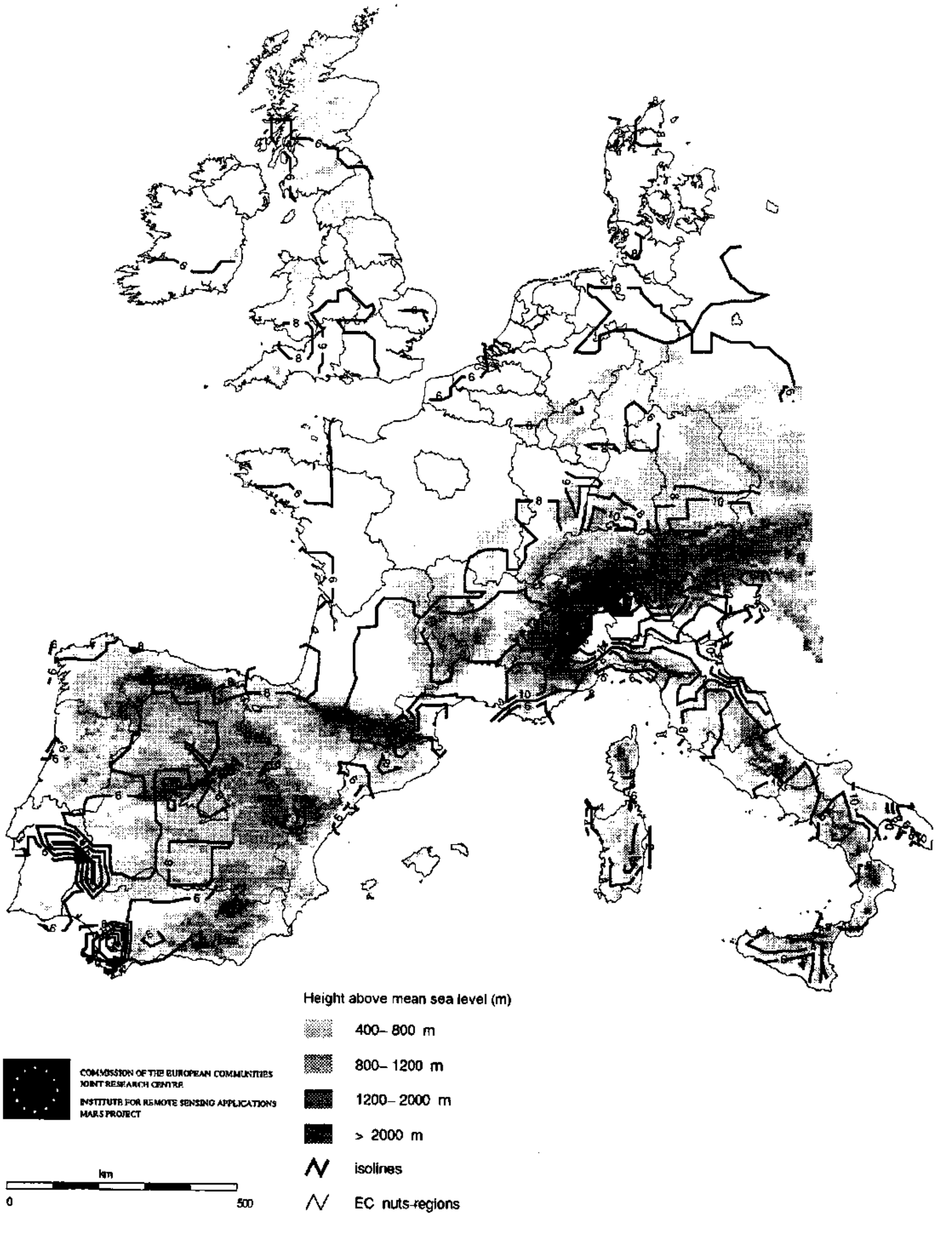

Fig. 24 Scale parameter of rain in July - normal conditions

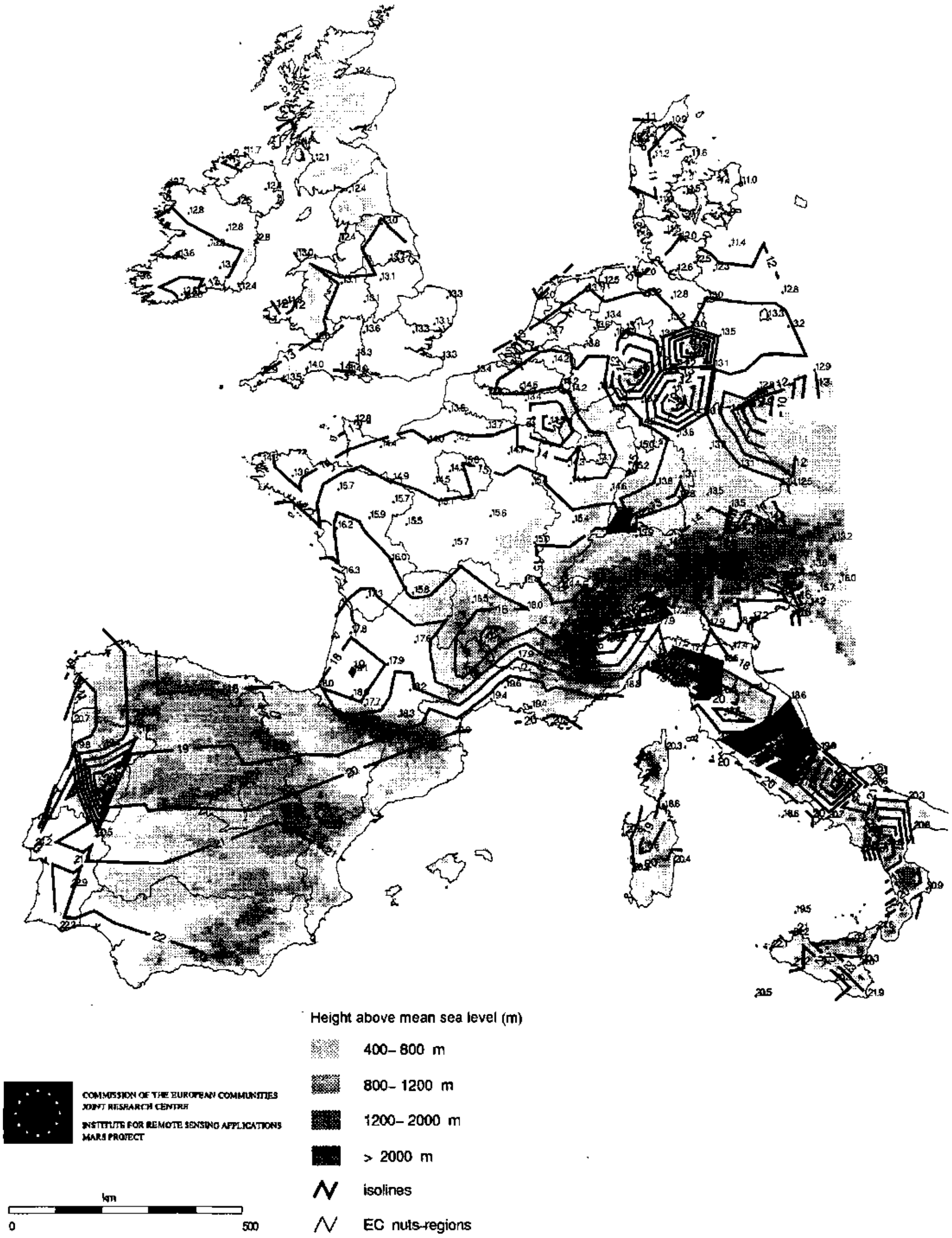

Fig. 25 Distribution of parameter values on weather stations for generating daily synthetic weather. Yearly average of maximum temperature - dry conditions [°C]

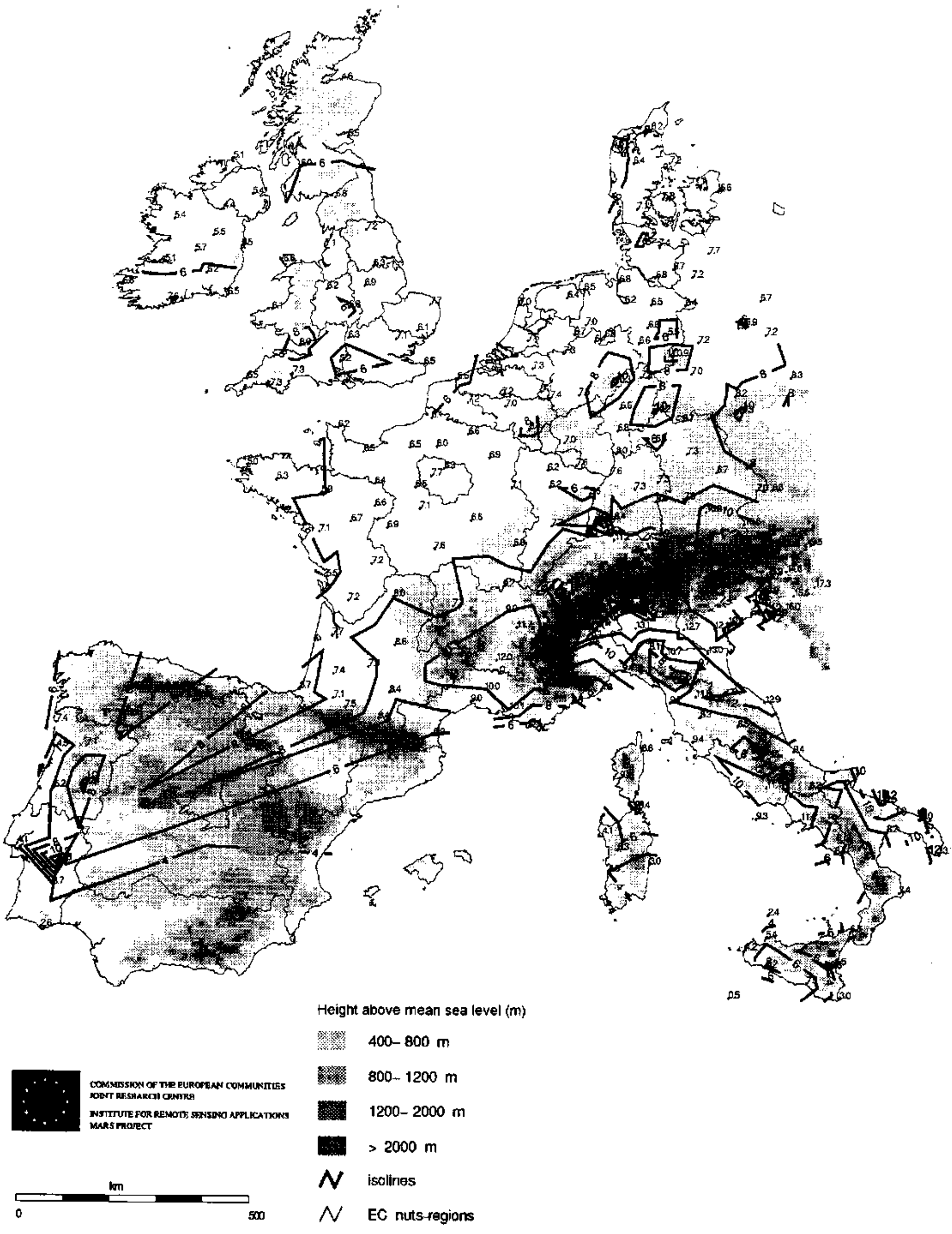

Fig. 26 Distribution of parameter values on weather stations for generating daily synthetic weather. Scale parameter of rain in July - normal conditions

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Guide to the Annexes

Annex 1 contains the user instruction and some technical information of the program **WANAL** (Weather ANALyser). WANAL derives parameter values for the models described in Section 2.1, and writes the results to a parameter file. WANAL could be used directly to estimate parameter values for each of the **stations**. To find these parameter values **on a grid base**, WANAL was adjusted and called **WANALGR** (Weather ANALyser on GRidpoints). Annex 3 contains the user instruction and some technical information of WANALGR. Subsequently, the program **WTHGEN** (WeaTHer GENerator) may read these parameter files and generate several years of synthetic weather. Annex 5 contains the user instructions and some technical information of WTHGEN. on the programmes. To run the above mentioned programs one may use command files. Annexes 2, 4, and 6 show examples of such command files running respectively WANAL, WANALGR, and WTHGEN on a VAX-VMS platform. Annex 7 gives an example of a batch file running WTHGEN on a MS-DOS platform.

To analyse weather on gridpoints, WANALGR needs to know the quality of the weather data on stations. The program MISSFIL gives this information: it produces the file MISPERC.HIS, containin for every station the yearly percentage of missing values for (calculated) radiation, minimum temperature, maximum temperature, wind speed, and rainfall. Annex 8 contains the description of MISSFIL.

The just mentioned file MISPERC.HIS is also used by another program: MKWANA-LL2. This program increases the quality of the output results of the weather analysis on stations with WANAL. It ensures that the first and last year that are analyzed have no more than 10 % of missing values for the variables (calculated) radiation, wind speed, rainfall, minimum and maximum temperature, and humidity. The program checks for the total amount of years that remain to be processed. If the amount of years becomes less than 20, the specific station is not analyzed. Annex 9 contains the program description of MKWANALL2.

The weather that can be generated by WTHGEN can be either in the compact binary DBMETEO output format or in ascii output format. To check the DBMETEO format, the program CONV_TOA offers the possibility to convert a binary file in DBMETEO format to a fixed length ascii file. Annex 10 describes the use of the CONV_TOA program.

Running WANAL produces for each station an output file with weather parameters. With the help of the program POSTPRST these files are converted to output files per weather parameter. The latter files form the basic for further spatial analysis with the GIS Arc/Info. The program POSTPRST2 has the same function as POSTPR-ST, with the exception that POSTPRST produces some normally distributed, while POSTPRST2 gives the gamma distributed equivalents: Normally distributed parameters appeared to be easier to interpret than the gamma distributed equivalents. The programs are described in resp. Annex 11 and 12. Similar programs are used to convert the output on grid-based output files. They are describe in resp. Annex 13 and 14.

The just mentioned output-files per weather parameter are used for further analysis within the GIS Arc/Info. Annex 15 describes how to import these files into the GIS. Next the imported results on gridpoints are localized by relating them to an Arc/Info gridpoint coverage (Annex 16). In Annex 17 and 18 is described how these results on gridpoints can be interpolated to realize interactively specified isolines. These isolines can be visualized creating maps. Annex 19 and 20 describe how to make these maps.

Annex 1 User instruction WANAL

First of all the main routine of the program prompts for the meteo-station to be used:

WMO number of meteo-station => 10763

The quality of the meteo-station is checked by looking for it in a list of stations that are known to contain data of bad quality: if the station is found, then the program stops and a message is given, e.g. for station 16726:

Bad station skipped: 16726

Next the file meteo.inf is opened to read the geographical information of all weather stations known. The program informs on the number of available stations:

Found 360 stations in meteo.inf-file

The latitude of the requested station is found and converted from degrees minutes to decimal degrees.

Next the program prompts for the first and last year to be analyzed:

Starting year: 1956
Last year: 1989

With this information the weather analysis can begin. In the subroutine ANALINP the proposed weather data are read and analyzed. The program opens the station-file wstrefin.his which holds information on where the reference weather for every station is located in the large file with reference weather. If this file cannot be opened the program stops and a message is given:

Error opening index-file: wstrefin.his, check if file exists, if not run EC_ALL

The reference weather file wstref.dat and the DBMETEO-file of the requested station (e.g. w10763.his) are opened.

If the file cannot be opened the program stops and a message is given:

Error opening w10763.his, check if file exists

Next all weather data are read. The weather of the requested years are identified and checked on the occurrence of missing data for the variables radiation, minimum temperature, maximum temperature, wind speed and rainfall. A missing value is tried to be replaced by the reference weather value of that station. Daily (saturated) vapour pressure is calculated from the minimum temperature.

The subroutine LATITU is called to calculate maximum solar radiation for each day as a function of the latitude of the requested station.

Monthly rainfall is calculated and put in a matrix RAIN (month,year).

One monthly line of rainfall data is rearranged in increasing order (of the years).

For every month the number of years with less than mean precipitation are determined.

The monthly values of the table DTOW are expanded to daily values.

The subroutine ANALINP returns to the main program, and the subroutine XSUMA is called. This subroutine calculates the average, mean, standard deviation, standard error and the coefficients of variation of the actual and of the simulated maximum temperature, minimum temperature, solar radiation, rain and wind speed data.

The results are written to a file, e.g. w10763_5689.sma (for an example see Annex 1).

Next XSUMA is ends and the main program opens the output file, e.g. w10763_5689-.par. The main program writes some basic information about the analysis to the file and calls for the subroutine TWGEN. TWGEN estimates the parameters which are used in the generation subroutine TEST (see Annex 5). The estimated parameters are written to the output file, e.g. w10763_5689.par.

The subroutine TWGEN is called by the main program three times, which refers to the determination of respectively 'dry', 'wet' and 'overall' weather parameters.

If the subroutine TWGEN is finished for the third time, the analysis is finished and the program stops with the final message:

**** Climate analysis finished ****

Annex 2 Example of a VAX-VMS command file wanal.com for WANAL

```
$ set def disk1:[bfro.koen.wsim]
$ ! nurnberg
$ run/nodebug wanal
10763
1956
1989
$exit
```

Annex 3 User instruction WANALGR-weather analysis on gridpoints

First of all the main routine of the program informs on the program to the screen:

**** CALCULATION OF THE CLIMATE PARAMETERS ****

Next the program prompts for the first and last year to be analyzed:

Starting year: 1960
Last year: 1989

The program determines the number of available gridpoints in the file grgeo.dat. If no gridpoints are found, the program stops and a message is given:

No gridpoints to process

Otherwise the number of gridpoints is written to the screen:

Found 1212 gridpoints to process

Next a do-loop is started for every grid point.

The latitude of the gridpoint is determined.

With this information the weather analysis can begin. In the subroutine ANALINP the proposed weather data are read and analyzed. Routine STATION_DBM is called to get interpolated weather data per year. In STATION_DBM the file misperc.his is read (once):

READING MISPERC.HIS

This file contains for every station the yearly percentage of missing values per weather variable. It is made by the pre-processing program MISSFIL (see Annex 8).

Next for every year a subset of all available stations is determined: these stations are located within 400 km. from the gridpoint, and have less than 50 % of missing values for (calculated) radiation, as well as minimum temperature, maximum temperature, wind speed, and rainfall. In every year at least one station should fit the above mentioned criteria, if not the year is skipped in further analysis.

Next the subroutine BEST_DBMSTATIONS returns the optimum combination of (maximum 4) stations to be used for the interpolation of weather data on the gridpoint for radiation, temperature, and wind speed. It also returns the optimum station to be used for the substitution of rainfall data. The optimum combination, as well as rainfall station are determined on the base of fixed geographical qualities that have been described in (Van der Voet et al., 1994).

The program writes to the terminal which combination was used:

Used set for grid 307 in the year 1967 is 8562 8557
Used set for grid 307 in the year 1968 is 8562 8557
Used set for grid 307 in the year 1969 is 8562 8557
Used set for grid 307 in the year 1970 is 8554
....
Used set for grid 307 in the year 1988 is 8485
Used set for grid 307 in the year 1989 is 8485

Next STATION_DBM call the subroutine IPOL_DBM to obtain the interpolated daily meteorological data for certain years, up to maximum of 40 years.

In IPOL_DBM the actual reading of DBMETEO data for certain years for a certain weather stations is done in GET_DBM. GET_DBM uses buffer-arrays of data to speed up data retrieval. The first time it opens the station-file wstrefin.his which holds information on where the reference weather for every station is located in the large file with reference weather. If this file cannot be opened the program stops and a message is given:

Error opening station-file: wstrefin.his, check if file exists, if not run EC_ALL.

The first time the reference weather file wstref.his is opened:

OPENING WSTREF.HIS

If the file cannot be opened the program stops and a message is given:

Error opening weather reference file: wstref.his, check if file exists, if not run EC_A-LL.

The DBMETEO-file of the requested station (e.g. w10763.his) is opened.

Next all weather data are read. The weather of the requested years are identified and checked on the occurrence of missing data for the variables radiation, minimum temperature, maximum temperature, wind speed and rainfall.

The missing value is tried to be replaced by the reference weather value of that station. If the station is not found in the station-indexfile wstrefin.his the program stops and a message is given:

Reference data for station 6400 not found.

After GET_DBM has returned the requested station data to IPOL_DBM, IPOL_DBM calculates the means of the station data on temperature, sunshine duration, radiation, wind speed and vapour pressure. Temperature and vapour pressure of the gridpoint are corrected for the altitude of the stations (see Van der Voet et al., 1994). The requested station data on rainfall are assigned to the gridpoint.

STATION_DBM returns the requested weather data on gridpoints from IPOL_DBM to ANALINP.

ANALINP calculates the number of years that can be used in the analysis. If there turn out to be less than 20 years that can be analyzed, no weather parameters are determined, and ANALINP returns to the main program. In the main program the next gridpoint is activated and a message is given:

GRIDPOINT : 817 CANNOT BE ANALYZED DUE TO LACK OF PROPER WEATHER DATA

If there are at least 20 years that can be analyzed, ANALINP
calls for the subroutine LATITU to calculate maximum solar radiation for each day as a function of the latitude of the requested station.

Monthly rainfall is calculated and put in a matrix RAIN(month,year).

One monthly line of rainfall data is rearranged in increasing order (of the years).

For every month the number of years with less than mean precipitation are determined.

The monthly value of table DTOW are expanded to daily values.

The subroutine ANALINP returns to the main program, and the subroutine XSUMA is called. This subroutine calculates the average, mean, standard deviation, standard error and the coefficients of variation of the actual and of the simulated maximum temperature, minimum temperature, solar radiation, rain and wind speed data.

The results are written to a file, e.g. w0307_6789.sma.

Next XSUMA is left and the main program opens the output file, e.g. w0307_6789.-par. The main program writes some basic information about the analysis to the file and calls for the subroutine TWGEN. TWGEN estimates the parameters which are used in the generation subroutine TEST (see Annex 5). The estimated parameters are written to the output file. e.g. w0307_6789.par.

The subroutine TWGEN is called by the main program three times, which is referring to the determination of respectively "dry", "wet" and "overall" weather parameters.

If the subroutine TWGEN is finished for the third time, the analysis of the gridpoint is finished and the output-file is closed. A message is given to the screen:

Processed gridpoint : 0307   Done :   0.1 %

The program continues with the next gridpoint. If the last gridpoint is finished the program stops with the final message:

*** *Climate analysis finished* ***

Annex 4 Example of a VAX-VMS command file wanalgr.com for wanalgr

```
$set def [bfro.koen.wsim]
$run/nodebug wanalgr
1960
1989
$exit
```

Annex 5 User instructions WTHGEN to generate weather

First of all the main routine of the program informs about the program to the screen:

*** *WEATHER GENERATION* ***

Next the program prompts for the file with weather parameters to be used in the weather generation.

Name of the INPUT FILE : w10763_5689.par

The program prompts for the first year to be generated:

STARTING YEAR (optional for output): 3000

Next the latitude of the location is asked for:

LATITUDE (degr.min.:) 49.30

Then the program offers the choice between a random or fixed sequence (see SUPIT, 1986).

'Fixed RANDOM SEED SEQ. (0=YES;1=NO): ' 0

This is followed by the number of years that have to be generated:

How many years have to be generated: 30

Next, one can choose between either DBMETEO or ascii output format for the generated weather:

DBMETEO output format? (0=ascii;1=dbmeteo): 1

Next one should specify for every month of the year if either dry, wet or normal weather has to be generated:

TYPE of weather to be generated each month:
1=DRY 2=WET 3=NORMAL

JAN. 3
FEB. 3
MAR 3
APR. 3
MAY. 3
JUN. 3
JUL. 3
AUG. 3
SEP. 3
OCT. 3
NOV. 3
DEC. 3

Finally the program asks if everything is correct and generation should start:

Everything correct ? (Y,N): y

If the last question is not answered with Y or y, one should answer all questions again. Otherwise the program opens the specified parameter-file, and reads all weather parameters. Next the subroutine LATITU is called. LATITU returns the maximum solar radiation for each day for the specified location.
This is followed by a call to subroutine TEST. In TEST the generation of daily weather data is organised (for a maximum of 55 years). The output files are opened and named in relation to the output format that has been specified. (***.wth or ***-.dbm for respectively ascii or dbmeteo-format, e.g. w10763_5689.dbm). The algorithm to generate the daily weather variables is described in Chapter 2.
Vapour pressure is calculated on the base of the minimum temperature. It is checked whether a year is a leap year. In that case the generated values of the 28th of February are copied to the 29th of February, and the number of days in that year is increased to 366. All generated value are written to the specified output-file. This file is closed and the routine returns to the main program.

The main program calls XSUMG. This subroutine calculates the average, mean, standard deviation, standard error and the coefficients of variation of the actual and of the simulated maximum temperature, minimum temperature, solar radiation, rain and wind speed data. The results are written to a file named 'inpnam'.smg, e.g. w10763_5689.smg.

Finally the program stops with the message:

**** Weather generation completed ****

Annex 6 Example of a VAX-VMS command file wthgen.com

```
$set verify
$ set def disk1:[bfro.koen.wsim]
$ Nurnberg
$ run/nodebug wthgen
w10763_5689.par
3000
49.30
0
30
1
3
3
3
3
3
3
3
3
3
3
3
3
y
$set noverify
```

Annex 7 Example of a MS-DOS bat-file wthgen.bat for wthgen

wthgen < wthgen.dat

with wthgen.dat as follows:

```
w06447.par
3000
52.06
1
30
0
3
3
3
3
3
3
3
3
3
3
3
3
y
```

Annex 8 Description MISSFIL

MISSFIL is a preprocessing program of WANALGR; it produces the file MISPERC.-HIS. This file contains for every station the yearly percentage of missing values for (calculated) radiation, minimum temperature, maximum temperature, wind speed, and rainfall. The program opens the file wstin.his, which should be located in the directory specified in the file FILENAMES.DAT (see the IPOLIB library made by Sterling, 1992).

From wstin.his is read for all available stations the first and last year with weather data.

Next a loop over the stations is started. For every station the corresponding DBME-TEO file is opened, and all weather data are read for all the available years. For every year the number of missing values per weather variable are determined. Finally the percentage of missing values per year are calculated. As mentioned before the results are written to the file MISPERC.HIS, which location is specified in the file FILENAMES.DAT as well.

Every time a station is finished, a message is given to the screen:

Determined number of missing values of station : 10763 Done: 10 %

Annex 9 Program description MKWANALL2

MKWANALL2 is a preprocessing program for WANAL to increase the quality of the output results of the weather analysis. The program checks for the occurrence of missing values in the first and last year for every station to be processed in the (VAX/VMS) command-file WANAL.COM. It produces a new command-file WANALL2.COM to run WANAL, with the first and last year having no more than 10 % of missing values for the variables (calculated) radiation, wind speed, rainfall, minimum and maximum temperature, and humidity. It uses the file MISPERC.HIS (see Annex 8) to determine for all available stations the percentage of missing values per year. The program checks for the total amount of years that remain to be processed. If the amount of years becomes less than 20, the specific station is skipped in the new command-file WANALL2.COM.

Annex 10 Program description CONV_TOA

CONV_TOA is a postprocessing program of wthgen. It converts a binary file in DBMETEO format to a fixed length ascii file. The program prompts for the binary file to be converted:

INPUTNAME BIN. FILE (e.g. w07110_5191.dbm) =>

The program attempts to open this file (if needed, the directory path should be included). Next the output file with the extension asc is opened and a message to the screen is given:

Opening outputfile: w07110_5191.asc

Next the conversion takes place, the ascii file is filled, and a message given to the screen for every 2000 records that are written:

2000 records written
4000 records written

etc.

Finally a message is given after the program is finished:

****** END PROGRAM ******

Annex 11 Description of POSTPRST

POSTPRST is a postprocessing program of WANAL. It converts the output of WANAL which is structured in parameter-files for each station into an output for each weather parameter. As an input a file named help.log should be present, listing all available parameter-files per station. This file can be made by system commands (e.g. the vms command: dir /out=help.log *.par).

The program starts a loop for all available stations, and reads all weather parameters into per station indexed arrays. If all station are processed, the output files per weather parameter are filled. These files get the extension .spr. The following 20 files are produced: meancos.spr, amplcos.spr, drypww.spr, drypwd.spr, drymnrai.spr, drysdrai.spr, drymnwin.spr, drysdwin.spr, wetpww.spr, wetpwd.spr, wetmnrai.spr, wetsdrai.spr, wetmnwin.spr, wetsdwin.spr, nrmpww.spr, nrmpwd.spr, nrmmnrai.spr, nrmsdrai.spr, nrmmnwin.spr, and nrmsdwin.spr.

For rainfall and wind speed the alpha and beta parameters of the gamma-distribution are converted into mean and standard deviation of a normal distribution:

mean = $\alpha * \beta$
s.d. = sqrt ($\alpha * \beta$)

Annex 12 Description of POSTPRST2

This program is doing the same as postprst, but it does not convert α and β parameters into mean and standard deviation. it produces the following 20 output files: meancos.Spr, amplcos.spr, drypww.spr, drypwd.spr, dryalrai.spr, dryberai.spr, dryalwin.spr, drybewin.spr, wetpww.spr, wetpwd.spr, wetalrai.spr, wetberai.spr, wetalwin.spr, wetbewin.spr, nrmpww.spr, nrmpwd.spr, nrmalrai.spr, nrmberai.spr, nrmalwin.spr, and nrmbewin.spr.

Annex 13 Description of POSTPRGR

This program works the same as postprst, but it converts grid-based output files of WANALGR. It uses as an input a file gridfiles.par, and produces the following 20 output files:
meancos.gpr, amplcos.gpr, drypww.gpr, drypwd.gpr, drymnrai.gpr, drysdrai.gpr, drymnwin.gpr, drysdwin.gpr, wetpww.gpr, wetpwd.gpr, wetmnrai.gpr, wetsdrai.gpr, wetmnwin.gpr, wetsdwin.gpr, nrmpww.gpr, nrmpwd.gpr, nrmmnrai.gpr, nrmsdrai.gpr, nrmmnwin.gpr, and nrmsdwin.gpr.

Annex 14 Description of POSTPRGR2

This program works the same as postprst2, but it converts grid-based output files of WANALGR. It uses as an input a file gridfiles.par, and produces the following 20 output files:

meancos.gpr, amplcos.gpr, drypww.gpr, drypwd.gpr, dryalrai.gpr, dryberai.gpr, dryalwin.gpr, drybewin.gpr, wetpww.gpr, wetpwd.gpr, wetalrai.gpr, wetberai.gpr, wetalwin-.gpr, wetbewin.gpr, nrmpww.gpr, nrmpwd.gpr, nrmalrai.gpr, nrmberai.gpr, nrmalwin.-gpr, and nrmbewin.gpr.

Annex 15 Description of GR_PARIN.CMI AND ST_PARIN.CMI

These info-command programs are importing the above mentioned weather parameter files for stations or grids (respectively with the extension ".spr" and ".gpr") into the arc/info database. The cmi-programs should be located in the info directory, and are started from the info prompt, e.g. :

info> comi st_parin.cmi

Earlier versions of the weather parameter files in the info database are deleted, and the ascii files located on the working-directory of the arc/info database, are imported into the info database. The parameter files within the info-database receive the same name as the original files.

Annex 16 Description of MK_GRIDBASE.AML

This Arc/Info program produces a grid-label coverage only for those labelpoints that can be related to records in one of the *.gpr parameter files; this means that only those labels are preserved for which weather parameters have been calculated.
The program uses as an input point coverage wnlgrd, which contains all of the gridpoint labels. As a result a gridpoint coverage named base with the item grid-code is produced.

Annex 17 Description of MAKEISO.AML

This Arc/Info program produces isolines on the base of the weather parameter values of gridpoints. The program needs the following arguments:

<cover> indicating the name of the output line cover that receives the isolines
<wfile> indicating the name of the weather parameter file with the calculated parameter values on gridpoints
<witem> indicating the name of the item from the weather parameter file
<start> the lowest value for which an isoline has to be calculated
<step> the interval between the isolines.

Moreover the program needs the gridpoint coverage base to locate the calculated parameter values, and a clipcoverage clipbase that will be used to clip the isolines into an area for which the isolines show a realistic view. The interpolation method to be used is part of the arc/info software and is described in Section 2.2.2. No smoothing factor has been used, to keep the interpolation mathematically as good as possible.

Annex 18 Description of RUNMAKEISO.AML

This Arc/Info program is used to run the makeiso program. For every weather parameter for which a pattern of isolines is requested, it contains one record with the proper arguments.

e.g.:

&run makeiso.aml mtmxwetm meancos.gpr tmxwetm -4 4

produces isolines for the mean value of the maximum temperature in wet conditions; isolines will be calculated with a lowest value of -4 for every 4 degrees Celsius.

Annex 19 Description of PLOTISO.AML

This Arc/Info program creates a plot of grid-based isolines and optionally of station based point using specified arguments for a certain weather parameter. The program requires the following arguments:

<cover> indicating the name of the grid based isoline cover to be plotted; the plotfile receives the name of the cover
<wfile> indicating the name of the station based weather parameter file with the calculated parameter values
<witem> indicating the name of the item from the station based weather parameter file

Annex 20 Description of RUNPLOTISO.AML

This Arc/Info program is used to run the plotiso program. For every weather parameter to be plotted, it contains one record with the proper arguments.

e.g.:

```
&run plotiso.aml mtmxwetm meancos.spr tmxwetm
```

It produces a plotfile with the grid based isolines for the mean value of the maximum temperature in wet conditions. Optionally the station based point values are added to the plotfile.