Report of the

Personal Service Agreement

From

15/9/2004

To

31/10/2004

by Dr. Jürgen Grieser

Introduction

The main aim of this contract was the calculation of potential evapotranspiration (PET) based on the actual data within the climatological data base of the Agromet Group of FAO/SDRN.

The work as well as this report is subdivided in the following sections

1.) The database and calculation of PET
This part of the report is linked to the topic of data availability and quality.

2.) New LocClim
Preparation of 8 variable-based files providing climatological information for all stations where the respective variable is observed. Related to this topic are minor changes to New LocClim and the generation of a binary format in order to effectively store and handle the data.

3.) New ClimWat
Preparation of at least 5000 station based files providing climatological information in a format readable by the programs Cropwat and Climwat, and reprogramming of Climwat.

4.) Recommendations on future developments
Here some recommendations are given about possibilities of further development.

1. The database and calculation of PET

Potential evapotranspiration (PET) describes the evaporation of a grassland surface under well defined restrictions. Evapotranspiration is a flux of water from the Earth surface into the atmosphere. It is linked to a latent heat transfer and thus can be estimated from the energy budget of the surface. This energy budget itself depends on the radiation budget, wind speed, water vapor saturation deficit and soil heat flux. Here Penman-Monteith Equation is used in order to estimate PET from observed meteorological variables. The necessary variables are

- Monthly mean of daily maximum temperature [°C],
- Monthly mean of daily minimum temperature [°C],
- Monthly mean wind speed [m/s],
- Monthly mean water vapor pressure [hPa], and
- Monthly mean solar radiation [$MJ/m^2/d$].
- Sunshine fraction

Some of these variables are not available at all stations within the database. However, in some cases they can be drawn from one ore more other variables, e.g. solar radiation from sunshine fraction.

In a first step the development of the Agromet data base since September 2001 is investigated. Results are shown in Table 1, subdivided by continents and variables. It can clearly be seen from Table 1 that the amount of water vapor and wind speed data has increased considerably. These have been the variables which limited the calculation of PET for years.

Table 1: Number of stations per continent and variable within the Agromet database in October 2004 (upper numbers) and September 2001 (lower numbers) as well as absolute and relative changes (last column).

	Africa	America	Antarctica	Asia	Europe	Oceania	Total	Change
Temp.	4921 4887	11851 11726	42 37	2556 2504	1346 1246	606 572	21322 20972	+350 +1.7%
Tmax	1376 1304	7334 7190	2 0	1975 1883	1096 754	554 410	12337 11541	+796 +6.9%
Tmin	1372 1302	7341 7199	2 0	1975 1882	1095 754	554 410	12339 11547	+792 +6.9%
Prec	6351 6331	14331 14310	25 23	4213 4162	1977 1819	973 921	27870 27566	+304 +1.1%
PET	1044 1044	1455 1455	0 0	1434 1434	283 283	71 71	4284 4284	+0 +0%
Wind	1106 1041	1373 958	2 0	1379 1283	895 487	287 8	5042 3777	+1265 +33.5%
Sun. Frac.	1076 1072	2361 2361	0 0	1229 1228	235 239	236 8	5137 4908	+229 +4.7%
Vapor Pressure	1133 1072	1376 966	6 2	1350 1262	1057 596	322 60	5244 3958	+1286 +32.5%
Total	18379 18050	47422 46165	79 62	16111 15638	7984 6178	3603 2460	93575 88553	+5022 +5.7%

The amount of data available did not only increase but preliminary estimates are changed by more reliable ones (see Table 2). Furthermore the spatial distribution of stations observing all the variables necessary in order to estimate PET has widened considerably from the tropical and subtropical latitudes to the colder regions of the northern hemisphere as well as Australia and New Zealand. The largest remaining gap now is in Kazakhstan.

Table 2: Changes to long term averages in the database since 2001.

	Stations, Sept. 2001	Changed Stations	Changes in %
Temp.	20972	1548	7.38
Tmax	11541	1150	9.96
Tmin	11547	1274	11.03
Prec	27566	1781	6.46
PET	4284	0	0
Wind	3777	614	16.26
Sun. Frac.	4908	0	0
Vapor Pressure	3958	1215	30.7
Total	88553	7582	8.56

In order to use the mean annual cycle (monthly resolution) of the different variables for the calculation of PET it is necessary to avoid months with missing values. However, some of the stations have gaps or rather strange (i.e. definitely wrong) values in the long term monthly averages. The wrong values had to be detected and removed or corrected.

Hundreds of duplicates within the database had to be removed together with the records revealing gaps.

The spatial distribution of the stations of the 8 investigated variables is displayed in the maps of Figure 1 to 8.

Some variables are estimated from the averages of other variables stored in the database. This is the case if

- 2 of the three different temperatures are available,
- Water vapor pressure, relative humidity, or dew point temperature are available and
- Global radiation or sunshine hours are available instead of sunshine fraction.

Water vapor pressure is the main variable for humidity within the database. If it is not available it can be estimated from dew point temperature via Magnus equation.
If dew point temperature is also not available vapor pressure can be estimated from relative humidity and maximum and minimum temperature or relative humidity and mean temperature. The calculation of missing water vapor pressure values is done in this order.

Sunshine fraction is a main variable. With the help of calculated top-of-atmosphere radiation it can be drawn from sunshine hours. Global radiation can be expressed in different units. First of all the different expressions of global radiation are converted to the unit MJ/m2/d. With the assumption of a linear relation between the ratio of top-of-atmosphere radiation to global radiation on the one hand and sunshine fraction on the other hand the regression coefficients (Angström coefficients) can be used to transform global radiation into sunshine fraction.

A summary of the number of averages that could be increased by using respective variables is provided in Table 3.

Table 3: Number of stations available in the data base, drawn from other variables or dropped because of gaps or errors. In case of PET old values are dropped if replaceable by new estimates.

	Now available	Observations within database	Drawn from other variables	Dropped because of gaps or wrong values
Tmax	12351	12337	21	7
Tmin	12350	12339	20	9
Tmean	21604	21322	299	17
Tnight	12350	0	12350	0
Tday	12350	0	12350	0
Sun. Frac.	6637	5137	1501	1
Radiation[MJ/m2/d]	5277	445	4832	0
Radiation [kcal/cm2/d]	5277	4928	349	0
Sun Hrs.	6637	1819	4818	0
Vapor Pressure	7014	5244	1817	47
Rel. Hum.	5727	3124	2603	0
Dew Point	1776	1776	0	0
Wind Speed	5034	5042	0	8
Precipitation	27850	27870	0	20
PET	5378	4284	4342	3248

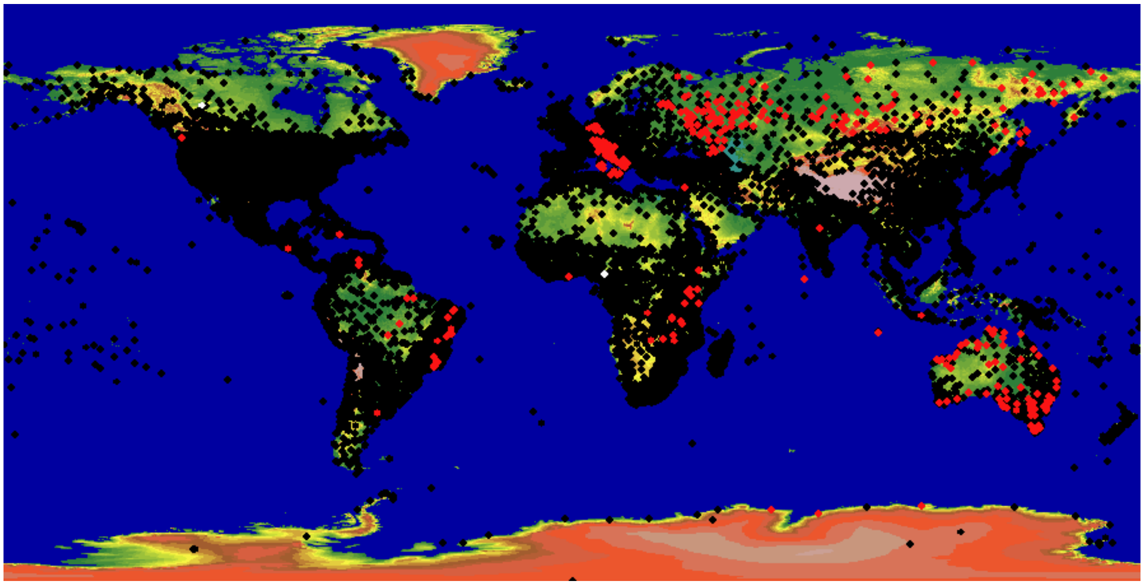

Fig. 1: Spatial distribution of Mean Temperature Observations (black: observations available, white: removed stations, red: calculated from related variables).

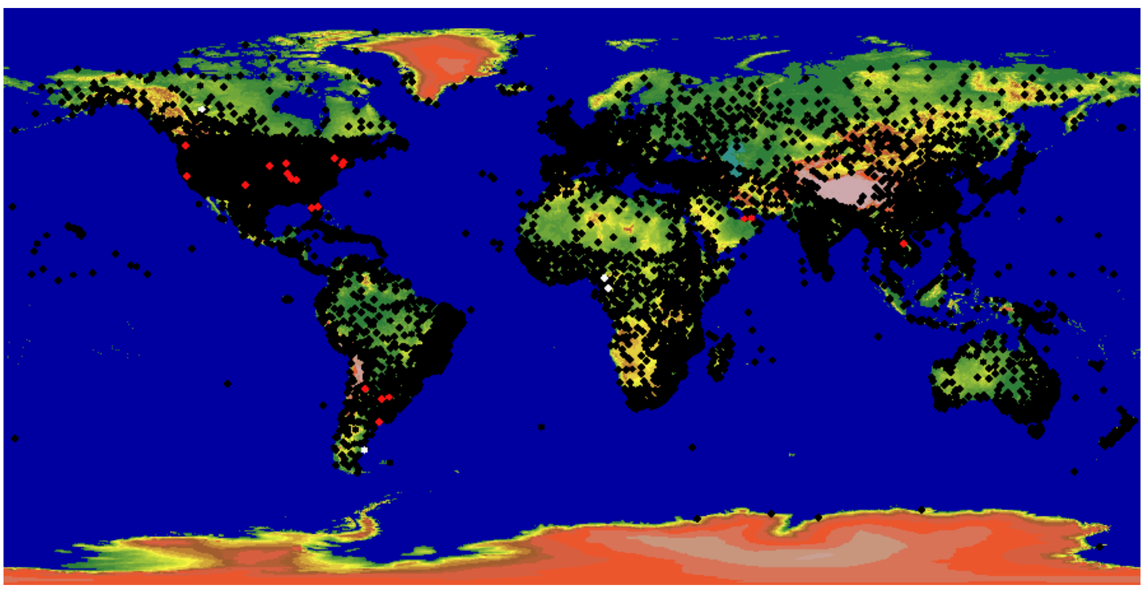

Fig. 2: Spatial distribution of Maximum Temperature Observations (black: observations available, white: removed stations, red: calculated from related variables).

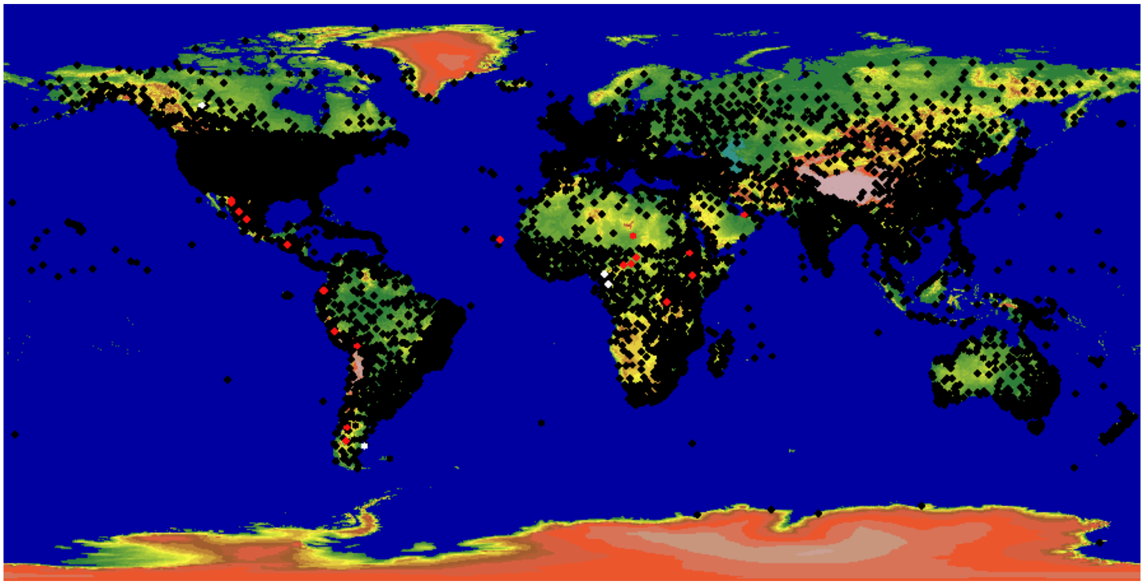

Fig. 3: Spatial distribution of Minimum Temperature Observations (black: observations available, white: removed stations, red: calculated from related variables).

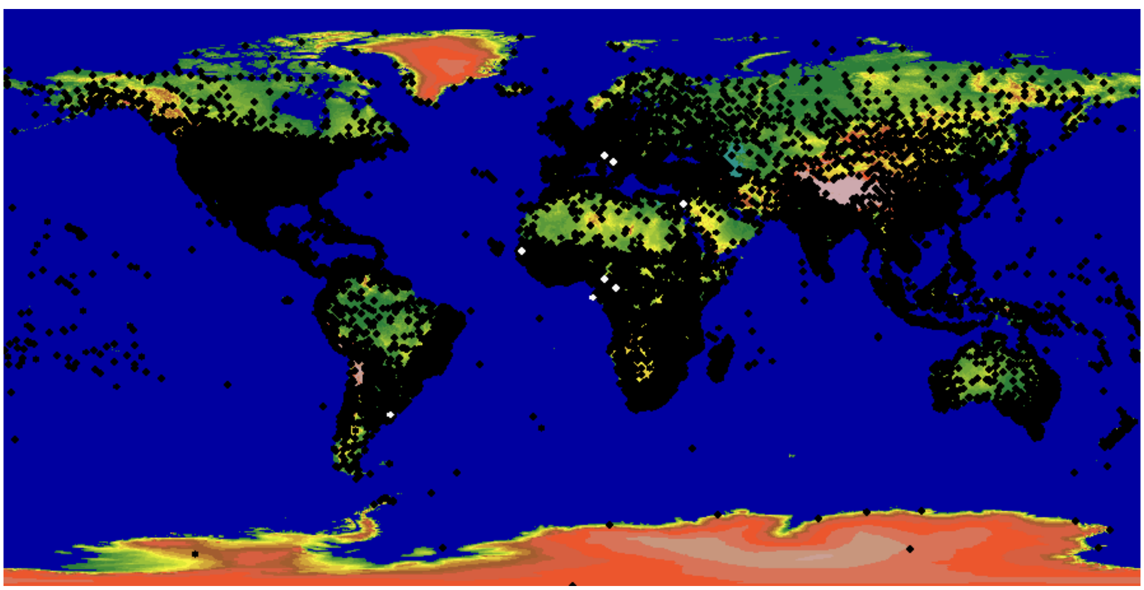

Fig. 4: Spatial distribution of Precipitation Observations (black: observations available, white: removed stations).

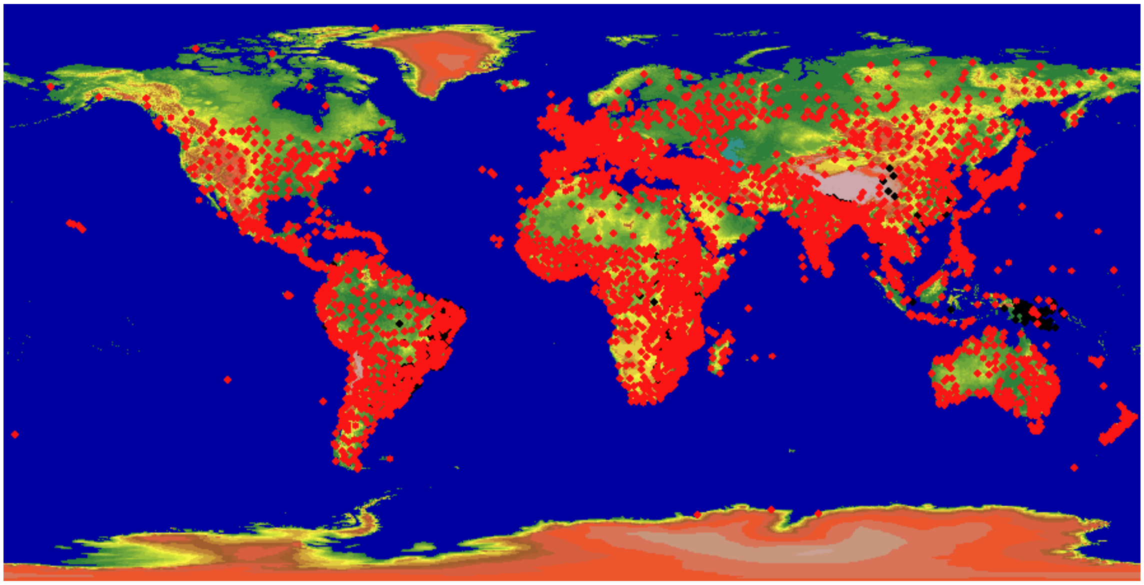

Fig. 5: Spatial distribution of PET Observations (black: observations available, red: calculated via Penman-Monteith Equation).

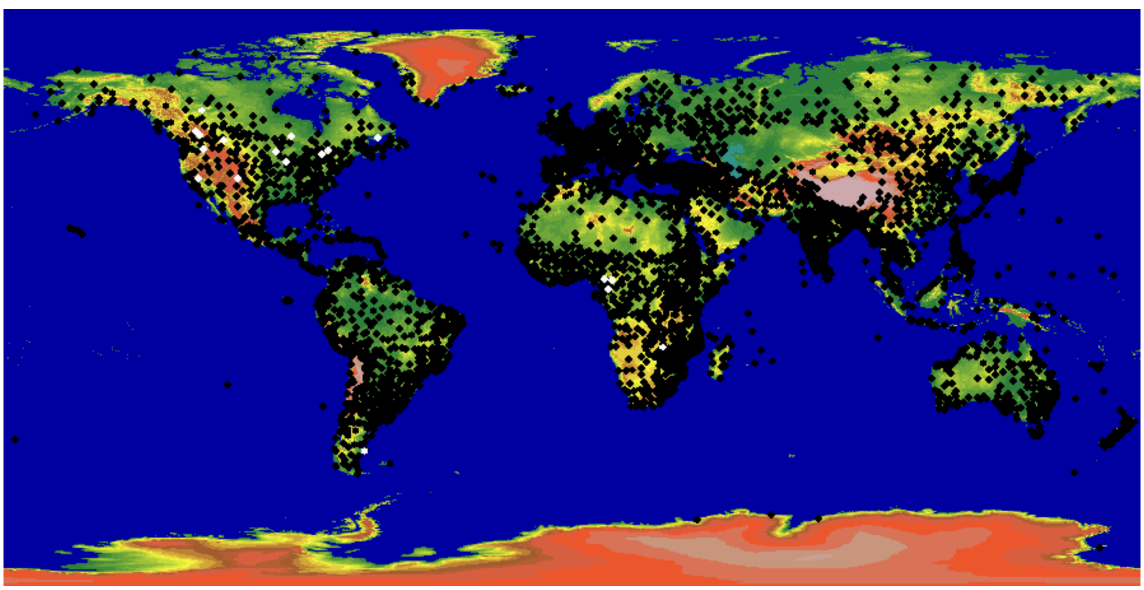

Fig. 6: Spatial distribution of Wind Speed Observations (black: observations available, white: removed stations).

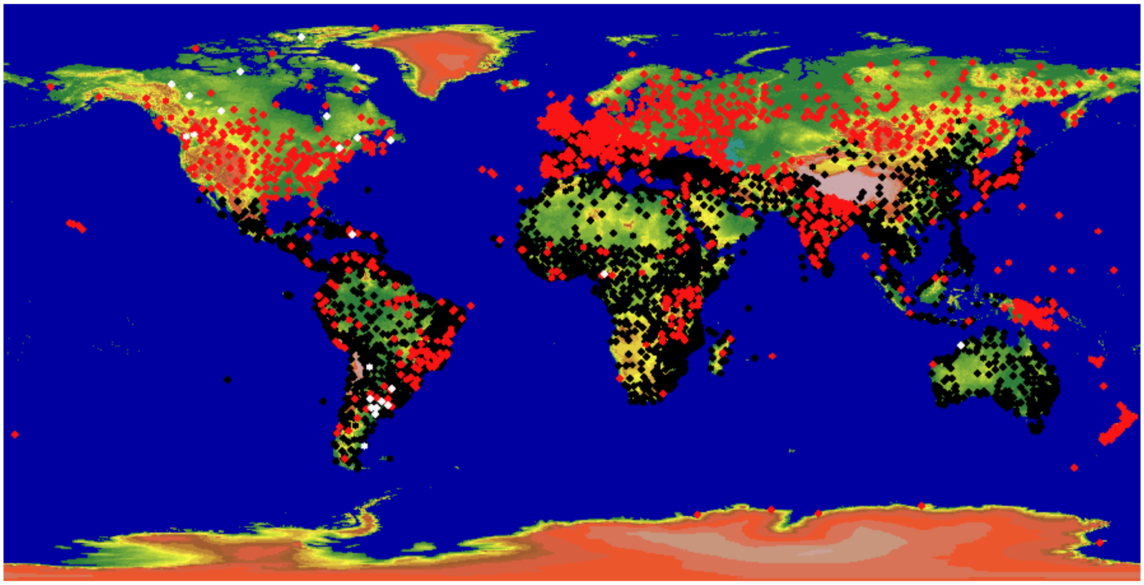

Fig. 7: Spatial distribution of Sunshine Fraction Observations (black: observations available, white: removed stations, red: calculated from related variables).

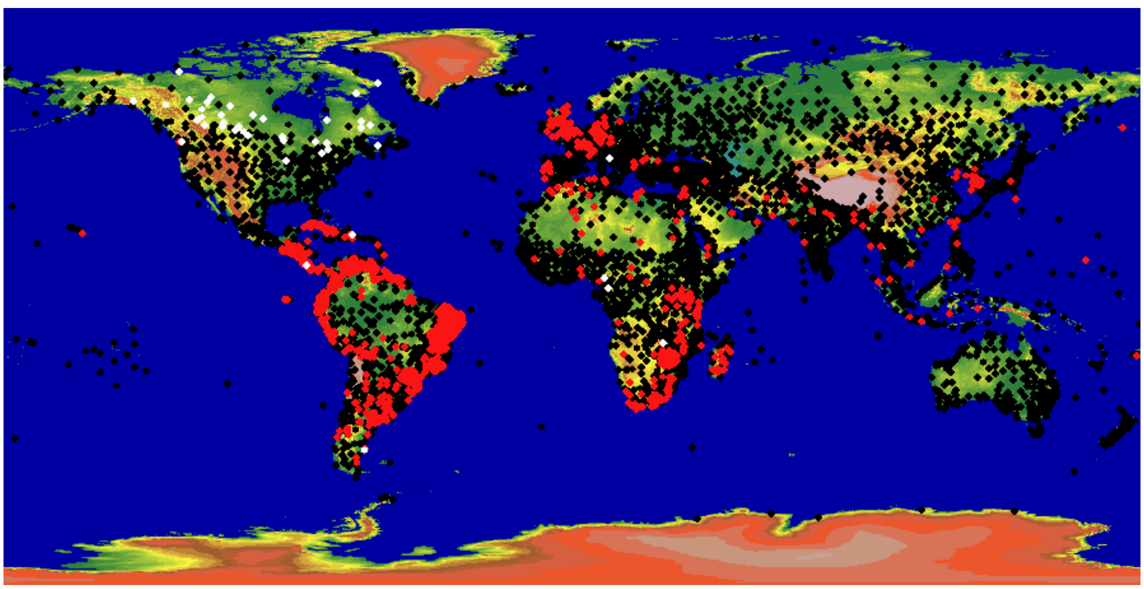

Fig. 8: Spatial distribution of Water Vapor Pressure Observations (black: observations available, white: removed stations, red: calculated from related variables).

As a result the actual number of stations providing water vapor pressure, sunshine fraction and PET has increased considerably. For comparison the stations for which PET was already available are displayed in Fig. 9.

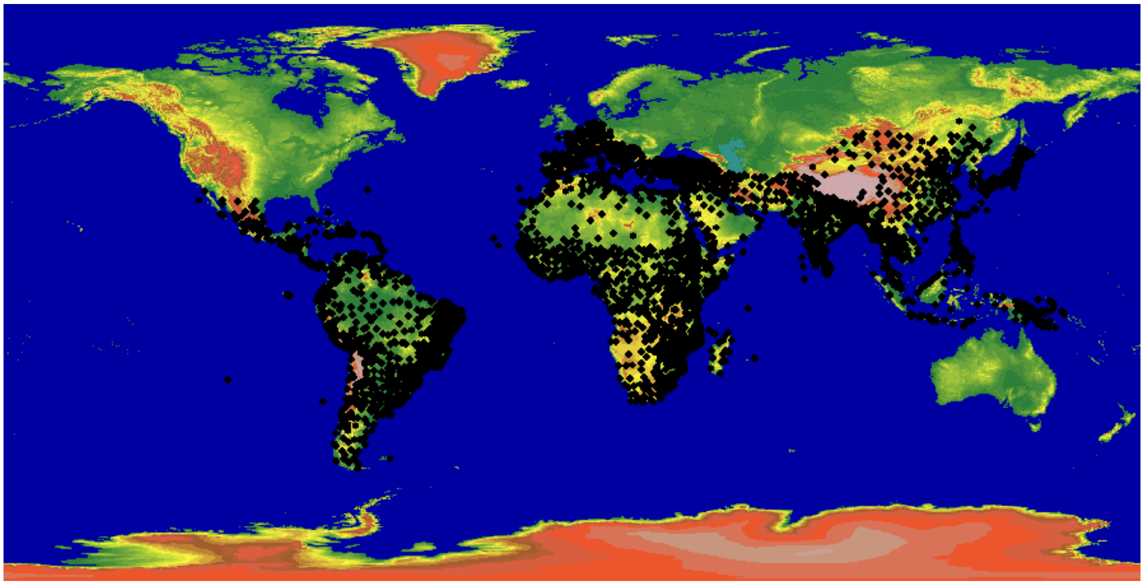

Figure 9: Distribution of stations providing PET before this work.

2. New LocClim

The database underlying New LocClim is extended by the data described in the previous section. Supplementary the data format is changed. The data are stored in the binary format provided in Table 4.

Table 4: New LocClim data format and description.

Name	Format	Description
Latitude	Integer	Latitude in decimal degrees *10
Longitude	Integer	Longitude in decimal degrees *10
Altitude	Integer	Altitude in m
Value	Integer *13	13 observations (scaled to fit in integers)
Country ID	String *3	3 letter ISO code
Country Name	String *24	
Station ID	String *8	Agromet station code
Station Name	String *24	Station Name

Some further but minor changes were done. Among them are

- The user could select stations for a country under investigation. In this case only stations within the country were selected. Now the user can choose whether he wants to only use stations within the selected country or also some nearby stations from surrounding countries.

- The single point mode of New LocClim now also allows to export data in the CropWat formats.
- CropWat format of New LocClim is extended to also provide estimates of radiation (calculated from sunshine fraction, calendar month, and latitude) as well as relative humidity (calculated from water vapor pressure, minimum and maximum temperature).

3. New ClimWat

ClimWat is a software tool prepared in 1993 in order to select stations for which climatological information necessary for CropWat is available. New ClimWat is a Windows version of this tool. It not only allows to select stations by country but also by target location. The user can either select to get all stations within a country, within and around a country or a desired number of stations closest to a target location. New Climwat prompts the list of stations that fulfill the requirements and displays their locations on a regional map. The station meta information displayed helps the user to choose a subset of these stations to be exported to a folder.

4. Recommendations for further developments

Local and regional climatic information is of high importance in order to estimate crop growing opportunities. Water availability, temperatures and radiation supply can limit crop growing season. Within the climatological database of the Agromet Group mean annual cycles of about 28,000 stations are stored. Temperatures are available at about 12,500 stations. Though the number of stations for which PET is available has considerably increased within the current work and its spatial distribution now is much more homogeneous than before, the investigation of water availability is still limited by PET (about 5,300 stations).

PET can be estimated by Penman-Monteith equation using temperatures, radiation, humidity and wind speed as input variables. However, simpler methods exist in order to reduce the necessary input information. In the most simple case Hargreaves method (HPET) as well as a highly simplified version of Penman-Monteith method (hereafter named poor man PET, pmPET) depend only on maximum and minimum temperature. Using these methods would easily allow to obtain a PET estimate for more than twice the stations it is available now. However, the estimates may not be of comparable accuracy. In order to investigate the errors, HPET and pmPET are calculated for all the stations for which PET is calculated by Penman-Monteith method and for which PET estimates have been available within the data base. The error statistics are provided in Table 5.

First, Table 5 shows that the new estimates of PET do not differ considerably from the old ones on average. Furthermore, the RMS suggests that there are pronounced differences in some cases which may be explained by the updated values of the database. The average error of the simplified methods is less than 10%. However, the error standard deviation is larger than 20% of the estimate. Therefore, instead of using simplified methods in order to estimate PET for more locations on Earth it is recommended to further update the database with observations of radiation, wind speed and humidity.

Table 5: Error statistics of different estimation methods for PET at 2484 stations. All information given in mm/Month. MAD = Mean absolute deviation, RMS = Root of mean squared error. StdDev = standard deviation of error.

Method	Average	Bias	MAD	RMS	StdDev
Penman-Monteith	114.1				
Old Values	111.2	-3	10.5	17.9	17.6
pmPET	125	10.9	21.4	27.3	25.1
HPET	121.8	7.6	20.3	26.7	25.6

Given all the stations within the database there are 1473 stations for which only one of the variables necessary to calculate PET is missing. For further 721 stations two variables are missing and for 6475 stations three are missing. Taking into account the stations for which temperature is already available radiation data are missing in 6699 cases, humidity in 6286 cases and wind speed in 7422 cases.

Given the actually available data density it is recommended to produce globally gridded maps of average climate conditions as a basis for the investigation of climatic constraints for agriculture. This would allow a fast comparison of different locations and regions on earth with respect to climate conditions.