COST action 718

“ METEOROLOGICAL APPLICATIONS FOR AGRICULTURE ”

Possibilities for use of satellite information as an input for CROPWAT software - preliminary study.

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WG1.1.

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1. Introduction.

CROPWAT is a practical tool for agro-meteorologists, agronomists and irrigation engineers to perform calculations for evapotranspiration and crop water requirements. It helps to design an irrigation schedule or recognise water deficit in case of irrigated or rainfed conditions. The algorithm for calculation of the crop water requirements and irrigation requirements is based on methodologies presented in FAO Irrigation and Drainage Papers No. 24 „Crop water requirements" and N0. 33 „Yield response to water". The FAO Penman-Monteith method (1992) were used. The method used, replaced FAO 24 procedures published in 1977. Former method is actually not recommended because of over estimation of evapotranspiration.

There are three versions of CROPWAT software available:

- **CROPWAT Version 5.7** has been published as Irrigation and Drainage paper No 46 in 1992 and include a Manual on the use of the computer programme and Guidelines on calculation procedures and applications in irrigation planning and management. The programme was written in BASIC and runs in the DOS environment. English version of this programme was replaced by CROPWAT Version 7.0. The French and Spanish versions are available and can be downloaded from the FAO FTP Server as **CRW57-FR.**zip (293 KB) or **CRW57-SP.zip** (204 KB) respectively and unzipped with the standard PKUNZIP programme in a suitable directory or on disk. The original directory structure is restored with the SETUP command.
- **CROPWAT Version 7.0** contains a completely new version in Pascal, developed with assistance of the Agricultural College of Velp, Netherlands. It overcomes many of the shortcomings of the original 5.7 version and Basic program. It is concise and fits easily on one diskette. The programme can be downloaded as **cropwat72.zip** (329 KB) and unzipped with the standard PKUNZIP programme. The original directory structure is restored with the SETUP command.
- **CROPWAT for WINDOWS** contains a CROPWAT version written in Visual Basic to operate in the Windows environment. It is developed with assistance of the International Irrigation & Development Institute (IIDS) of the University of Southampton, UK. The programme can be downloaded as **crw4w3.zip** together with manual **crw4w-mn.zip** and unzipped with the standard PKUNZIP programme. The programme is subsequently installed with the SETUP command. Actually available version 4.3 was developed by: Martin Smith (FAO), Derek Clarke (Institute of Irrigation and Development Studies - Southhampton University UK) and Khaled El-Askari (National Water Research Center - Cairo, Egypt) .

All versions of software are compatible with use of the same CLIMWAT database and rainfall files. **CLIMWAT for CROPWAT** is a world-wide climatic database to be used in combination with CROPWAT. The climatological data in this database are: maximum and minimum temperature, mean daily relative humidity, sunshine hours, wind speed, precipitation and calculated values for reference evapotranspiration and effective rainfall. The original data base has been compiled by the Agrometeorological Group of the FAO Research and Technology Development Division and has been converted into a format suitable for use by CROPWAT.

Unfortunately the standard data covers only selected points in some countries. Among European countries CLIMWAT database covers following areas:

Belgium	3 sites
France	44 sites
Italy	60 sites
Cyprus	27 sites
Greece	20 sites
Luxembourg	1 site
Portugal	3 sites
Spain	58 sites
former Yugoslavia	21 sites

Users outside of listed sites have to prepare own climatic data to feed CROPWAT programme. The data base includes data from a total of 3262 meteorological stations from 144 countries divided into six continental regions and 144 countries. The data are contained in six continental files which can be downloaded from the CLIMWAT directory on the ftp.fao.org server.

- **ASIA.ZIP:** Asia and the Pacific
- **AFRICA.ZIP:** Sub-Saharan Africa
- **NEAREAST.ZIP:** Near East and North Africa
- **EUROPE.ZIP:** Europe
- **SAMERICCA.ZIP:** South America,
- **CARIBEAN.ZIP:** Caribbean isles and Central America

All versions use are user friendly, flexible menu system. Specially Windows version uses extensive graphics for presentation of input data and results. The main differences between CROPWAT 7.0 and CropWat for Windows are:

- The same equations are used, however due to different interpolation methods calculations may differ occasionally up to 2 %.
- CropWat for Windows uses graphs and forms to display results, user may choose between tables and graphs.
- Windows version can deal with multiple crops up to 30 ones in cropping pattern. Irrigation schedule can be calculated for individual blocks of each crop.
- CropWat for Windows uses monthly climatic data only while CROPWAT 7.0 can use monthly, decade or daily data from measurements.
- CropWat for Windows allows user-defined irrigation events

The set of necessary input data is very limited, mainly climatic information and crop data are required. Standard crop data are included in program.

2. Input data.

The available versions of CROPWAT software differs a little between each other but main input data are the same or similar.

2.1. CROPWAT 7.0 (DOS version).

The DOS version of CROPWAT (7.0) requires in minimum following input data to perform calculations of Crop Water Requirements:

Climate data for calculation of reference evapotranspiration from CLIMWAT data base (files *.pen):

Monthly means of : minimal temperature [°C],
maximal temperature [°C],
humidity [%],
wind speed [km/day],
sunshine hours [hours].

Own climate data with monthly means of presented above values (files *.pem) or decade means (files *.pec) could be applied. Edition of own data files is supported by CROPWAT 7.0 programme.

From presented above data the reference evapotranspiration ETo [mm/day] are calculated by using Penman-Monteith method and radiation [MJ/m^2/day] for each month or decade are calculated by programme. Also mean annual values are calculated automatically. User may define own input data file containing values of:

- measured monthly ETo data (files *.pmm),
- measured decade ETo data (files *.pmc).

Second climatic parameter is included in Rainfall Data available in CLIMWAT database (files *.cli): monthly means of rainfall amount [mm]. Use may define own files with rainfall information:

- measured monthly rainfall data (files *.crm),
- measured decade rainfall data (files *.crc),
- measured daily rainfall data (files *.crd).

In all files with rainfall data, the effective rainfall is automatically calculated. The user is able to choose formula:

- fixed percentage of rainfall - percentage interactively defined by user,

- dependable rain (FAO/AGLW formula):
  Peff = 0.6 * Pmon - 10 for Pmon <= 70 mm
  Peff = 0.8 * Pmon - 24 for Pmon > 70 mm

- empirical formula (locally derived) - possible modification of all coefficients and thresholds in FAO/AGLW formula,

- USDA Soil Conservation Service:
  Peff = (Pmon*(125-0.2*Pmon))/125 for Pmon <= 250 mm
  Peff= 125+0.1*Pmon for Pmon>250 mm

For calculation of Crop Water Requirements and Water deficit the following additional data are required:
- Crop data
- Planting data
- Field file

For determination of necessary Irrigation Schedule the following additional data are required:
- Crop data
- Planting data
- Soil data
- Field file
- Optional data: Irrigation timing, application and efficiency

2.2. CropWat for Windows.

There are many similarities between CROPWAT 7.0 and CropWat for Windows regarding input data. Necessary input data for Crop Water Requirements calculation are:
- Climate data or ETo data,
- Crop data and crop planting date or cropping pattern data.

Details are listed below:

- Monthly Climatic Data - monthly means of:
  - minimum temperature [°C],
  - maximum temperature [°C],
  - air humidity [%],
  - wind speed (at 2 m height) [km/day],
  - daily sunshine [hours].
  From presented above data the daily ETo is calculated using Penman-Monteith method.
- ETo data - monthly means from measurements or calculated values.
- Monthly Rainfall Data - total rainfall, tables include also calculated effective rainfall.
- Cropping Pattern Planning - type of crop, planting date and percentage of total planted area.
- Crop Coefficients - Kc values, number of days for each stage, root depth, depletion, Ky values.

For irrigation schedule planning the additional information is required:
- Soil Data - total available soil moisture, maximum infiltration rate, maximum root depth, initial soil moisture depletion,
- Scheduling criteria.

The Windows version of Cropwat software allows to make modifications in Calculation Methods. The following options may be modified:

- ETo calculation:
  - possible modification of Angstrom's Coefficients a and b,
  - selection of ETo distribution model.
- Rainfall - selection of rainfall distribution model,
- Effective rainfall - selection of effective rainfall calculation method (same possibilities as in CROPWAT 7.0).
- Scheduling Criteria - application timing, depth and start of scheduling.

CropWat for Windows in standard way doesn't allow for use of rainfall data for shorter periods then month. There is a possibility to introduce daily values of rainfall by using User Adjustments in Irrigation Schedule. When Daily Soil Moisture Balance is selected it is possible to introduce Soil Moisture Adjustments. Reasons for doing this might be:

- to apply actual rainfall data,
- to allow for capillary rise contribution to the soil moisture,
- to allow for deep percolation out of soil profile,
- to amend the SMD (Soil Moisture Deficit) to bring it to the line with field measurements of soil moisture.

The advantage of CROPWAT software is very limited number of necessary input data practically consisting of climatic information. Therefore the possibility to use satellite information is also limited.

3. Possible use of satellite information for CROPWAT software.

The CROPWAT software is prepared to be used in conditions where available input data are limited, specially ground measurements may be absent for long period. This is a reason, that climatic means are sufficient to feed the programme. Of course, taking into account variability of meteorological conditions in each year, results may substantially differ from real situation when only climatic values are applied. That is the reason, that users who have actual measurements of input values, may use them as input data. Importance of detailed information concerning such a parameters like: precipitation, evapotranspiration and solar radiation is clear. Actual measurements made in standard synoptic or specialised agrometeorological stations may be a source of data to create the monthly, decade or daily values. The well known problem is how representative are point measurements for certain area taking into account existing density of ground posts. The second solution is use of information from meteorological satellites, which differs from standard measurement and have following features:

- information from the area not from point,
- relatively large areas covered by satellite images,
- time repetition from 10 minutes to several hours,
- ground resolution 1 - 10 km,
- low cost of information,
- quick access to data covering whole country (or more).
- satellites measures radiances, not physical values - methods converting radiances to physical values are available or still in development,
- often ground calibration is necessary,

- big difficulties in comparison of satellite derived products to ground measurement - users very often do not trust to quality of satellite measurements.

The ground measurements are treated as precision and real physical values but measuring network is not very dense in many countries. Distances between posts very often are in order of 200 km or more. It is a reason of high importance of good spatialisation methods, producing distributed information covering certain area from point measurement. Taking into account presented above features of two information sources is not curious, that use of satellite information is in rapid progress. Many methods for products creation were prepared. Current meteorological satellite information available in Europe may be received from following systems:

- METEOSAT 7 - current operational satellite (every 30 min, 3 channels),
- METEOSAT 6 - Rapid Scan images from European sector (every 10 min., 3 channels),
- NOAA - 12, 14, 15, 16 - AVHRR, TOVS and ATOVS instruments (up to 10 times per 24 hours from all available satellites),
- limited access to scientific missions - not on operational basis.

In this decade European countries will have operational access to following new meteorological satellite systems:

- MSG (*Meteosat Second Generation*) to be launched in June 2002 - 12 channels of SEVIRI instrument, practically doubled space and time resolution comparing to existing METEOSAT satellite,
- METOP - first satellite of EPS (European Polar System) will be launched in 2005, many completely new instruments (IASI, ASCAT) together with NOAA compatible payload,
- NPOESS - first satellite from this series planned on 2008, payload still under discussion.

CROPWAT software is not prepared for direct use of satellite information. Even it was not purpose of this software, rather situations when data are not regular or not available were considered. Continuation of this idea is replacement of not existing or sparse data by possible satellite measurements. We have to consider existing possibilities and future application due to rapid development of satellite systems.

Generally speaking the use of satellite information for CROPWAT is limited to rainfall, evapotranspiration and sunshine hours estimation. Generation of actual data is very important due to substantial differences between years and seasons. Unfortunately construction of the software make impossible bigger changes of parameters or processed input data used in Penman-Monteith method.

3.1. Rainfall data.

As it was mentioned before, precipitation information is necessary for calculation of Crop Water Requirements and Irrigation Scheduling. Input data may be supplied in form of climatic means or measured monthly, decade or daily values. CropWat for Windows accepts only monthly values while CROPWAT 7.0 accepts all three types of data. Taking into account big spatial and temporal diversity of precipitation, very frequently measurements taken from rain gauges installed on synoptic stations are not representative for the area investigated by CROPWAT programme e.g. planting area. Such a situation is connected mainly with not enough density of rain gauges, but also measurement errors are substantial. In many countries rain gauges are installed with distances 100-200 km between each other. To avoid such an uncertainties usually data from surrounding synoptic station are taken to obtain rain amount in selected point and spatialisation methods are applied. It often leads to big mistakes, specially when convective storms pass over the area of interest. Such a local diversification of precipitation is a usual situation in mid latitudes, specially in late spring and summer period, when storms are very frequent.

The interesting solution is use of satellite derived rain rates for estimation or even determination of daily, decade or monthly precipitation. The advantages of satellite information were listed above. Characteristics of each type of satellite information is presented below.

Table 1. Possible sensors on operational weather satellites for rain analysis.

Satellite	Sensor	advantages	disadvantages
METEOSAT	IR	• data available day and night, every 30 min, • possible estimation of amount of precipitation in selected period,	• relatively poor relation between cloud top temperature and rain intensities, • stratiform rain not well represented.
METEOSAT	VIS+IR	• better then only IR,	• only in daytime, • requires good Sun position correction,
METEOSAT Rapid Scan	VIS+IR	• interesting tool for analysis of rapidly changing precipitation (storms), • temporal resolution 10 min,	• not available continuously, twice a week - 12 hour break occurs,
NOAA	AVHRR	• good results in daytime, when cloud classification is much more precision • good spatial resolution (1-1.5 km on 60 % of pass)	• poor temporal resolution (6-10 times a day from all NOAA satellites) - problematic values of daily amounts,
NOAA	microwave	• more direct measurements, • algorithm do not depend on Sun position (day and night),	• poor temporal and spatial resolution, • problems with very heavy precipitation, • problems with underlying surface,
Combined METEOSAT + NOAA	all sensors	• possible calibration of Meteosat measurements by NOAA derived estimates,	• solved problem of temporal resolution,
MSG	SEVIRI	• possible assimilation of NOAA techniques to SEVIRI data, • best temporal resolution (15 min), • good spatial resolution (1-3 km),	• lack of microwave sensors, • different day and night algorithms,

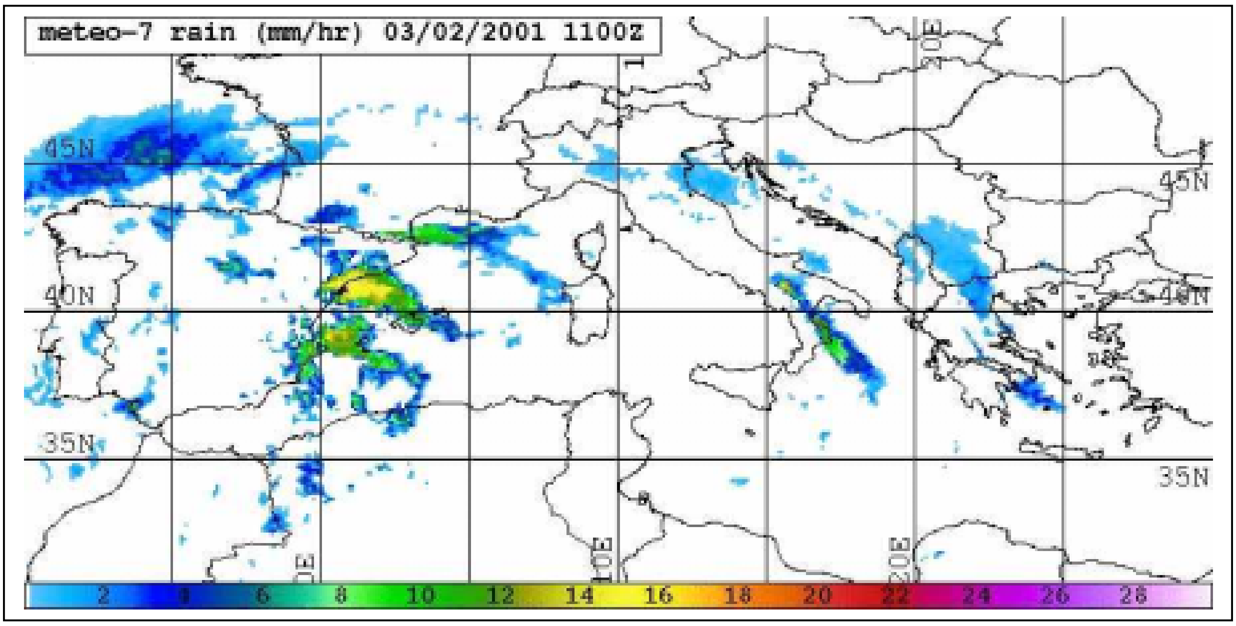

Fig.1. Rain rate determination from METEOSAT data.

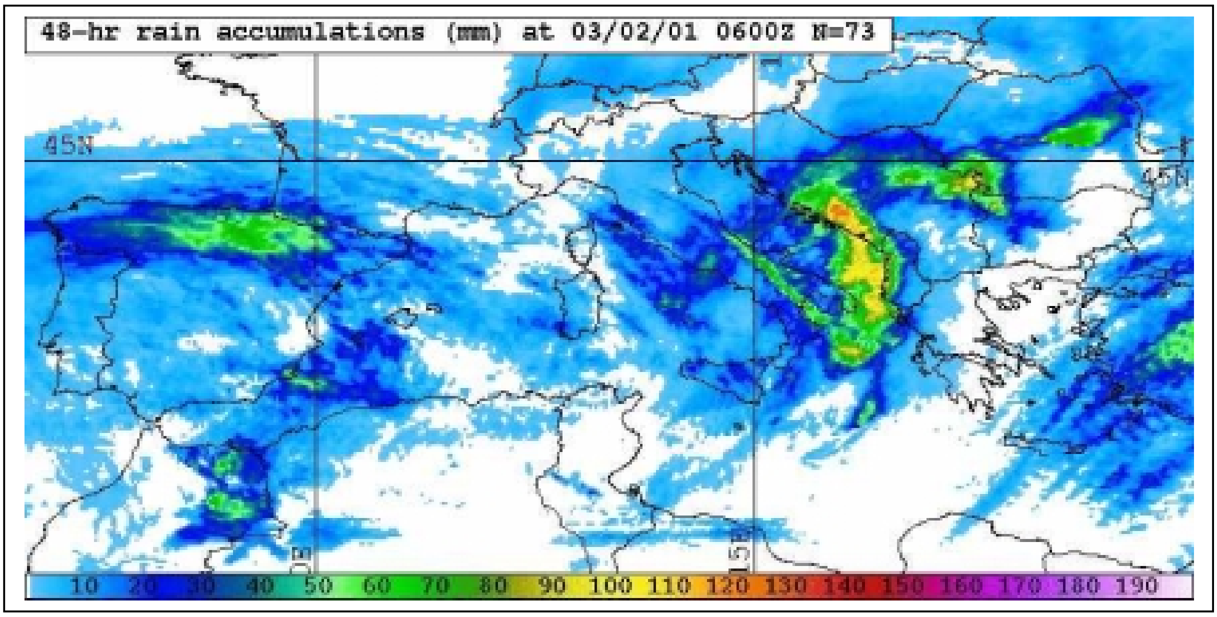

Fig. 2. Rain accumulation during 48 hours - METEOSAT data used.

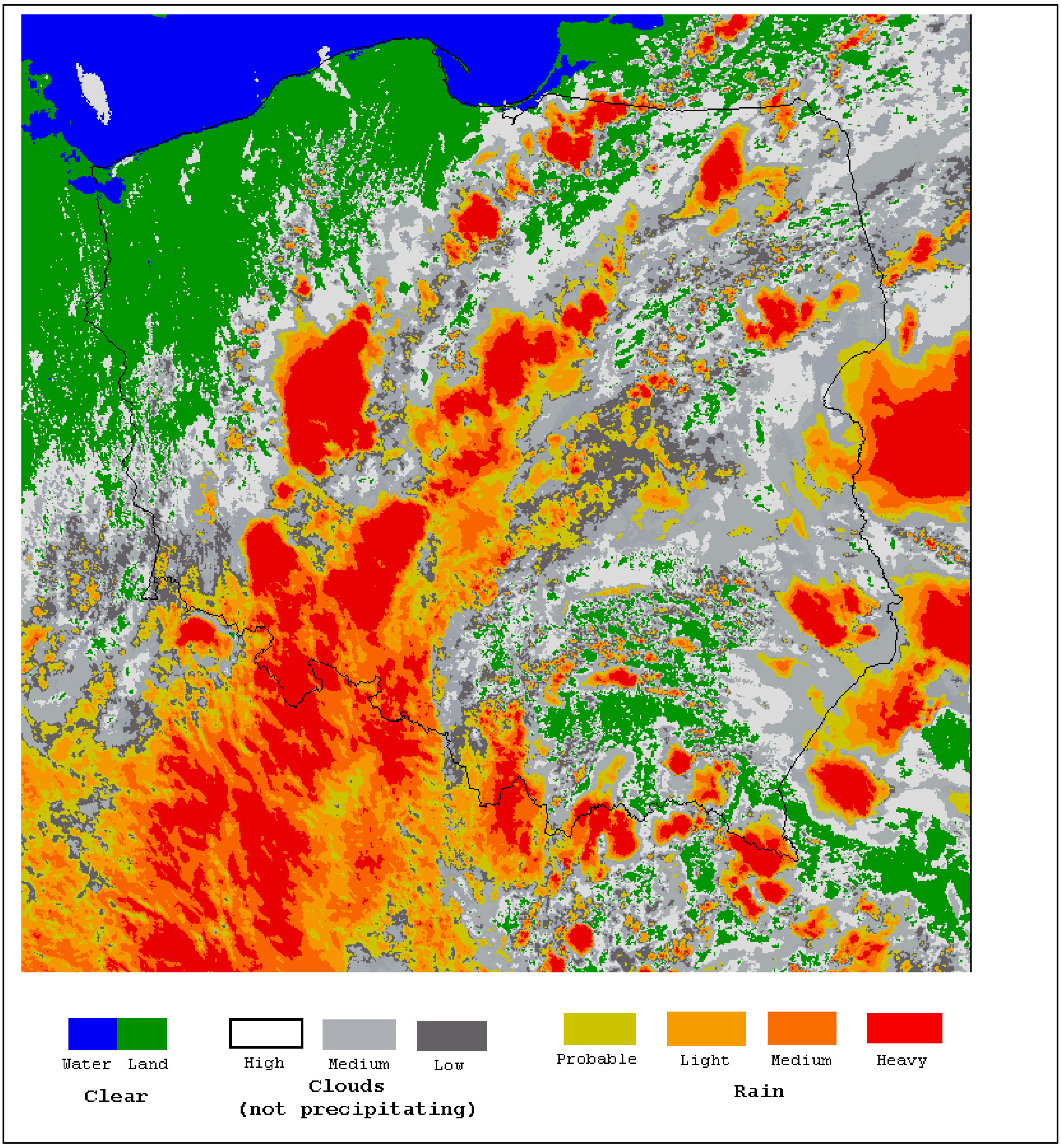

Fig. 4. Rain rate classification using NOAA/AVHRR data (example).

Precipitation algorithms - conclusions:

- IR (IR+VIS, IR+VIS+WV) methods - indirect method, satisfactory for convective rains, poor for stratiform rains (needs corrections), good temporal and spatial resolution (geostationary platform) - usually overestimation of rain amount.
- Passive microwave - more direct then IR method, may be used for “calibration” of optical method which has better time/space resolution, worse temporal and spatial resolution (polar platform) - usually underestimation of rain, rain rates 0-35 mm/h, problems with underlying surface.

- Active microwave (precipitation radar) - 3D analysis of rain fields, the worst temporal resolution at present (every 50 h), problematic relation: reflectivity ~ droplet size distribution, future polar systems.

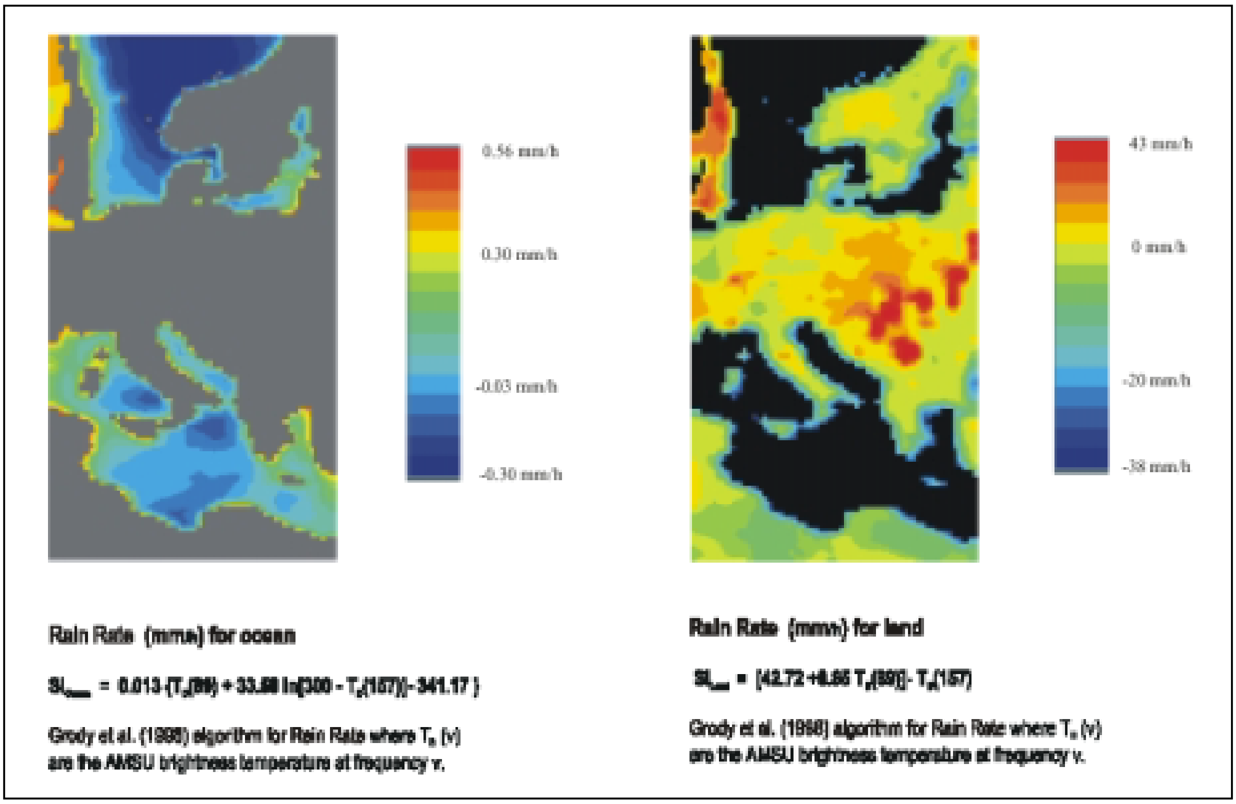

Fig.3. Rain rate for land and sea from ATOVS/NOAA passive microwave sensor - 7 July 1999.

The scope of this study is not to analyse available satellite methods for precipitation monitoring but rather find the availability to feed CROPWAT software with satellite derived parameters. The separate study concerning Utilisation of RS data to estimate rainfall was already done in COST-718 Action. Regarding precipitation, there following comments must be done:

- There are many existing methods of rain rate determination from satellite imagery, their quality depend on sensor.
- Future satellite systems (MSG) will be more suitable for determination of rain accumulation due to better temporal and spatial resolutions and more available channels.
- Data merging techniques combining optical and microwave sensors are of high importance.
- Satellite data together with conventional measurements may be used for better spatialisation of rain fields, producing in result more accurate information for CROPWAT software.
- Certain programmatic work is required to improve linkage between different satellite products and CROPWAT input files.

- Detailed studies for assessment of satellite rain information in conjunction with CROPWAT model is required (high importance).

3.2. Evapotranspiration.

In general, remote sensing techniques cannot measure evaporation or evapotranspiration (ET) directly. However, remote sensing does have two potentially very important roles in estimating evapotranspiration. First, remotely sensed measurements offer methods for extending point measurements or empirical relationships, to much larger areas, including those areas where measured meteorological data may be sparse. Secondly, remotely sensed measurements may be used to measure variables in the energy and moisture balance models of ET.

The question of how to use the spatial nature of remote sensing data to extrapolate point ET measurements to a more regional scale has been addressed in several ways. Using the temperature sounders on the meteorological satellites in a linear regression model, Davis and Tarpley [1983] estimated shelter temperatures with an error of about 2K for clear or partly cloudy conditions Price [1982] used thermal data from the Heat Capacity Mapping Mission (HCMM) to estimate regional scale ET rates which were found to be comparable to pan evaporation data. Jackson [1985], and Gash [1987] have proposed an analytical framework for relating the horizontal changes in evaporation to horizontal changes in surface temperature. Kustas et al [1990] demonstrated these concepts for an agricultural area under clear sky conditions. Humes et al, [1994] has proposed a simple model using remotely sensed surface temperatures and reflectances for extrapolating energy fluxes from a point to a regional scale; however, other than for clear sky conditions, variations in incoming solar radiation, meteorological conditions and surface roughness limits this approach.

Several variables related to energy balance equation can be measured by remote sensing and simple meteorological measurements. Generally the latent heat term is determined as the residual of the other terms in the energy balance. Incoming solar radiation can be estimated from satellite observations of cloud cover, primarily from geosynchronous satellites [Brakke and Kanemasu, 1981; Tarpley, 1979]. Pinker and Laszlo [1992] have proposed a model that infers incoming short wave fluxes and surface albedos from GOES data. Pinker et al [1994] used this model to demonstrate that incoming short-wave radiation can be measured quite accurately, even under variable cloud conditions, at the basin scale.

For clear sky conditions, the surface albedo may be estimated by measurements covering the entire visible and near infrared waveband, while empirical relations using narrow spectral bands can be used to determine albedo over heterogeneous surfaces [Jackson, 1985; Brest and Goward, 1987]. Although albedo estimated this way is not the true hemispherical albedo [Kimes at al, 1980], the lack of directional data or simple models to make this correction have not been developed.

Surface temperature can be estimated from measurements in thermal infrared wavelengths that is, the 10.5 to 12.5 micron waveband, either assuming a surface emissivity (close to unity for natural surfaces) or having measured values of the surface emissivity [Wan and Dozier, 1989]. Surface temperatures can be used to estimate the outgoing long wave radiation term in the net radiation equation [Kustas et al, 1994].

The soil heat flux term can be estimated with remote sensing measurements. A simplified approach defines the ratio of soil heat flux to net radiation in terms of vegetation cover which, in turn, is determined from visible and near infrared measurements [Clothier et al, 1986, Choudhury et al, 1987, Kustas and Daughtry, 1990]. The diurnal effects [Owe and van de Griend, 1990] and influence of soil moisture [Brutsaert, 1982] are assumed to be secondary for large areas [Kustas et al, 1994]. The sensible heat flux can be estimated using several approaches including the bulk resistance approach proposed by Monteith [1973] and similarity principles for the unstable boundary layer [Brutsaert and Sugita, 1992], where the surface temperatures are measured by remote sensing. These approaches have met with varying degrees of success [Hall et al.,1992, Brutsaert and Sugita, 1992, Brutsaert et al., 1993, Kustas et al., 1994].

One formulation of potential ET that lends itself to remote sensing inputs is that developed by Priestley and Taylor [1972]. The Priestley-Taylor equation is the basis for the model which Kanemasu et al. [1976], used for estimating ET with satellite data. Estimates of the net radiation from geostationary satellite data are used by Heilman et al. [1977] in a Priestley-Taylor type of equation to estimate ET.

Additional approaches for estimating ET from remote sensing data are being explored. Barton [1978] and Davies and Allen [1973] have modified this formula for evaporation from an unsaturated land surface by the surface layer soil moisture. Barton used airborne microwave radiometers to sense soil moisture remotely in his study of evaporation from bare soils and grasslands. Soares et al [1988] demonstrated how thermal infrared and C-band radar could be used to estimate bare soil evaporation. Choudhury et al, [1994] have shown strong relationships between evaporation coefficients and vegetative indices. Another approach being pursued is the development of numerical models that simulate the heat and water in the soil and drive it with the energy balance at the surface [Camillo et al., 1983, Taconet et al., 1986]. Taconet and Vidal-Madja [1988] have used this approach with Advanced Very High Resolution Radiometer (AVHRR) and Meteosat data.

The CROPWAT software may work in two modes: calculation of reference evapotranspiration from climatic data or direct use of evapotranspiration measurement. Therefore possible use of satellite information is:

- the measured evapotranspiration may be replaced by estimations made from satellite information,
- satellite measurements may be used for better spatialisation of ground measurements,
- satellite information may be used to determine parameters necessary for reference evapotranspiration calculations.

In CROPWAT 7.0 evapotranspiration measurements may be supplied as decade or monthly values. In CropWat fo Windows only monthly values are possible as input data. There are many published methods for determination of evapotranspiration by using satellite information. Generally methods may be divided to: empirical methods and models. In empirical methods satellite information is used for determination of NDVI, surface temperature, soil moisture etc. In models, energy balance is investigated and evapotranspiration is then determined. Satellite data are used for surface short wave and long wave fluxes determination. Detailed analysis of existing method is out of the scope of this preliminary study. Accuracy of evapotranspiration measurements using satellite information is relatively good, specially when long periods are considered.

The recommended future works should concern following tasks:

- selection of methods for further analysis,
- preparation of interfaces to use satellite products to CROPWAT software,

- analysis of CROPWAT results by using climatic data, conventional evapotranspiration measurements and satellite estimations,
- possible use of satellite information for better spatialisation of conventional measurements of evapotranspiration.

3.3. Sunshine.

Good radiation data are of crucial importance in view of their predominance in the ETo estimation formula. The satellite information is very useful for determination of available solar energy at ground surface. The example of comparison between ground measurements and satellite estimations is presented on fig. 5. The mentioned application of satellite data is use of this type of information as an input data used by Penman-Monteith method. In such CROPWAT software needs monthly means of air temperature (min and max), humidity, wind speed, sunshine hours. Among presented above parameters sunshine hours may be determined properly from satellite information. The separate study on the Utilisation of RS data to estimate Solar Radiation was already done in COST-718 Action by L. Toulios. The existing methods and their application was discussed.

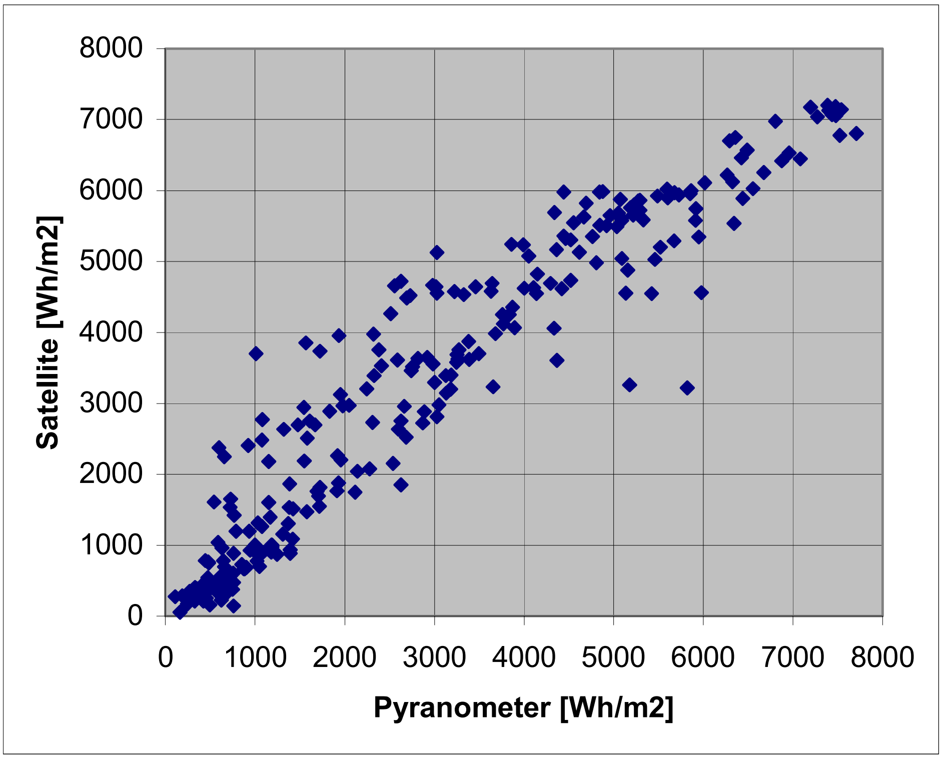

Fig. 5. Comparison between daily solar energy on the Earth surface, detected by satellite and ground measurements - period XI.1999 - IX.2000, Krakow [Struzik, 2000].

The CROPWAT software is not designed to use detailed information on radiation fluxes at the surface. In original Penman-Monteith method the radiation term consists of: Net Shortwave Radiation and Net Longwave Radiation terms:

$$R_n = R_{ns}\downarrow - R_{nl}\uparrow$$

where: R_n : net radiation [MJ m^{-2} d^{-1}]
R_{ns} : net incoming shortwave radiation [MJ m^{-2} d^{-1}]
R_{nl} : net outgoing longwave radiation [MJ m^{-2} d^{-1}]

Net shortwave radiation is determined from incoming solar radiation. This parameter may be also obtained from satellite measurements. Unfortunately designers of CROPWAT software tried to simplify input parameters so they decided to use empirical formula for calculation of shortwave radiation:

$$R_s = \left(a_s + b_s \frac{n}{N}\right) R_a$$

where: a_s : fraction of extraterrestrial radiation (Ra) on overcast days ≈ 0.25 for average climate
$a_s + b_s$: fraction of radiation on clear days ≈ 0.75
b_s ≈ 0.50 for average climate
n/N : relative sunshine fraction [ ]
n : bright sunshine hours per day [hr]
N : total daylength [hr]
R_a : extraterrestrial radiation [MJ m^{-2} d^{-1}]: see equation (19)

Available local radiation data can be used to carry out a regression analysis to determine the Angstrom coefficients a_s and b_s according to the following relationships:

$$R_{so} = (a_s + b_s)\ R_a \approx (0.75) R_a$$

$$R_{sc} = a_s\ R_a$$

where: R_{so} : measured shortwave radiation during bright sunshine [MJ m^{-2} d^{-1}]
R_{sc} : measured shortwave radiation for completely overcast sky [MJ m^{-2} d^{-1}]
R_a : extraterrestrial radiation [MJ m^{-2} d^{-1}]: see equation (19)

Depending on atmospheric conditions (humidity, dust) and solar declination (latitude and month) the Angstrom values (a_s & b_s) will vary. The Angstrom values may be changed only in CropWat for Windows software.

When no actual solar radiation data are available and no calibration has been carried out for improved a_s and b_s parameters the following values are recommended for average climates:

a_s = 0.25 b_s = 0.50

For α = 0.23 : reference crop (grass)

Net shortwave radiation can thus be estimated according to the following general equation:

$$R_{ns} = 0.77\,(0.25 + 0.50\,\frac{n}{N})\;R_a$$

According to such a simplifications the possible input satellite data are limited to amount of sunshine hours during each month. The advantage of such a use of satellite information is, that amount of sunshine hours is highly dependent on cloudiness. The number of sunshine hours may be determined from geostationary satellites, using cloud detection schemes.

Recommendations for future works:

- selection of the method for sunshine hours determination from satellite data,
- analysis of possible impact of satellite derived sunshine hours on results from CROPWAT software.

3.4. Soil moisture.

Recent advances in remote sensing have shown that soil moisture can be measured by a variety of techniques. However, only microwave technology has demonstrated a quantitative ability to measure soil moisture under a variety of topographic and vegetation cover conditions so that it could be extended to routine measurements from a satellite system [Engman, 1990]. The major factor inhibiting wide spread use of remotely sensed soil moisture data in hydrology and agrometeorology is the lack of data sets and optimal satellite systems. For the most part, scientists have been restricted to data from short duration aircraft campaigns, or analysis of the SMMR and SSM/I passive microwave satellites. Although the available passive systems do not have the optimum wave lengths for soil moisture research has demonstrated that in areas of sparse vegetation that a valuable estimate can be obtained [Owe et al, 1988]. Historical data from the SSMR passive microwave system is more valuable than the SSM/I data because it had a C-band radiometer which is a better instrument for soil moisture [Choudhury and Goulus, 1988, Owe et al. 1992]; however, its period of record is limited to 1982 to 1987. In both cases the footprint is rather large, varying from about 25 km for the SSM/I to about 150 km for the C-band SMMR. Experimental passive microwave systems using aperture synthesis such as the Electronically Steered Thinned Array Radiometer (ESTAR) offer hope for higher resolution satellite systems. The airborne ESTAR has been demonstrated in the Walnut Gulch watershed in Arizona [Jackson et al., 1993].

The SAR systems offer perhaps the best opportunity to measure soil moisture routinely over the next few years. Currently, the European Remote Sensing (ERS-2) C-band, Japanese Earth Resources Satellite (JERS) L-band SARs and the Canadian RADARSAT (also C-band) are operating. Although it is believed that an L-band system would be optimum for soil moisture, the preliminary results from the ERS-1 and 2 demonstrate its capability as a soil moisture instrument. Change detection techniques have been used to detect changes in soil moisture in a basin in Alaska [Villasenor et al., 1993]. However, Merot et al., [1994] have shown that radar data become ambiguous when pounding in variable source areas. One main drawback to the existing SAR systems is that there are no existing algorithms for the routine determination of soil moisture from single frequency, single polarization radars. Oh et al., [1992] have developed a semi-empirical algorithm but it needs multi polarization data. A second limitation comes from their long period between repeat passes; for the most part 35 to 46 days although the RADARSAT should have three day capability for much of the globe in a SCANSAR (wide swath, 500 km) mode.

Soil moisture has many possible applications in hydrology and agrometeorology, but the primary areas are in evaporation and runoff modelling

CropWat for Windows allow for advanced analysis of Soil Moisture Balance and possible adjustments by the user. This option is a path to introduction of daily rainfall data to the calculations or soil moisture measurements (daily or periodically). Using this option also the soil moisture estimation from satellite information may be applied.

Soil moisture measurement from satellite data is not trivial task. Also it is very difficult to evaluate the quality of results. Soil moisture is highly variable in space so ground measurements often cannot be compared with satellite estimations. The satellite sensors useful for soil moisture measurement are:

- Infrared - thermal inertia, rise of temperature during morning hours,
- Visible - albedo of bare soil,
- Microwave (passive and active) - dielectric properties of soil dependent on water content.

The use of visible sensors is limited to bare soil cases. The IR methods have to take into account influence of vegetation cover. Practically thermal properties of very thin layer of soil is measured, so soil moisture of this thin layer is determined. The microwave methods are more accurate. Passive microwave sensors installed on meteorological satellites may be used for global estimations - climatic studies. The active microwave sensors installed on environmental satellites like: ERS, Radarsat, Almaz, JERS are the best for agriculture applications. From the second hand also some difficulties exist when such a sensors are used for soil moisture estimation:

- limited penetration of microwaves to deep layers of the soil (dependent of frequency),
- influence of vegetation cover and surface roughness,
- character of measurement - Synthetic Aperture Radar instrument (specles).

The possible application of soil moisture estimation from satellite data may be considered as an optional task.

4.0. Conclusions

Presented above possibilities for use of satellite information as an input of CROPWAT software, proved that even in very simple model designed for use of very limited input data some update to actual possibilities is available. The satellite information have a completely different character then conventional measurements. This is a reason, that many communities do not believe in their quality and advantages. The most important feature of this information is frequent availability, large area coverage, distributed character of information, relatively low cost. The future tasks in frame of COST 718 Action ought to focus on existing methods and possible use of satellites which will be available in Europe in very near future. The studies and field campaigns to compare results from CROPWAT software when input data are:

climatic means, conventional measurements, satellite information (where applicable) are very important. Such a comparison may be good for evaluation of different methods based on satellite information and their advantages for agriculture.

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