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FINAL REPORT

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TITLE : WATERMED (WATer use Efficiency in natural vegetation and agricultural areas by Remote sensing in the MEDiterranean basin)

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ABSTRACT

As water consumption increases and water reserves fall dramatically, Mediterranean countries (European and non-European) have to re-evaluate their assets and future development in terms of their reserves. In this context the research on water use efficiency and water management focuses on water saving, particularly in agriculture recently becoming a European priority. The WATERMED project has this concern as the main objective; approaching the problem from a new point of view namely based on combined use of historical and current space-based remote sensing databases, vegetation models and field measurements. In this sense, the major results of the WATERMED project that contribute to the study of water use efficiency are:

(i) the development of new operative algorithms for estimating physical and biophysical parameters (surface temperature, emissivity, total atmospheric water vapour, albedo) from remote sensing data,

(ii) the elaboration of a new physical upscaling method which is necessary to improve surface flux estimation in heterogeneous terrain widespread in Europe and North Africa,

(iii) the establishment of new methodologies for estimating evapotranspiration model input parameters with the required accuracy, which will improve the retrieval of daily evapotranspiration. It is an important factor for monitoring water requirements of crops and water consumption at a regional scale, and for integrating evapotranspiration through the whole phenological cycle which is also closely related to the crop final productivity,

(iv) the development of a software package for processing high and low resolution remote sensing satellite data which has allowed the elaboration of maps of critical parameters,

(v) the building of local GIS for efficient water management strategy in the Marrakech region (Morocco) and in the northern Sinai Peninsula (Egypt),

(vi) the realization of field experiments in different test sites where ground and satellite data have been collected, to assess the accuracy and demonstrate the usefulness of combining ground and remote sensing data for estimating evapotranspiration at different space time scale, and

(vii) the elaboration of an intergrated database combining remote sensing, in-situ and GIS data with open access to scientists and local administration managers.

In addition the project has allowed the establishment of new scientific relationships within northern and southern countries in the Mediterranean Basin and the strengthening of research teams. Furthermore the project brings researchers together with managers and other stakeholders to jointly evaluate research results and user needs and to set research priorities. The project facilitates the rapid assimilation of new technologies, analytical tools, and modelling approaches for a more efficient management of water resources in water scarse areas. Water managers are now testing a new management strategy where water allocation is decided based on the demand rather than the availability. This allowed to set priorities for water allocation in case of water shortages and crises. The latter is the current situation. Future actions should be directed toward the use of the actual project output to build a decision support system for integrated management of water resources. This will make possible to establish a sound scenario for the consequences of political actions on the sustainability of water resources.

SUMMARY OF THE FINAL REPORT

The aim of the WATERMED project is to develop a comprehensive method for the study of the water use and the resistance to the drought of the natural and irrigated vegetation in the Mediterranean Basin, by means of combined historical and current space-based remote sensing database, vegetation models and field measurements. The general concept is to integrate all available data of the environments under study. A retrospective study of the Mediterranean Basin at the regional level, using satellite data from 1981 to present, allowed quantification of land cover change within the last 20-year period. Furthermore the study of water use efficiency in four specific test areas in Spain, Morocco, France and Egypt is performed. This is done by using field measurements and high resolution imagery. In these areas the methodology was checked in high detail and the proposed algorithms were validated and improved over different scenarios. During the four years of duration of the contract, the project has reached the objectives foreseen in the technical annex. This has been possible thanks to the complementarities between the WATERMED partners. The achieved objectives correspond to the following tasks:

1. Processing of satellite data.
2. Estimation of physical and biophysical variables from satellite imagery
3. Land cover monitoring methods using satellite imagery
4. Evapotranspiration estimation
5. Upscaling
6. Analysis of natural vegetation resistance to drought periods in the Guadalentin Basin (Spain).
7. Local GIS for the analysis of remotely sensed changes
8. Integrated system for water management
9. Field measurements
10. WWW project home page.

All deliverables of the previous tasks are summarized hereafter as follow:

✓ ***1.- Processing of Satellite data:***

A software package has been developed for processing satellite data. The software, developed by us, has been adapted to the specific characteristics of the high and low resolution satellite images used in WATERMED. The software allows obtaining the land surface temperature, the land surface emissivity, the total amount of atmospheric water vapour, the albedo, and the normalized vegetation index. The programs for processing the low resolution remote sensing data (PATHFINDER-AVHRR Land) were edited in Turbo C programming language and the programs for processing the high resolution remote sensing data (DAIS airborne sensor) were edited in IDL programming language. The software code is operative, simple and easy to use by anyone whose objective is to extract the physical and biophysical variables from NOAA-AVHRR, MODIS and DAIS data. This is a clear advantage because nowadays there is no similar commercial software that permits exploiting the information provided by these images. A copy of the software package is included in a CD attached to this Final report.

✓ ***2.- Estimation of physical and biophysical variables from satellite imagery:***

The main objective of this part is the estimation of physical and biophysical variables from satellite images. We have developed accurate and operative algorithms for estimating land surface temperature (LST), emissivity (LSE) and total atmospheric water vapour content (W) from AVHRR data. The algorithms have been validated and allowew to retrieve LST, LSE and W with a standard deviation lower than 1.3 K, 0.01 and 0.5 g/cm^2 respectively. The important point to highlight here is the fact that these algorithms can be applied to any satellite sensor with 2 bands in the atmospheric thermal window. Once the algorithms were derived, the second step was their application to PATHFINDER AVHHR LAND (PAL) data over the Mediterranean Basin. To this end we have established a methodology that permits obtaining maps of each parameter for all months from July 1981 to August 2001.

Analogously we have developed new algorithms and a new methodology to retrieve LST, LSE and W from airborne high resolution data, such as the provided by the DAIS (Digital Airborne Imaging Spectrometer) sensor over test areas of Alpilles (France) and Barrax (Spain).

✓ ***3.- Land cover dynamic monitoring methods using satellite imagery.***

A method for land cover dynamic monitoring using PAL data has been developed to characterise changes in terrestrial ecosystems. The method is defined on the basis of biophysical relationships in the LST – NDVI feature space. The method named Vector of Land Cover Dynamic Monitoring (VLCD) is based on the analysis of the evolution of the slope and the module of the line whose extremities are defined by the LST and NDVI of the months of April and July. The VLCD method has the advantage of characterising the temporal trajectories and the separation of the different zones according to the evolution of the vegetative systems. The application of the method allows to know the exact limits of the transition zone in order to study the evolution of the ecotones (the most fragile area to climate and/or human induced changes) in the course of time.

As a complement of this study a comparison between PAL data and climatic data provided by data of the REANALYSIS project covering the period 1981-2001 over the Mediterranean basin is presented. The Reanalysis Project is a joint project between the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR). The goal of this joint effort is to produce new atmospheric analyses using historical data (1948 onwards) and as well to produce analyses of the current atmospheric state (Climate Data Assimilation System, CDAS). The comparison of both sources of data relates the interannual responses of NDVI to precipitation and reveals the relationship between LST and air temperature. This demonstrates the consistency of PAL data for climate studies and permits a major understanding of the land cover dynamics of the Mediterranean Basin. Further analysis will be carried out in the future to corroborate these interesting results.

✓ ***4.- Evapotranspiration estimation***

To derive evapotranspiration maps from remote sensing is not an easy work. To do that different procedures have been considered. First, flux calculations have been done using the SEBAL model (see first year and third year reports), the initial version and the new version (which includes a new parameterisation for thermal roughness) of the Danish microscale aggregation model from RISOE (second and third years reports), the direct combined model (second and third years reports) and a new developed version of the simplified relationship model (third year report). Several models were compared together to ground data giving almost similar accuracy (~70 Wm^{-2} or < 1 mm d^{-1}). These calculations used the different required input maps of albedo, emissivity and roughness that were derived from Polder data and surface temperature. Maps of net radiation were also generated in order to derive evapotranspiration maps. The sensitivity of sensible heat flux was analysed in detail to different versions of input parameter maps (emissivity, albedo, roughness) and meteorological variables (air temperature and wind speed) (see second and third year reports, Olioso et al. 2002b, 2002c).

On the other side the University of Valencia (in collaboration with INRA) performed flux calculations based on the S-SEBI model (Roerink, et al, 2000) (see Reports by the University of Valencia). It requires very few inputs (albedo, NDVI and surface temperature maps). Performances of the model over the Alpilles dataset (Polder and Inframetrics data) were good: RMSE on ground heat flux was 43 Wm^{-2} and 75 Wm^{-2} for net radiation, while daily evapotranspiration was obtained with accuracy better than 1 mm d^{-1}. The model was also applied to DAIS data over the Alpilles dataset and the experimental zone in Barrax in Spain with similar accuracy.

A new approach has been proposed for estimating heat flux from dual angle thermal infrared measurements. New expressions of sensible heat flux as a function of two directional temperature measurements were derived by manipulating the theoretical equations for turbulent and radiative transfers (these expressions slightly differed according to hypothesis made in the radiative transfer equations). The results showed that as far as heat flux was concerned, there was no need for a complex radiative transfer model. Based on this finding, a generic parameterisation of the sensible heat flux was analytically derived in terms of the (nadir) radiative-air temperature gradient and a corrective term involving the nadir-oblique temperature differences. This approach will be evaluated over new dataset in the future (and in particular the dataset which was acquired in 2003 in Morocco and which is under processing).

Finally we propose new methods for flux estimation that are based on the assimilation of remote sensing data into crop models and Soil-Vegetation-Atmosphere Transfer models (SVAT models). These models were designed for analyzing the interactions between plant canopy processes and the environment. They give priceless information for production and yield monitoring, management of water resources, assessment of water requirements and more recently for carbon cycle studies in relation with climate research. These models may be operated without a systematic use of remote sensing data by intrinsically providing the means for interpolating energy and water fluxes or biomass production between remote sensing data acquisitions.

✓ *5.- Upscaling:*

First scaling analysis were presented in the first and the second annual report (comparison of flux estimation from NOAA data, SEBAL results and spatial flux aggregation to scintillometric measurements) and published by Watts et al. 2000, Chehbouni et al. 2001c, Lagouarde et al. 2002. Investigations based on the microscale aggregation model made it possible to simulate heat fluxes over the Alpilles test site and to analyse upscaling of roughness. This analysis was used as an input for investigating the possible utilisation of the simplified relationship (as reformulated) at the 1 km-pixel scale (typical size for meteorological satellite such as NOAA-AVHRR). The differences found between flux estimations at 1km and averaged flux over the same area (mean flux computed from the 20 m scale), were an indication of the error that can be committed by AVHRR based flux estimates in comparable areas. We shown that errors on upscalling emissivity and surface temperature were negligible, while errors linked to the estimation of momentum and thermal roughness may lead to errors up to 1.5 mm d^{-1} which cannot be neglected.

This analysis was used for proposing a new physical upscaling method. This method is able to calculate the roughnesses of the heterogeneous terrain from field scale to regional scale (e.g. AVHRR). It includes roughness for momentum to improve wind prediction and roughness for sensible heat to improve evapotranspiration estimation. It is relevant in upscaling, i.e. to assess regional scale evapotranspiration balance from the local scale measurements. The main potentials are weather forecasting, climate modelling and regional hydrological balance. Furthermore it can be used for downscaling e.g. air pollution of local deposition.

✓ ***6.-Analysis of natural vegetation resistance to drought periods in the Guadalentin Basin (Spain).***

Variation in the state of the vegetation cover is one of the most important factors controlling the drought, erosion and desertification processes in arid and semi-arid lands. For this reason, monitoring the vegetation cover is one of the important applications of remotely sensed data. The imagery used to obtain this result is Landsat Thematic Mapper. Specific software was developed to process this imagery. In order to analyse the relationship between climatic data (accumulated precipitation and temperature) and NDVI variation in Guadalentin basin, the obtained climatic data were used to generate precipitation and temperature images. In order to produce maps at the same scale of the multitemporal NDVI images (calculated with Landsat-TM data), the total accumulated precipitation and mean temperature was then used to generate precipitation and temperature image corresponding to the UTM image coordinates scale of the existing NDVI images (30 m resolution). For such purpose, the kriging method was used for the generation of both precipitation and temperature images. Once the precipitation and temperature images were generated, both are used jointly with the multitemporal NDVI images for the analysis of the vegetation cover variation in the area.

✓ ***7.- Local GIS for the analysis of remotely sensed changes***

The development of a Geographical Information System (GIS) is necessary to understand how climatic or human changes influence in economic and social terms. The GIS will serve as a basis subsequently to the stakeholders in terms of management of the territory in the last phase. A GIS has been developed for the Marrakech-Tensift-El Haouz region in Morocco. It includes rainfall, piezometric and soil occupation data and also a characterization of irrigated sectors in the Tensift region. The GIS layers are included in the CD attached to this final report.

✓ ***8.- Integrated system for water management***

NARSS has developed an information system integrating remote sensing, in-situ and GIS data for water use efficiency and decision making in the northern Sinai Peninsula (Egypt). The Geographic Information System selected a topographic map of the north Sinai, scale 1:50000, as base map, which has been overlayed with the following thematic layers: soils, geomorphology, geology, hydrogeology, land cover and land use, water resources, mineral resources, energy, climatological data, socio economic data, tourist and human resources. The remote sensing data necessary for building the database has been obtained from Landsat images corrected in an appropriate way and also using the High Resolution Picture Transmission (HRPT) data received at the station of the Egyptian partner.

✓ ***9.- Field measurements***

In order to test and validate the developed algorithms and maps in the test areas different field measurements campaigns in Spain and Morocco, organised by partners 1 and 4, have been carried out. During the project, the Alpilles-ReSeDA dataset (South East of France) and the SALSA dataset (Mexico) were also used and managed by partner 2 (and subcontractor). The objective of these experiments was to assess the usefulness of combining ground and remotely sensed data to monitor water requirement and use it in an irrigation district. The collected measurements are presented in the CD attached to this final report.

- ✓ **10.- Management, cooperation and design of a WWW**

The international cooperation NORTH-SOUTH was one of the most important aspects of the project. To this end many meetings and symposiums have been organised by the partners of the three European countries of the project (Spain, France and Denmark) and the partners of the two non-European countries (Morocco and Egypt). Among them it is necessary to highlight the first International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS), which was organised by the WATERMED coordinator and welcomed the participation of more than 50 international organisations and 200 researchers. Besides, each partner devoted a significant part of their budget to the training of young scientists. Other of the major outcomes of the project is to bridge the gap first between the different managers concerned with water management and second between university scientists and the managers. This project allowed for establishment of trusted relationship between the science and the management communities. Water managers in the Marrakech region are now testing a new management strategy where water allocation is decided based on the demand rather than the availability. This allowed for setting priorities for water allocation in case of water shortages or crises which is rather the actual situation. Future action should be directed toward the use of the actual project output to build a decision support system for integrated management of water resources and also to extend this initiative to other areas. To facilitate this cooperation a web page located in the web site of partner 1 has been created and used as a tool for dissemination and exchange. All the partners have contributed with their suggestion, data and results.

MAIN PUBLICATIONS (ARTICLES)

This project has reached many scientific achievements, which have been made in manifest by the several publications and proceedings resulted from the work carried out into the frame of this project. These publications have acknowledged the EC funding in the acknowledgements paragraph of each paper. Hereafter, the list of the main articles produced during the project.

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-NUMBER OF MSc AND PhD

-Seven Msc and one PhD carried out by Partner 1, University of Valencia and one Msc at INRA partner 2, have been developed during WATERMED, corresponding to the following students:

Msc degree

1- Jauad El Kharraz, 2001, UV.
2- Juan Carlos Jiménez-Muñoz, 2002, UV
3- Guillem Sòria, 2002, UV
4- Mónica Gómez, 2003, UV (in collaboration with partner 2, INRA).
5- Astrid Schneeweiss, 2003, UV
6-Mireia Romaguera, 2004, UV
7-Agnes Austerliz, 2000, INRA

PhD degree

Jauad El Kharraz, PhD, 2004.

Currently, 5 PhD are in progress.

- Juan Cuenca (partner 1)
- Juan Carlos Jimenez-Muñoz (partner 1).
- Mónica Gómez (partner 1 in collaboration with partner 2).
- Salah ER-RAKI (Partner 4).
- Jamal EZZAHAR (Partner 4)

CONSOLIDATED SCIENTIFIC REPORT

1.-OBJECTIVES

As water consumption increases and reserves fall dramatically, Mediterranean countries (European and non European) have to re-evaluate their assets and future development in terms of their reserves. In this context the research on water use efficiency and water management focuses on water saving, in particular in agriculture, becoming a European priority. The WATERMED project has made of this concern their main objective; it has approached this problem from a new point of view based on the use of a combined historical and current space-based remote sensing database, vegetation models and field measurements in the Mediterranean basin. The general concept is to integrate all available data of the studied environments. This was made by means of a retrospective study of the Mediterranean Basin at the regional level, using satellite data from 1981 to present, which allowed studying the land cover change in the chosen period, and by a study of water use efficiency in four specific test areas in Spain, Morocco, France and Egypt. This has been carried out by using field measurements and high resolution imagery. In these areas the methodology was checked in more detail and the algorithms proposed were validated and improved over different scenarios. During the four years of duration of the contract the project has reached the objectives foreseen in the technical annex. This has been possible thanks to the complementarities between the WATERMED partners. The objectives achieved correspond to the following tasks:

1. Processing of satellite data.
2. Estimation of physical and biophysical variables from satellite imagery
3. Land cover monitoring methods using satellite imagery
4. Evapotranspiration estimation
5. Upscaling
6. Analysis of natural vegetation resistance to drought periods in the Guadalentin Basin (Spain).
7. Local GIS for the analysis of remotely sensed changes
8. Integrated system for water management
9. Field measurements
10. WWW project home page.

2.-ACTIVITIES

The specific activities of the WATERMED project during the project duration to achieve the aforementioned objectives were:

2.1. Processing of satellite data

The development of a software package for processing satellite data was the main objective of this activity. Partner 1 was the responsible of this activity. The software should be capable of processing low (Pathfinder AVHRR Land database from 1981 to 2001 and MODIS data on board TERRA and AQUA satellites) and high resolution remote sensing images DAIS (Digital Airborne Imaging Spectrometer) acquired in two test zones of Spain (Barrax) and France (Avignon).

2.2. Estimation of physical and biophysical variables from satellite imagery

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The main objective of this activity was the estimation of accurate and operative algorithms for estimating land surface temperature (LST), emissivity (LSE) and total atmospheric water vapour (W) from AVHRR data. The algorithms were be validated and once the algorithms are derived the second step consists of application to PATHFINDER AVHHR LAND (PAL) data over the Mediterranean Basin. Partner 1 was the responsible of this activity. Analogously it was necessary to develop new algorithms and a methodology that allows the retrieval of LST, LSE and W from airborne high resolution data, like the provided by the DAIS (Digital Airborne Imaging Spectrometer) sensor over test regions of France (Alpilles) and Spain (Barrax).

2.3. Land-cover monitoring method using satellite imagery.

According to the technical annex of the WATERMED contract our objective was to get an evolution overview on land cover during the period of study. The study area was the Mediterranean Basin, located between 23.75º N and 46.25º N latitude and between 36.25º E and 17.5º W longitude (see Figure C-1 of first year report). Partner 1 presented a combined use of historical satellite and climate data over the Mediterranean basin, covering the period 1981-2001. The Pathfinder AVHRR Land (PAL) has been used to monitor this area. In our case we have used the images corresponding to all the months from July 1981 to April 2001 (Table 9, pp. 35, second year report). As a complement to this study Parner 1 presented a comparison between PAL data and climatic data provided by REANALYSIS project over the Mediterranean basin.

2.4. Evapotranspiration estimation

The general objective of partner 2, in collaboration with Risø National Laboratory and University of Valencia, was to evaluate the possibility of assessing evapotranspiration from remote sensing data. We first check different methodologies at the local scale, i.e. by using data from high spatial resolution sensors. In a second time, we analysed the possibility of estimating evapotranspiration using data from sensors like AVHRR. The low spatial resolution of these sensors (around $1km^2$) does not allow to implementing directly the previous methodologies (this is due to the combination of spatial heterogeneity inside a pixel and non-linearity of the physical processes governing evapotranspiration). Mathematical and physical methods that were developed for studying scaling issues were used. A new approach has been proposed by Partner 2 for estimating heat flux from dual angle thermal infrared measurements. Also, methodologies for assimialting remote sensing data into crop models and Soil-Vegetation-Atmosphere Transfer (SVAT) models have been designed for analysing the interactions between plant canopy processes and the environment.

2.5. Upscaling

Understanding upscaling is a critical step for assessing the validity of evapotranspiration map derived from coarse resolution sensors such as AVHRR. Partner 3 in collaboration with partner 2 consolidated a new method for surface flux upscaling. The upscaling results from the Alpilles area include evapotranspiration maps and sensible heat flux and momentum flux maps. The upscalling was validated to field data and also compared to evapotranspiration results from other regional models at regional scale.

2.6. Analysis of natural vegetation resistance to drought periods in the Guadalentin Basin (Spain).

The study of the drought resistance and water use efficiency was carried out using high-resolution imagery in selected pilot areas. A detailed and updated vegetation cover and soil/lithology maps were already developed by partner 1 and was used to verify the effect of the soil background nature of the vegetation dynamics. The relationships between climatic data were carried out by generating precipitation and temperature maps from ground recording stations data. Climatic data are already available over the selected area and has been treated in accordance with the Landsat TM imagery timing. Relationships between climatic data and vegetation dynamics were studied by the analysis of the vegetation response to the climatic data. Consequently, the drought resistance and water use efficiency were estimated from the nature of the statistical relationships of each vegetation cover.

2.7. Local GIS for the analysis of remotely sensed changes

The analysis of the remotely sensed land surface changes will be done by relating each landscape unit to information on ecological characteristics, on land use, on agricultural practices, as well as past uses and conditions. A local GIS on selected test sites, developed by partners 4 and 5, will allow to input also climatic data. A local GIS on the ReSeDA-Alpilles test site was also be used to gather information required for evapotranspiration assessment.

2.8. Integrated system for water management

Partner 5 built an information system to facilitate the access and integration of various data sources and information for water management for north Sinai region, in particular, and the whole coastal area of Egypt in general.

2.9. Field measurements

In order to test and to validate the developed algorithms and maps in the study areas, several field measurement campaigns, organised by partners 1 and 4 and with the participation of partners 1, 2 and 4 were organised. The objective of these experiments was to assess the usefulness of combining ground and remotely sensed data to monitor water requirement and use it in non irrigated (Guadalentin, Spain) and irrigated areas (Barrax in Spain, Tensift in Morocco). Data from other experiments were also processed when required.

In these field campaigns the GCU has used thermal radiometers (CIMEL, EVEREST, RAYTEK, etc), sunphotometer and spectroradiometer, thermocouples for thermometric temperature measurements, a box for emissivity measurements, and a calibration source. In this way we have provided a lot of measurements of radiometric surface temperature, emissivity and atmospheric water vapour.

2.10. Coordination, management and dissemination

The international cooperation NORTH-SOUTH was one of the most important aspects of the project. An intense work of coordination has been made for partners 1, 2, 3 and 4, this include the organization on several meetings, field campaigns, the elaboration of a database of satellite images (PAL data) and field measurements for different test regions, monitoring the project results, decisions on the structure and content of the reports, and dissemination activities.

Among these it is necessary to highlight the web page implemented at the partner 1 site with the information relevant to the WATERMED project that has been constructed and revised periodically by partner 1 with collaboration of all partners.

3.-RESULTS ACHIEVED

✓ *3.1.- Processing of Satellite data:*

A software package has been developed for processing satellite data. The software, developed by ourselves, has been adapted to the specific characteristics of the high and low resolution satellite images used in WATERMED. The software allows obtaining the land surface temperature, the land surface emissivity, the total amount of atmospheric water vapour, the albedo, and the normalized vegetation index (first year report). The programs for processing the low resolution remote sensing data (PATHFINDER-AVHRR Land) were edited in Turbo C programming language and the programs for processing the high resolution remote sensing data of DAIS (Digital Airborne Imaging Spectrometer) sensor were edited in IDL programming language (fourth year report).

The software code is operative, simple and easy to use by anyone whose objective is to extract the physical and biophysical variables from NOAA-AVHRR, MODIS and DAIS data. This is a clear advantage because nowadays there is not similar commercial software that permits exploiting the information provided by these images. A copy of the software package is included in the CD attached to this Final WATERMED report.

✓ *3.2.- Estimation of physical and biophysical variables from satellite imagery:*

The main objective of this part is the estimation of physical and biophysical variables from satellite images. We have developed accurate and operative algorithms for estimating land surface temperature (LST), emissivity (LSE) and total atmospheric water vapour (W) from AVHRR data. The mathematical structure of these algorithms is given in the first WATERMED annual report for PAL. The algorithms present the advantage of allowing the retrieval of the aforementioned parameters only from the satellite data and they are easy to use. The algorithms have been validated and allow the retrieval of the LST, LSE and W with standard error lower than 1.3 K, 0.01 and 0.5 gcm^{-2} respectively (Sobrino et al, 2000, 2002, Sobrino and El Kharraz, 2003). These errors are lower than others existing in the bibliography (see first annual report where our algorithms for LST, LSE and W were compared to other algorithms). The important point to highlight is the fact that these algorithms can be applied to any satellite with 2 bands in the thermal atmospheric window.

Once the algorithms have been derived the second step consisted of their application to PATHFINDER AVHHR LAND (PAL) data over the Mediterraean Basin. To this end a methodology that permits obtaining maps of each parameter for all months from July 1981 to August 2001 has been developed.

We have also included operational algorithms to retrieve LST and W from MODIS (Moderate Resolution Imaging Spectrometer) data (fourth WATERMED annual report). It has been shown that using these algorithms, LST can be obtained from MODIS data with an error of 0.7 K and the W can be obtained with an error of 0.4 g cm^{-2}. These results have indicated that building a PML (Pathfinder Modis Land) data in future would improve the results provided by PAL database.

Analogously we have include new algorithms and a methodology to retrieve of LST, LSE and W from airborne high resolution data, like the provided by the DAIS sensor over test regions of France (Alpilles) and Spain (Barrax) (see the fourth annual report and Sobrino et al, 2004).

✓ *3.3.- Land cover monitoring methods using satellite imagery.*

According to the technical annex of the WATERMED contract our objective is to get an evolution overview on land cover during the period of study. The study area is the Mediterranean Basin, located between 23.75º N and 46.25º N latitude and between 36.25º E and 17.5º W longitude (see Figure C-1 of first year report). This particular geographical position gives the area great bioclimatic diversity. The Mediterranean climate of the area is characterised essentially by two seasons: a hot and dry summer and a short winter with concentrated precipitation. The climate is also variable according to region and marked by strong annual and interannual irregularity. The area is also subjected to a significant problem with regard to desertification. The Pathfinder AVHRR Land (PAL) has been used to monitor this area. In our case we have used the images corresponding to all the months from July 1981 to April 2001 (Table 9, pp. 35, second year report).

In order to avoid monitoring land cover dynamics per pixel, which is time consuming and difficult to interpret, we have analysed the evolution of varied landscapes of the study area. The different zones of interest were defined using as mapping criterion the image of the Total Average of NDVI (TANDVI) for the whole period. Following this procedure we defined a total of six zones (Table 9, pp. 35, second year report). The TANDVI interval in each zone is 0.1, this was adopted in order to yield zones that match the different climatic zones in the study area. The study of each zones was made by applying the proposed algorithms for LST, LSE and W to these PAL images (activity 2.2) through the developed sofware (activity 2.1). Thus if has been shown that; i) these regions present a good behaviour in terms of homogeneity, with a standard deviation lower than 0.03 for NDVI and 4 K for LST, ii) the arid zones (NDVI lower than 0.1) show small variations during the whole period, the intermediate zones (NDVI between 0.1 and 0.3) present a seasonal variation with maximum peak vegetation in Spring while the areas of vegetation (NDVI higher than 0.3) present the maximum peak vegetation in Summer. More results and analysis in terms of monthly and annual evolution are included in Sobrino et al. (2002) and in the first and second year reports.

Even though we have analysed the evolution in time of LST and NDVI separately. Our objective was to develop a method for land cover dynamic monitoring using PAL data that analyses the evolution of both parameters conjointly. This is a new and original idea. The method was defined on the basis of biophysical relationships in the LST – NDVI feature space. The method named Vector of Land Cover Dynamic Monitoring (VLCD) is based on the analysis of the evolution of the slope and the module of the line whose extremities are defined by the LST and NDVI in the months of April and July (Sobrino et al., 2002). The VLCD method has the advantage of characterising the temporal trajectories and the separation of the different zones according to the evolution of the vegetative systems. The application of the method allows knowing the exact limits of the transition zone in order to study the evolution of the ecotones (the most fragile area subjected to climate and/or human induced changes) in the course of time (first and second annual report). According to Figure 19 (Second Annual Report, page 53), we observe that regions with abundant vegetation are well separated from the rest of the regions, showing an arctangent value inferior to 75º. The application of the VLCD method allowed us to give the average images of the arctangent and the module over the whole period considered (20 years), from these images and the considerations relieved on the evolution of each region throughout the studied period, we give the image application of the VLCD method (see Figures 23 and 24, Second Annual Report, page 59) for the Mediterranean Basin. Consequently, we can distinguish and define the limits of the arid zone, vegetation zone and transition zone. The central issue in knowing the limits of the transition zone is to study the evolutions of the ecotones over the time, because it is the most fragile area subjected to climate and/or human induced changes.

As a complement to this study a comparison between PAL data and climatic data provided by REANALYSIS over the Mediterranean basin was presented. Based on REANALYSIS data, we have provided maps that show the spatial distribution of the precipitation, the air temperature and the precipitable water vapour during the period of study of PAL data (1981-2001). These images corroborate the classification used initially based on Figure C.2 of the first annual report data. The information provided by REANALYSIS data is highly useful to check the reliability of the algorithms developed. The comparison of both sources of data allows relates the interannual responses of NDVI to precipitation and reveals the relationship between LST and air temperature. This demonstrates the consistency of PAL data for climate studies and permits a major understanding of the land cover dynamics of the Mediterranean Basin (see third and fourth year reports). Further analysis will be carried out in the future to corroborate these interesting results.

✓ *3.4.- Evapotranspiration estimation*

To derive evapotranspiration maps from remote sensing is not an easy work. To do that different procedures have been considered. First, flux calculations have been done using the SEBAL model (see first year and third year reports), the initial version and the new version (which includes a new parameterisation for thermal roughness) of the Danish microscale aggregation model from RISOE (second and third years reports), the direct combined model (second and third years reports) and a new developed version of the simplified relationship model (third year report). Several models were compared together to ground data giving almost similar accuracy (~70 Wm^{-2} or < 1 mm d^{-1}). These calculations used the different required input maps of albedo, emissivity and roughness that were derived from Polder data and surface temperature. Maps of net radiation were also generated in order to derive evapotranspiration maps. The sensitivity of sensible flux was analysed in detail to different versions of input parameter maps (emissivity, albedo, roughness) and meteorological variables (air temperature and wind speed) (see second and third year reports, Olioso et al. 2002b, 2002c).

On the other side the University of Valencia (in collaboration with INRA) performed flux calculations based on the S-SEBI model (Roerink, et al, 2000) (see Reports by the University of Valencia). It requires very few inputs (albedo, NDVI and surface temperature maps). Performances of the model over the Alpilles dataset (Polder and Inframetrics data) were good: RMSE on ground heat flux was 43 Wm^{-2} and 75 Wm^{-2} for net radiation, while daily evapotranspiration was obtained with an accuracy better than 1 mm d^{-1}. The model was also applied to DAIS data over the Alpilles dataset in France and the experimental zone in Barrax in Spain with similar accuracy.

A new approach has been proposed for estimating heat flux from dual angle thermal infrared measurements. New expressions of sensible heat flux as a function of two directional temperature measurements were derived by manipulating the theoretical equations for turbulent and radiative transfers (these expressions slightly differed according to hypothesis made in the radiative transfer equations). The results showed that as far as heat flux was concerned, there was no need for a complex radiative transfer model. Based on this finding, a generic parameterisation of the sensible heat flux was analytically derived in terms of the (nadir) radiative-air temperature gradient and a corrective term involving the nadir-oblique temperature differences. This approach will be evaluated over new dataset in the future (and in particular the dataset which was acquired in 2003 in Morocco and which is under processing).

Finally we propose new methods for flux estimation that are based on the assimilation of remote sensing data into crop models and Soil-Vegetation-Atmosphere Transfer models (SVAT models). These models were designed for analyzing the interactions between plant canopy processes and the environment. They give priceless information for production and yield monitoring, management of water resources, assessment of water requirements and more recently for carbon cycle studies related with climate research. These models may be run without a systematic use of remote sensing data by intrinsically providing the means for interpolating energy and water fluxes or biomass production between remote sensing data acquisitions

✓ *3.5.- Upscaling:*

First scaling analysis were presented in the first and the second annual report (comparison of flux estimation from NOAA data, SEBAL results and spatial flux aggregation to scintillometric measurements) and published by Watts et al. 2000, Chehbouni et al. 2001c, Lagouarde et al. 2002. Investigations based on the microscale aggregation model made possible to simulate heat fluxes over the Alpilles test site and to analyse upscaling of roughness. This analysis was used as an input for investigating the possible utilisation of the simplified relationship (as reformulated) at the 1 km-pixel scale (typical size for meteorological satellite such as NOAA-AVHRR). The differences found between flux estimations at 1km and averaged flux over the same area (mean flux computed from the 20 m scale), were an indication of the error that can be committed by AVHRR based flux estimates in comparable areas. We shown that errors on upscalling emissivity and surface temperature were negligible, while errors linked to the estimation of momentum and thermal roughness may lead to errors up to 1.5 mm d^{-1} which cannot be neglected.

This analysis was used for proposing a new physical upscaling method. This method is able to calculate the roughnesses of the heterogeneous terrain from field scale to regional scale (e.g. AVHRR). It includes roughness for momentum to improve wind prediction and roughness for sensible heat to improve evapotranspiration estimation. It is relevant in upscaling, i.e. to assess regional scale evapotranspiration balance from the local scale measurements. The main potentials are weather forecasting, climate modelling, regional hydrological balance. Furthermore it can be used for downscaling e.g. air pollution of local deposition.

✓ *3.6.-Analysis of natural vegetation resistance to drought periods in the Guadalentin Basin (Spain).*

Variation in the state of the vegetation cover is one of the most important factors controlling the drought, erosion and desertification processes in arid and semi-arid lands. For this reason, monitoring the vegetation cover is one of the important applications of remotely sensed data. The imagery used to obtain this result is Landsat Thematic Mapper. Specific software was developed to process this imagery. The details of the imagery used and the software are shown in the First year Report.

In order to analyse the relationship between climatic data (accumulated precipitation and mean temperature) and NDVI variation in Guadalentin basin, the obtained climatic data was used to generate precipitation and temperature images. Precipitation data was considered as the accumulated precipitation while the mean temperature was calculated by averaging the temperature from April to March of the following year. The accumulated precipitation was calculated by adding the monthly mean precipitation from the end of August till the date of each image (generally April of each year in the case of annual variation and to the image date in case of the seasonal change). In order to produce maps at the same scale of the multitemporal NDVI images, the total accumulated precipitation and mean temperature were then used to generate precipitation and temperature image corresponding to the UTM image coordinates scale of the existing NDVI images (30 m resolution). For such purpose, the kriging method was used for the generation of both precipitation and temperature images. Kriging is a regression method used with irregularly spaced data in two or three dimensional space for the estimation of the values at unsampled locations or for the estimation of the spatial average over a length area or volume. The estimation is linear in the data and the weights are obtained from a system of linear equations where the coefficients are the values of variograms and covariance functions quantifying the correlation between data at two sample location and the location to be estimated. Once the precipitation and temperature images were generated (see Figure 2, First Annual Report, page 29), both are used jointly with the multitemporal NDVI images for the analysis of the vegetation cover variation in the area (third annual report, page 44). This study shows that the annual evolution of the natural vegetation presents different tendencies. The seasonal grasses disperse matorral and rosemainus show very high correlation with the accumulated precipitation, whereas the pine forests and the stipa class show lower correlation. The seasonal grasses, disperse matorral and Rosemarinus classes show high and quick response to the precipitation but lower resistance to drought period. These tendencies of the different vegetation responses fit an exponential function in terms of precipitation (third annual report, page 45-46).

✓ *3.7.- Local GIS for the analysis of remotely sensed changes*

The development of a geographical Information System (GIS) is necessary to understand how climatic or human changes influence in economic and social terms. The GIS will serve as a basis subsequently to the stake in tools of management of the territory in the last phase. A GIS has been developed for the Marrakech-Tensift-El Haouz region in Morocco. It includes rainfall, piezometric and soil occupation data and also a characterization of irrigated sectors in the Tensift region. The GIS layers are included in the CD attached to this final report.

✓ *3.8.- Integrated system for water management:*

NARSS has developed an information system integrating remote sensing, in-situ and GIS data for water use efficiency and decision making in the northern Sinai Peninsula (Egypt). The Geographic Information System selected a topographic map of the north Sinai, scale 1:50000, as base map, which has been overlayed with the following thematic layers: soils, geomorphology, geology, hydrogeology, land cover and land use, water resources, mineral resources, energy, climatological data, socio economic data, tourist and human resources. The remote sensing data necessary for building the database has been obtained from Landsat images corrected in an appropriate way and also using the High Resolution Picture Transmission (HRPT) receiving station of the partner.

✓ *3.9.- Field measurements:*

In order to test and validate the developed algorithms and maps in the test areas different field measurements campaigns in Spain and Morocco, organised by partners 1 and 4, have been carried out. During the project, the Alpilles-ReSeDA dataset (South East of France) and the SALSA dataset (Mexico) was also used and managed by partner 2 (and subcontractor). The objective of these experiments was to assess the usefulness of combining ground and remotely sensed data to monitor water requirement and use it in an irrigation district.

The experimental setup in the joint field experiment in an irrigated zone in the Marrakech region, consisted of deploying a classical meteorological station at 9m height so that atmospheric forcing are captured over the entire irrigation district. Additionally, eddy correlations devices measuring turbulent fluxes were installed over 3 different sites. Over each site measurements of net radiation, soil heat flux, surface temperature, soil temperature and moisture profiles were collected. In order to capture the spatial variability of surface characteristics, surface reflectance and temperature were collected using hand held radiometers (Cropscan and Exotech) over transects spanning several sites. Over the same transects, soil moisture was collected using both Theta-probe and gravimetric methods, vegetation height, cover and hemispherical photo (leaf area index was derived from) were collected.

The measurements have been carried out concordantly with the overpass of different satellites in order to correct and validate the algorithms developed and the remote sensing products obtained from satellite images. More information on the development of the field campaigns is included in second and fourth annual reports. Finaly it should be noticed that the collected measurements are presented in the CD attached to the final report.

✓ *3.10.- Management, cooperation and design of a WWW:*

The international cooperation NORTH-SOUTH was one of the most important aspects of the project. To this end many meetings and symposiums have been organised by the partners of three European countries of the project (Spain, France and Denmark) and the partners of the two non-European countries (Morocco and Egypt). Among these it is necessary to highlight the first International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS), which was organised by the WATERMED coordinator and welcomed the participation of more than 50 international organisations and 200 researchers. Besides, each partner devoted a significant part of their budget to the training of young scientists. Other of the major outcomes of the project is to bridge the gap first between the different managers concerned with water management and second between university scientists and the managers. This project allowed for the establishment of trusted relationship between the science and the management communities. Water managers in the Marrakech region are now testing a new management strategy where water allocation is decided based on the demand rather than the availability. This allowed for setting priorities for water allocation in case of water shortages or crises which is rather the actual situation. Future action should be directed toward the use of the actual project output to build a decision support system for integrated management of water resources and also to extend this initiative to other areas. To facilitate this cooperation a web page located in the server of partner 1 has been created and used as a tool for dissemination and exchange. All the partners have contributed with their suggestion, data and results.

4.-PROBLEMS ENCOUNTERED

The major problems encountered during the course of the project were:

- We expected to compare several methods for estimating evapotranspiration over the same dataset. This objective was not fully completed, since the delay in processing the airborne images did not allow us to implement all the methods on the same dataset. As a matter of fact dual angle thermal infrared data were not available over the Alpilles site (this will be done in the future). As the experiment in Morocco was running only since the beginning of 2003, it has not been possible to test in details methods to estimate evapotranspiration from remote sensing data over another test site than the Alpilles area yet. As a consequence if a new methodology for estimating evapotranspiration over large areas may be proposed, it has still to be consolidated over other datasets.

- Most of the airborne remote sensing images we expected to use over the Alpilles test site were inaccurate; we had to spend several months for assessing data quality, and then to recalibrate and navigate again these images.

- The modification of project schedule (4 years instead of 3 years) due to the change in Moroccan partner and budget problem also perturbed the expected work; however this had the advantage of including a new partner (University of Marrakech) who is working in close relation with IRD (subcontractor) and then facilitated the possibility of managing the field experiment in Morocco.

- The administrative aspects related with the entrance in the project of the University of Marrakech (Morocco) in substitution of the former Morocco partner of the project, the CRTS (Centre Royal de Teledetection Spatiale of Rabat, Morocco) who decided to get off the project before the end of the first year of the contract. This fact caused a considerable delay in the project that was solved with two amendments of the contract; the inclusion of the University of Marrakech and the temporal extension of the contract in 12 months. As a consequence of this partner 1 has had to carry out part of the work (processing of low resolution images) that should be carried out by partner 4.

- The financial aspects: as a matter of fact the local university (partner 4, Morocco) and the NARSS (partner 5, Egypt) does not advance any money and therefore these partners had to wait until the money got in and this supposes important problems in the organization of both partners.

- The lost that suppose for the consortium the death of the fifth partner's coordinator: Dr. Sami Abdel Rahman. This, obviously, influenced the proper progress of partner 5 and has made imposible to organise a field campaign in north Sinai in Egypt, as it was expected.

5. - TECHNOLOGICAL IMPLEMENTATION PLAN

A Technological implementation Plan for the WATERMED project has been elaborated in Microsoft Word format. This document has been completed electronically and returned by e-mail and surface mail to our project officer (Enrique.PLAYAN@cec.eu.int).

6.-PUBLICATIONS AND PAPERS

Articles

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12. Jiménez Muñoz, Juan Carlos, Estimación de la temperatura de la superficie terrestre a partir de datos DAIS: La Experiencia DAISEX, MSS degree, University of Valencia, 2002.
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7.-CONCLUSION

For our groups, benefits arising from the project are mainly related to the large progress made in the elaboration of a software package for processing satellite data, the algorithms for estimating LST, LSE and W, the processing of the PAL data for the Mediterranean Basin and the introduction of the REANALYSIS data in the study. This has made possible the development of a new promising land cover monitoring method from remote sensing data. Other important benefits arising from the project are mainly related to the large progress made in the elaboration of a methodology for estimating evapotranspiration at various scales. We think it is now possible to propose simple (operational) methodologies for delivering accurate estimation of evapotranspiration. In the future, we would like that this thinking is consolidated over other areas and that interaction with water managers at several scale (regional, farmers, researchers in water decision making…) may be initiated in order to implement operational products useful for water management. The development of new methods based on dual angle observation in the thermal infrared or based on the assimilation of remote sensing data into dynamic models (SVAT models or crop models) appeared also promising and will be investigate further in the future. Also the direct benefits arising from the new upscaling model are that it is possible to calculate more reliable maps of the sensible heat flux, and evapotranspiration for heterogenous landscape. This is provided that inputs from satellites are available as well as meteorological large-scale data.

The project has also made possible

- Obtain interesting results on surface parameters and evapotranspiration mapping and upscaling ending up in a possible proposition for operational methodology and several articles or presentations in conferences
- built a unique database for analysing evapotranspiration estimation from remote sensing, but also for analysing other processes such as plant production and determinism of microclimate (The database elaborated on the Alpilles test area will be available on the Web)
- complete the instrumentation and research equipment of the partners
- generate collaborations between UVEF, INRA, CESBIO and University of Marrakech that were very successful and will go on in the future
- contribute to the organisation of the first International Symposium on Recent Advances in Quantitative Remote Sensing
- begin the realization of 7 Msc and 5 PhD

Articles were sent to a range of journals from various scientific community including remote sensing, agricultural, water and geophysical sciences (Remote Sensing of Environment, International Journal of Remote Sensing, Agricultural and Forest Meteorology, Agronomie, La Houille Blanche, Irrigation and Drainage Systems, Revista Española de Teledeteccion, Journal of Hydrology, Journal of Geophysical Research).

In the future, and thanks to the WATERMED project we will consolidate our results using the existing database and thanks to the establishement of the new relationships acquired with northern and southern partners.

The project is a success story since it brings researchers together with managers and other stakeholders to jointly evaluate research results and needs and set research priorities. The project facilitates the rapid assimilation of new technologies, analytical tools, and modelling approaches for a more efficient management of water resources in water scare areas. Water managers are now testing a new management strategy where water allocation is decided based on the demand rather than the availability. This allowed for setting priorities for water allocation in case of water shortages or crises which is rather the actual situation. Future action should be directed toward the use of the actual project output to build a decision support system for integrated management of water resources. This will allow for incorporating up to data and technology for day-to-day water management issues and then to establish a sound scenario for the consequences of political actions on the sustainability of water resources.

MANAGEMENT REPORT

ORGANISATION OF THE COLLABORATION

The activities of WATERMED project have been expanding continuously since the beginning, and have included regular meetings and exchanges of ideas and planning by email, and through the web page of the project (http://www.uv.es/ucg/watermed). The University of Valencia has co-ordinated the organisation of the meetings, the measurements campaign in collaboration with the University of Marrakech, the researchers exchange, the common published works and the symposium communications.

MEETINGS

The members of the consortium have participated in the following meetings:

- Kick-off Meeting of all partners in Valencia (Spain) during 14-16 April 2000. The purposes were to define priorities of the following months.

- Attendance of the WATERMED Coordinator to the Co-ordinators Meeting in Brussels 27th and 28th June 2000.

- Meeting in Avignon (France): 5-6th January 2001, all partners except partner number 4. This second technical meeting focused on satellite data processing, building of time series, and radiometric rectification based on ground measurements.

- Joint field experiment in Murcia, (Spain, April 2001). During this experiment in Spain, partners 1, 2, and 5 were represented, the techniques for field data collection, field data processing and handling were tested and compared on a real case. The results of this test were discussed in a workshop to define complementary measurements needed, as well as satellite data selection and acquisition schemes in the future.

- Meeting in Valencia (Spain): 16-18th September 2002, all partners. This third technical meeting focused on present the results of the investigation carried out by each group from the last meeting and also to plan the future work, field campaigns, etc. The partners presented were: UVEG, INRA, RISOE and the University of Marrakech. Results: discussions on methodologies more promising. Planning of the field campaign of Marrakech'2003. Discussion and agreement; about the best way to take advantage of the collected data, and results.

- Joint field experiment and third WATERMED progress meeting in Marrakech, (Morocco) on March 2003. During this experiment the techniques for field data collection were tested and compared on a real case. The partners present were the University of Valencia, the Institut National de la Recherche Agricole (INRA) and the University of Marrakech.

- Final convergence workshop in Valencia (Spain), 17-18th November, 2003, in which all the partners were present. The purpose was to present the results of the investigation carried out from the beginning of the contract and also to discuss the content of the Final Report.

EXCHANGES AND SCIENTIFIC VISITS

- A. Olioso (partner 2) to RISOE (partner 3), Denmark, August 2001.
- A. Olioso (partner 2) and C. Hasager (partner 3), Nice, 2001.
- S. Abdel and Sameh (partner 5) to the University of Valencia (partner 1), 2001.
- G. Chehbouni (partner 2) to the University of Marrakech (partner4), 2001.
- C. Hasager and A. Olioso, Montpellier (France), 2001.
- N. Guemmouria (partner 4) to the University of Valencia, Valencia, August 2002.
- G. Chehbouni (partner 2) to the University of Valencia (partner 1), September 2002.
- A. Olioso (partner 2) to the University of Valencia (partner 1), September 2002.
- C. Hasager (partner 3) to the University of Valencia (partner 1), September 2002.
- J. El-Kharraz (partner 1) to Faculté des Sciences Semlalia. Université Cadi Ayyad, Marrakech, Morocco (Partner 4), December 2002.
- University of Marrakech (partner 4) to the University of Valencia (partner 1), July 2002
- A. Olioso (Partner 2) to Univerity of Marrakech (partner 1) and IRD (subcontractor), December 2002
- M. Gómez (partner 1) to INRA (partner 2), Avignon (France), May 2003.
- A work group of 7 people from University of Valencia (partner 1) to University of Marrakech (partner 4), Marrakech (Morocco), March-April 2003.
- A group of 2 people from INRA (partner 2) to University of Marrakech (partner 4), Marrakech (Morocco), March-April 2003.
- Several meetings wigth local partnes in Morocco: 7 with ORMVAH and 4 with ABHT.
- Organisation of the Symposium International sur les zones arides surveillées depuis l'espace:12-15 Novembre 2001, Marrakech Maroc.
- Organisation of the First Intenational Symposium Recent Advances in Quantitative Remote Sensing:16-20 September 2002, Valencia, Spain.

PROBLEMS

The main problem encountered during the course of the project were,

- The administrative aspects related with the entrance in the project of the University of Marrakech (Morocco) in substitution of the former Morocco partner of the project, the CRTS (Centre Royal de Teledetection Spatiale of Rabat, Morocco) who decided to get off the project before the end of the first year of the contract. This fact supposed a considerable delay in the project that was solved with two amendments of the contract; the inclusion of the University of Marrakech and the temporal extension of the contract in 12 months. As a consequence of this partner 1 has had to carry out part of the work (processing of low resolution images) that should be carried out partner 4.

- The financial aspects: as a matter of fact the local university (partner 4, Morocco) and the NARSS (partner 5, Egypt) does not advance any money and therefore these partners had to wait until the money got in and this supposes important problems in the organization of both partners.

- The lost that suppose for the consortium the death of the fifth partner's coordinator: Dr. Sami Abdel Rahman. This, obviously, influenced the normal progress of partner 5 and has made imposible to organise a field campaign in north Sinai in Egypt, as it had been our intention.

INDIVIDUAL PARTNER FINAL REPORT

1 February 2000 to 31 January 2004

PARTNER 1

CO-ORDINATOR

University of Valencia – Estudi General
GLOBAL CHANGE UNIT

(UVEG)

Valencia, SPAIN

PARTNER LEADER'S SUMMARY: University of Valencia, Global Change Unit.

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1.-OBJECTIVES

The general objective of the Global Change Unit in the present project is the retrospective study of the Mediterranean basin region at the regional level, using NOAA data from 1981 to present by the use of a combined historical, current space-based remote sensing database, vegetation models and field measurements from the visible (VIS), near infrared (NIR) and thermal infrared (TIR). We provide maps of critical parameters at regional scale, such as land surface temperature, emissivity, atmospheric water vapour content, and Normalised Difference Vegetation Index (NDVI) from different satellite data: AVHRR and MODIS. In addition, one of our aims is to evaluate the vegetation resistance to the aridity and the severe drought periods (summer periods and the severe inter-annual periods) for mapping the grade of water use efficiency. This study will be carried out by using field measurements and high-resolution imagery as airborne remote sensing measurements. In these areas the methodology was checked in more detail and the algorithms proposed were validated and enhanced in different scenarios.

Other important objective of our group was the coordination and establishment of new scientific relationships within north and southern countries in the Mediterranean basin and the dissemination of the project activities and results via the organizations of symposiums, workshops and the construction of a project web page.

2.- ACTIVITIES

The specific activities of the University of Valencia during the project duration to achieve the aforementioned objectives were:

2.11. Development of a software package for processing satellite data.The software should be capable of processing low (Pathfinder AVHRR Land database from 1981 to 2001 and MODIS data) and high resolution remote sensing images, as DAIS (Digital Airborne Imaging Spectrometer).

2.12. Elaboration of new algorithms for estimating surface temperature, emissivity and total water vapour content from Pathfinder AVHRR Land data over the Mediterranean Basin and MODIS and DAIS images.

2.13. Design of a land-cover monitoring method using satellite imagery over the Mediterranean basin, covering the period 1981-2001.

2.14. Development (in collaboration with INRA partner 2) of a methodology to estimate the evapotranspiration from remote sensing using an energy balance model.

2.15. Analysis of natural vegetation resistance to drought periods in the Guadalentin Basin (Spain)

2.16. Realization of field measurements and elaboration of a database where ground and satellite data are included

2.17. Management, coordination and dissemination results.

3.-RESULTS

3.1.-Software package for processing satellite images

A software package has been developed for processing satellite data. The software, developed by ourselves, has been adapted to the specific characteristics of the high and low resolution satellite images used in WATERMED. The software allows the retrieval of the land surface temperature, the land surface emissivity, the total amount of atmospheric water vapour, the albedo, and the normalized vegetation index (first year report). The programs for processing the low resolution remote sensing data (PATHFINDER-AVHRR Land) were edited in Turbo C programming language and the programs for processing the high resolution remote sensing data of DAIS (Digital Airborne Imaging Spectrometer) sensor were edited in IDL programming language (fourth year report).

The software code is operative, simple and easy to use by anyone whose objective is to extract the physical and biophysical variables from NOAA-AVHRR, MODIS and DAIS data. This is a clear advantage because nowadays there is not similar commercial software that permits exploiting the information provided by these images. A copy of the software package is included in the CD attached to this Final WATERMED report.

3.2.- Estimation of physical and biophysical variables from satellite imagery

The main objective of this part is the estimation of physical and biophysical variables from satellite images. We have developed accurate and operative algorithms for estimating land surface temperature (LST), emissivity (LSE) and total atmospheric water vapour (W) from AVHRR data. The mathematical structure of these algorithms is given in the first WATERMED annual report for PAL. The algorithms present the advantage that allows the retrieval of the aforementioned parameters from the satellite data alone and are easy to use. The algorithms have been validated and allow the retrieval of the LST, LSE and W with standard error lowers than 1.3 K, 0.01 and 0.5 gcm^{-2} respectively (Sobrino et al, 2000, 2002, Sobrino and El Kharraz, 2003). These errors are lower than others algorithms existing in the bibliography (see first annual report where our algorithms for LST, LSE and W were compared to other algorithms). The important point to highlight is that these algorithms can be applied to any satellite with 2 bands in the atmospheric thermal window.

Once the algorithms have been derived the second step was their application to PATHFINDER AVHHR LAND (PAL) data over the Mediterraean Basin. To this end a methodology that permits obtaining maps of each one of these parameters for all months from July 1981 to August 2001 has been developed.

We also included these operational algorithms to retrieve LST and W from MODIS (Moderate Resolution Imaging Spectrometer) data (fourth WATERMED annual report). It has been shown that using these algorithms LST can be obtained from MODIS data with an error of 0.7 K and the W can be obtained with an error of 0.4 g cm^{-2}. These results indicated that building a PML (Pathfinder Modis Land) data in future would improve the results provided by PAL database.

Analogously we include new algorithms and a methodology that allows the retrieval of LST, LSE and W from airborne high resolution data, like the provided by the DAIS sensor over test regions of France (Alpilles) and Spain (Barrax) (see the fourth annual report and Sobrino et al, 2004).

3.3.-Land cover dynamic analysis over the Mediterranean basin by means of remotely sensed and climate data.

According to the technical annex of the WATERMED contract our objective is to get an evolution overview on land cover during the period of study. The study area is the Mediterranean Basin, located between 23.75º N and 46.25º N latitude and between 36.25º E and 17.5º W longitude (see Figure C-1, first year report). This particular geographical position gives the area great bioclimatic diversity. The Mediterranean climate of the area is characterised essentially by two seasons: a hot and dry summer and a short winter with concentrated precipitation. The climate is also variable according to region and marked by strong annual and interannual irregularity. The area is also subjected to a significant problem with regard to desertification. The Pathfinder AVHRR Land (PAL) has been used to monitor this area. In our case we have used the images corresponding to all the months from July 1981 through April 2001 (Table 9, pp. 35, second year report).

In order to avoid monitoring land cover dynamics per pixel, which is time consuming and difficult to interpret, we have analysed the evolution of varied landscapes of the study area. The different zones of interest were defined using as mapping criterion the image of the Total Average of NDVI (TANDVI) for the whole period. Following this procedure we defined a total of six zones (Table 9, pp. 35, second year report). The TANDVI interval in each zone is 0.1, this was adopted in order to yield zones that match the different climatic zones in the study area. The study of each of the defined zones was made by applying the proposed algorithms for LST, LSE and W to these PAL images (activity 2.2) through the developed sofware (activity 2.1). Thus it has been shown that; i) these regions present a good behaviour in terms of homogeneity, with a standard deviation lower than 0.03 for NDVI and 4 K for LST, ii) the arid zones (NDVI lower than 0.1) show small variations during the whole period, the intermediate zones (NDVI between 0.1 and 0.3) present a seasonal variation with maximum peak vegetation in Spring while the areas of vegetation (NDVI higher than 0.3) present the maximum peak vegetation in Summer. More results and analysis in terms of monthly and annual evolution are included in Sobrino et al. (2002) and in the first and second year reports.

Even though we have analysed the evolution in time of LST and NDVI separately. Our objective was to develop a method for land cover dynamic monitoring using PAL data that analyse the evolution of both parameters conjointly. This is a new and original idea. The method was defined on the basis of biophysical relationships in the LST – NDVI feature space. The method named Vector of Land Cover Dynamic Monitoring (VLCD) is based on the analysis of the evolution of the slope and the module of the line whose extremities are defined by the LST and NDVI in the months of April and July (Sobrino et al., 2002). The VLCD method has the advantage of characterising the temporal trajectories and the separation of the different zones according to the evolution of the vegetative systems. The application of the method allows knowing the exact limits of the transition zone in order to study the evolution of the ecotones (the most fragile area to climate and/or human induced changes) in the course of time (first and second annual report). According to Figure 19 (Second Annual Report, page 53), we observe that regions with abundant vegetation are well separated from the rest of the regions, showing an arctangent value inferior to 75º. The application of the VLCD method allowed us to give the average images of the arctangent and the module over the whole period considered (20 years), from these images and the considerations relieved on the evolution of each region throughout the studied period, we give the image application of the VLCD method (see Figures 23 and 24, Second Annual Report, page 59) for the Mediterranean Basin. Consequently, we can distinguish and define the limits of the arid zone, vegetation zone and transition zone. The central issue in knowing the limits of the transition zone is to study the evolutions of the ecotones over the time, because it is the most fragile area to climate and/or human induced changes.

As a complement to this study a comparison between PAL data and climatic data provided by REANALYSIS over the Mediterranean basin was presented. Based on REANALYSIS data, we have provided maps that show the spatial distribution of the precipitation, the air temperature and the precipitable water vapor during the period of study of PAL data (1981-2001). These images corroborate the classification initially used based on Figure C.2 of the first annual report data. The information provided by REANALYSIS data is highly useful to check the reliability of our algorithms developed to use for satellite data. The comparison of both sources of data allows to relate the interannual responses of NDVI to precipitation and to reveal the relationship between LST and air temperature. This demonstrates the consistency of PAL data for climate studies and permits a major understanding of the land cover dynamics of the Mediterranean Basin (see third and fourth year reports). Further analysis will be carried out in the future to corroborate these interesting results.

3.4.-Evapotranspiration estimation using the S-SEBI model

In collaboration with INRA (partner 2) we have developed a methodology to estimate evapotranspiration. This methodology based on the S-SEBI model, is very simple, even as compared to other simplified approach such as the simplified relationship. It requires very few inputs (albedo, NDVI and surface temperature maps), which may be very interesting when remembering that surface flux model were very sensitive to meteorological data and to roughness lengths estimations (see previous reports). In future works, it will be compared to the other models that were used in this project. Performances of the model over the Alpilles dataset (Polder and Inframetrics data) were good: RMSE on ground heat flux was 43 Wm^{-2} and 75 Wm^{-2} for net radiation, while daily evapotranspiration was obtained with accuracy better than 1 mm d^{-1}. The model was also applied to DAIS data over the Alpilles dataset and the experimental zone in Barrax in Spain with similar accuracy (see fourth annual report).

3.5.-Analysis of natural vegetation resistance to drought periods in the Guadalentin Basin (Spain)

Variation in the state of the vegetation cover is one of the most important factors controlling the drought, erosion and desertification processes in arid and semi-arid lands. For this reason, monitoring of the vegetation cover is one of the important applications of remotely sensed data. The imagery used to obtain this result is Landsat Thematic Mapper. Specific software was developed to process this imagery. The details of the imagery used and the software are shown in the First year Report.

In order to analyse the relationship between climatic data (accumulated precipitation and mean temperature) and NDVI variation in Guadalentin basin, the obtained climatic data was used to generate precipitation and temperature images. Precipitation data was considered as the accumulated precipitation while the mean temperature was calculated by the averaging the temperature from April to March of the following year. The accumulated precipitation was calculated by adding the monthly mean precipitation from the end of August till the date of each image (generally April of each year in the case of annual variation and to the image date in case of the seasonal change). In order to produce maps at the same scale of the multitemporal NDVI images, the total accumulated precipitation and mean temperature was then used to generate precipitation and temperature image corresponding to the UTM image coordinates scale of the existing NDVI images (30 m resolution). For such purpose, the kriging method was used for the generation of both precipitation and temperature images. Kriging is a regression method used with irregularly spaced data in two or three dimensional space for the estimation of the values at unsampled locations or for the estimation of the spatial average over a length area or volume. The estimation is lineal in the data and the weights are obtained from a system of linear equations in which the coefficients are the values of variograms and covariance functions quantifying the correlation between data at two sample location and the location to be estimated. Once the precipitation and temperature images were generated (see Figure 2, First Annual Report, page 29), both are used jointly with the multitemporal NDVI images for the analysis of the vegetation cover variation in the area (third annual report, page 44). This study shows that the annual evolution of the natural vegetation show different tendencies. The seasonal grasses disperse matorral and rosemainus show very high correlation with the accumulated precipitation, whereas the pine forests and the stipa class show lower correlation. The seasonal grasses, disperse matorral and Rosemarinus classes show high and quick response to the precipitation but lower resistance to drought period. These tendencies of the response of the vegetation classes follows an exponential form in terms of precipitation (third annual report, page 45-46).

3.6.- Field measurements and elaboration of a database

The Global Change Unit (GCU) of the University of Valencia, project coordinator, have carried out several campaigns in different sites (Guadalentin Basin and Barrax in Spain and the area of Tensift located in Marrakech, Morocco) during the project duration. The objective of these experiments was to assess the usefulness of combining ground and remotely sensed data to monitor water requirement and use in non irrigated (Guadalentin) and irrigated areas (Barrax, Tensift).

In these field campaigns the GCU has used thermal radiometers (CIMEL, EVEREST, RAYTEK, etc), sunphotometer and spectroradiometer, thermocouples for thermometric temperatures measurements, a box for emissivity measurements, and a calibration source. Temperature measurements of selected surfaces were performed by making transects along the plot at the time of satellite overpass. All available radiometers were inter-calibrated before and after the field measurements using a calibration source. In order to extract kinetic temperature from radiometric measurements, the effect of emissivity and downwelling atmospheric radiance has to be corrected. To this end, emissivity data were collected and the atmospheric radiance was measured periodically while measuring in the specific bands of 8-13 μm, 8.2-9.2 μm, 10.3-11.3 μm and 11.5-12.5 μm. On the other hand surface emissivity was not measured directly, but derived from a series of temperature measurements. Several plots were selected in the test area with different cover types. Emissivity was measured in all available bands using the box method with either the two-lid or one lid approach, depending on the weather conditions. Soil samples were collected to make further emissivity measurements in the laboratory.

In this way we have provided a lot of measurements of radiometric surface temperature, emissivity and atmospheric water vapour. The measurements has been carried out concordantly with the overpass of different satellites in order to correct and validate the algorithms developed and the remote sensing products obtained from satellite images. More information on the development of the field campaigns is included in second and fourth annual reports. Finaly it should be noticed that the collected measurements are presented in the CD attached to the final report.

3.7.- Coordination, management and dissemination

The international cooperation NORTH-SOUTH was one of the most important aspects of the project.During these four years of the project an intense work of coordination has been made for partner one, this include the organization on several meetings, field campaigns, the elaboration of a database of satellite images (PAL data) and field measurements for different test regions, monitoring the projects results, decisions on the structure and content of the reports, and dissemination activities.

Among these it is necessary to highlight the first International Symposium on Recent Advances in Quantitative Remote Sensing (RAQRS), which was organised by the WATERMED coordinator and welcomed the participation of more than 50 international organisations and 200 researchers and the web page implemented at the partner 1 site with the information relevant to the WATERMED project that has been constructed and revised periodically by partner 1 with collaboration of all partners; this page supports a broad range of display options with an easy-to-use interface. The page has been enhanced with the results, images and details of each experimental field site.

Future action should be directed toward the use of the actual project output to build a decision support system for integrated management of water resources. This will allow for incorporating data and technology for day to day water management issues and then to establish a sound scenario for the consequences of political actions on the sustainability of water resources.

4.-PROBLEMS

The major problems encountered during the course of the project were,

- The administrative aspects related with the entrance in the project of the University of Marrakech (Morocco) in substitution of the former Morocco partner of the project, the CRTS (Centre Royal de Teledetection Spatiale of Rabat, Morocco) who decided to get off the project before the end of the first year of the contract. This fact supposed a considerable delay in the project that was solved with two amendments of the contract; the inclusion of the University of Marrakech and the temporal extension of the contract in 12 months. As a consequence of this partner 1 has had to carry out part of the work (processing of low resolution images) that should be carried out by partner 4.

- The financial aspects: as a matter of fact the local university (partner 4, Morocco) and the NARSS (partner 5, Egypt) does not advance any money and therefore these partners had to wait until the money got in and this supposes important problems in the organization of both partners.

- The lost that suppose for the consortium the death of the fifth partner's coordinator: Dr. Sami Abdel Rahman. This, obviously, influenced the normal progress of partner 5 and has made imposible to organise a field campaign in north Sinai in Egypt, as it had been our intention.

5. PUBLICATIONS AND PAPERS

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6.-CONCLUSION

For our group, benefits arising from the project are mainly related to the large progress made in the elaboration of a software package for processing satellite data, the algorithms for estimating LST , LSE and W, the processing of the PAL data for the Mediterranean Basin and the introduction of the REANALYSIS data in the study. This has made possible the development of a new promising land cover monitoring method from remote sensing data. Other important benefit arising from the project is mainly related to the elaboration of methodology for estimating evapotranspiration using high resolution images data. In the future, we would like that this is consolidated over other areas and that interaction with water managers at several scale (regional, farmers, researchers in water decision making…) may be initiated in order to implement operational products useful for water management.

The project makes it also possible to:

- begin the realization of 5 Msc and 4 PhD
- complete the instrumentation and research equipment of our group
- built an interesting database for analysing evapotranspiration estimation from remote sensing,
- generate collaborations with INRA, CESBIO and University of Marrakech that were very successful and will go on in the future
- contribute to the organisation of the first International Symposium on Recent Advances in Quantitative Remote Sensing

Articles were sent to a range of journals from various scientific community including remote sensing, agricultural, water and geophysical sciences (Remote Sensing of Environment, International Journal of Remote Sensing, Revista Española de Teledeteccion, Journal of Hydrology, Journal of Geophysical Research).

In the future, and thanks to the WATERMED project we will consolidate our results using the existing database and thanks to the establishement of the new relationships acquired with northern and southern partners.

Institut National de la Recherche Agronomique

INDIVIDUAL PARTNER FINAL REPORT

1 February 2000 to 31 January 2004

PARTNER 2
Institut National de la Recherche Agronomique

(INRA)

Avignon, FRANCE

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1.-OBJECTIVES

General Objectives

The general objective of our group was, in collaboration with Risø National Laboratory and University of Valencia, to evaluate the possibility of assessing evapotranspiration from remote sensing data.

We first want to check different methodologies at the local scale, i.e. by using data from high spatial resolution sensors. With such data, it is possible to implement various semi-empirical or more physical methods that have been developed in the last years at the field scale. At this scale, it will be also possible to analyse the accuracy of evapotranspiration estimates by comparison to field measurements. The consistent experimental dataset which has been acquired during the ReSeDA program over the Alpilles test site in the South-East of France in 1997 will mostly be used.

In a second time, we want to analyse the possibility of estimating evapotranspiration using data from sensors like AVHRR. The low spatial resolution of these sensors (around 1km²) does not allow to directly implement the previous methodologies (this is due to the combination of spatial heterogeneity inside a pixel and non-linearity of the physical processes governing evapotranspiration). Mathematical and physical methods that were developed for studying scaling issues will be used.

It will be then possible to propose a methodology for estimating evapotranspiration over large areas.

Position of the problem

Daily evapotranspiration is an important factor for monitoring water requirements of crops and water consumption at a regional scale. The integrated evapotranspiration through the whole phenological cycle is also closely related to the crop final productivity. Evapotranspiration estimation from remote sensing is based on the assessment of energy balance through surface temperature (evapotranspiration is corresponding to latent heat flux). Many attempts that have been made in the past for estimating evapotranspiration using remote sensing approach (see the reviews done in the frame of the project by Olioso and Jacob 2002, Courault et al. 2004, Olioso et al. 2004).

One of the main objectives of our work in the frame of the WATERMED program consists in comparing different approaches for estimating evapotranspiration on the same dataset. One of the difficulties of such work is to gather all the information which is necessary to test all the methodologies together in details. Recently, the EC ReSeDA program was developed in order to implement a detailed database gathering satellite and airborne remote sensing data, as well as ground data, that may be used for implementing and testing evapotranspiration modelling from remote sensing data (Olioso et al. 2002a). It is possible to find in this database most of the information required to test the models. Other databases that have been acquired in semi-arid conditions are also available, such as the SALSA database (Chehbouni et al. 2000a). The acquisition of a new database was performed in 2003 in Morocco (in relation with the Moroccan partner in Marrakech) and will be used for evapotranspiration assessment (see e.g. Duchemin et al. 2002, 2003a and b). At present, a first assessment of the acquired data has been done (see the report by University of Marrakech). This work will continue in the next future after the end of the WATERMED program.

The test of evapotranspiration estimation from remote sensing data required different steps. In a first step, we defined the parameters required as input of different models. In a second step we derived the required parameters from the information in the databases and in a third step we run the models, test their accuracy and compare them together. This was done in a first time on the data that have been acquired during the ReSeDA program over the Alpilles test-site in the South-East of France. Detailed characterisation of surface processes (including flux measurements) have been done concomitantly to the acquisition of high spatial resolution, multispectral and multi-angular satellite and airborne remote sensing data. Other test sites were to be used if enough information has been gathered to test in details these methods. Some aspects which were not assessed during the ReSeDA program required to use data from other experiments such as the SALSA experiment (Chehbouni et al. 2000a).

2.-ACTIVITIES

2.1-The first part of the work in this project was dedicated to the estimation of the required information for running evapotranspiration models from high spatial resolution sensors over the Alpilles test site in South of France

- meteorological data from meteorological measurement station or re-analysis of weather forecast models
- land cover maps in order to derive parameters that may be not directly obtained from remote sensing data (such as stomatal conductance parameters)
- thermal infrared images for deriving surface temperature maps
- reflectances for deriving albedo, NDVI, emissivity, fraction of vegetation cover...

This information was derived from the ground data and remote sensing images in the ReSeDA database (http://www.avignon.inra.fr/reseda). The main issues that were addressed concerned:

- the definition and the test of algorithms to derive albedo, which is a key parameter of energy balance since it determines the amount of solar radiation absorbed by the surface, providing the energy used for evapotranspiration (Jacob et al. 2002a, 2002c, 2002d, Jacob and Olioso 2004)
- the derivation of an accurate land cover map which is required for determining some of the energy balance parameters depending on the type of vegetation, as well as for having an exhaustive view of the vegetation cover types in order to analyse in details model results and evapotranspiration estimations
- the definition of methodologies to estimate aerodynamic roughness and emissivity, two key parameters when dealing with thermal infrared data, from reflectance measurements (Olioso et al. 2002b)
- the derivation of LAI and fraction of vegetation cover (using methodologies that have been developed prior to the project at INRA)
- the derivation of thermal roughness on the basis of the work performed during WATERMED by Risø (Jensen et al. 200a, 2002b, Hasager et al. 2002b, 2004).

2.2-The second part of the project is dedicated to the estimation of fluxes (and evapotranspiration) from remote sensing data using various models.

- Four existing models (SEBAL, direct flux equation, microscale aggregation model, S-SEBI) were tested and compared in collaboration with Risø and University of Valencia. Roughness, emissivity and surface temperature maps were used for computing sensible heat flux. Albedo, emissivity and surface temperature maps were used for computing net radiation maps and then latent heat flux and evapotranspiration maps. A detailed analysis of the sensitivity of the models to their inputs has been done in order to assess the most critical parameters in evapotranspiration estimation (Jacob et al. 2002b, Lagouarde et al. 2002, Olioso and Jacob 2002, Sobrino et al. 2004a and b, Olioso et al. 2002b, 2002c).

- We also developed new approaches based on:
  –I) a new simplified relationship which differs from the other model by the possibility of estimating daily evapotranspiration directly, instead of instantaneous evapotranspiration at the time of image acquisition (Wassenaar et al. 2002);
  -II) the use of the new formulation of the thermal roughness developed by Risø (Jensen et al. 200a, 2002b, Hasager et al. 2002b, 2004)
  -III) the use of dual angle thermal infrared measurements, which is expected to better constrain crop energy balance than when using one single measurement (Chehbouni et al. 2001a, 2001b, Merlin and Chehbouni 2004);
  -IV) the assimilation of remote sensing data into Soil-Vegetation-Atmosphere Transfer models and crop models, which have the advantage of providing a continuous monitoring of evapotranspiration instead of only snapshots at the time of remote sensing image acquisitions (Duchemin et al. 2002, 2003b, Olioso et al. 2003, 2004).

2.3-The third part of the project analyses the possibility of using coarse resolution data for estimating evapotranspiration. Estimation of flux using remote sensing over coarse resolution pixel was compared to measurements of area-averaged flux performed by using scintillometers (Watts et al. 2000, Lagouarde et al. 2002). However, as such validation data were not often available, the effect of scale was also investigated by comparing low resolution estimations of evapotranspiration (1 km- pixel scale) with estimation at high spatial resolution (20 m scale) averaged at the kilometre scale. As a first approximation, we based our analysis on mono-dimensional evapotranspiration model (the direct flux equation and the new simplified equation, (Wassenaar et al. 2002)). In order to better account for the effect of surface heterogeneities on turbulent flow over the landscape we also based our analysis on the simulations performed with the microscale aggregation model by Partner 3 (Risø (Jensen et al. 200a, 2002b, Hasager et al. 2002b, 2004)). A 3D boundary layer model was also used to investigate the variability of surface meteorological variables at the 50 m resolution, a factor which is not usually accounted for in scaling studies (Courault et al. 2002).

2.4-In order to acquire data in a different climatic situation, we participated to the joint experiments organised (1) near Marrakech in collaboration with University of Marrakech and University of Valencia and (2) near Murcia in collaboration with University of Valencia.

3.-RESULTS ACHIEVED

3.1-Parameter derivation

Airborne data and some satellite data from the ReSeDA database were used to develop new methodologies for mapping evapotranspiration model parameters.

- A procedure for compositing thermal infrared brightness temperature maps from the numerous thermal images (200 to 300) acquired for one acquisition flight over the Alpilles site with the airborne INFRAMETRICS sensor (this includes geometric matching, time normalisation and signal calibration); the final resolution is 20 m (report available on the Watermed database).

- Various methodologies for estimating albedo either from multidirectional reflectance measurements (airborne POLDER data) or from nadir measurements (SPOT, Landsat). They required two steps, *-I)* the estimation of hemispherical reflectances from a limited number of directions sampled by the sensor by fitting Bidirectional Reflectance Distribution Function models over the POLDER measurements in the different wavelengths; and *–II)* the spectral extrapolation from the limited number of hemispherical reflectances to the whole solar spectrum thanks to a linear combination Errors of estimations were low (0.016 or ~8%) when using the full POLDER directional sampling, and somewhat higher when using nadir data only (error ~10 %). The diurnal course of albedo was also derived generating low error on solar radiation absorption estimation along the day (11.5 Wm^{-2}). See papers by Jacob et al. 2002a, 2002c, 2002d, Jacob and Olioso 2004).
- A methodology for mapping emissivity from NDVI (Normalized Difference Vegetation Index). A new model has been developed and tested with success on in situ data from the ReSeDA database and data newly acquired in Morocco in collaboration with University of Marrakech and University of Valencia (fourth year report).
- A methodology for estimating aerodynamic roughness from TSAVI (Transformed Soil Adjusted Vegetation Index). It is based on statistical relationships which included TSAVI, as well as plant phenology and LAI or fraction of vegetation cover (Olioso et al. 2002b).
- A new model has been proposed by Risø (Partner 3) for estimating thermal roughness from momentum flux and LAI (Jensen et al. 200a, 2002b, Hasager et al. 2002b, 2004).

Maps of all the parameters were made available together with the land cover map (derived from ground and aerial surveys, as well as SPOT data), NDVI, TSAVI, LAI and fraction of vegetation cover maps (derived from POLDER data).

3.2-Evapotranspiration and flux estimations

The quality of evapotranspiration maps (and flux maps) over the Alpilles test site has been evaluated in Hasager et al. 2002b, Jacob et al. 2002b, Lagouarde et al. 2002, Olioso et al. 2002b, 2002c, Wassenaar et al. 2002, Sobrino et al. 2004a and b. With the models used at the time of remote sensing data acquisition (SEBAL, 1D equation flux, initial and new versions of the microscale aggregation model), error on flux estimates was between 60 Wm^{-2} and 80 Wm^{-2} (which corresponded to a relative error around 20%). When compared to other studies in the literature, this quality level was not particularly high, but it was important to notice that it was obtained over a very large variability of situations (whole crop cycle of several types of crops all over one year) which was not usually the case in other studies. It is important also to notice that models were highly sensitive to some of the input data (in particular roughness and air temperature) and that errors in their determination may have a significant effect on heat flux estimates. The sensitivity may differ from one model to another. Error on the determination of daily evapotranspiration with model such as S-SEBI and the new simplified relationship were around 1 mm d^{-1}, which also corresponded to 20-25 % relative errors. Other results concerned the possibility of generating intrinsic values of thermal roughness (before, it was required to give a priori values which was not easy), the possibility of deriving air temperature and wind speed from the combination of thermal and albedo images. All these results may be used for proposing a new, simple, but physically sound and accurate, methodology for estimating evapotranspiration.

New methods for estimating evapotranspiration based on dual angle measurements were also developed and evaluated by Chehbouni et al. 2001a, 2001b and Merlin and Chehbouni 2004. A new expressions of sensible heat flux as a function of two directional temperature measurements was derived by manipulating the theoretical equations for turbulent and radiative transfers (these expression slightly differed according to hypothesis made in the radiative transfer equations). The results showed that as far as heat flux was concerned, there was no need for a complex radiative transfer model. Based on this finding, a generic parameterisation of the sensible heat flux was analytically derived in terms of the nadir radiative-air temperature gradient and a corrective term involving the nadir-oblique temperature difference. Typical error were in the range 50-60 Wm^{-2} but on data acquired during the SALSA experiment. Evaluation on the same environment (Morocco), simultaneously with other models, will be performed in the next future. For this purpose, Landsat ETM+ data have been acquired all along the crop cycles of wheat.

New methods for estimating evapotranspiration based on assimilation of remote sensing data into the ISBA SVAT model was partially evaluated (concerning only wheat fields in the Alpilles test site) in Olioso et al. 2003 and 2004, giving a good agreement (relative error of 10%) over the whole crop cycle of wheat in the Alpilles area. Test of assimilation into the STICS crop growth model were also performed over the Moroccan area (Duchemin et al. 2002, 2003b). These two studies illustrated some of the advantages of using dynamic model in combination with remote sensing data to derive evapotranspiration and crop water processes: *-i)* this approach provided a continuous monitoring of evapotranspiration, while this may be difficult when using classical evapotranspiration mapping methods based on using operational satellite remote sensing data (Landsat); *-ii)* crop or SVAT models may also be used to monitor evapotranspiration without utilising TIR ; *-iii)* the possibility of combining several remote sensing system was enhanced ; *-iv)* it was possible to simulate many processes other than evapotranspiration (soil water balance, crop growth, crop production) as well as their interactions with crop management practices.

At the moment evaluation of evapotranspiration mapping over other specific areas was only performed over the Barrax area in Spain on a limited amount of data (Sobrino et al. 2004a, 2004b). Work is in progress for the Morocco zone.

Evapotranspiration maps were made available on the Watermed database.

3.3-Upscaling

First scaling analysis was performed thanks to scintillometric measurements performed over SALSA and Alpilles (Watts et al. 2000, Chehbouni et al. 2001c, Lagouarde et al. 2002). The potential of scintillometric measurements to derive area-averaged flux over several hundreds of meters or few kilometres was first checked. Then, flux estimation from remote sensing data were compared to the measured integrated flux showing a fairly good agreement.

In a second time, investigations based on the direct flux equation and the microscale aggregation model from Risø made it possible to simulate heat fluxes over the Alpilles test site and to analyse upscaling of roughness. This analysis was used as an input for investigating the possible utilisation of the simplified relationship (as reformulated) at the 1 km-pixel scale (typical size for meteorological satellite such as NOAA-AVHRR). The differences found between flux estimations at 1km and averaged flux over the same area (mean flux computed from the 20 m scale), was an indication of the error that can be committed by AVHRR based flux estimates in comparable areas. We shown that errors on upscaling emissivity and surface temperature were negligible, while errors linked to the estimation of momentum and thermal roughness may lead to errors up to 1.5 mm d^{-1} which cannot be neglected. This analysis was used by Risø for proposing a new physical upscaling method.

4. PROBLEMS

We expected to compare several methods for estimating evapotranspiration over the same dataset. This objective was not fully completed, since the delay in processing of airborne images did not allow us to implement all the methods on the same dataset. As a matter of fact dual angle thermal infrared data were not made available over the Alpilles site (this will be done in the future). As the experiment in Morocco was running only since the beginning of 2003, it has not been possible yet to test in details methods to estimate evapotranspiration from remote sensing data over another test site than the Alpilles area. As a consequence if a new methodology for estimating evapotranspiration over large areas may be proposed, it still has to be consolidated over other datasets.

The main reasons for this were: *-i)* most of the airborne remote sensing images we expected to use over the Alpilles test site were inaccurate; we had to spend several months for assessing data quality, and then to recalibrate and navigate again these images; *-ii)* a change in the rule for hiring non-permanent personnel at INRA, which occurred at just at the beginning of the project did not allow for following the expected schedule (it had not been possible to recruit the expected person, who was fully qualified for performing the research work, for more than six month instead of two years as scheduled); *-iii)* the modification of project schedule (4 years instead of 3 years) due to the change in Moroccan partner and budget problem also perturbed the expected work; this however had the advantage of included a new partner (University of Marrakech) who is working in close relation with IRD (subcontractor) and then facilitate the possibility of managing the field experiment in Morocco.

5.PUBLICATIONS AND PAPERS

1-Papers in refereed publication

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2. Submitted papers to refereed publication

17. Jacob, F. and Olioso, A., **2004**. Derivation of diurnal courses of albedo and reflected solar radiation from PolDER data. *Submitted to Journal of Geophysical Research*.
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6.-CONCLUSION

For our group, benefits arising from the project are mainly related to the large progress made in the elaboration of methodology for estimating evapotranspiration at various scales. We think it is now possible to propose simple (operational) methodologies for delivering accurate estimation of evapotranspiration. In the future, we would like that this thinking is consolidated over other areas and that interaction with water managers at several scale (regional, farmers, researchers in water decision making…) may be initiated in order to implement operational products useful for water management. The development of new methods based on dual angle observation in the thermal infrared or based on the assimilation of remote sensing data into dynamic models (SVAT models or crop models) appeared also promising and will be investigate further in the future.

The project made it also possible to:

- built an interesting database for analysing evapotranspiration estimation from remote sensing, but also for analysing other processes such as plant production and determinism of microclimate
- obtain interesting results on surface parameters and evapotranspiration mapping and upscaling ending up in a possible proposition for operational methodology and several articles or presentations in conferences
- generate collaborations with Risø and University of Valencia that were very successful and will go on in the future

The database elaborated on the Alpilles test area will be available on the Web.

Articles were sent to a range of journals from various scientific community including remote sensing, agricultural, water and geophysical sciences [Remote Sensing of Environment (2), International Journal of Remote Sensing (1), Revista Española de Teledeteccion (1), Agricultural and Forest Meteorology (3), Agronomie (6), La Houille Blanche (1), Irrigation and Drainage Systems (2), Journal of Hydrology (1), Journal of Geophysical Research (1)].

In the next year, we will consolidate our results on the newly acquired database in Morocco. Collaboration with IRD and University of Marrakech will make it possible to test the operationallity of proposed methodologies.

INDIVIDUAL PARTNER FINAL REPORT

1 February 2000 to 31 January 2004

PARTNER 3

Risoe National Laboratory

(RISOE)

Roskilde, Denmark

PARTNER LEADER'S SUMMARY

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1.-OBJECTIVES

Evapotranspiration at landscape scale is an important part in the hydrological cycle. It is a challenge to measure this at landscape scale. Typically only few local measurement points are available. Observations from these can then be used in models to infer the landscape scale evapotranspiration.

The overall objective is to evalaued the evapotranspiration at a specific area with a new upscaling method (D4).

More specifically this includes:

- to produce high-resolution maps of fluxes of evapotranspiration, sensible heat and momentum (D5)
- comparison evapotranspiration over regional models (D6)
- evapotranspiration maps over specific area (Alpilles) (D10)
- comparison with field flux data (D11)
- evaluation of evapotranspiration maps at regional scale (D14)

2.-ACTIVITIES

RISOE undertook the work to further develop the upscaling model (1) to include the scalar fluxe, i.e. focussing on temperatures in the current context. The model development is based on a physical set of equations of motion in the atmosphere and the interaction between the air and the land surface below. Land surface types are divided into water, soil, buildings, and various vegetation types. For the vegetation especially the leaf area index (LAI) and the roughness (z0) for momentum is of importance at the local scale. Both are estimated based on a combination of satellite/airborne optical remote sensing data and field observations.

The new method for surface flux upscaling is able to calculate the regional values of effective roughnesses for momentum and temperature directely. The effective roughness values can be used succesfully in weather forecasting and climate modelling (2). For the Danish landscape the momentum roughness was validated to meteorological measurements at three tall masts. The roughness maps at the Alpilles site are produced with great accuracy using unique field observations of canopies in most vegetation types in the area. All observations fromt the Alpilles site are from INRA.

A very close collaboration between INRA and RISOE has taken place over the project years: exchanging ideas, data, results and joint publication. It also includes several work meetings. However most correspondance was through email.

3.-RESULTS ACHIEVED

Description of the newly developed upscaling model is given in detail in (3). It a theoretical scientific development that constitutes an alternative to simpler modelling methods. From a practical aspect is especially relevant for scientific verification of surface flux results in heterogenous landscapes. (It can however also be used in operational terms.) In the current context the focus is on applied use over the Alpilles area. It includes a validation of the results to field observations and comparisons to other surface flux model results.

In regard to the project deliverables the results are succesfully obtained as:

The model is further developed to include scalar surface fluxes (D4). The upscaling results from the Alpilles area include evapotranspiration maps (D10), and sensible heat flux and momentum flux maps (D5). The upscaling is validated to field data (D11) and also compared to evapotranspiration results from other regional models (D6) at regional scale (D14).

The major achievements are

- the new upscaling model is fully developed and validated
- maps for sensible heat for the Alpilles site are succesfully compared to field data and other surface flux model results

The advantage of the new upscaling model is the possibility to calculate the effective roughness for scalar heat transport ($<z_{0t}>$ in m) directly. In the previous version of the model, one had to estimate the effective roughness as a simple ratio to the effective roughness for momentum ($<z_0>$ in m). The brackets signify that it is a spatial average of the value. It is customary to estimate the two values equal to each other, or as a fraction of each other, e.g. $<z_{0t}>/<z_0>$ 0.1 or less. It is well-known that simple ratios do not hold even for simple homogenous landscape with different types of land cover. Over landscapes the situation is even less clear, but the results found for Alpilles seem very reasonable.

It is found that the ratio 0.01 gives reasonable results on sensible heat fluxes for the 16 cases investigated based on a very large amount of airborne data, radiosounding data, METEO France Arpège met-model data and *in-situ* field data (all from INRA) but also that the ratio is changing from one case to the next when directly calculated.

Comparison results of the sensible heat flux maps to other evapotranspiration models (simplified relationship, SEBAL, etc) shows reasonable results (see Partner 2 annual reports).

The possibe impact of the new upscaling is related to a more accurate estimation of the sensible heat flux and hence the evapotranspiration in heterogenous landscapes.

The new upscaling model is a pc software that works very fast. An area of say 10 km by 10 km all surface fluxes and the effective roughnesses can be calculated within 30 seconds provided adequate inputs are available. This renders the model useful also for large scale calculations, e.g. at national scale.

4.-PROBLEMS

The only problem is general availability of high-resolution satellite observation combined with meteorological observations. In the current study the excellent database from the Alplilles experiment allowed a through investigation. In the future also the Marocco database from the field campaign can be used.

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6.-CONCLUSION

Direct benefits of the new upscaling model is that it is possible to calculate more reliable maps of the sensible heat flux, and evapotranspiration for heterogenous landscape. This is provided that inputs from satellites are available as well as meteorological large scale data.

The recommendation for future action is to use the model at national level (as testet at national level for Denmark for the roughness), also in semi-arid areas. In semi-arid areas the water use and evapotranspiration is of major concern, hence improved methods for local to regional scale survey and modelling is of importance.

The new upscaling method is a success story in the sense of more advanced modelling, with quick software is now publically available.

جامعة القاضي عياض

INDIVIDUAL PARTNER FINAL REPORT

1 February 2000 to 31 January 2004

PARTNER 4

University of Cadi Ayyad,

Faculty of Sciences Semlalia

Marrakech, Morocco

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1.- OBJECTIVES

Developing countries in arid and semi-arid regions where economical and social situations are usually unstable are the most vulnerable to changes related to human or climatic activities. The prediction of the consequences of these changes on water resources and its sustainability requires an overall understanding of the dominant processes that control water balance and hydrological cycle at different time space scale. This is the first step before conceiving methodologies that can be used by managers for sound management of water resources where the legitimate need for development is performed in a way that natural resources are preserved for future generation.

2.-ACTIVITIES

In the framework of WATERMED, the general objectives of the University of Marrakech are:

A) Building a local GIS as a tool for effective water management strategy at the basin scale.

B) Organizing joint field measurement campaign where ground and satellite data are collected

C) Contributing with other partners to the development of simple remote sensing based methods to assess spatial and temporal variability of Evapotranspiration.

D) Establishing close relationship with managers and endusers and other stakeholders first to evaluate the developed products/algorithms and ultimately to assimilate them in their management strategy.

E) Contributing to the project home page.

3.-RESULTS

3.1.- Correction of satellite images

Historical satellite images have been acquired (MSS and TM) over the basin. These data were geo-referenced, radiometric calibration were performed. In collaboration with SUDMED project SPOT data were also purchased; geometric, radiometric and atmospheric corrections were performed.

3.2.- Estimation of physical and biophysical variables from satellite imagery

SPOT as well as LANDSAT7 data were used to monitor vegetation status and dynamics throughout the 2002-2003 growing season. Through NDVI the cycle of the growing season of annual vegetation was monitored. We developed an indicator of water-shortage index which derived as the product of the length and the amplitude of vegetation cycle.

3.3.- Field measurements

Joint field experiment with partner 1 and 3 was carried out over an irrigated zone in Marrakech region during the 2002-2003 season. The objective of this experiment was to assess the usefulness of combining ground and remotely sensed data to monitor water requirement and use in an irrigation district.

The experimental setup consisted of deploying a classical meteorological station at 9m height so that atmospheric forcing is captured over the entire irrigation district. Additionally eddy correlations devices measuring turbulent fluxes were installed over 3 different sites. Over each site measurements of net radiation; soil heat flux, surface temperature, soil temperature and moisture profiles were collected.

In order to capture the spatial variability of surface characteristics, surface reflectance and temperature were collected using hand held radiometers (Cropscan and Exotech) over transects spanning several sites. Over the same transects, soil moisture using theta-probe and gravimetric methods, vegetation height, cover and hemispherical photo (from which leaf area index were derived) were collected. To investigate the loss of water due to flood irrigation, an olive field was also instrumented using a classical meteorological station and an eddy correlation device. To estimate plant transpiration a sap flow device was installed on several trees.

The main results obtained were:

i) Regarding the SAP flow method we notice that the transpiration represents almost 100 % of the evapotranspiration before the irrigation, and only about 72% after irrigation. This difference is due to the soil evaporation **knowing that Marrakech region represent about 40% of the total olive production in the country a saving of 30 % of water can be very significant.**

ii) Regarding the comparison between the FAO- PM, Priestly Taylors, Makkink methods, we notice that we have the same variation of the reference evapotranspiration. We also notice that the FAO-Penman Monteith (FAO-PM) based estimate is some time higher than the others. This difference mainly due to the way of parametrizing the aerodynamic term (see fouth annual report). These results are of interest since we can know use remotely sensed vegetation index to compute crop water requirement instead of using FAO lookup table values which are not site specific.

3.4.- Land cover monitoring methods using satellite imagery

The Tensift region is constituted by 3 different zones (irrigated Perimeters, pluvial agriculture ("Bour"), Mountain). Each of these zones recovers from a specific methodology for the characterization of the soil occupation from satellite images. In order to study the variation of the soil occupation from 1975 to 2003, three Landsat TM images (June 1986, August 2000, May 2003) and one MSS (November 1975) at different vegetation phonological states were acquired. We present a robust and reproducible method to map the main irrigated cultures in Tensift Al Haouz region, using a time series of four high resolution images. These images were then used to generate a NDVI profile for each pixel using ENVI software (Copyright RSI) and the associated IDL language, then applying a stretch for masking the non irrigated cultures. After that, a combination of final images was applied for mapping a variation of irrigated cultures from 1975 to 2003. This result are included in the fourth annual report.

3.5.- Local GIS for the analysis of remotely sensed changes

A local GIS has been building, this included the following layers:

Piezometric fluctuations:

In this part, we have studied the variation of the piezometric level in the Haouz plain during period 1986-2002. We noticed that the drainage came from the south side in direct of the North side We also noticed that the evolution of the piezometric level varies sharply in the plain.

- *Oriental Haouz:* the piezometric evolution is very moderate. In the North and in the center, the piezometers show weak variations in decrease or increase according to climatic periods.
- *Central Haouz:* in central Haouz we were able to distinguish several zones of piezometers:

i) Northeast zone of Marrakesh, where piezometers show very weak variations marked generally by a light descent. Indeed, the zone located near the oued Tensift has the good hydrodynamic characteristics.

ii) In the West of Marrakesh, piezometers have shown an increase of 6 m.

iii) In the South and the southeast of Marrakesh, the evolution is regular showing an increase of the piezometric level.

- *Occidental Haouz:* In Sidi Zouine zone we have a considerable number of water takings by khettaras, sources and private pumpings, what explains the regular decrease of the piezometric level.
- *Zone N'Fis:* in this zone the piezometry is very variable, with an increase of the piezometric level about 15 m. This increase is due to the succession of good years of hydraulicity. Furthermore, measures were taken by the responsible recommending the use of surface waters (from the canal Rocade and dam Lalla Takerkoust), while proceeding to an artificial food of the tablecloth.

- ***Rainfall study***

We have studied the variation of the rainfall from 1972 to 2001 for many stations in the Tensift region. We noticed that the averaged rainfalls increase from the North to the South. It's completely normal because the south is characterized by big heights (High Mountains).

4.-PROBLEMS

The major problem encountered during the course of the project is related the fact the university got inboard after the CRTS decided to get off the project. The other problem is financial, as a matter of fact, the local university does not advance any money and therefore we had to wait until EU money got in. However, some of the work was initiated before thanks to collaboration with Sudmed project.

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6.-CONCLUSION

For our group the project is a success story since it brings researchers together with managers and other stakeholders to jointly evaluate research results and needs and set research priorities. The project facilitates the rapid assimilation of new technologies, analytical tools, and modelling approaches for a more efficient management of water resources in water scare areas.

Water managers are now testing a new management strategy where water allocation is decided based on the demand rather than the availability. This allowed for setting priorities for water allocation in case of water shortages or crises which is rather the actual situation.

Future action should be directed toward the use of the actual project output to build a decision support system for integrated management of water resources. This will allow for incorporating up to data and technology for day to day water management issues and then to establish a sound scenario for the consequences of political actions on the sustainability of water resources.

INDIVIDUAL PARTNER FINAL REPORT

1 February 2000 to 31 January 2004

PARTNER 5

National Authority For Remote Sensing

and Space Sciences

(NARSS)

Cairo, EGYPT

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1.- OBJECTIVES

The general objective of NARSS in WATERMED is to develop an information system integrating remote sensing, in-situ and GIS data for water use efficiency and decision making in the northern Sinai Peninsula (Egypt).

2. ACTIVITIES

NARSS has developed an information system integrating remote sensing, in-situ and GIS data for water use efficiency and decision making in the northern Sinai Peninsula (Egypt). The Geographic Information System selected a topographic map of the north Sinai, scale 1:50000, as base map, which has been overlayed with the following thematic layers: soils, geomorphology, geology, hydrogeology, land cover and land use, water resources, mineral resources, energy, climatological data, socio economic data, tourist and human resources. The remote sensing data necessary for building the database has been obtained from Landsat images corrected in an appropriate way and also using the High Resolution Picture Transmission (HRPT) receiving station of the partner.

3. RESULTS

i) Digital image processing

Non-supervised and supervised classification techniques were used to discriminate between the different land cover types within the mapped units. SPOT panchromatic data was also used in this study to map different land use units in the area. On screen digitizing technique has been applied to map the land use – land cover units in the study area. The main land units were; beaches, sand flat, sand dune, hummocks, swamps, vegetation, cultivated lands, urban area, roads, airport, and evaporates. False Colour Composite (FCC, 247) satellite image of LANDSAT data as will as non supervised classified image were used in this study. Detailed maps were presented in the past reports. Merged technique was also used to compile the advantages in SPOT panchromatic (fine resolution 10M) with high spectral signatures of LANDSAT TM (7 bands, 30M). In the other hand, the Mediterranean off-shore plain in northern Sinai is mainly covered by a large tract of sand accumulations in the form of considerable sand sheets and sand dunes. Dunes of transverse and barchan types are well developed in the form of long belts extending nearly parallel to the Mediterranean coast and forming nearly the major part of the Quaternary sand dunes in North-western Sinai. These sand dunes are generally dense in the area south of El-Bardwill Lake to Gebel El-Maghara dome, where dunes circulate around the plunging area of the dome and cover the areas between hills and mountains. Dunes become less dense towards the east near El-Arish and to the west. The lack of relief results in a homogeneous type of sand dunes. However, prevailing wind direction and other climatic features have direct impact on the formation of different dune belt.

ii) Climate conditions and its evaluation for some common crops

The remote sensing process of clouds and precipitation focusing on developing a better understanding of the global hydrologic cycle that examines how climate change may or may not impact the availability of water, that works as a component for Global information system for better management of water resources. The current research interests, determining global precipitation and its physical characteristics as seen from space- and ground-based sensors, include hydrological parameters that involve the adaptation of cloud-scale and mesoscale models. Representative cloud profiles created by the models, and the blending of these with radiative transfer computations and satellite observations, give a complete picture of rainfall processes that are physically and dynamically consistent, and an integral part of his study of the Global Hydrologic Cycle and

Climate Change. The mission is to contribute to global development through the provision of technical know-how that serves to promote the sustainable management and a safe use of the global water resource, the marine environment and water-related infrastructures. The advanced knowledge in environmental technology engineering, chemistry, water resources, water environment, informatics and marine technology is involved in R&D and in product and problem solutions in water resources and river hydraulics, urban hydraulics, marine technology and coastal hydraulics, and marine environment and oceanography. Coastal areas especially in the Sinai Peninsula of Egypt depend mainly on precipitation and groundwater recharge and that comes mainly through infiltration. Infiltration as a main component in the hydrological cycle, at the surface, many factors effect the spatial distribution of infiltration, as well as the ratio of infiltration to surface runoff. Some of these factors include surface elevation, surface geology (rock/soil types, local terrain variability, local and regional structural geology), vegetation, and climate. All of these aspects may be measured directly or as -cost effective- it could be built through remote sensing data. Once water infiltrates the subsurface, however, its fate is only generally understood. Flow and transport through the unsaturated zone plays a critical role; it is dictated by surface infiltration, the state of the unsaturated zone, and the state of the saturated zone below.

Physical properties of the different zones are important, as well as climate and climatic history. Our understanding of this interrelationship is limited mostly to theoretical constructs. However remote sensing data would provide a great value for better understanding of this process. Specifically, it is necessary to identify and characterize (1) which subsurface factors influence the ratio of infiltration to runoff, (2) how flow and transport in the unsaturated zone responds to infiltration, (3) how unsaturated zone flow and transport are influenced by the fluctuating state of the saturated zone, and (4) the roles that climate and climatic history play in all of these processes.

These issues are a critical gap in our understanding of the full hydrologic cycle. Filling this gap is critical in as much as water resources exploration and exploitation become increasingly important as population grows.

An ideal set of measurements would include incorporating remote sensing data coupling with a dense, 3-dimensional subsurface distribution.

The model processes fluid pressures/flow rates, fluid chemistry (e.g., dissolved constituents, isotopic measurements, etc.), and temperature, among other variables.
Also needed is an effective 3-dimensional subsurface geological characterization including structure, mineralogy/lithology, facies/depositional environments, thermal conductivity, and permeability, among other properties.

The possible research studies include four fundamental components:

a) The Development Of Remote Sensing Of Soil Moisture
Soil moisture information can be utilized for efficient irrigation water management, early warning of droughts, and crop water yield forecasting. In addition, it plays an important role in the development of environmental protection strategies, especially in Egypt where water rationalization is becoming a promising national goal.

Remote sensing of soil moisture from space is advantageous because of its spatial coverage and temporal continuity. Research in soil moisture remote sensing began in the mid 1970’s.

Recent advances in remote sensing have shown that soil moisture or at least “surface wetness” can be measured by several methods. Quantitative measurements of surface layer soil moisture have been most successful using both passive and active remote sensing in the microwave region.

Early attempts to measure soil moisture from space using passive microwave sensors were hindered by what is now considered a less-than-optimal frequency and/or coarse spatial resolution.

The lowest frequency of the Scanning Multi-channel Microwave Radiometer (SMMR), Microwave Imager (SSM/I), launched in 1987, was 19.3 GHz and had a resolution of about 40 km. In addition to problems of spatial resolution, attenuation of microwave radiation in the presence of even small amounts of vegetation becomes a problem at relatively high frequencies, such as the 19.3 GHz SSM/I channel.

Two examples of new radiometers may offer some hope for satellite remote sensing of surface wetness. The Tropical Rainfall Measuring Mission (TRMM) Microwave Imager (TMI), launched in 1997, had a ground resolution of about 45 km for its 10.65 GHz channel. The Advanced Microwave Scanning Radiometer (AMSR) launched on NASA's Earth Observing System (EOS) Aqua satellite and on the Japanese Advanced Earth Observing Satellite-II (ADEOS-II) in 2002 that have a resolution of 70 km at 6.9 GHz.

b) Detailed 3-dimensional geological characterization:
Characterization of all strata that the mine penetrates, from the surface to maximum depth and lateral extent including assessment of relative rock properties such as lithology, facieses or depositional environment description, porosity, permeability, thermal properties, etc.

c) Continuous measurements of relevant processes:
Most important aspects include fluid flow/moisture content measurements, temperature measurements, and chemical evolution, including isotopic aspects. Detailed precipitation, runoff, recharge and climate information must be measured continuously at the surface.

d) Comparison or tracking of correlation between subsurface conditions and surface conditions:
Continuous histories of data and conditions from the surface through the subsurface were recorded. Conceptual models were developed based on correlations between conditions at the surface and responses in the subsurface. Linking of specific recharge areas to different portions or flow-paths may be possible using isotopes or other tracers, given the great lateral extent of the mine.

Tracking of recharge: runoff ratios as a function of seasonal climatic variation, and climatic variation over the longer term, will be sought. Anthropogenic changes to the geological/hydrological regime, including the presence of the mine and its effect on the regional hydrologic regime, must be accounted for in these analyses. Additionally, factors and possible changes to the geological environment associated with other scientific studies, including physics and geological research, must also be tracked and evaluated for possible hydrologic effects.

iii) Agricultural Weather Data System (AWDS)

In the complex of the various factors that determine the agricultural potentialities of a region, climate is certainly the most important issue. The Agricultural Weather Data System has considered especially:

1-Classification of climate in the investigated area: This classification has included average daily maximum, average daily minimum and average of the lowest temperature, vapour pressure and precipitation.

2-Ecological classification of the dominant crops: This classification has included the possibilities and limitations of the climate for each crop and type of agriculture in the studied area. Climatic and ecological classification were correlated with the different growth periods i.e. vegetative stage, flowering stage, ripening stage etc.This system is currently developed to fulfil the requirements of the classification under the Egyptian conditions. Some parameters are currently calculating i.e.

1-Potential evapotranspiration.
2-Water storage.
3-Humidity index.

iv) Integrated Remote Sensing, in situ & GIS system for Water Use Efficiency

In the previous stage of the project, a general survey of the groundwater resources of the Quaternary aquifer, as it represents 95% of water resources in the vicinity of the study area since there is no irrigation feeders from the Nile reaches that region. The present stage of the project is committed to carrying out a mission with an ethic that embraces the already water wells clusters and data from the previous stage, information about water use categories, water management policies, remote sensing data, in-situ measurements, principles and guidelines of sustainable development.

These system entries were used to upgrade and construct a geographic information system (GIS). This system is highly valuable in providing the methods, tools and information for water use efficiency and decision-making. The drilled water wells were digitally plotted on the digital maps, which were previously prepared from the landsats TM images. Attribute tables were constructed for these wells and all the available data about the water point were attached to each specific point, such as, geographic location, well depth, aquifer type, aquifer thickness, water level, total dissolved solids (TDS), chemical parameters, discharge and specific capacity.

GIS offer major benefits to collecting, storing, retrieving, transforming and displaying spatial data from the real world. These attributes make it also a powerful tool for modeling purposes. The close relationship between remote sensing and GIS arises from the capability of remote sensing to efficiently supply large volumes of relevant data to GIS, which can then be merged and analyzed with other data input from other sources. In this project GIS ARC/INFO software has been used. This software can initially be thought of as storing a map comprising a range of geographic information that is stored as a series of layers named coverages, e. g. hydrogeological maps, soil maps, topographic maps and land use maps. The coverages can be easily manipulated within the GIS. The ongoing work of constructing such an information system is systematically constructed through the following activities:

- ❖ Using landsat TM, spot images and others for mapping purposes and production of important essential maps.
- ❖ Evaluate and manage surface water and groundwater resources to ensure sustainable development.
- ❖ To provide infrastructure data, plans and related information as required for structural and non-structural (planning) investigations related to water resources.
- ❖ Maintaining a database of the project areas and the infrastructure details including maps, drawings, field water points inventory, photographs, and feasibility study reports.
- ❖ Flow and water level measurement.
- ❖ Hydrologic investigations.
- ❖ Development and maintain comprehensive, accessible, water management database.

- Assessments of present and future water availability and different categories of water uses to assist in estimating the water use efficiency for vegetated areas and for different types of crops.

v) Water resource and water/land-use inter-connection

The relationship between land use and water use is of major importance in the projected area. In this context, extensive areas are undergoing land use change. The largest changes in terms of land area, and arguably also in terms of hydrological impacts, often arise from agricultural activities. While demands for agricultural land increasing pressure on the dwindling indigenous water resources, demands for foods are leading to increasing areas undergoing.

Increasing industry, increasing urban populations without adequate sewage treatment facilities, and greater intensification of agriculture, while not significantly affecting the quantity of the resource, all pose problems for its quality. These are the problems faced by Egyptian country when trying to maintain their water resources. New approaches to integrated water resources management are being developed. The concepts of demand management and valuing the resource in economic terms that allow competition between higher value uses such as industry and water supply to conurbations, as opposed to low value usage such as irrigation, are becoming increasingly accepted.

Water resources in the projected area are mainly from groundwater and seasonally rainfall. The groundwater is principally provided by the quaternary aquifers. These aquifers are divided into three units, which are hydraulically inter-connected in El-Arish area. On the other hand, the aquifer is divided into two units in rafah-Sheikh Zuwaid area. Rainfall is a secondary water resource where it is increasing from the west to east, from about 90mm to about 250mm in the most eastern part at Rafah. Agricultural activities depend mainly on groundwater resources, due to the depressive rainfall quantities in winter seasons. The groundwater of the Quaternary aquifers is recharged by the rainfall, where the recharge is estimated to be 47,000 m3/day in El-Arish and about 42,000 m3/day in Rafah-Sheikh Zuwaid area (third report).The total abstraction of water from groundwater is about 83,000 m3/year in El-Arish and about 74,500m3/day in Sheikh Zuwaid-Rafah areas. There are some cultivated areas that depend mainly on rainfall. These areas are estimated to be about 25,000 feddan. The main crops are palm trees, olive, grapes, figs, peach and barely.

It could be concluded that the over consumption from the groundwater aquifers will lead to a comprehensive decrease of water levels and deterioration of water quality, due to the salt water encroachment. From this point of view, water management policies are highly needed and supported in this vital economic area.

vi) Water management policies

Being one of the most important factors influencing the economic development of the study area, water is a natural, yet limited resource. Methods and tools used for the purpose of utilizing and controlling water for the benefit of the society is commonly referred to as water resources planning and management. For the efforts made in this respect to be successful, what is required to be known is not only the quality and quantity of water, but also, among others, the temporal and special distribution of it. Although this information could be made available through field observations at various locations and times, what we would end up with in this case would only consist of historical information. Since all water resources projects are planned and designed for meeting the needs of future generations, historical information alone would obviously not suffice; however, it could well serve as a basis for the prediction of future distribution – both in time and space – of quality and quantity of water.

The water resource development in the study area as well as all other types of development efforts must be sustainable. Sustainability in terms of water suggests that water resources must be managed and conserved in such a way as to meet the needs of the present agricultural, domestic and industrial projects without compromising the needs of future generations.

Management of water resources cannot be accomplished without a sound assessment of water resources, which was mostly performed during the previous phase of the project. This assessment includes the determination of sources, extent, dependability, and quality of water resources, on which was based an evaluation of the possibilities of their utilization and control. It should, however, be noted that the numerical values of each component are still under investigation and they are representing the natural conditions without any development. These values are annual averages and approximated using the available data and evaluation techniques. Water resource management policies will be settled according to the renowned approved ones, and still need a detailed work.

vii) Groundwater pollution and water demand at EL-ARISH-RAFAH area

Groundwater in the study area is considered the main renewable source of water. This resource has to be properly managed and utililized in order not to be liable to pollution in its different forms or to be some day scarce. Water pollution is classified according to its source and kinds of pollutants as chemical- biological pollution. Water scarcity is due to an increase in rates of discharge and consumption of the groundwater, and with rates increasing the recharge. This leads to a decline in the groundwater table. For example, in the delta Wadi El-Arish, the decline ranges between +0.2 and 3.80 m from 1980 to 1993 where the groundwater level in 1993 ranges between +0.5 and -1.50. The water demand in El Arish-Rafah area is estimated to be 52.5 million m^3 /year for different consumption patterns.

From the above study; it can be concluded that in 1991 there was a water shortage of about 7.7 million m3/year in addition to the need for more water resources for the population increase expected in 2015. This shortage in addition to the increase in discharge and water consumption has led to a number of problems, namely:

1. Increase in the salinity, to about 4000ppm, of some wells located east to Rafah due to the increase in recharging rates.
2. Increase in the salinity due to salt water intrusion and mixing with fresh water in the aquifer. This is clearly found in the area north-east El-Arish where T.D.S. reached 6000 ppm and in the area west to Sheikh-Zuwayid where the salinity reached 3000 ppm.
3. Decline in the water level in some areas.

Prediction of salt - water intrusion at El Arish-Rafah area based on the results of hydrogeologic investigations during the 1991-1993 period and salt-water intrusion models at El-Arish, El-Sheikh Zuwayid and Rafah areas, the following conclusions can be made:

1. The danger of salt-water intrusion into the Quaternary aquifer system at El-Arish-Rafah area is increasing as a result of heavy ground-water pumping, lack of significant ground-water recharge, and establishment of a sewer system for El-Arish City.
2. The seaward side of salt water-fresh water interface (represented by the 36,000 pprn contour line) along El-Arish hydrogeologic cross section (A-A') has moved 25 m landward during the 1988-1993 period and is predicted to move 50 and 100 m after 15 and 25 years, respectively. The landward side of this interface (represented by the 5,000 ppm contour line) has moved 100 in inland during the 1988-1993 period and is predicted to move 250 and 2000 m after 15 and 25 years, respectively.

3. Because of the low ground-water pumping at El-Sheikh Zuwayid area, the seaward side of the salt-water-fresh water interface along the profile showed a vary limited landward movement with the elapse of time. However, the landward side of the interface has moved 200 m during the 1988-1993 period and is predicted to move 350 m after 15 and 25 years, respectively.
4. Despite the relatively high ground-water pumping at the Rafah area, slow landward movement of the seaward side of the salt water-fresh water interface along the (C-C) cross section is noticed as a result of high ground-water recharge rate (average annual precipitation in this area ia 300 mm). The landward side of the interface has moved 225 m during the 1988-1993 period and is predicted to move 300 and 1100 after 15 and 25 years, respectively.
5. Model calculations at two observation points show that the ground-water salinity in the Well No. (147) at El-Arish area is predicted to reach 2900, 4900, and 6800 ppm after 5, 15, and 25 years, respectively; whereas, the ground-water salinity in the Well No. (221) at Rafah area is predicted to reach 2500, 3700 and 5000 ppm after 5, 15 and 25 years, respectively.
6. Despite the progressive increase in ground-water salinity, it is predicted that ground-water levels in the Quaternary aquifer along the modeled cross sections will remain above sea level and ground-water flow will be in the seaward direction

viii) WATERMED www page contribution

As a contribution by NARSS in the WWW home page of WATERMED Project, the provided material is especially dedicated to the project for quick and efficient dissemination of activities and results. It is worthy to mention that this material is subjected to updating and some changes according to recent achievements. The www page is structured in differents parts. The first part speaks about Egypt in general terms and about the study area. Some images are provided to understand better the location of the study zones. The second part is the flow chart of the NARSS staff related with WATERMED project. The last part is a brief summary of the WATERMED objectives and the research obligations of the NARSS partner.

4.-PROBLEMS ENCOUNTERED

The major problems encountered during the course of the project were,

- The financial aspects: as a matter of fact the NARSS does not advance any money and therefore we had to wait until the money got in and this supposes important problems in the organization.

- The lost that suppose for the consortium the death of our coordinator: Dr. Sami Abdel Rahman. This, obviously, influenced the normal progress of our work and has made imposible to organise a field campaign in north Sinai in Egypt, as it had been our intention.

5.-PUBLICATIONS

1. Abdel Rahman, S.I., M.H. Ahmed and A. H. El Nahry (2002). Water Use Efficiency for natural vegetation and cultivated lands in the south–eastern Mediterranean Basin using Satellite Data, International workshop in modeling of water resources, ICARDA, Cairo, March, 2002.

2. Ahmed, M. H, M.A.R. Abdel Moati and Abdel Rahman; S. I, (2001) Integrated Coastal Zone Management for Northeastern Sinai, Egypt. Med-coast Conference, Tunisia, April 2001.

3. Abdel Rahman, S.I.; M.H. Ahmed; and Essa, M.M. (2001). Drought Monitoring in the South-Eastern Mediterranean Basin using Satellite Data IGARSS, IEEE (2001) Intern. Geosc. And Rem. Sens. Symp., Univ of New south Wales, Sydney, Australia 9-13 July, 2001.

4. Jose A. Sobrino, Naoufal Raissouni, Albert Olioso, Charlotte Bay Hasager, Mohamed Ait Belaid , Sami Abdel Rahman and A.Ghani Chehbouni (2001). WATERMED WATer use Efficiency in natural Vegetation and agricultural areas by Remote Sensing in the MEDiterranean Basin, IGARSS, IEEE (2001) Intern. Geosc. and Rem. Sens. Symp., Univ of New south Wales, Sydney, Australia 9-13 July ,2001

5. Abdel Rahman, S.I., M.H. Ahmed and A. H. El Nahry. (2002). Mapping of the Agriculture and natural vegetation along El- Zaranik - Rafah Coastal Zone of North Sinia**.**

6. Abdel Rahman, S.I., M.H. Ahmed and A. H.M.A.R Abdel -Moati and H. Habib. (2002) Assessment of Evaluation of water resources of Northeastern Coastal Zone of Sinai.

6.-CONCLUSION

For our group the project is a success story since it has allowed developing an information system integrating remote sensing data with in-situ and GIS information to provide methods, tools and information for water efficiency and decision making in the northern region of the Sinai Peninsula in Egypt. Besides the project have permited new scientific relationships within north and southern countries in the Mediterranean Basin and the establishment of close relationship with managers and end-users and other stakeholders to evaluate the developed products.

ANNEXES

Additional information is attached to this Final report in a CD that includes software for processing remote sensing data, field measurements, power point presentations of the partners and GIS layer in Arc-view format. In addition we include a relevant procedure for mapping evaopotranspiration.

A PROCEDURE FOR MAPPING EVAPOTRANSPIRATION FROM REMOTE SENSING DATA: outlines

Type of remote sensing data

1 remote sensing data
- high spatial resolution
- low spatial resolution

1-1- high spatial resolution
- bidirectional reflectances Spot-HRV, TM or ASTER type data
- multidirectional reflectance airborne PoLDER type data
- thermal infrared TM type data
- thermal infrared ASTER or DAIS type data
- thermal infrared airborne INFRAMETRICS type data

1-2- low spatial resolution
- NOAA-AVHRR type data
- TERRA-MODIS type data

Atmospheric correction

- reflectances Spot-HRV, TM or ASTER type data
  atmospheric correction using SMAC (**Jacob et al. 2002b**)
- multidirectional reflectance airborne PoLDER type data
  atmospheric correction using SMAC (**Jacob et al. 2002b**)
- thermal infrared TM type data
  atmospheric correction using Modtran (**Jacob et al. 2002b, Sobrino et al. 2004d**)
- thermal infrared ASTER or DAIS type data
  atmospheric correction using Modtran (**Sobrino et al. 2004c,** *Jacob et al. 2004*)
  atmospheric correction using split-window algorithm(**Jiménez-Muñoz et al. 2003,Sobrino et al. 2004c**)
- thermal infrared airborne INFRAMETRICS type data
  atmospheric correction using Modtran (*Jacob et al. 2003*)
- NOAA-AVHRR data
  atmospheric correction using split-window algorithm (**Sobrino et al. 2001, Sobrino et al. 2002a**)
- MODIS data
  atmospheric correction using split-window algorithm
  (**Sobrino and El-Kharraz, 2003**)

Albedo estimation with 1-1-high spatial resolution data

Depending on having multidirectional data or not:

- albedo from close to nadir reflectances (**Jacob and Olioso 2002d**)
- albedo from multidirectional reflectances (**Jacob et al. 2002a and 2002c**)

Albedo estimation with low spatial resolution data

Idem to high spatial resolution data since albedo is a linear model of reflectances (**Wassenaar et al. 2002**)

Momentum roughness estimation with high spatial resolution data

Depending on available information on land use and vegetation development:
- from land use and expected phenology (**Olioso et al. 2002a**)
- from relationship with vegetation index and expected phenology (**Olioso et al. 2002a**)
- from relationship with vegetation index, LAI, fraction of vegetation cover and phenology (**Olioso et al. 2002a**)

Momentum roughness estimation with low spatial resolution data

Depending on available information on land use and vegetation development
- from land use, expected phenology and up-scaling using the microscale agregation model (**Hasager et al. 2002b, Wassenaar et al. 2002**)
- from relationship with vegetation index, expected phenology and up-scaling using the microscale agregation model (**Hasager et al. 2002, Wassenaar et al. 2002**)
- from relationship with vegetation index, LAI, fraction of vegetation cover and up-scaling using the microscale agregation model (**Hasager et al. 2002, Wassenaar et al. 2002**)
- from land use and hedge information using the microscale agregation model (*Hasager et al. 2003*)

LAI and fraction of vegetation cover estimation from high spatial resolution data

Depending on having multidirectional data or not:
- from close to nadir reflectances using specific inversion procedure (*Lauvernet and Baret 2004*)
- from multidirectional reflectances using neural net (*Weiss et al. 2002*)

LAI and fraction of vegetation cover estimation from low spatial resolution data

Depending on having multidirectional data or not:
- from close to nadir reflectances using specific inversion procedure (*Garrigue 2004*)
- from multidirectional reflectances using neural net (see *Weiss and Baret 1999*)

Emissivity estimation from high spatial resolution data

Depending on having multispectral thermal infrared data or not
- from NDVI (**INRA fourth year report**)
- from multispectral thermal infrared data using the TES method

(**Sobrino et al. 2002b**, **Jiménez-Muñoz et al. 2003,** *Jacob et al. 2004*)

Emissivity estimation from high spatial resolution data

Depending on the available bands:

- from NDVI since emissivity was shown only little sensitive to up scaling (**Wassenaar et al. 2002, Sobrino et al. 2001**)
- using the TISIE method (*Jacob et al. 2004*)

Air temperature

Depending on available information:

- Estimation from surface temperature at high NDVI assuming almost no sensible heat flux (**Olioso et al. 2002b, Hasager et al. 2002**):
  may be very interesting when thermal infrared data are not very accurate
- From analysis of weather forecast model (**Olioso et al. 2002b, Hasager et al. 2002**)

Net radiation

Require albedo, emissivity and surface temperature derived from remote sensing data and solar radiation from meteorological data
(**Jacob et al. 2002b, Wassenaar et al. 2002, Sobrino et al. 2004a and b**)

Ground heat flux

As a fraction of net radiation and fraction of vegetation cover or LAI or NDVI (**Jacob et al. 2002, Sobrino et al. 2004a and b**)

Wind speed

Depending on available information:

- Estimation over bare soil surfaces by inverting the heat flux equation
  (**Jacob et al. 2002b, Olioso et al. 2002c**):
  require net radiation, ground heat flux, and air – surface temperature gradient
- From analysis of weather forecast model (**Olioso et al. 2002c, Hasager et al. 2002b**)

Momentum flux

From wind speed and momentum roughness

Thermal roughness estimation from high spatial resolution sensor

Depending on available information:

- as a fraction of momentum roughness and empirical information (**Jacob et al. 2002b, Olioso et al. 2002c**)
- as a fraction of momentum roughness depending on LAI and momentum flux (**Hasager et al. 2002b, 2004, Jensen et al. 2002a, 2002b**)

Thermal roughness estimation from low spatial resolution sensor

Upscaled using the microscale agregation model (**Hasager et al. 2004, Jensen et al. 2002a, 2002b)**

Sensible heat flux

From air-surface temperature gradient, wind speed, momentum and thermal roughness (**Jacob et al. 2002b, Olioso et al. 2002b**)

Latent heat flux

Depending on the avaibility of roughness:

- from net radiation, ground heat flux and sensible heat flux using the energy balance equation (**Jacob et al. 2002b**)
- from net radiation and ground heat flux using S-SEBI (**Sobrino et al. 2004a, 2004b**)

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The general objective of this project is to develop a comprehensive method for the study of the water use and the resistance to the drought of the natural and irrigated vegetation in the Mediterranean Basin, by means of a combined historical and current space-based remote sensing database, vegetation models and field measurements. This will be made by a restrospective study of the Mediterranean Basin at a regional level, using NOAA data from 1981 to present, which will permit to distinguish the most fragile areas to the drought and the evolution of the ecotones, and by a study of water use efficiency in four specific test areas. In these areas the methodology will be cheked in more datail and the algorithms proposed will be validated. The consortium of this project brings together three European partners (Spain, France, Denmark) with two Northern African countries (Morocco and Egypt) strongly involved in the study of water use efficiency and prevention of desertification. The general concept is to integrate all availabel data on the studied environments.

RESULTS ACHIEVED

(1) the development of new operative algorithms for estimating physical and biophysical parameters (surface temperature, emissivity, total atmospheric water vapour, albedo) from remote sensing data, (2) the elaboration of a new physical upscaling method which is necessary for improved surface flux estimation in heterogeneous terrain widespread in Europe, (3) the establishment of new methodologies for estimating evapotranspiration model input parameters with the required accuracy, which will improve the retrieval of daily evapotranspiration, which is an important factor for monitoring water requirements of crops and water consumption at a regional scale, and for integrated evapotranspiration through the whole phenological cycle which is also closely related to the crop final productivity, (4) the development of a software package for processing high and low resolution remote sensing satellite data which has allowed the elaboration of maps of critical parameters, (4) the building of a local GIS for effective water management strategy in the Marrakech region (Morocco) and in the northern Sinai Peninsula (Egypt), (5) the realization of field experiments in different test sites where ground and satellite data has been collected, to assess the usefulness of combining ground and remote sensing data for estimating evapotranspiration at different space time scale, (6) the elaboration of a database integrating remote sensing, in-situ and GIS data whose access is open to scientists and local administration managers, the publication of more than 40 papers in scientific reviews and 80 papers in proceedings of symposiums and (7) the establishment of new scientific relationships within north and southern countries in the Mediterranean Basin and the strengthening of research teams. Furthermore the project brings researchers together with managers and other stakeholders to jointly evaluate research results and needs and set research priorities.

Contract number : ICA3-CT-1999-00015	**Years** : **Feb-2000 to Jan-2004**

Data sheet for final report
(to be completed by the co-ordinator for the whole project)

1. Dissemination activities

	Totals (cumulative)
Number of communications in conferences (published)	85
Number of communications in other media (internet, video, …)	6
Number of publications in refereed journals (published)	48
Number of articles/books (published)	12
Number of other publications	10

2. Training

Number of PhDs	2
Number of MScs	9
Number of visiting scientists	48
Number of exchanges of scientists (stays longer than 3 months)	0

3. Achieved results

Number of patent applications	0
Number of patents granted	0
Number of companies created	0
Number of new prototypes/products developed	1
Number of new tests/methods developed	15
Number of new norms/standards developed	0
Number of new softwares/codes developed	21
Number of production processes	0

4. Industrial aspects

Industrial contacts	no ☐
Financial contribution by industry	no ☐
Industrial partners: - Large	no ☐
- SME[1]	no ☐

5. Comments

During these years WATERMED was establishing close relationship with other European projects such as SIFLEX, SUDMED, managers, end-users and other stakeholders. Moreover WATERMED results were broadly diffused in numerous forums, symposiums, seminars, conferences and media.

[1] Less than 500 employees.