The Tensift basin: an ideal outdoor laboratory to investigate basin scale hydrological functioning in the Mediterranean region: The SUDMED Program

Chehbouni A.[1*] , G. Boulet[1], B. Duchemin[1], V. Simmoneaux[1], R. Escadafal [1], B. Mougenot[1], L. Hanich[2] ,L. Jarlan[1], S. Khabba [2], M. Le Page[1], S. Erraki [2], J. Ezzahar[2], R. Hadria[1,2] , O. Merlin[2], A. Abourida[2], A. Cheggour[2] , I. Benhadj[2] , A. Boudhar[2], A. Chaponnière[1], P. Maisongrande[1], H. Kharrou [3], N. Guemouria[2], N. Alaa[2] , and B. Berjami[4].

1 IRD/CESBIO: UMR CNES-CNRS-IRD-UPS; 18, avenue Edouard Belin, 31401 Toulouse Cedex 9 – France.

2. Université Cadi Ayyad, Marrakech , Maroc.

3. ORMVAH, Marrakech , Maroc. Toulouse, France.

4. Agence de bassin de Tensift (ABHT), Marrakech, Maroc

* corresponding author : ghani@cesbio.cnes.fr Fax+33-5.61.55.85.00

ABSTRACT

The issue of the impact of human and natural induced changes on hydrological cycle and water resources has been of a prime concern not only for the scientific community but also for the resources managers, decision makers and to the general public. In this context, it was expected that scientists provide insight about the expected short, medium and long term consequences of these changes and more importantly to provide guidance to decisions managers so that appropriate actions can be taken to mitigate the impact of the above changes. In this regard, hydrologist community has dedicated substantial efforts for developing process based models so that the impact of environmental changes on water resources can be well understood and accurately predicted. This is however not a trivial issue especially in arid and semi-arid regions where heterogeneity in both surface characteristics and atmospheric forcing is rather the rule. The objective of this paper is to provide an overview of the results of a research program (SUDMED program) which has taken place in the Tensift basin in central Morocco and aimed at understanding the integrated hydrological response of the basin to human and natural changes. The lessons learned, the unsolved issues and the forthcoming challenges are presented.

1- Introduction

In Southern Mediterranean regions, population and thus urbanization growth, irrigated agriculture intensification and tourism development have lead to tremendous increase in water consumption while available water resources are becoming increasingly scarce. The serious environmental and economic consequences of these changes have led to a pressing societal need for detailed scientific studies of these complex processes. The tasks are: first to understand the impact of these alterations; and then to improve forecasts of the probable consequences of these continuing disturbances (whether natural or human-induced) on the scarce natural resources, and finally to provide scientific tools for decision

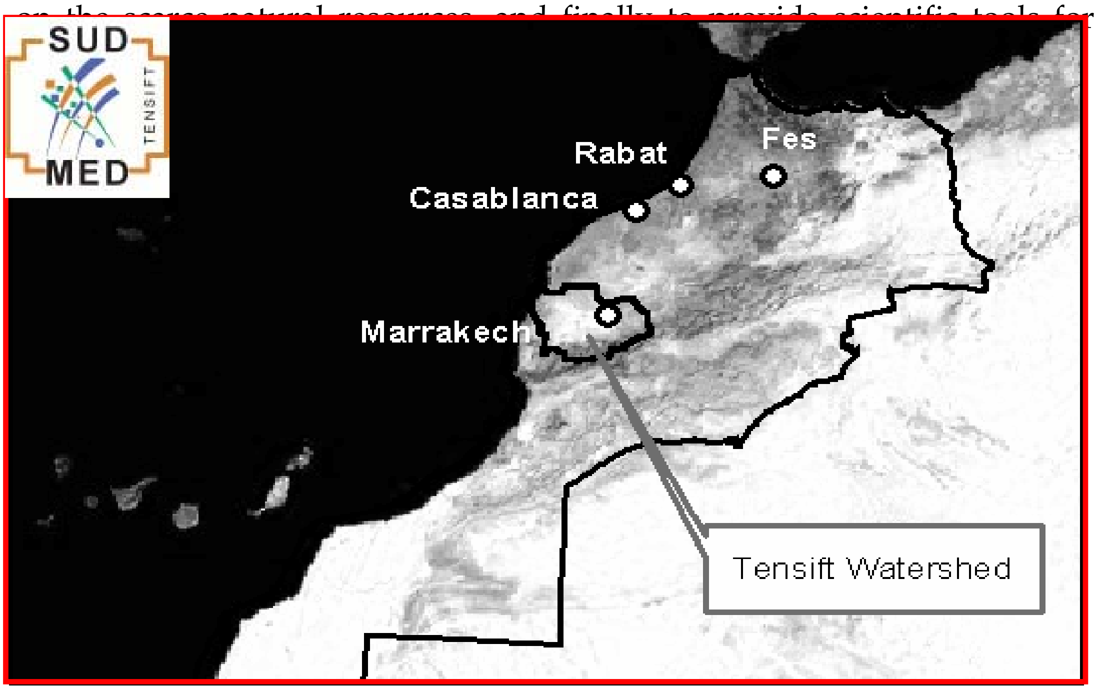

Figure 1: Site location

In this context, a consortium of universities, research laboratories and government agencies from France and Morocco designed the SUDMED Program (Chehbouni et al. 2008). The primary goal of SUDMED is to combine process model, ground and satellite data to understand, model and predict the consequences of natural and human-induced change on the basin-wide water balance and ecological functioning. The program is taken place over the Tensift basin (20500 km^2), which originates in the Atlas Mountains and flows into the Haouz plain before reaching the Atlantic Ocean in the west (See Figure 1). However, since the ecological, hydrological, meteorological and socioeconomic processes involved are not specific to the Tensift basin, this basin presents an ideal opportunity as an outdoor laboratory for long term investigation of the combined effect of human and natural induced changes on the hydrological cycle and water resources in semi-arid Mediterranean conditions. The objective of this paper is first to describe the objectives of the SUDMED project and second to review the progress made over the past 5 years associated with its different trust areas and, finally, to summarize the unsolved issued of future challenges are outlined.

2- Specific objectives and trust areas

The specific objectives of the program are:

- Document the changes that occurred in the basin during the past 30 years, identifying the different drivers and assess the impact of these changes on water resources in the basin.
- Describe in integrated manner, the dominant processes that control the overall hydrological functioning of the basin by making full use of recent technological and scientific developments (Modelling, Remote Sensing, Assimilation)

- Provide operational tools to managers while assuring compatibility between the level of technology and the user's ability to operate them.

To achieve the above objectives, the program has been structured into the following trusts areas. We first characterized the basin by pulling together existing data collected during previous projects and/or available from different government administrations, and then we formatted them so than it can upload into a Geographic information system. This GIS is now used for both scientific and management purposes. The second theme concerned understanding mountain hydrology since the Atlas represents the water tower in the basin (i.e. the production zone). Here we tackled the issues of snow dynamic characterization, surface hydrology and ground water recharge. The next important issue is the estimation of evapotranspiration with important emphasize on water use for irrigation agriculture which amounts to about 85% of the total available water. This has been addressed at different scales (field, district and basin scale). The motivation of this increasing scale is both scientific and operational. Scientifically the challenge is estimating ET over surfaces made up of different vegetation types which require the development and the validation of aggregation and disaggregation schemes if one wants to take fully advantage of different sources of remote sensing data. From operational perspective, the diversity of the nature of end users required information about ET at different scales. For example the farmers are mostly interested about water need and consumption at the field scale while irrigation managers are interested on this same information at the district scale. Finally the basin agency is mostly requiring information at the basin scale. Finally we addressed the question of educational training, capacity building and knowledge transfer.

3- Site Description and historical background of the basin conditions

As stated above, the basin originates in the atlas mountain and flows west to the Atlantic Ocean. The basin embodies a number of characteristics which make it an exceptional outdoor laboratory for addressing a large number of scientific challenges in arid and semi-arid hydrology, meteorology, ecology, and social and policy sciences. It is characterized by a significant topographic and vegetation variation, and a highly variable climate: from desert type to wet mountainous climate. The annual rainfall ranges from around 150 mm in the dry part to 850 mm in the mountain, with the majority of annual precipitation occurring during the winter season. The precipitation pattern depicts strong annual to inter-annual variability. In this basin about 85%to 90% of available water is used in the plain for irrigation. Major irrigated vegetation types include olive (40% of the national production), oranges and wheat. Due to a tremendous expansion of the main city within the basin, i.e., Marrakech (increase of about 35 %) as well as of the surface of irrigated zones (increase of about 40 %) during the past 30 years , water resources is facing an enormous pressure. This has been translated to an over-exploitation of ground-water, and as a result its level decreases of about one meter a year (Abourida et al. 2003).

4- Experimental strategy

An experimental protocol has been designed to achieve the objectives of the study. First a basin wide meteorological network made up of 9 automatic stations that measure incoming radiation, wind speed and direction, air temperature and humidity, and rainfall has been installed throughout the basin. In the mountain site a dense network of rain gauges was deployed to try capturing the spatial variability of rainfall. Additionally measurements of snowfall and snow depth as well as surface runoff are made. Geochemical sampling has been taken to document the contribution of surface runoff to recharge.

In the flat part of the basin (the Haouz plain), the evapotranspiration (ET) is the dominant term of the water balance. Thus, a comprehensive sampling strategy has been implemented. It consisted in measuring ET at different scales and over the dominant vegetation types. This has been achieved through the use of sap-flow devices, Eddy Correlations systems and scintillometers (See Figure 2). Moreover, isotopic samplings were taken to separate soil and vegetation contributions to total evapotranspiration (Williams et al. 2004).

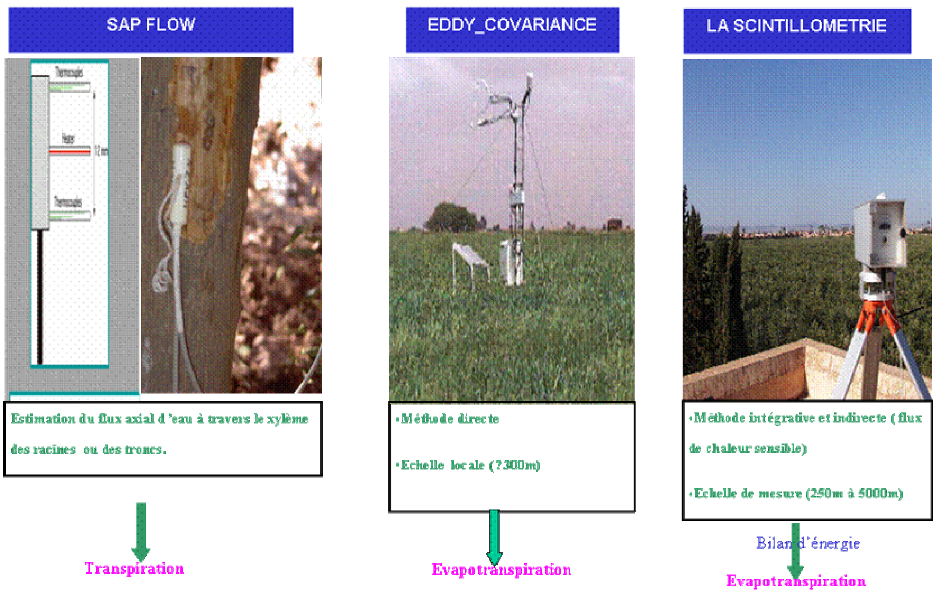

Figure 2: devices for measuring ET at different scales.

The sampled surfaces include wheat during different growing seasons and management practices; old and young olive trees under drip and flood irrigation, and orange orchards under both irrigation systems. Additional measurements of soil temperature and moisture, radiative surface temperature, net radiation and soil heat flux were taken in each individual station. Vegetation characteristics (Fraction cover and Leaf Area Index) have been made over each station using either destructive sampling and/or , LICOR-LAI 2000 and hemispherical photos.

Regarding remote sensing data, ground based surface reflectance and temperature were collected during different seasons using a hand held radiometer (Cropscan). Historical satellite data were acquired over a period of 30 years (MSS and

LANDSAT). Additionally time series of SPOT and LANDSAT-TM, VEGETATION, MODIS and ASTER images were collected starting 2003. In 2006, high spatial and high temporal satellite data (FORMOSAT) data were collected throughout the growing season (Duchemin et al., 2008). Finally a sun photometer (CIMEL) was installed since 2003 to collect data required for atmospheric correction.

5- Results of the first phase of the program

In the following section, a brief summary of significant preliminary results associated with each trust areas mentioned above are provided. The results obtained have been published in about 20 articles in per review journal. The list of publications can be consulted in the following website www.irrimed.org.

Thanks to the good working relationship established with the different state agencies in the basin, topography, soil type, geological, and groundwater data which were stored in different administrations and formats have been gathered and homogeneously formatted. All these layers of information were included in a Geographic Information System (Cheggour et al., 2004). This system is now used for both research and management operations. Land-use and land-cover maps have been derived from a series Landsat-TM and spot images (Simonneaux et al. 2007). However, since these maps need to be updated every year and knowing the cost of high resolution satellite data, an alternative approach has been developed so that land use maps can be updated. The approach consisted in combining un-mixing technique with freely available coarse or moderate resolution satellite data such as SPOT-VEGETATION or MODIS (Benhadj *et al.* 2008).

As stated above, the Atlas Mountain represents the water tower in the basin. It is thus of prime importance to accurately quantify the precipitation in both liquid and solid forms. The main question that we aimed to address is whether a physically based hydrological model that provides good simulation of streamflow guarantees a realistic representation of intermediate water balance processes such as storage terms (e.g. snowmelt) and lateral flow redistribution (e.g. groundwater flow). Boulet et al. (2008, this issue) provides a comprehensive review of the issue and the results obtained in this trust area. Briefly, we found out that the fact that a hydrological model provides accurate estimates of the runoff does not necessary guarantee that the other hydrological components are well described. For example, Chaponnière et al. (2007) showed that the snowmelt parameterisation in SWAT, as well as the representation of surface-subsurface interactions were not realistic while the total runoff was well reproduced. Therefore, progress requires more physics and more data. In the future, we will improve the control of the system/model through the combination of remotely sensed based estimates of snow dynamics and basin scale estimate of ET using measurements of XLAS and remotely sensed available energy. We are also planning to use geochemical sampling to improve the physics of the poorly described surface-water /ground water interaction.

Regarding estimates of evapotranspiration, we first implemented a complex physically based Soil-Vegetation-Atmosphere-Transfer (SVAT) Model ICARE (Gentine et al. 2007) over several sites. The results show that this model provides accurate estimates of surface fluxes. However, ICARE as other similar complex SVAT require several input parameters that are not routinely available at the appropriate space-time scale. One avenue to overcome this difficulty is through the use of assimilation technique. In this regard, Alaa et al (2007) show that ICARE initial parameters can be efficiently derived from surface temperature time series using a variational technique. Additionally this type of model are difficult to use operationally since they not are designed for this purpose, however they can provide insight of the functioning of the interface soil-plant-atmosphere and they can be used to assess the realist and the robustness of simple models (Boulet al. 2007).

For operational purposes, we first assess the efficiency of the irrigation through the comparison of crop water requirement (EC) and the sum of irrigation and rainfall. Figure 3 presents such comparison over olive and orange sites. It can be seen that the farmers over-irrigates of about 30% for both sites. In the same vein Ezzahar et al; 2007b, showed that despite this over-irrigation, the vegetation suffered from water stress during the summer: the wrong quantity in the wrong moment.

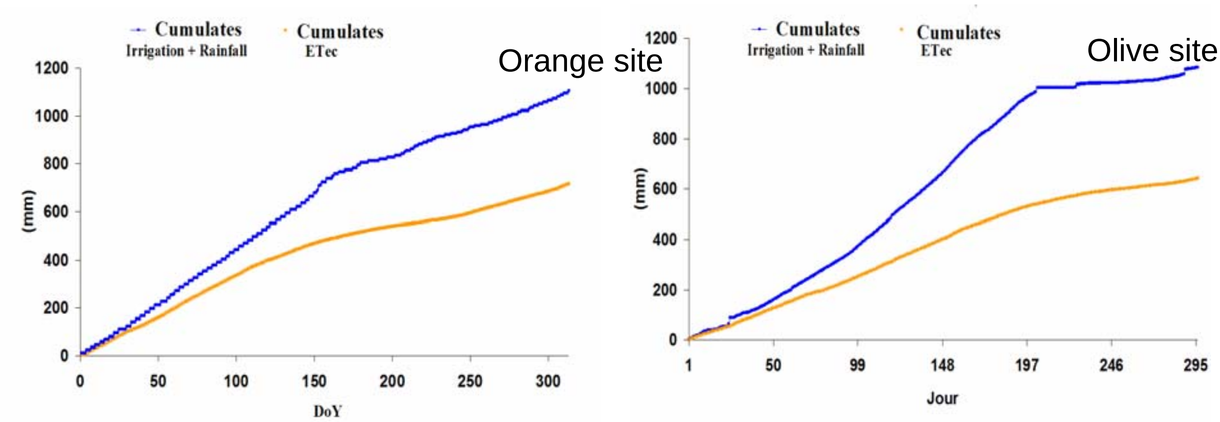

Figure 4: Comparison between water use and water requirement (Kamil et al. 2007)

Then the FAO-56 model was adapted to use satellite based vegetation index (Erraki *et al.* 2007 and Duchemin et al. 2007). The results show that relating the basal crop coefficient (Kcb) to remotely sensed vegetation index greatly improves the performance of FAO-56 Method. This approach has been applied to the entire plain and provides reasonable or at least realistic estimates despite the simplicity of the model and some theoretical limitation of its parameterisations for the soil water balance. However Erraki et al. (2006) showed that the performance of the FAO method has some limitations when there is high soil evaporation or when stress occurs (Figure 5).

To overcome this problem and then enhance the FAO-56 performances, ET derived from thermal infrared (TIR) observations was assimilated into FAO-56 single source model (Erraki et al. 2008). Thermal infrared based AET was obtained through the combination of a simple energy balance model and thermal infrared observations. The latter were collected with the ASTER sensor in 2003 and from ground based measurements in 2004. The results showed a clear improvement for

FAO-56 performances after assimilation: for 2003 and 2004, the RMSE values between measurements and simulations respectively dropped down from 0.61 to 0.52 and from 0.69 to 0.46 (corresponding to relative reductions of 15 and 40%, respectively). Figure 6 presents the result of this improvement using ASTER data over tall and sparse olive trees filed during 2003 season.

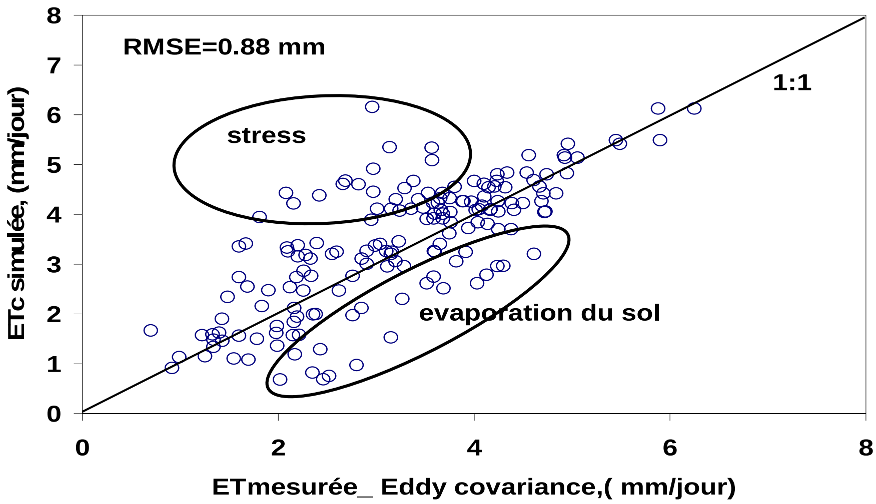

Figure 5: Comparison between FAO-based and Eddy correlation-based values of ET.

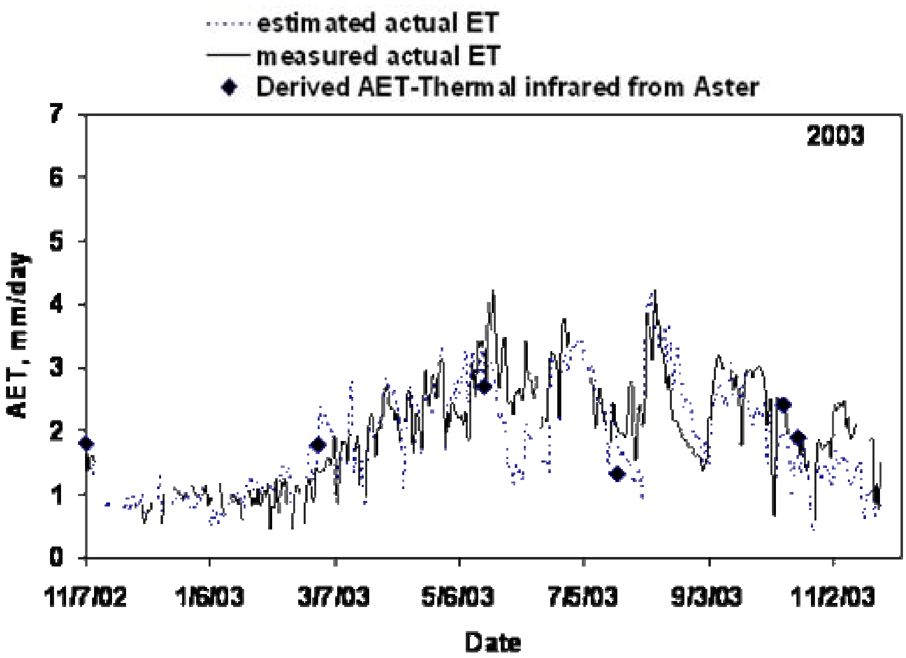

Figure 6: Comparison between observed (solid line) and simulated (dotted line) ET using the FAO-56 single crop coefficient approach for 2003 of olives orchard, after the data assimilation. The values of AET (lozenge) derived from thermal infrared of ASTER during 2003

It should be mentioned that since FAO-56 runs on daily time step while TIR based methods provide only estimates during the satellite overpass (snap-shot) a procedure to scale-up ET estimates from instantaneous to daily ones is required. In this regard, Hoedjes et al. (2008) developed an original study which aims to investigate the diurnal course of Evaporative Fraction (EF: The ratio of ET to available energy); EF is widely used to scale up values of ET from instantaneous estimates to daily totals with the assumption that EF is constant during a given day. They found out that this assumption only holds during dry conditions, while EF exhibits a strong diurnal shape under wet conditions (See Figure 7). They then developed a robust method which allows deriving daily values of evaporative fraction and available energy and thus ET from satellite based instantaneous ones.

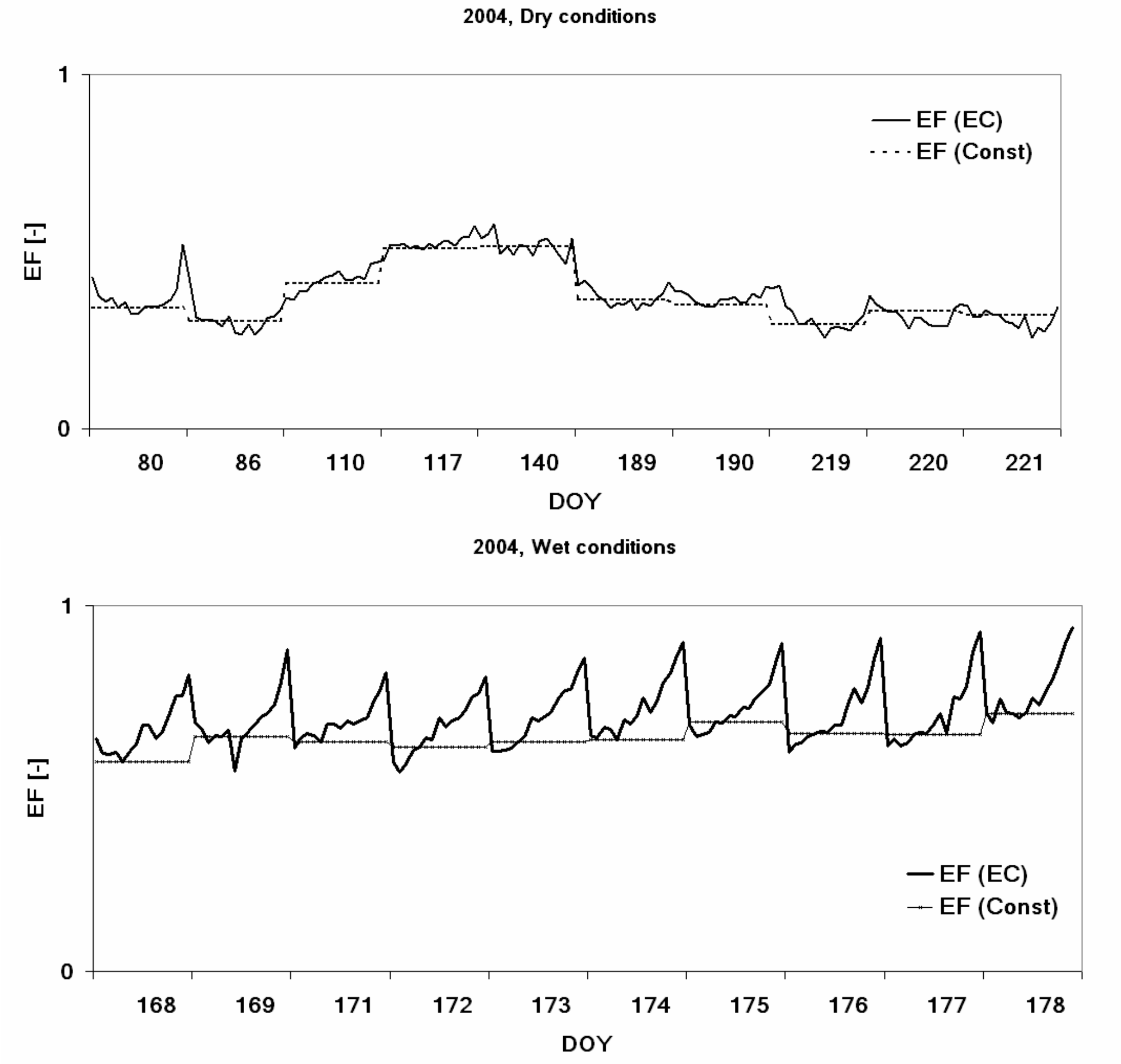

Figure 7: Diurnal behaviour of Evaporative fraction under dry and wet conditions respectively

The issue of surface heterogeneity has been addressed from both experimental and theoretical perspectives. Experimentally we took a full advance of the ability of the Large Aperture Scintillometer (LAS) to provide measurement of sensible heat flux, and thus an estimate of latent heat flux, over a large transect (of about 5 km for the LAS and up to 10 km for the XLAS). However, in contrast to the Eddy Correlation system, the scintillometer is an indirect method since it required the use of Monin-

Obukhov M-O Similarity theory. We thus first verified that the M-O similarity theory holds over heterogeneous surface. As far as we know, this has never been checked before. As shown in Figure 8, the LAS data behaves according to M-O theory despite the fact that this theory has been developed for homogeneous surfaces.

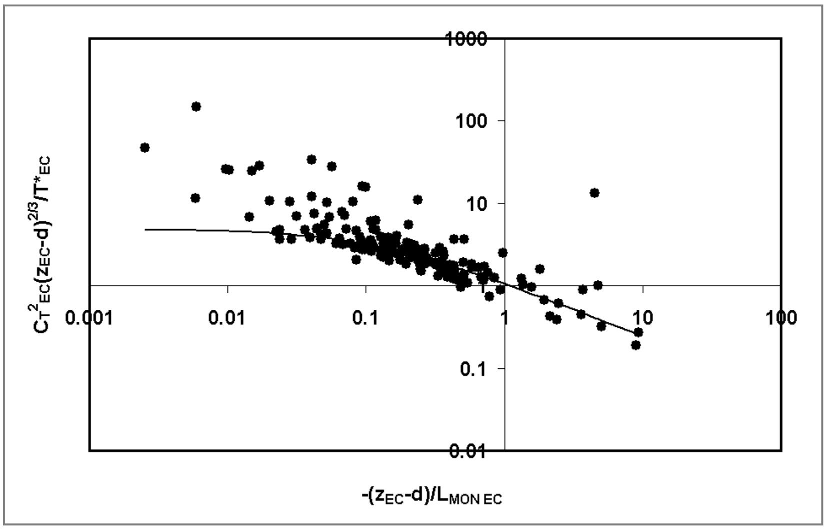

Figure 8: Verification of M-O theory over heterogeneous surfaces.

In the same vein, the disaggregation issue has been investigated in the context of the Soil Moisture and Ocean Salinity (SMOS) Mission. SMOS will provide soil moisture map at the nominal spatial resolution of 40km starting 2008 and will not be of very much use to basin scale hydrological modelling if this information is not disaggregated to at least 1 km. In this context, Merlin et al. (2005, 2006a-b, 2008) developed several disaggregation schemes with different degrees of complexity so that SMOS data can be used for hydrological and land-surface interaction modelling. These schemes are based on the principle of combining a land surface model (SVAT) and high resolution (1km) information of surface temperature and LAI/vegetation index. The near-surface soil moisture derived from SMOS type data is disaggregated at fine scale and assimilated using an ensemble Kalman filter into a distributed SVAT model. One interesting outcome of Merlin et al. study is that they have shown that assimilating the disaggregated soil moisture into a SVAT can help in reducing the error associated with the lack of availability of fine scale precipitation derived from satellite data ((Merlin et al. 2006b). This finding is of prime interest for integrated water management especially since the quantity of water extracted from ground water is not available because large number of farmers is pumping water from underground without declaring it to water authority as it is required by law.

Finally with regard to education, capacity building and knowledge transfer, 9 PhD students (6 from Morocco and 3 from Europe) as well as 15 Masters Students have been working in the project. Additionally several training sessions in remote sensing, geographic information systems, micrometeorology were organized in Marrakech during the course of the project. These training sessions were open to students, young scientists and engineers working for different government agencies partners in the project. Finally an operational Decision Support System for better management of irrigation water has been developed (Simonneaux et al. 2006); it is now under testing procedure before handing out to the managers.

6- Concluding remarks

Substantial results have been obtained during this first phase of the Sudmed project. A remote sensing data base has been constructed. Advances in each trust area have been accomplished. However it should be mentioned that we are far from achieving all the objectives of the project. The second phase of Sudmed will build up on the achievement of the first phase and it will be directed towards:

- Integrative modelling
- Aggregation and desegregation issues
- The use of low to very low resolution satellite data (VEGETATION, MSG, SMOS).
- Completing the development of the Decision Support System and most importantly building the bridge between scientific community and decision maker.

However, achieving all the objectives of this ambitious program cannot be fulfilled without:

- first a close integration of the individual components of the hydrological cycle, i.e., vegetation functioning, surface water groundwater interaction, surface-atmosphere interaction.
- Second the transfer of research results to policy makers; this requires an integration of the physical and the social sciences. The local conditions are very appropriate for such integration.

This is why we take advantage of this forum to call the national and international scientific community involved in this field to join us in this zone on "open market" basis so that the Tensift basin can be used as outdoor laboratory in the context of the future SICMED program.

Acknowledgments

This research was situated within the framework of SUDMED. In addition to IRD's financial support for this study, additional support was provided by EC in the framework of several projects (Irrimed, Pleaides) and by the French *PNTS and the French space agency (CNES)* .. We are indebted to the staff and the directors of ORMVAH , IRATE, ABHT for their assistance during the course of this study.

Cited References

Abourida A., Errouane S., Chehbouni A., Cheggour A., 2004, Impact of the dryness on the underground water potentialities of the Haouz plain (Central Morocco). 25-30 April/2004. in: 1st Gen. Assem., (Nice , France).

Alaa N., W. Bouarfi.; G.Boulet; A.Chehbouni; R.Khiri; L.Hanich. (2007). Variational assimilation: application to the control of the initial data in ICARE model. International Journal of Ecological Economics & Statistics (IJEES), Volume 9, pp13-26, F07, 2007.

Benhadj I. , B. Duchemin, P. Maisongrande, V. Simonneaux, S. Khabba, A. Chehbouni Automatic unmixing of MODIS multitemporal data for inter-annual monitoring of land use at regional scale (Tensift, Morocco), 2008 , IJRS, in revision.

Boudhar A., B. Duchemin, L. Hanich, A. Chaponnière , P. Maisongrande, G. Boulet, J. Stitou and A. Chehbouni. Snow covers dynamics analysis in the Moroccan High Atlas using SPOT-VEGETATION data, Sécheresse 2007 ; 18 (4) : 278-88.

Boulet al. (2008). Hydrological modelling in the High Atlas mountains with the help of remote-sensing data: milestones of the SudMed project. This issue.

Boulet, G., Chehbouni, A., Gentine, P., Duchemin, B., Ezzahar, J, and Hadria, R . 2007, Monitoring water stress using time series of observed to unstressed surface temperature difference. Agricultural and Forest Meteorology. Vol 146/3-4 pp 159-172.

Chaponnière A., Maisongrande P., Duchemin B., Hanich L., Boulet G., Escadafal R., Elouaddat S. (2005). "A combined high and low spatial resolution approach for mapping snow covered area in the atlas mountain". International Journal of Remote Sensing 26: 2755-2777.

Chaponnière, A., Boulet, G., Chehbouni, A. and Arsmouk, L., 2007, Assessing Hydrological processes under scarse data and complex environment. Journal of hydrological procecces. doi:10.1002/hyp.6775

Cheggour A., A., Errouane, S., Simonneaux, V., Chehbouni, A. and Abourida, A., 2004, Interest of the Geographic Information System for the management of natural resources in the Tensift region. 32nd International Geological Congress, 20-28 August 2004, Florence, Italy.

Chehbouni A., J. C. B. Hoedjes , J-C Rodriquez C. Watts , J. Garatuza , and Y. H. Kerr, 2008b. Remote sensing based estimates of daytime area-averaged surface fluxes over contrasted agricultural patchwork in a semi-arid region., Agricultural and Forest Meteorology. 14 8 (2008) 330-342

Chehbouni, A., et al . 2008a. An integrated modelling and remote sensing approach for hydrological study in semi-arid regions: the SUDMED Program. International Journal of Remote Sensing. In press.

Chehbouni, A., Ezzahar, J., Watts, C., Rodriguez, J. C., Garatuza-Payan, J. (2008c) Estimating area-averaged surface fluxes over contrasted agricultural patchwork in a semi-arid region. In: Advances in Remote Sensing and Geoinformation

Processing for Land Degradation Assessment (ed. by J. Hill & A. Röder). Taylor and Francis (In Press).

Duchemin B., Hadria R., Er-Raki S., Boulet G., Maisongrande P., Chehbouni A., Escadafal R., Ezzahar J., Hoedjes J.C.B., Kharrou M.H., Khabba S., Mougenot B, Olioso A., Rodriguez J.C., Simonneaux V., 2006. Monitoring wheat phenology and irrigation in Center of Morocco: on the use of relationship between evapotranspiration, crops coefficients, leaf area index and remotely-sensed vegetation indices. Agricultural Water Management., 79; 1–27.

Duchemin, B., Hagolle O., Mougenot B., Simonneaux V., Benhadj I., Hadria R., Ezzahar J., Hoedjes J., Khabba S., Kharrou M.H, Boulet G., Dedieu G., Er-Raki S., Escadafal R., Olioso A., Chehbouni A.G.. Agrometerological study of semi-arid areas: an experiment for analysing the potential of FORMOSAT-2 time series of images in the Tensift-Marrakech plain. 2008 , International Journal of Remote Sensing (Accepted).

Duchemin B., Maisongrande P., Boulet G, Benhadj. I (2008). A simple algorithm for yield estimates: calibration and evaluation for semi-arid irrigated winter wheat monitored with ground-based remotely-sensed data. Environmental Modelling and Software 23:876-892 (doi:10.1016/j.envsoft.2007.10.003).

Er-Raki S; A. Chehbouni, N. Guemouria a, B. Duchemin , J. Ezzahar, R. Hadria: 2007. Combining FAO-56 model and ground-based remote sensing to estimate water consumptions of wheat crops in a semi-arid region Agricultural Water Management. 8 7, 4 1 – 5 4.

Er-Raki, S., Chehbouni, A., Guemouria, N., Duchemin, B., Ezzahar, J., Hadria, R. and BenHadj, I., 2006b, Driven FAO-56 dual crop coefficient approach with remotely-sensed data for estimating water consumptions of wheat crops in a semi-arid region. Second Recent Advances in Quantitative Remote Sensing, Ed. José A. Sobrino, Servicio de Publicaciones, Universitat de Valencia, Valencia, 2006, pp. 431-636.

Er-Raki, S., Chehbouni, A., Hoedjes, J., Ezzahar, J., Duchemin, B., Jacob, F. 2008a. Improvement of FAO-56 method for olive orchards through sequential assimilation of thermal infrared-based estimates of ET. Agricultural Water Management Volume 95, Issue 3, Pages 309-321

Ezzahar J., Chehbouni A., Hoedjes, J.C.B., Er-raki S., Chehbouni Ah, and J-M Bonnefond, and De Bruin, H.A.R. 2007a. The use of the Scintillation Technique for estimating and monitoring water consumption of olive orchards in a semi-arid region, Agriculture water management, 89, 173-184.

Ezzahar J., Chehbouni A. G., Hoedjes J. C. B. and Chehbouni Ah. (2007b) On the Application of Scintillometry over Heterogeneous Grids. Journal of hydrology. In press.. Journal of hydrology , Vol 344 , Issue 3-4, Pages 493-501 .

Gentine P., D. Entekhabi A. Chehbouni, G. Boulet and B. Duchemin (2007) Analysis of Evaporative Fraction Diurnal Behavior, Volume 143, Issues 1-2, 16, Pages 13-

29Agricultural and forest meteorology.

Hadria R., Duchemin B., Lahrouni A., Khabba S., Er-Raki S., Dedieu G., Chehbouni A., Olioso A. (2006). "Monitoring of irrigated wheat in a semi-arid climate using crop modelling and remote sensing data: Impact of satellite revisit time frequency". International Journal of Remote Sensing 27:1093-1117 (doi: 10.1080/01431160500382980).

Hadria R., Khabba S., Lahrouni A., Duchemin B., Chehbouni A., Carriou J., Ouzzine L. (2007). "Calibration and Validation of the STICS Crop Model for Managing Wheat Irrigation in the Semi-Arid Marrakech/Al Haouz Plain". Arabian Journal for Science and Engineering 32:87:101. (special issue potential water challenges and solutions in the new millennium in arid regions, http://www.kfupm.edu.sa/publications/ajse/articles/321C_P.07.pdf).

Hagolle O., Dedieu G., Mougenot B., Debaecker V., Duchemin B., Meygret A. (2008). Correction of aerosol effects on multi-temporal images acquired with constant viewing angles: application to Formosat-2 images. Remote Sensing of Environment 112:1689-1701 (doi:10.1016/j.rse.2007.08.016).

Hoedjes J.C.B, A. Chehbouni, F. Jacob, G. boulet, J. Ezzahar (2008). Deriving daily evapotranspiration from remotely sensed instantaneous evaporative fraction, Journal of Hydrology, In press

Hoedjes, J. C. B., Chehbouni, A., Ezzahar, J., Escadafal, R. & De Bruin, H. A. R. (2007) Comparison of large aperture scintillometer and eddy covariance measurements: Can thermal infrared data be used to capture footprint induced differences? J. of Hydrometeorol. 8, 144–159.

Kamil, A. (2007) Mesure et Modélisation de l'évapotranspiration de l'olivier et de l'oranger dans la région de Tensift Al Haouz. Diplôme d'Études Supérieures Approfondies (DESA) « PROTECTION ET AMENAGEMENT DES RESSOURCES EN EAU », 70 pp.

Merlin O., Chehbouni A., Kerr Y., Njoku E. G., Entekhabi D., 2005. A combined modeling and multi-spectral/multi-resolution remote sensing approach for disaggregation of surface soil moisture: Application to SMOS configuration. IEEE Trans. Geosci. Remote Sensing, 43 : 2036-2050.

Merlin O., Chehbouni A. G., Kerr Y., Goodrich D., 2006a. A downscaling method for distributing surface soil moisture within a microwave pixel: application to the Monsoon '90 data. Remote Sens. Environ (101), 379-389.

Merlin O., Chehbouni A.G., Boulet G., Kerr Y., 2006b. Assimilation of the disaggregated microwave soil moisture into hydrological modeling using coarse resolution meteorological data: a study case based on the Monsoon '90 data. J. Hydrometeorol. 7(6), 13081322.

Merlin Olivier, Abdelghani Chehbouni , Jeffrey P. Walker, Rocco Panciera and Yann Kerr. A simple method to disaggregate passive microwave based soil moisture.

2008. IEEE Trans. Geosci. Remote Sens., in press.

Olioso A., Sòria G., Sobrino J., Duchemin B. (2007). Evidences of low land surface thermal infrared emissivity in presence of dry vegetation. Geosciences and Remote Sensing Letters 4:112-116 (doi: 10.1109/LRGS.2006.885857).

Rodriguez J.-C., Duchemin B., Hadria R., Watts C., Garatuza J., Chehbouni A., Khabba S., Boulet G., Palacios R., Lahrouni A. (2004). "Wheat yield estimation using remote sensing and the STICS model in the semiarid valley of Yaqui, Mexico". Agronomie 24:295-304.

Simonneaux V., D. Helson, J. Metral, H. Kharrou, M. Cherkaoui, B. Duchemin, G. Chehbouni, 2006. Samir, a tool for irrigation monitoring using remote sensing for landcover mapping and evapotranspiration estimation. 2nd International Symposium, Recent Advances in Quantitative Remote Sensing, September 25-29, 2006, Valencia, Spain.

Simonneaux V., B.Duchemin, D. Helson, S. Er-Raki, A. Olioso, G. Chehbouni. 2008.Using high resolution image time series for crop classification and evapotranspiration estimate over an irrigated area in south Morocco. International Journal of Remote Sensing. International Journal of remote Sensing, 29(1):95 – 116.

Williams D.G., Cable W., Hultine K., Hoedjes J.C.B., Yepez E., Simonneaux V., Er-Raki S., Boulet G., de Bruin H.A.R., Chehbouni A., Hartogensis O.K., Timouk F., 2004. Evapotranspiration Components determined by Stable Isotope, Sap Flow and Eddy Covariance. Agric. and Forest Meteorol., 125(3-4):241-258.