Background of TELERIEG project

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The use of remote sensing and geographic information systems for irrigation management in Southwest Europe

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Abstract. Irrigation management is now possible by monitoring plant and soil water status in a special location in a field that is supposed to well represent a larger surface. This place, used as a reference, is often equipped with point sensors (as EnviroScan and others) to measure the precise variation of the available water into the root zone. Completed with weather forecast it enables a decision taking about the best moment and best amount of irrigation, preventing any risk of stress by lack of water or lack of air (brief saturation with anoxia) and reducing diffuse pollution by drainage (see PRECIRIEG project, www.precirieg.net). As it is quite expensive and time consuming to install probes in many locations the TELERIEG (www.telerieg.net) project is trying to reveal the potential of remote sensing tools in order to extend the principles of precise irrigation advice over larger irrigated areas. In this article we describe the different objectives and principal findings that are presented in other papers in this book.

Keywords. Irrigation management – Capacitance probe – Remote sensing – Precise irrigation – Water management.

Le contexte du projet TELERIEG

Résumé. *La gestion de l'irrigation à échelle fine s'appuie de plus en plus sur le suivi de parcelles de référence équipées pour observer le fonctionnement des plantes et l'évolution de l'humidité du sol. Ce lieu référentiel est généralement équipé d'outils de mesures précis de l'humidité du sol au sein du système racinaire (sondes EnviroScan et autres). En complément avec une prévision du temps il est possible de décider quand il faut irriguer la quantité optimale, de manière à : (i) éviter tout risque de stress par déficit hydrique ou par manque d'air (état de saturation avec anoxie) ; et (ii) réduire les phénomènes de pollution diffuse par drainage (voir projet PRECIRIEG, www.precirieg.net). Cependant comme il est difficile d'installer des sondes dans tous les champs irrigués (coûts d'investissement et de fonctionnement) le projet TELERIEG (www.telerieg.net) vérifie le potentiel des outils de télédétection pour étendre sur de plus grandes surfaces les conseils basés très localement sur les principes de l'irrigation de précision. Nous présentons ci-après notre démarche et nos objectifs et les principales conclusions de ce travail de 3 ans qui est décrit plus précisément dans ce livre.*

Mots-clés. *Pilotage de l'irrigation – Sondes capacitives – Télédétection – Irrigation de précision – Gestion de l'eau.*

I – Short history

Precise irrigation management is necessary for preserving a sustainable water resource allowing at the same time a better efficiency and quality of food production. Antique knowledge preserved by Arabic and Asiatic civilisations allowed until now sustainable gravity irrigation in many Mediterranean and Asiatic countries. New technologies based on available energy at quite low cost have permitted during the last decades the development of pressured-based irrigation through sprinkling and dripping systems. We present here what it has been used and experimented by ACMG (Association Climatologique de la Moyenne-Garonne, see at www.acmg.asso.fr) in the South-West of France since 1960. Other presentations in this book will explain what it has been accomplished by the other partners in other places of South-West of Europe. This short history allows understanding why we have been working all together for developing remote sensing tools and the directions of work that we have been taking during the 3 years of the TELERIEG project.

One of the first tools for better monitoring irrigation has been water balance models resting on the estimation of the so-called ETo or Potential EvapoTranspiration (PET) obtained directly from the daily observed evaporation of water in a Sunken Colorado pan or from Piche evaporimeter or through a micrometeorological equation (Penman-Monteith) including several parameters as solar energy, wind velocity, temperature and moisture of the air (Allen *et al*., 1998). The objective is to determine the water needs of the plants from atmospheric parameters. This method was mainly developed in the years 1950 to 1970, while not many tools were available or it was too expensive to monitor the real water consumption in the soil. The Water Balance is still used in many zones but the precision is low and, for example, it does not take correctly into account the vertical transfer of water from or to the water table. Our experience here in the South-West of France in the mid 80^{ties} showed that we were over irrigating more than 1/3 of the fields and it forced us to abandon that theoretical tool.

The development of new technologies and cost reduction of electronics allowed measuring indicators and parameters directly from the plant and from the soil, in situ in the root system where the exchange of water and minerals with the plant takes place. The first tool available and that we used since 1963 at ACMG is the neutron probe, then we used the Pressure Chamber or Scholander bomb completed by the gravity method, the tensiometer and the dendrometer or Pepista in France.

The pressure chamber or Scholander bomb (Scholander *et al*., 1995) remains today the reference for giving the water potential of plant tissues. It gives directly at which pressure the transpiration, activated by solar energy, "pumps" the water through the roots in the soil toward the stomata where most of that water is transpired. The higher that pressure is, the more difficult the water is taken from the soil, and the more the plant is stressed. Once measured only just at down, stem base potential is now used during day time to follow the maximum of stress and it can be used for interpreting other indicators of water stress. Within the TELERIEG program this tool has been used by most of us to complete other methods. The difficulty of its use prevented from developing the service or irrigation scheduling assessing based on this method.

The neutron probe (Musy and Higy, 2004; AIEA, 2003) was quite largely used and it is still used to measure soil water content at different depths. It uses a vertical tube installed in and below the root system and a radioactive source equipped with a receptor that is slid into the tube. The interaction of fast neutrons produced by the source and hydrogen nuclei present in the soil produces slow neutrons that are measured by the detector. Since most of the hydrogen nuclei are supposed to be contained by the water, it gives a measure of soil moisture. The problems with safety are making quite difficult to employ routinely this device that has been used in the 80^{ties} and early 90^{ties} by consultants in different countries. We stopped using it after early 90^{ties} when we had to pay more to store the old radioactive source than to buy a new one. We used instead the classic gravimetric method, taking samples of soil within the root system every 10 cm, weighing it, drying it at 110°C during 24 h and weighing again to obtain through the difference of weight the exact quantity of water relative to the mass of dry soil. With that method we monitored from 1987 till 2003 up to 550 fields every week from May till September with 4 to 5 technicians. We knew we were making errors by sampling every time a different soil even though it was at only a distance of 50 cm but we were obtaining a relative good profile of moisture and we were often doing root profiles, therefore learning much from them.

Meanwhile we tested other tools as tensiometers with water, Watermark and gypsum blocks, TDR probes (Robinson *et al*., 2003) (*Time Domain Reflectivity – it measures the travel time of an electromagnetic wave on a transmission line. The velocity depends of the water content along the line*), dendrometer (PEPISTA) (Crété *et al*., 2008), eddy covariance and some others means without much success as it was either expensive, difficult to handle for all a season, or too much perturbing the soil and the root system. For example with the TDR we have had to make a big hole to put the probes horizontally at different depths to obtain a profile and this produced bias as the root system was damaged and the structure of the soil seriously modified. With the tensiometers with water and the Watermark it is possible to use them in loam soils but more difficult in clay and sandy soils and the technicians used to the gravimetric method did not feel as confident with these measurements. The dendrometer is a device used mainly in forestry to measure the diameter of branches or trunks. When associated with an electronic device able to measure microns it can show the reduction of size of this diameter or contour as the sap flow is drained by transpiration. If we put that sensor around young branches it allows observing the growing during the season with natural daily variation, minimum during the hottest hours, maximum at night. If the minimum stops progressing during the growing season, it shows an ongoing stress. The main difficulty is to be able to follow the same tree for more than a year and pruning may harm the equipment.

In early 2000 with the University of Paris Jussieu we tested a system aimed to measure the soil conductivity based on a technology developed earlier to look for water or oil into deep layers of the soil and called multielectrode earth resistivity testing (Samouelian *et al*., 2005). It is precise but difficult to use in a routine way by technicians. It helped us to confirm that electrical parameters of the soil are there to be measured. We found out that in Australia the Sentek Company (http://www.sentek.com.au/products/sensors.asp#soil) had developed an equivalent tool based on the measure of the dielectric of the soil through a sensor that uses capacitance based technology (Sentek, 2001) (Fig. 1).

Fig. 1. Sentek probe in a field of corn.

We have tested this product during two seasons in 2003 and 2004, and we are now using it for assessing directly or through trained persons more than 1000 farmers in France and abroad. This number of persons has been increasing every year since 2007 and in France most of the neutron probe operators are now using or planning to use the portable soil water monitoring device, Diviner 2000. It allows to follow 99 sites making profiles in preinstalled tubes of 56 mm diameter down to 1.60 m if necessary and generally with a 1 m probe. In some of the locations for reducing manpower and trip costs we leave fixed probes as EnviroScan (same size of the tube for the Diviner) or EasyAg connected to the web via a GPRS modem. See for example http://agralis.fr/sentek/carte_ref_2.php

II – Remote sensing option and directions of work

We know that we cannot equip all the fields with EnviroScan probes or tubes for Diviner, therefore it is important to better assess the spatial representativeness of the measurements with the aim to advice objectively the farmers over larger surfaces. That is why since the end of the 80^{ties} we are working with remote sensing technologies provided mainly through airborne and satellite platforms.

First we used a thermal infrared thermometer to verify remotely the canopy temperature but the precision of our tool did not give us a good signal and we abandoned it in 1990. Then we started making our own near infrared vertical pictures using a small aircraft. It allowed us to make thousands of observation of NDVI (Normalized Differential Vegetation Index) (Fig. 2) and Brilliance Index over the fields of South-West of France. We were able to diagnose the problems in the fields related to lack of water but also lack of nutrients or presence of diseases (Colette and Colette, 1999). We favoured using a small aircraft as we were able to get a higher spatial resolution when needed (vineyards) and to contour the cumulus clouds, taking data of sunny fields whereas with the satellite the picture is often not available. Also we were ready to make flights any time when the best conditions were supposed to happen in the fields (no rain during the last 8/10 days, high temperature, light wind and low cloudiness). We stopped making NDVI pictures when the technology with special Kodak infrared film stopped in 2004/2005 and we did not invest into a new digital near infra red camera while we were testing the new Sentek probes.

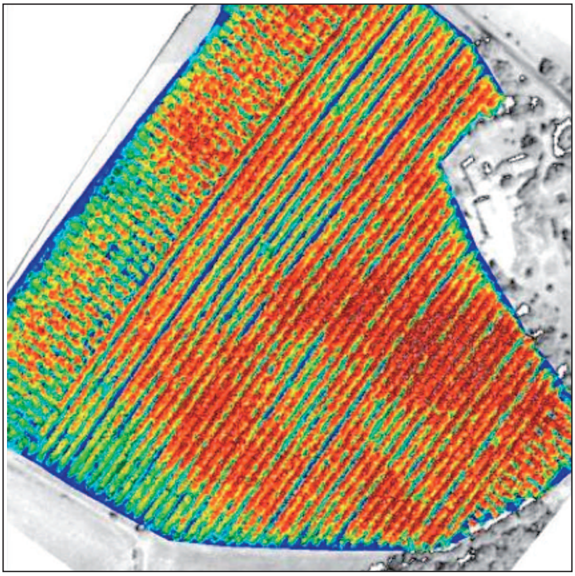

Fig. 2. NDVI map of a nuts field made with an aircraft.

At the end of the PRECIRIEG project in 2008, when we developed a methodology of consulting resting on Sentek capacitance probes and ETo forecast, we proposed our partners to start a new project where we would focus on the possibility to use remote sensing technologies for assessing the water status and comfort of the plants based on both the local field measurements (profiles of moisture, etc.) and maps obtained through remote sensing.

Three scales have been explored and are presented in this book by the different partners:

(i) The finer scale with a pixel of less than 10 cm with for example the observation of a tree from a short distance or from above canopy with a near infrared and visible camera coupled with a thermal camera *(CEMAGREF and IVIA).*

(ii) A pixel of 10 cm to few meters using cameras installed on light aircrafts *(Avion Jaune, IRTA, IVIA, UNICOQUE, ACMG)* or model aircraft *(IRTA, IVIA)* and satellites with high resolution as SPOT, DMC *(CEMAGREF, ACMG).*

(iii) a spatial resolution higher than 50 m to more than a km including thermal, visual and near infrared waves length as Landsat 5 (120 m) and 7 (60 m), HJ (China), NOAA, MODIS (240 m for visible and 960 m for thermal), *(IMIDA, COTR, ACMG, IVIA).*

When we wrote down our proposal we thought that we could use only SPOT type pictures but we have been quite disappointed to reveal that when a visual or near infra red wave signature gives a warning, it is already too late for the farmer to react for helping the plant to recover. The harm is already done when it is visible through remote sensing using waves length from visible to near infra red and resilience is not possible. We confirmed that in 2009 by comparing the NDVI of different trees having different moisture availability. At the same time we confirmed that pictures taken at noon (local time) were already well representative of the gradients shown later during the day when the maximum stress is reached between 14 and 17 h (local time).

We were quite disappointed by these results as from our past experience we had seen many local signatures of reduced NDVI related to reduced irrigation. We thought it was possible to look at the gradient and to diagnose early enough the stage where still it was possible to irrigate and to help the plant to recover. But no, the NDVI or later the NDWI (Gao, 1996) for Normalized Difference of Water Index ((NIR-SWIR) / (NIR+SWIR) where SWIR is the Short Wave Infrared waves length, were not able to give an enough early alert of water stress in the plants. The SWIR reflectance varies in both the vegetation water content and the structure in vegetation canopy but it is a reflectance form the sun light that is measured. An example of a daily NDWI can be found from http://edo.jrc.ec.europa.eu/php/index.php?action=view&id=34 and below in Fig. 3 we show two pictures of NDVI and NDWI computed over the Middle Garonne form a Landsat picture taken on April 9th 2011. Legend is the same for both.

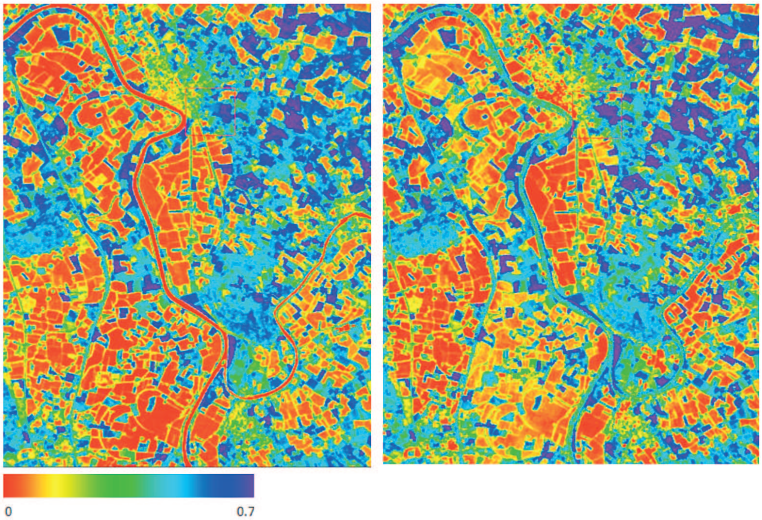

Fig. 3. Map of NDVI (left) and NDWI (right) computed over Middle Garonne from a Landsat picture taken on 2011 April 9th.

We concluded that the NDVI and NDWI are good indicators of the maximum water need at one location but it does not give any early information on the level of moisture still available in the soil. When the NDVI drops it is too late for an advice in real time.

Luckily our partner from CEMAGREF had conducted on one of our experimental fields some other measurements with thermal camera at two scales, 5 cm pixel with a camera from an elevated work platform over the canopy and 0.5 m pixel from an ultra light aircraft (http://www.lavion-jaune.fr). From that last scale we were able to look at differences in temperature in two orchards with walnuts and nuts that were explained by differences in amount of water available through irrigation while the NDVI was quite similar. The principle is simple, when there is transpiration, the latent heat of evaporation of the transpired water is taken from the leaves and the air cools against it and by convection drops to the soil with more moisture where it makes a sort of buffer zone (cool air is heavier) preventing evaporation of the soil moisture when the wind is not strong enough to take it away and to replace it with hotter and drier air. When there is not enough water available in the soil (for example below the easy to use water level), the transpiration rate is reduced, some plants are closing their stomata, other not as the kiwi, and the temperature of the leaves is getting hotter than the air. The thermal signature allows comparing zones where the leaves are cooler than the air (enough water available in the soil profile) with other warmer zones where we can suppose that a hydraulic stress is already ongoing as the total available moisture gets just above the permanent wilting point. *We know that the surface temperature of a plant canopy gets warmer than the air when the rate of moisture that the roots can uptake is less than what the plant should transpire through the stomata.*

Confronted to our past bad experience with the thermal signature obtained with a single thermo point, we contacted Richard G. Allen (Tasumi and Allen, 2007) who developed an algorithm called METRIC that computes ET (daily evapotranspiration) using remote sensing measurement and mainly resting on the energy balance at land surface: incoming energy as solar radiation and atmospheric emissions equals outgoing energy fluxes as reflected solar energy, surface emission (thermal signature), sensible heat flux, soil flux and latent heat flux (ET). We can measure the ongoing fluxes with a pyranometer or by knowing the transmittance of the atmosphere; the albedo (reflection coefficient) allows to compute the reflected solar energy, the thermal camera airborne or on the satellite is giving us the energy emission at large wave length, the sensible heat flux (H) and soil heat flux (G) can be measured by weather stations or derived from observations, remains the ET or latent heat flux (W/m²) with ET = Rn – G – H where Rn is the net radiation flux at surface = incident flux – (reflected flux + emitted flux).

Dr. Allen is using a derived model from the Surface Energy Balance Algorithm for Land (SEBAL) developed by Bastiaanssen *et al*. (2005) from WaterWatch Company in Netherlands who is running this model and with who we are working since. See at http://www.waterwatch.nl

In this introduction we are not presenting all the details and explanation on how SEBAL works as it is done directly in one paper by Dr Wim Bastiaanssen, but we are just bringing up our first results and comments on this very impressive way of looking at the future of water management.

III – First conclusions and perspectives

In 2010 and 2011 we received, during the summer season, pictures taken through different satellites over our zone of work in the middle Garonne, between Toulouse and Bordeaux in the South-West of France. These pictures were selected by WaterWatch and included the wavelength needed to run the SEBAL model with visible, near infrared and thermal infrared. WaterWatch made the computing of NDVI, temperature and ET (Fig. 4) for the fields where we had positioned our probes for a ground truth comparison.

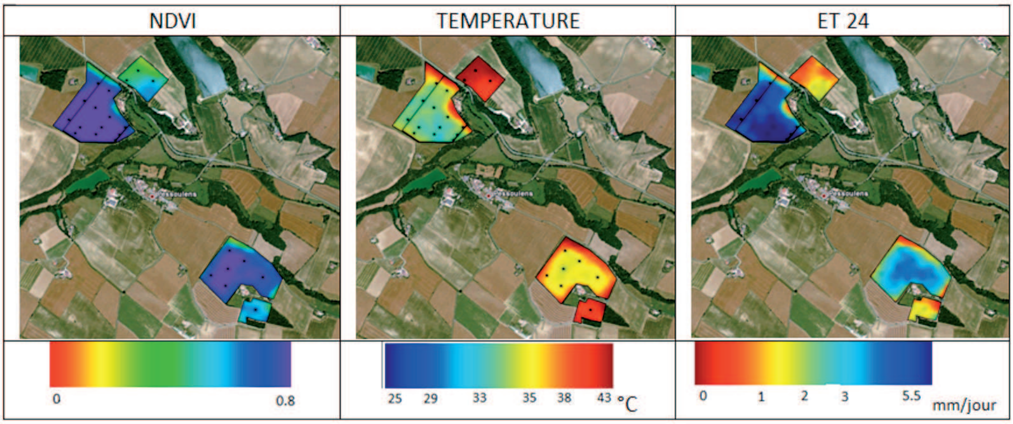

Fig. 4. Example of pictures sent to the farmer 3 days after taken by the satellite and showing on the left NDVI, center the temperature and right the ET computed with SEBAL.

During the two years we have been running a network of weather stations and Sentek probes over about 50 farms with continuous logging and over more than 250 fields with the portable device Diviner. From the first selection of 50 farms over the 250 we are already servicing on irrigation monitoring and consulting, we selected 5 farmers who were very interested by the project and who really wanted to improve their way of managing their irrigation. In each farm about 10 to 20 tubes were installed to record the moisture variation in the profiles of soil where the plants are feeding. From these local measurements we provided the farmer a once a week consultancy, either directly on the web or sent by e-mail. An example is given in Fig. 5 of a graph sent to the farmer or available on the net.

In our region the clouds are the main obstacle for providing a service for irrigation management on an entire farm based upon only remote sensing using satellites! The actual low number of satellites providing thermal pictures is the second problem. Europe has not such a satellite and we have to rest on old generation of satellites from the USA, Landsat 5 and 7; in 2011 none of these 2 platforms were able to take a good picture over our zone during the summer season! We tried using Chinese HJ new generation of satellite that are like MODIS with a bigger thermal pixel but associated simultaneously with visual and near infra red pictures taken with high good precision at 30 m over a very large zone.

Using a sharpening method, WaterWatch produced a thermal map with a 30 m pixel (Jeganathan *et al*., 2011). The physical justification is that high NDVI pixels are related to cooler vegetation and poor NDVI with high albedo to warmer fields driven by sensible heat flux rather than latent. While there is no other option for the moment we used these sharpened pictures of temperature and ET. It looks like a fair representation of the reality but we found that biases are increasing the errors and therefore we have decided not to use for the moment these sharpened thermal pictures for our diagnostic. More research is needed to improve the precision of that solution and to secure the consultancy based on that observation.

But the cloud problem remains and the perfect timing for observing the fields is also central as we got for example a picture just a day after a good rain that erased all the differences.

To contour this main problem of satellite application in our zones where clouds happen often (in dryer countries it is more the dust and bad transmittance that will make troubles) we believe there are more than one solution:

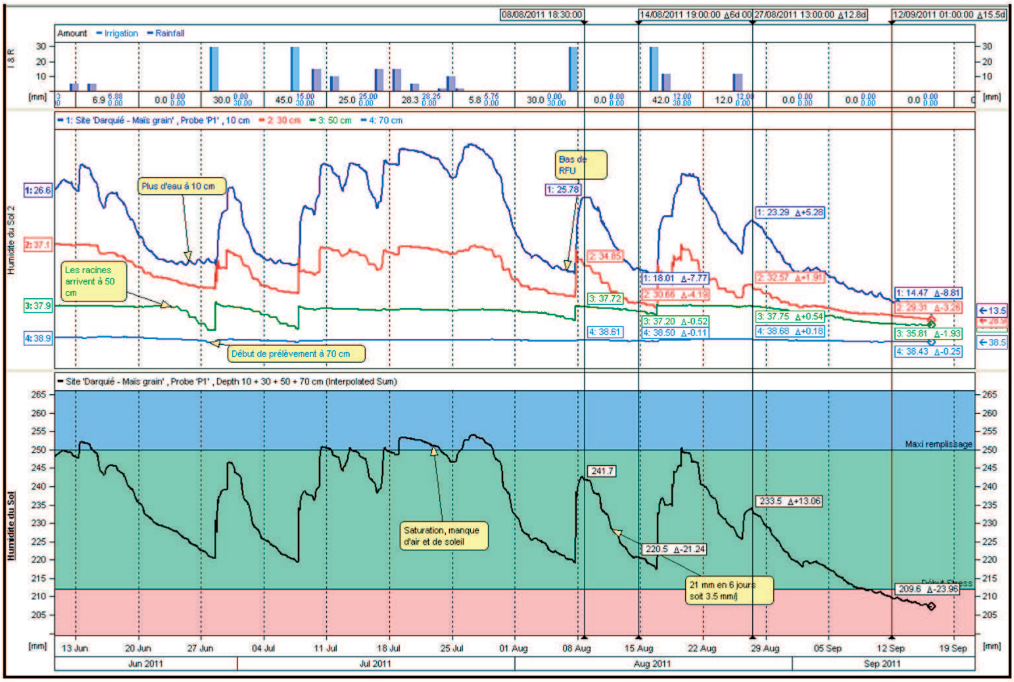

Fig. 5. Soil humidity measured by Sentek probe from June till September in a field of corn. Top graph is giving quantity of rain and irrigation; middle graph shows the variation of humidity in mm/10 cm at 10 cm (blue), 30 cm (red), 50 cm(green) and 70 cm (clear blue); bottom graph presents the interpolated sum of humidity in mm for 70 cm of soil profile (blue zone where there is lack of air, green zone the better available water and rose zone where water stress happens).

(i) To use an airborne platform as a small aircraft to be able to fly around the shades made by the convective cumuli clouds. Generally when cumuli clouds form, their life time is from 10 to 20 min and light wind pushes them at 10 to 30 km/h. therefore our experience is that it is possible to wait just few minutes to get an entire field in the picture. But this system has a cost of about 150/200 000€ for the equipment to put on the aircraft plus about 250 €/h for the flight if it is a light aircraft, a little less if it is an Ultra light aircraft but with lower cruise speed and therefore smaller surface covered during one flight from 1 to 4 pm.

(ii) To have more satellites available in order to get more chances to have a picture the needed day. Unfortunately for the moment only one new Landsat is ready to be launched in December 2012. ESA has no project and China is not yet organized to sell us with a short delay their pictures, their main tasks being over their country. CESBIO with Gérard Dedieu has a project of one research satellite at 120.000.000 € able to provide a thermal picture every day and night but it needs funding and ESA just declined to invest in it.

(iii) To base the consulting not on remote sensing as the main tool but as a complementary tool that will provide, when pictures with good resolution (less than 60 m) are available, a map of water evapotranspiration (ET), temperature and NDVI. From these maps the farmer or the consultant should be able to extrapolate over large areas the consulting done in one single place by the Sentek probes or any other type of probe providing with a good precision the humidity profile in the soil and the humidity consumption. It is possible to associate these direct measurements with models providing a water balance of the moisture of the soil. However our experience with such models shows that they need to be recalibrated based on direct measurements minimum once every 7/9 days in clay soils and every 4/5 days in sandy soils.

For countries where the clouds are not a problem, there is a huge potential and the technology is ready associating remote sensing with a network of moisture probes completed with temperatures of soil and air, amount of rain and irrigation and weather forecast.

Acknowledegments

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