# Defining the revisit frequency for the MISTIGRI project of a satellite mission in the thermal infrared

Jean-Pierre Lagouarde, Albert Olioso, Jean-Louis Roujean, Gilles Boulet, Benoît Coudert, Sylvia Dayau, Sonia Castillo, Marie Weiss

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J.-P. Lagouarde [(1)], A. Olioso [(2)], G. Boulet [(3)], B. Coudert [(4)], S. Dayau [(1)], S. Castillo [(2)], M. Weiss [(2)], J.-L. Roujean [(5)], E. Delogu [(4)], N. Puche [(4)]

*[(1)] UR 1263 EPHYSE, INRA, 71 av. E. Bourlaux, F-33140 Villenave d'Ornon, France*

*[(2)] INRA-EMMAH UMR 1114, Domaine St Paul, Site Agroparc, F-84 914 Avignon Cedex 9*

*[(3)] IRD, CESBIO, 18 av. E. Belin, F-31401 Toulouse cedex 9, France*

*[(4)] CESBIO, 18 av. E. Belin, F-31401 Toulouse cedex 9, France*

*[(5)] CNRM-GAME, Météo-France, 42, av. G. Coriolis, F-31057 Toulouse, France*

Email corresponding author: lagouarde@bordeaux.inra.fr

ABSTRACT. *Both for scientific (monitoring of rapid temporal changes in the water status of surfaces) and for technical reasons (choice of the orbit height), the revisit is a crucial specification in the definition of the recent projects of microsatellites (such as MISTIGRI and TIREX) combining high spatial resolution and revisit capacities in the thermal infrared. The revisit must be adapted to cope with cloud frequency constraints and with the accuracy requirements on derived surface fluxes. The paper first presents a study of cloud frequency and of potential satellite data availability based on the analysis of a long meteorological dataset on France and on MODIS cloud masks on Europe. The impact of the revisit on the accuracy of derived evapotranspiration is then evaluated using long term series of surface fluxes either directly obtained from measurements or from simulations. The impact of the overpass time is simultaneously studied. Even though they have to be confirmed to other locations and climates in the world, the results clearly reveal the need of a 1 day revisit in the TIR.*

## 1 INTRODUCTION

This study aims at defining the revisit of the MISTIGRI and TIREX missions. MISTIGRI is a project of a microsatellite in the thermal infrared conducted by CNES in cooperation with Spain, and currently in A phase (Lagouarde et al., 2011, in this issue). TIREX (Sobrino et al., 2011, in this issue) is a proposal made at ESA to the recent call for Earth Explorer Opportunity Missions. The originality of MISTIGRI and TIREX is to combine a high spatial resolution (~50m) with high revisit capabilities of 1 or 2 days compatible with water budget monitoring objectives. The revisit must be defined carefully both for scientific reasons (ability to retrieve accurate fluxes) and technical constraints (orbit altitude). It must cope with cloudiness for acquiring a sufficient number of images with the required quality, and at the same time allow one to monitor rapid changes in surface water status and fluxes during short time scale events such as drying after rainfall or irrigation. One must finally makes sure it is compatible with the specified accuracy on fluxes retrieval. These different constraints are examined in the paper. The complementary question of the overpass time is simultaneously addressed.

## 2 ANALYSIS OF CLOUD FREQUENCY AND POTENTIAL AVAILABILITY OF DATA

The combination of cloud occurrence and of revisit first governs the potential number of available cloud free data. Two methods have been used to evaluate it.

### 2.1 Method 1: evaluation of the data availability from a statistical analysis of a meteorological data base

This method was based on the analysis of an 18 year-dataset (INRA AGROCLIM, 1992-2009) of hourly solar incoming radiation. Eight French stations located all over the country and corresponding to different climates were considered. The principle for discriminating cloud free conditions considered a threshold criterion in the solar radiation. For a given location, the maximum observed radiation in the 18 values available at any given date and time of the year was first assumed to correspond to clear sky conditions at that moment. In fact the data set was not long enough and this was not always the case, resulting in a remaining noise on the evolution of the maximum radiation throughout the year, which required a final smoothing using an empirical solar radiation model to be done (Figure 1). For a given location and time we generated a typical yearly curve of the evolution of the solar incoming radiation to be compared with. A realistic value of 90% was chosen - and justified afterwards- to identify cloud free conditions all along the 18 year-dataset.

We based our study on a criterion of 1clear day by 5 day-periods, often considered as a good requirement for monitoring water budgets, which is the first objective of the MISTIGRI mission. The average number of clear days by 5 days-periods estimated on the whole dataset directly provided the potential availability of data with a one day revisit. By sampling the 18 year-dataset, we could similarly study the impact of the revisit.

The results obtained for 3 of the studied locations in France, Avignon, Bordeaux and Rennes are presented in Figure 2. They revealed that the 1/5 day-availability criterion can be fulfilled all year long only with a 1 day-revisit. It can also be seen that, as expected, the frequency of cloud free conditions decreased from Avignon to Rennes corresponding to Mediterranean and oceanic climates respectively, and that the 2 day-revisit is quite insufficient for Rennes. Five days revisit never matched the requirements.

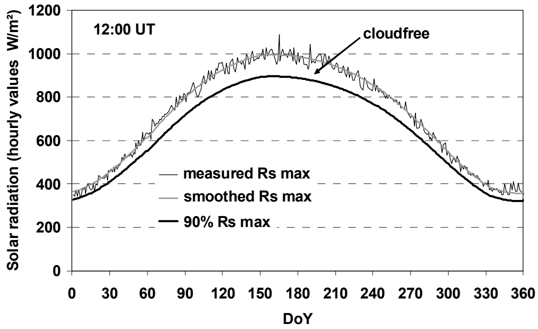


Figure 1. *Principle of selection of cloudfree conditions on the AGROCLIM database.*

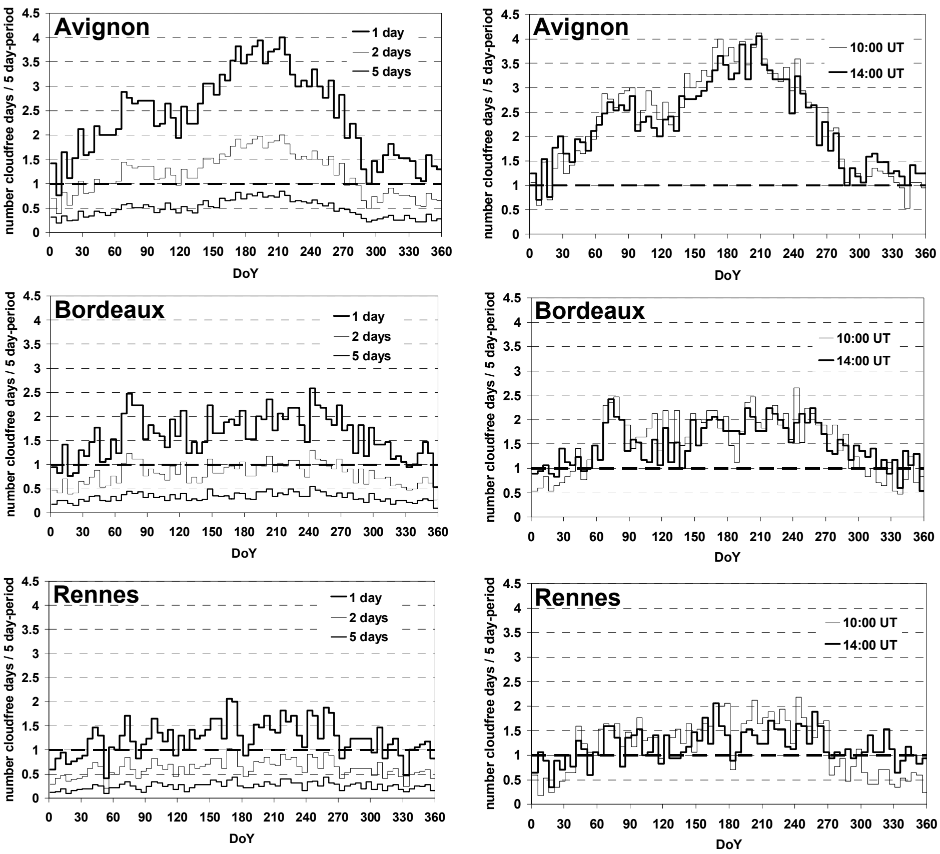


Figure 2. *Availability of cloudfree days per 5 day-periods along the year for 3 revisit frequencies (1, 2 and 5 days) (left) and impact of the overpass time (right) for 3 French locations.*

We could simultaneously study the impact of the time acquisition. For clarity only the potential data availability for 10 and 14 UT acquisition times for a 1 day-revisit are presented in Fig. 2. Morning haze or fog are likely to explain the data deficit observed in winter for 10 UT. On the opposite, the slight decrease appearing in summer for 14 UT could possibly be related to convective clouds development phenomena. In this idea, the 12 UT acquisition time (not presented in figure 2) seems to be best suited, but this remains to be confirmed on a large panel of locations and climates.

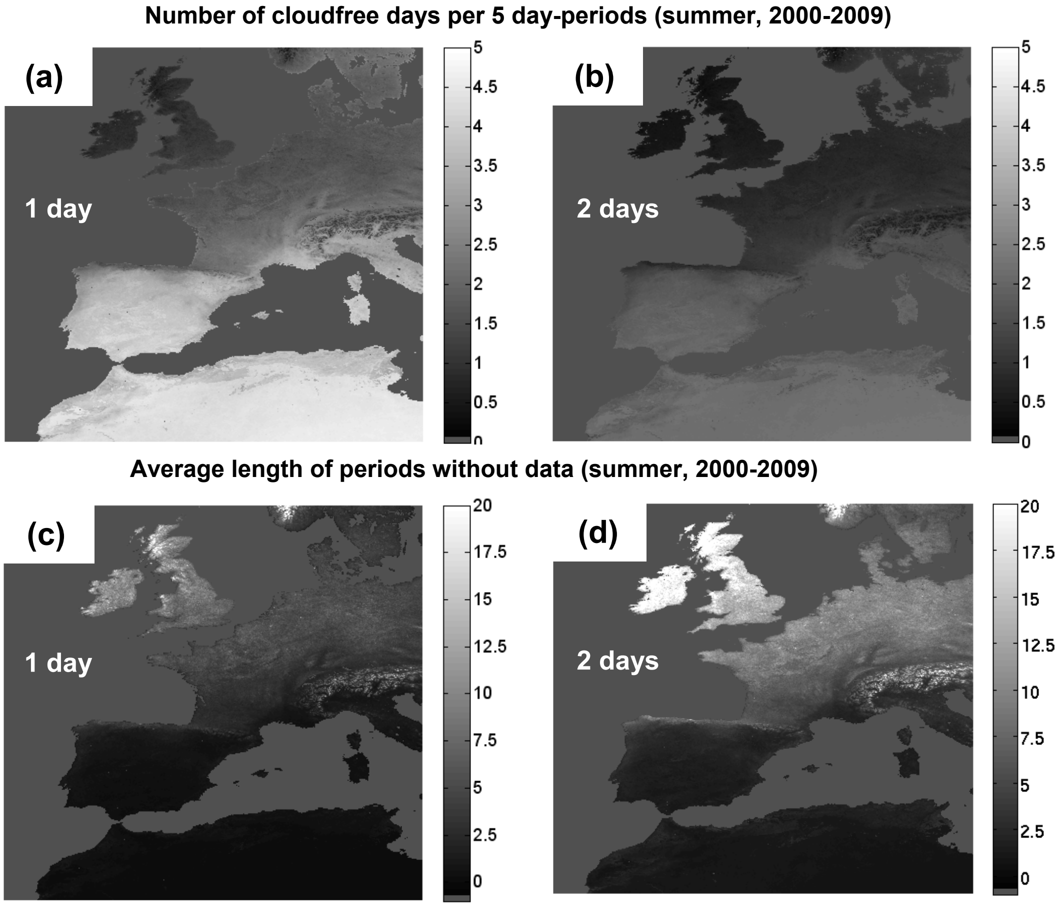


Figure 3. *Average number of cloudfree days per 5 day-periods on the years 2000-2009 over Europe for summer (June 1st - August 31st ) for 1 day- [up left] and 2 day-revisit [up right]. Down: average corresponding length of periods without data (expressed in days).*

2.2 Method 2: analysis of MODIS cloud masks

The number of cloudfree days per 5 day-periods over Europe was also estimated directly using the standard MODIS Terra Surface Reflectance MOD09GA products (https://wist.echo.nasa.gov/api/). A retrospective analysis of actual MODIS cloud masks was performed at the European scale on the period 2000-2009 (Figure 3). Despite some artifacts over mountainous regions due to difficulties to discriminate clouds from snow, it emphasized the previous results quite well and the need of a 1 day-revisit was confirmed at least for all northern Europe. Another interesting indicator was the average length of periods without data: it brought complementary information as it allowed one to reduce the weight of partly redundant information available in the case of consecutive clear days. The analysis on western Europe for spring and summer (Fig. 3 c and d) showed that, excepted for southern Europe countries, the average length of periods without data varied on a range between 5 and 10 days for a 1 day-revisit, but may reach up to 20 days for a 2 day revisit. Other case studies should obviously be examined on other climates and regions of the World to generalize these results and confirm the need of daily revisit. Data from geostationary satellites could also be used for that purpose.

## 3 IMPACT OF THE REVISIT ON THE ESTIMATION OF EVAPOTRANSPIRATION

### 3.1 Modelling approach

The impact of the revisit on the accuracy of satellite-estimated annual evapoptranspiration was tested using a simulation approach. Continuous reference series of evapotranspiration (ET) were first generated based on simulations by the ISBA-A-gs model (Calvet et al. 1998, 2008). Simulations of vegetation growth and daily ET were performed for 3 sites in France (Avignon, Bordeaux and Versailles close to Paris), 3 vegetation types (irrigated corn, deciduous and coniferous forests) and 3 soils (differing in water holding capacity). Climate forcing corresponded to ARPEGE climate models simulations between 1950 and 2100 (scenario A1B from the last IPCC exercise).

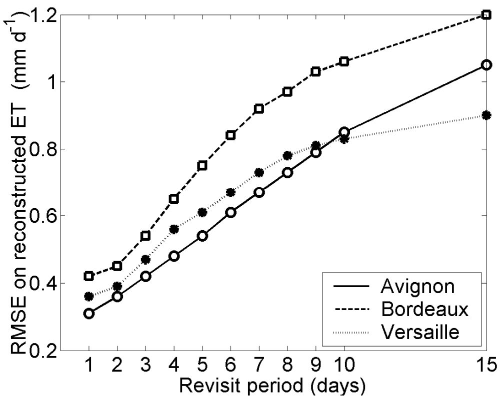


Figure 4. *Influence of revisit on the RMSE of reconstructed time series of daily evapotranspiration ET for 3 sites.*

Series of daily ET as derived from satellite were then simulated by combining a revisit frequency with a selection of cloudfree conditions. Several thresholds on solar radiation Rs were successively considered (80 %, 90 % or 95 %), in order to generate different cloud frequencies. In total, 12150 years were simulated (3 sites x 3 plant types x 3 soil types x 3 threshold values x 150 years). An error (RMSE 0.8 mm $d^{-1}$) was then given to the selected ET estimates in order to account for the errors in daily ET satellite mapping algorithms. Continuous series of daily ET were finally reconstructed using a linear interpolation of the ratio ET/Rs between the discrete satellite ET estimates available for clear days. They were compared against the continuous original simulations (without added errors) using a simple RMSE criteria. Revisit frequencies between 1 and 15 days were tested.

Figure 4 displays the variation of RMSE with the revisit. It can be seen that the RMSE increased rapidly with the revisit. The rather smooth aspect of the curves was explained by the fact that the RMSE were estimated at year scale on the whole 150 years-datasets (combining years, thresholds, plants and soils). The impact of the revisit may be even much more critical for shorter periods or periods with particular meteorological conditions. For example, revisit and cloud frequencies may combine in generating rather long periods without available data, preventing to catch drying periods between water supplies by rain or irrigation.

### 3.2 Experimental approach

The previous results were confirmed by a similar approach applied on experimental datasets. /leteorological and micrometeorological observations ιcquired for whole cultural seasons at 4 sites (France: \vignon, Auradé, Lamasquère, Morocco: Sidi ₹ahal/R3) were used to produce available energy (Rn-Ġ) and latent heat flux (LE) data in a large range of ·onditions varying from stressed to nearly potential. ˜he identification of cloudfree sky days were based on n-situ solar radiation and clear sky solar radiation ιccording to the Meeus model (Annear and Wells, :007). This model displayed a Nash Efficiency ›etween computed and observed solar radiation of ı.75 and a bias less than 60 W/m². Daily values of ·vapotranspiration on days without image acquisition vere obtained by interpolating linearly either the ›bserved evaporative fraction EF=LE/(Rn-G) or a stress factor SF=LE/LEpot between two successive satellite acquisitions (LE was the latent heat flux and LEpot its value in potential conditions).

Figure 5 shows the impact of the revisit frequency on the performance of reconstructed daily LE if SF was linearly interpolated between two acquisitions. The error significantly increased for the Moroccan site whereas it remained low for Auradé. This was explained by the absence of water stress over this site contrarily to Marrakech where water stress occurred several times during the growing season.

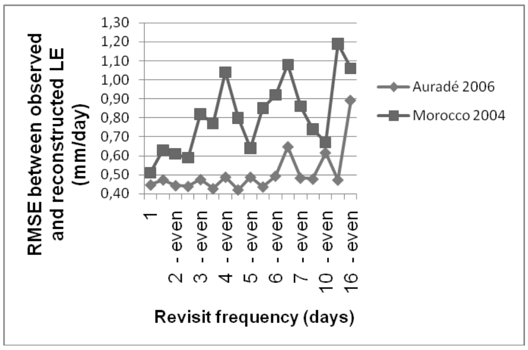


Figure 5. *Evolution of the RMSE in reconstructed LE as a function of revisit frequency.*

The analysis of the same datasets additionally allowed investigating the impact of the time of overpass on the accuracy of retrieved LE fluxes. One assumed that instantaneous Rn-G, LE and LEpot were perfectly known when an image was acquired; LE was then extrapolated from this instantaneous value to a daily estimate assuming either the evaporative fraction EF or the stress factor SF constant throughout the day or assuming a known course of EF throughout the day (Hoedjes et al., 2008). We can see in figure 6 that acquisition times between 12:00 and 13:00 provided the best estimates of daily actual latent heat flux.

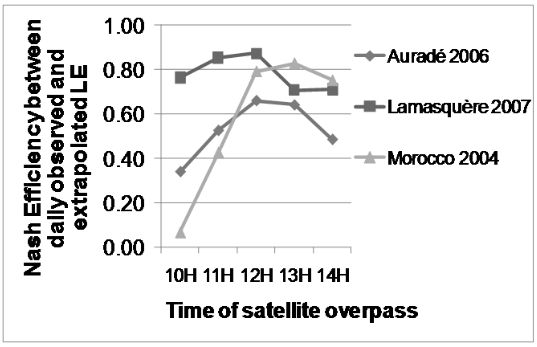


Figure 6. *Evolution of the Nash efficiency for the extrapolation of LE according to time of satellite overpass from 10AM to 2PM.*

3.2 Statistical analysis of the potential data availability per stress periods (from experimental data)

The analysis of the data availability for 1 day-revisit on stress periods on the South-West of France (Auradé 2005-2007 and Lamasquère 2006-2007) and Morocco (SudMed project, 2004) sites showed that the threshold of at least 1 data per stress period is not always reached for this sample of 6 years in real conditions. As an example, on Lamasquère, there were 4 stress periods 4 to 5 days long between 2005 and 2007 and only 1.5 day (statistically) with a data available (clear sky conditions and stress). The criterion of having at least 1 TIR observation per stress period is particularly important for regions with extensive irrigation. Together with the criteria of having at least 1 data per 5 day-period, it emphasizes the recommendation of a daily revisit for MISTIGRI and TIREX missions.

4 CONCLUSIONS

In this study, several approaches have been followed and several criteria used to determine the revisit specification for the MISTIGRI and TIREX missions. The cloud frequency analysis performed using hourly solar radiation meteorological datasets on French locations and MODIS cloud masks over Europe clearly revealed that a 1 day revisit was necessary to get at least 1 clear day observation per 5 day-periods on most of northern Europe. For southern countries, and considering only the same criteria, one could imagine that a 2 day revisit could be enough. However, such regions often suffer from dry and sometimes semi-arid conditions and include a number of irrigated areas for which it was demonstrated on some case studies that only the 1 day revisit was adapted -and even not always- to provide at least one data per stress period: for example for Morocco, a 2 days revisit hardly met this requirement and for Lamasquère this requirement was already not fulfilled with a 1 day revisit. This revisit frequency was also shown to provide the best accuracy on retrieved evapotranspiration estimates: the differences were not very important between 1 and 2 day revisits (but for the particular examples of temperate areas considered), but they provided very strong improvement compared to ~7 or ~15 days revisits (the latter being obtained with Landsat satellites). Our study additionally revealed that simple methods based on a linear interpolation of EF or LE/Rg performed well when there was a lack of data (cloudy day, or no visit from satellite) to derive the seasonal evapotranspiration.

Moreover it was also shown that an overpass time around 12:00 would be more suited.

Further work is needed to analyze in details specific temporal sequences during which the water supply is not known (for precision irrigation management applications for instance) and to generalize the results by considering other climates.

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