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Notes du Pôle de Modélisation

A GCM experiment on time sampling for remote sensing of near-surface soil moisture

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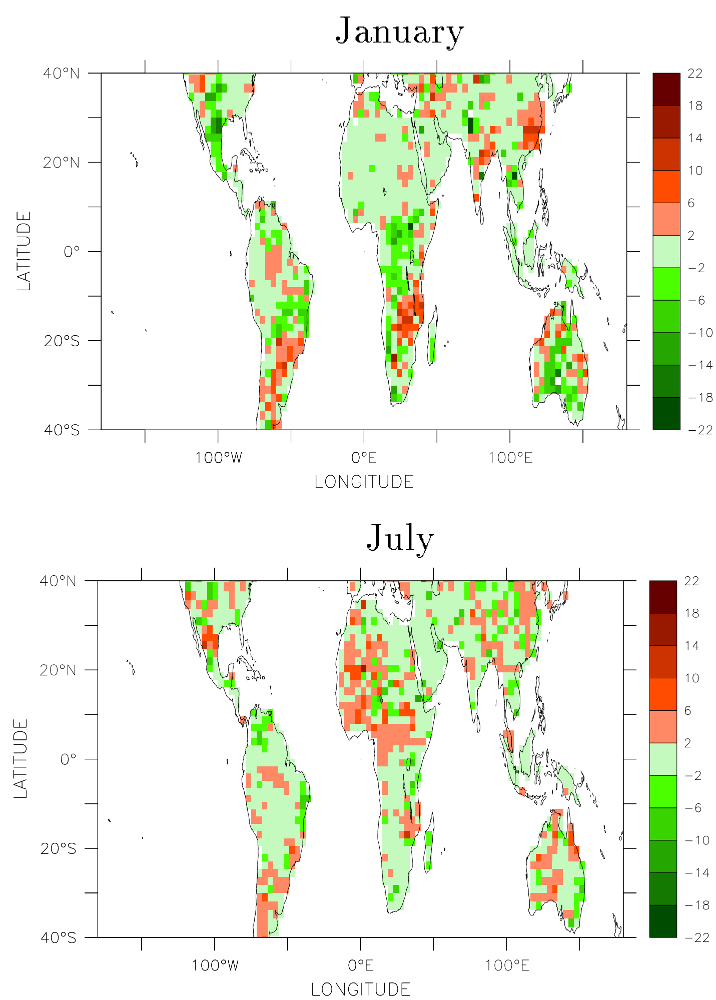

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The use of microwave remote sensing opens new possibilities to study the global soil moisture dynamic. The measured signal is proportional to the surface moisture and temperature on a thin soil layer. Several low frequency microwave sensor, such as AMSR-E in C band and SMOS in L band, are scheduled to be launched on sun-synchronous satellite platforms in the near future. Because of the diurnal cycle of the measured surface soil moisture content and its temporal variability, the restricted time sampling by an instrument in sun-synchronous orbit, may be a source of error in the monthly mean quantities used for climate and land surface processes models. This paper presents a large scale time sampling experiment, conducted with a general circulation model, in order to estimate the representativeness of the observations of the near surface soil moisture, at a given time of the day, for the knowledge we can gain of the monthly mean soil moisture. Due to the high temporal variability of the near surface soil moisture, the impact of the revisit time of the satellite is shown to be critical for the estimated monthly mean soil moisture. This study emphasizes the requirement to develop and to use assimilation methods to produce meaningful soil moisture values from remotely sensed data sets.

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Abstract

The use of microwave remote sensing opens new possibilities to study the global soil moisture dynamic. The measured signal is proportional to the surface moisture and temperature on a thin soil layer. Several low frequency microwave sensor, such as AMSR-E in C band and SMOS in L band, are scheduled to be launched on sun-synchronous satellite platforms in the near future. Because of the diurnal cycle of the measured surface soil moisture content and its temporal variability, the restricted time sampling by an instrument in sun-synchronous orbit, may be a source of error in the monthly mean quantities used for climate and land surface processes models. This paper presents a large scale time sampling experiment, conducted with a general circulation model, in order to estimate the representativeness of the observations of the near surface soil moisture, at a given time of the day, for the knowledge we can gain of the monthly mean soil moisture. Due to the high temporal variability of the near surface soil moisture, the impact of the revisit time of the satellite is shown to be critical for the estimated monthly mean soil moisture. This study emphasizes the requirement to develop and to use assimilation methods to produce meaningful soil moisture values from remotely sensed data sets.

1 Introduction

Soil moisture is a key component of the continental hydrological cycle and climate system. Soil moisture content interacts with the atmosphere through the root water uptake and bare soil evaporation, on various time scales on the order of hours for near

surface soil moisture (Raju et al. 1995), to inter-seasonal (Delworth and Manabe 1988) and inter-annual scales (Beljaars et al. 1996) for root zone and deep soil moisture. The partitioning of energy between sensible and latent heat fluxes is linked to the seasonal variability of soil moisture which influences the low frequency atmospheric variability
(Delworth and Manabe 1988; Shukla and Mintz 1982). Furthermore Koster and Suarez (1995) emphasizes the role of the land surface soil moisture condition for the prediction of precipitation. Milly and Dunne (1994) have shown that the land surface energy balance is strongly influenced by the soil moisture storage capacity. Resulting surface fluxes are distributed over large scales and affect the regional and continental atmospheric circulation (Beljaars et al. 1996; Polcher 1995).
The variations of soil moisture over small spatial and time scales is a major problem for monitoring large scale soil moisture.
Global observation of soil moisture does not exist at time and space scales relevant for use in General Circulation Models (GCMs) or weather prediction models. However the need for the global scale observation of the soil moisture is clear for weather forecasting, climate modeling, soil hydrology, and water resources management (Walker and Houser 2001; Kerr et al. 2001; Njoku and Entekhabi 1996).
Over continental areas it has been established that the microwave emission at low frequencies (1.4 to 10GHz) of the surface is very sensitive to the soil moisture content (Jackson et al. 1999; Wigneron et al. 1998; Schmugge 1983). But until today the development of passive microwave remote sensing of soil moisture from satellite was hindered by the low ground resolution of the passive microwave radiometers (Kerr et al. 2000). Recent technical improvements in the interferometric method opens the possibility to install low frequency microwave sensor on satellite platforms. The Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) with a C-band channel will be launched on the EOS-AQUA platform in March 2002 on the Japanese ADEOS satellite (sun-synchronous orbit). Soil Moisture and Ocean Salinity (SMOS), with L-band interferometer, is proposed for a launch in 2005. The aim of the SMOS project is to access information on concerning the soil moisture and its dynamic over continental surfaces and to retrieve the ocean salinity over oceans. The ground resolution has been selected to be between 27 and 50 km, the orbit is sun-synchronous with a local time of acquisition at 6am ascending and 6pm descending. The repeat time varies between 2 and 4 days depending on the latitude (Kerr et al. 2001).
L band (1.4GHz) is proved to be optimal to determine the soil wetness (Wigneron et al. 1998). In contrast to higher microwave frequency, the vegetation cover, if not too heavy (below $5kg/m^2$), does not mask the soil microwave emission of the surface. But remote sensing remains limited to measurement of the top few centimeter at most of the soil moisture content. This thin moisture layer interacts with the atmosphere on short time scales and is highly variable both in space and time (Raju et al. 1995).

In contrast, the climate and hydrological communities are interested in the the root zone soil moisture content. Calvet et al. (1998) have shown the feasibility of the root zone water content retrieval from a measurement of surface soil moisture. The studies of Walker and Houser (2001), Njoku and Entekhabi (1996), Entekhabi et al. (1994) emphasize the fact that the development and use of soil moisture obtained from remote sensing data requires to use a sophisticated

land surface scheme with explicit representation of the vegetation, and fine enough modeling of the soil moisture profile dynamic.
Moreover the ground resolution of the soil moisture observed from space is rather coarse. Each pixel of the SMOS or AMSR satellite considers areas of hundreds km square with a large diversity of soil and vegetation types (Njoku and Entekhabi 1996). Thus land surface schemes used together with remote sensed soil moisture (for modeling and assimilation) must take into account sub-grid scale variabilities as well as physical processes of soil-plant-atmosphere interactions.

In spite of these difficulties, the future space missions for soil moisture monitoring at the global scale will allow us to access information on soil water content and its dynamics at time and space scales consistent with atmospheric processes. The resulting better knowledge of soil moisture is expected to strongly improve our understanding and the modeling of the coupling between the continental water cycle and the atmosphere. In addition, a better knowledge of the initial soil moisture conditions may improve the performances of the seasonal prediction models.

Because of the time variability of the measured surface soil moisture, the restricted time sampling by an instrument in sun-synchronous orbit, *e.g.* as SMOS or AMSR, may be a source of error in the monthly mean quantities used for climate and land surface processes models. If the variation in the diurnal cycle were random, the daily or monthly products from a single satellite measurement with sparse time sampling would be appropriate. But several studies show that in most regions of the globe strong diurnal variations dominate the meteorology and persist over several weeks (Heaffelin et al. 1999). Thus, as shown by Haeffelin et al. 1999 for the sun-synchronous ERBE (Earth Radiation Budget) satellite, for solar reflected and earth emitted radiation, the monthly estimates of a variable related to meteorological conditions may be biased, even for perfect individual measurements.

In the present paper, a land surface scheme coupled to a GCM is used to generate a synthetic "true" data set, from which surface soil moisture "observations" are derived at different possible local times, and which will be used to evaluate the results. The purpose of this paper is not to analyze the simulated diurnal cycle of the soil moisture, neither to estimate the periods of the land surface variability, nor to find a method in order to correct the time sampling error of the remote sensed soil moisture. Rather, our aim is to quantify at the global scale how much a sparse temporal sampling, of the observed surface soil moisture, affects the monthly mean estimates. The analysis focuses on the time sampling error alone in the theoretical case of a perfectly accurate measurement of the surface soil moisture. The monitoring of the surface soil moisture by the future space missions will be affected by instrumental errors and uncertainties on different surface characteristics (as vegetation cover and water content, surface temperature and roughness...). These sources of errors are not analyzed here.

Despite some uncertainties in their simulated climate, GCMs are currently the only tool which enable us to do time sampling experiments at the global scale. To the soil hydrology and the soil-plant interaction models in this paper use of the physically based land surface scheme SECHIBA (Schématisation des EChanges

Hydriques à l'Interface entre la Biosphère et l'Atmosphère) (de Rosnay et al. 2002; Ducoudré et al. 1993). The fine vertical resolution in the soil in this model allows the represention of the time and space evolution of the surface soil moisture that would be measured by a remote sensing satellite. And an original approach of sub-grid scale variability of vegetation and soil texture is taken into account to represent the surface heterogeneities in this scheme (de Rosnay et al. 2002; de Rosnay and Polcher 1998).
In the next section we present the model and the numerical experiment, section 3 is devoted to the analysis of the GCM simulation and the impact of the time sampling on the monthly mean estimates of soil moisture. Section 4 concludes.

2 Models and experiment

The present study is based on the analysis of a one year integration of the LMD GCM coupled to the land surface model SECHIBA (Ducoudré et al. 1993). The observed annual cycle of mean sea surface temperatures over the period 1978-1988 is used as boundary conditions. Version cycle 6 of the LMD GCM is used here with a horizontal resolution of 96 x 72 points and 15 vertical levels in the atmosphere. The LMD GCM is documented in Polcher and Laval (1994) , Le Treut and Li (1991) and Sadourny and Laval (1984). The time step of the model is 30 minutes.

2.1 Land surface scheme

Description

SECHIBA is used here to compute the land surface fluxes and the soil hydrology in the GCM. It was recently enhanced by the inclusion of the bare-soil hydrological model of the Centre for Water Resources Research (de Rosnay et al. 2000; de Rosnay et al. 2002). The Fokker-Planck equation (Darcy law, in the case of unsaturated one dimensional ground water flow in an isotropic and homogeneous soil, combined with the mass balance equation) is used to compute the vertical soil water flow :

$$\frac{\partial\theta(z,t)}{\partial t} = \frac{\partial}{\partial z}[D(\theta)\frac{\partial\theta(z,t)}{\partial z} - K(\theta)] - S(\theta) \quad (1)$$

where θ (m^3m^{-3}) is the volumetric water content, $K(\theta)$ (ms^{-1}) is the hydraulic conductivity of the soil, $S(\theta)$ $(m^3m^{-3}s^{-1})$ is the sink term which represents the soil water extraction by roots, z (m) is the vertical coordinate positive downward, t (s) is time, $D(\theta)$, (m^2s^{-1}) is the soil water diffusivity.

The soil is assumed to be two meters deep with 11 layers. The vertical grid spacing in the soil increases geometrically with depth downward, leading to a number of 4 layers in the top 2.15 cm of the soil column. De Rosnay et al. (2000) have shown that this choice of discretization of the soil in SECHIBA is an acceptable compromise between a detailed vertical resolution of the soil column and stability of calculated fluxes. The bottom boundary condition is taken to be a free drainage condition, and the upper boundary condition depends on both the soil moisture at the surface and the atmospheric forcing. The van Genuchten-Mualem model is used to compute the relationship, for a given soil, between its hydraulic conductivity, volumetric water content and matrix potential. It is widely used by the hydrological community because it agrees well with soil water flux measurements and gives particularly good results near saturation. This formulation is suitable for large scale modeling as it has been shown to be relevant for soil types with a large range of pore size distribution (van Genuchten and Nielsen 1985).

The soil-plant interaction is based on the concept of soil moisture and root profile interactions which allows us to represent the soil water extraction variations in the vertical profile. The seasonal variation in the soil moisture profile influences the root water uptake which in turn affects the soil moisture vertical distribution. (de Rosnay et al. 2002).

SECHIBA represents sub-grid scale variabilities of both vegetation and soil texture types by a tile approach to account for the surface heterogeneities. Up to 8 vegetation types and 3 soil texture types are allowed for each grid box of the model. Each of them occupies a specified fraction of the surface of the mesh determined from Matthews (1984) and Zobler (1986) global scale distributions. For each sub-grid tile the land surface fluxes are computed independently. Mean fluxes for the grid-cell are then computed from a weighted average of the sub-grid fluxes. All the tiles for the box share the same atmospheric forcing.

De Rosnay et al. (2002) show that the combination of a fine vertical soil moisture profile with root profiles lead to a land surface scheme which is able to simulate complex physical processes of the soil plant atmosphere interaction at continental scales. Knowledge of soil type is critical for modeling the soil water diffusion processes. The resulting fluxes and surface-atmosphere interactions are very sensitive to its representation. For a given vegetation type, and climate conditions, the computed transpiration may vary by a factor of two depending on the soil type. Moreover the depth of the root extraction varies seasonally and regionally, with shallow uptake during the rainy season and deep extraction in the dry season. The main features of the strong seasonal contrasts in the soil moisture profiles are well represented in the GCM. Despite some limitation in the availability of data about soil-plant distribution at global scale, it allows a physical representation of land surface processes and provide a platform for considering the diversity of the soil-plant-atmosphere interactions in climate modeling at continental scale.

In the context of large scale studies for soil moisture remote sensing, SECHIBA is a suitable tool. The horizontal spatial scale, with sub-grid scale variabilities of soil and vegetation types, is consistent with the ground resolution of soil moisture remote sensing (about 50km). Furthermore the time and space evolution of the soil moisture profiles are represented in the model with fine enough vertical resolution to simulate prognostic evolution of the observable from space surface soil moisture. The surface soil moisture which is highly variable in space and time is physically represented in interaction with vegetation cover and atmospheric processes. Such a land surface scheme allows to link the scales of the satellite remote sensed surface soil moisture, root zone soil moisture and atmospheric processes by a physical approach.

2.2 Numerical experiment

A one year global scale experiment is conducted with the LMD GCM coupled to the land surface scheme SECHIBA. The initial conditions of the model are those obtained after 2 years of spin up which was used previously by de Rosnay et al. (2002). This simulation allows us to generate synthetic mean daily soil moisture profiles considered as the "truth" over the land surfaces (averages based on the 48 half an hour time steps available each day). In addition, the simulated surface soil moisture is output twice every day to represent the surface soil moisture that would be measured by a virtual remote sensing satellite. Different cases of local time from 6 to 11 (am and pm) are first studied (corresponding to the range of possible ascending and descending orbit of the future SMOS. To satisfy technical constraints, the choice of 6am-pm was finally retained). This allow to estimate how much the diurnal cycle of the measured variable affects the monthly mean estimates. Then to estimate the influence of the daily variability, the sensitivity to the revisit time is analyzed with sparser output ("observations") of the model, every two days (the planed revisit time for SMOS varies between two and four days).

As shown in Figure 1, the local time of the day for data acquisition depends on the latitude belt. Thus the time sampling analysis presented here takes into account the latitude range according to Figure 1 and the geographical distribution of the land surfaces over the earth. Two latitude belts are studied: between 40^{o}S and 40^{o}N the morning and evening local time for "observation" are identical (example 6am-6pm), and between 40^{o}N and 70^{o}N, ascending and descending local time are non-symmetric (example 6am-8pm).

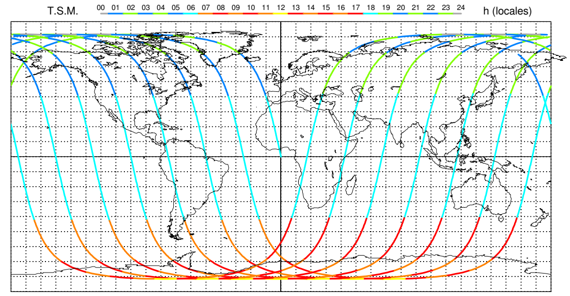

Figure 1: Local time of data acquisition for the future SMOS satellite simulated by M. Capderou for a sun-synchronous orbit at 757 km height (Capderou 2000). The couple of acquisition is 6 am/pm (ascending/descending) is in the range of latitudes between 40^{o}S-40^{o}N. For higher latitudes, between 40^{o}N and 70^{o}N the observation is at 5am and 7pm for this orbit.

3 Results of the global scale time sampling experiment

Figure 2 shows the zonal averages over land surfaces of the Root Mean Square (RMS) of the relative difference between "estimated" and "true" surface soil moisture (four top soil layers, ie top 2.15 cm of the soil). This figure considers the theoretical case with two (am and pm) measurements every day. In January (top panel) the southern hemisphere is characterized by larger RMS differences than the northern Hemisphere. The larger RMS difference associated with larger errors in this Hemisphere are due to the fact that in the summer Hemisphere the diurnal cycle is accentuated by a stronger solar insolation during the daytime. The seasonal contrast between northern and southern hemisphere is confirmed by the second panel, which indicates symmetric features for July. Larger RMS differences in the south Hemisphere in January compared to north Hemisphere in July are explained by the different repartition of continental surfaces in the two Hemispheres. Lower number of continental points in south Hemisphere emphasize the spatial variability and lead to larger RMS than in the north Hemisphere.

As shown, the differences also depend on the local time of observation without any systematic dependance on latitude. This points out that the strong diurnal cycle of the surface soil moisture leads to a sensitivity of the monthly mean estimates to the

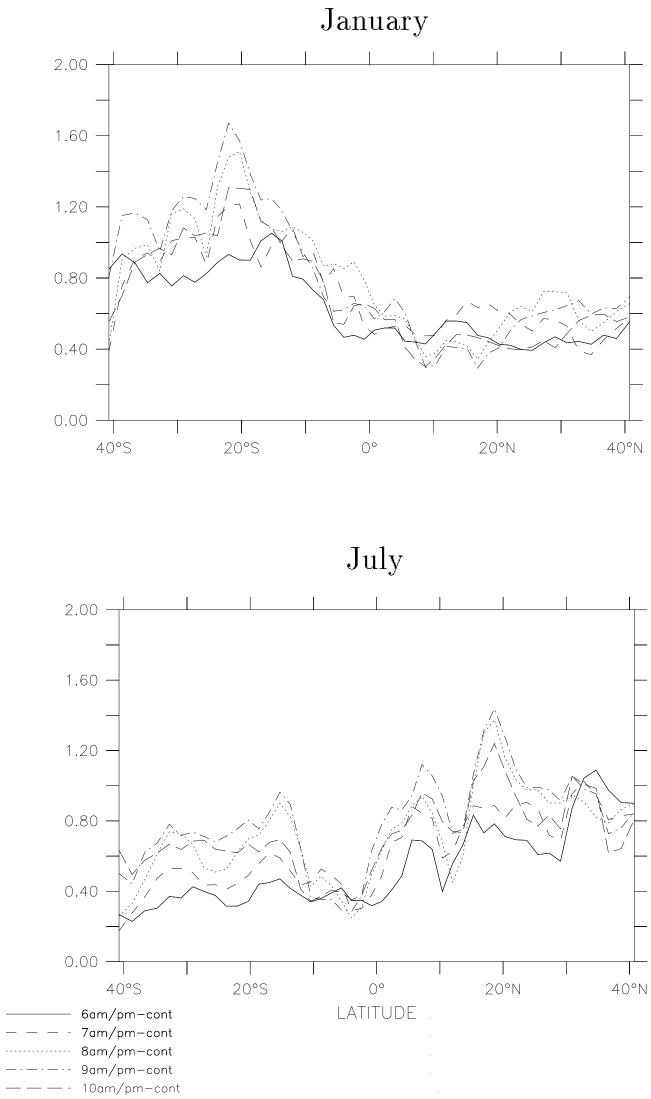

Figure 2: Root mean square of the relative difference between estimated and "true" monthly mean surface soil moisture for January and July (in %). The estimations are computed from two daily "observations". Different local time of the day for the observation are represented by different lines.

precise local time of the day for acquisitions. In general, lower RMS differences are shown for 6am-pm observations, compared to larger RMS for 9am-pm acquisition, but not at all latitudes. But the RMS differences only vary in a range of about 1 % depending on the local time of acquisition. The influence of the local time is important regarding to the time sampling error which remains very low in this experiment, below 2%. However it is rather tricky to point out, from a GCM experiment, a suitable precise local time for acquisition of surface soil moisture as the simulated diurnal cycle over land surfaces by GCMs is shown to be shifted as compared to observations. The maximum of precipitation is shown to occur several hours too early (Guichard and Petch 2001; Redelsperger 2001).

Figure 2 shows that the RMS values of the relative differences remains below 1 % in the winter Hemisphere and varies between 1.0 and 1.9 % in the summer Hemisphere. An analysis of the ascending (am) and descending (pm) measurements indicates that this pair of measurements leads to a minimization of the errors on the estimated averaged values (not shown). The morning time sampling error is mainly compensated by evening error (with opposite sign). This set of two acquisitions allows the capture of the mean daily values of soil moisture despite of its diurnal cycle.

This good agreement between "estimated" monthly soil moisture, from two daily observations, and simulated "true" soil moisture is shown in the Figure 3 both for the tropics and for the mid-latitudes. This global scale analysis clearly indicates that two daily observations of the surface soil moisture is relevant to produce accurate estimates of the surface soil moisture on larger time scales.

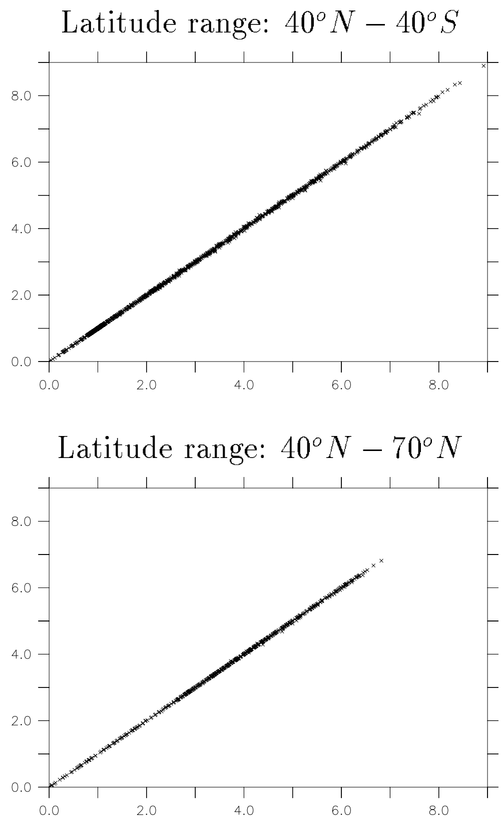

Figure 3: Monthly mean surface soil moisture (top 2.15 cm) in January (in kg/m^2) "estimated" from **two daily observations** versus "observed". The top panel refers to the latitude belt 40°S-40°N for observations at 6am and 6pm. The bottom panel refers to the mid-latitude belt between 40°N and 70°N with non-symmetric data acquisition at 6am and 8pm. For both latitude belts, the time sampling of two daily observations of the surface soil moisture allows to give accurate estimates of the monthly mean soil moisture.

The above analysis focused on daily observations of soil moisture in the LMD GCM. The time sampling of the future satellites for remote sensing of the surface soil moisture will allow a revisit time of at most 2-4 days depending on the latitude. While the relevance of measurements with one day revisit time is influenced by the shape of the diurnal cycle of the measured variable, a sparser time sampling will be influenced by its synoptic variability. In particular, some studies have emphasized at regional scales the role of the 3-5 days variability of the rainfall over West Africa (Taylor and Clark 2001). They indicate that the diurnal forcing of the incoming solar radiation is shown to be transfered through the land surface properties from the diurnal to synoptic scales (Taylor and Clark 2001; Gash et al. 1997).

The result of two measurements every second day is presented on Figure 4. In this experiment, the time sampling error may be underestimated as compared to a real satellite which will allow at most one measurement every second day, with alternation between am and pm acquisitions. But this theoretical experiment allows us to study, using the LMD GCM, the impact of a decrease in the time sampling for the estimation of monthly mean estimates of soil moisture.

Figure 4 shows that the agreement between the simulated "estimated" and "true" monthly mean soil moisture, is lower for every two days than for every day measurement (Figure 3). Thus the reduction in the frequency of the data acquisition leads to an increased error. The results shown here for January are representative of the time sampling error for the other months, with a smaller scatter for the mid-latitude belt.

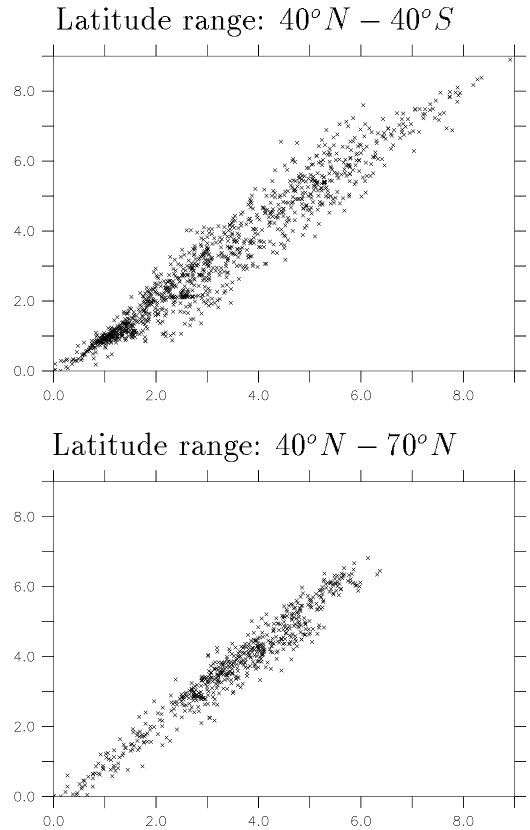

Figure 4: Monthly mean surface soil moisture (top 2.15 cm) in January (in kg/m^2) "estimated" from **two observations every second day** versus "observed". The top panel corresponds to the latitude belt 40°S-40°N for observations at 6am and 6pm. The bottom panel corresponds to the mid-latitude belt between 40°N and 70°N corresponds to the non-symmetric data acquisition at 6am and 8pm. For both latitude range, the sparse time sampling of the surface soil moisture lead to lower accuracy in the estimation of the monthly mean soil moisture compared to Figure 3.

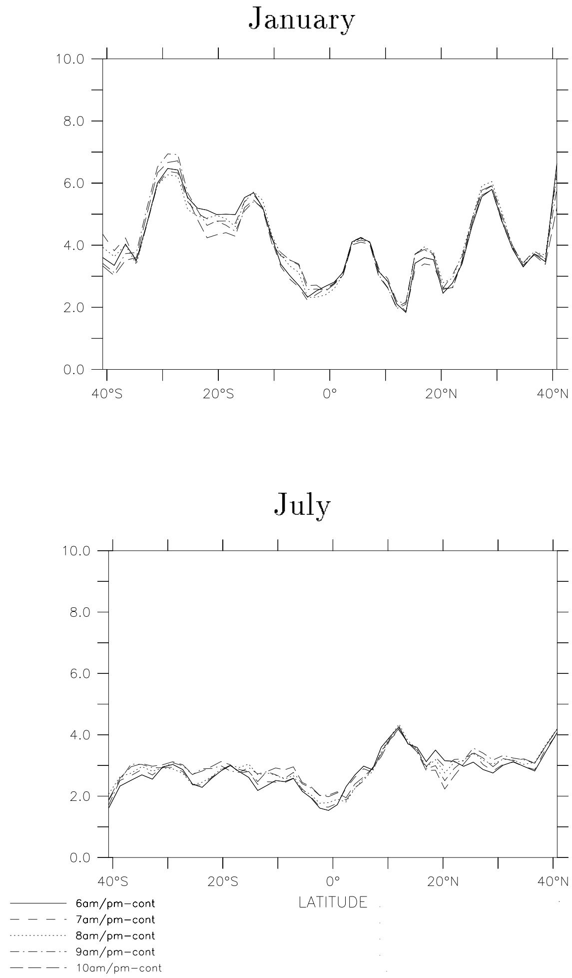

Figure 5: Root mean square of the relative difference between estimated and "true" monthly mean surface soil moisture for January and July (in %). The estimations are computed from two "observations" every two days. Different local time of the day for the observations are represented by different lines.

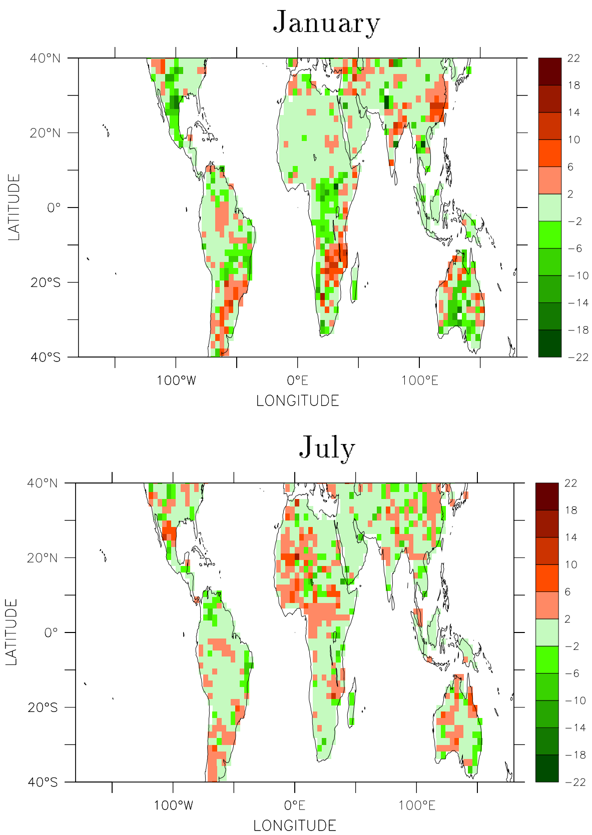

Figure 6: Map of the relative difference between estimated and observed monthly mean surface soil moisture for January and July (in %). The estimations are computed from two "observations" every two days at 6am and 6pm.

The zonal averages for the $40^o N - 40^o S$ latitude belt is shown Figure 5 for January and July. As for every day acquisitions, every second day outputs of the model indicate a similar sensitivity to the time sampling in mid-latitude than in tropics. It is clear from comparing this figure with Figure 2, that the RMS of the errors strongly increases when the time sampling of the remote sensed soil moisture is sparser. While the RMS was limited to 1.9 % for every day acquisition (Figure 2), it reaches 7% in the summer Hemisphere, and stay above 2 % in the winter Hemisphere for every two day acquisitions. It appears from the Figure 5 that the precise local time for acquisition has a very low influence on the RMS of the error compared to the value of the RMS itself. As observed with daily acquisition, there isn't agreement between the RMS values of the summer Hemisphere for the two months. The increase in the time sampling error when frequency of the observations decreases is explained by the temporal variability of the surface soil moisture during the interval. This indicates that a two days repeat time for the measurement of the surface soil moisture does not allows us to capture the day to day variability simulated in the GCM.

Figure 6 gives the geographical distribution of the relative error on the monthly mean estimates of the surface soil moisture in January and July. The maximum value of the RMS difference at 30 ^{o}S on Figure 5 for January is explained by strong positive errors in South America and negative in Australia which leads to high spatial variability of the errors. In Northern Hemisphere, strong RMS differences shown in Figure 5 for January are also explained by longitudinal differences in relative error of the monthly mean estimates. These longitudinal differences result from regional differences in the time scale of the meteorological variability in the model. Figure 6 shows that the absolute value of the relative error on the monthly mean estimates is above 10 % in a large number of regions. These time sampling errors (for two acquisitions every two days) are very large. They are caused by the too sparse time sampling for the observation of the surface soil moisture which is characterized by high day to day variability. This analysis suggests that due to the high time variability of the near surface soil moisture, the repeat time of the satellites is critical for the soil moisture remote sensing.

4 Conclusions

This paper addresses the question of the time sampling error on the estimated monthly mean surface soil moisture from the remote sensed soil moisture by future low frequency passive microwave sensors on satellites. These sun-synchronous satellites will allow at most one acquisition every two days of the surface soil moisture (top few centimeters). The upper few centimeters of the soil are the most exposed to the atmosphere, their soil moisture varies rapidly in response to rainfall and evaporation, from diurnal to synoptic scales (Walker and Houser 2001).

We use a GCM experiment to generate both synthetic "true" near surface soil moisture, and "observed" surface soil moisture that would be measured by a remote sensing satellite. Different local time and repeat time of the satellite measurements are tested. The purpose is not to influence the orbital definition of these future satellites (the chosen sun-synchronous orbits result from strong technical constraints). The aim is to evaluate, with a GCM, the error on the monthly mean estimates of the surface soil moisture depending on the revisit time of a sun-synchronous satellite.

The first part of the study analyses the idealized case of two daily observations of the soil moisture. In this case the RMS errors on the monthly mean estimates are shown to be less than 2 %. Such a high frequency for measurement of the soil moisture enables the capture of the mean daily soil moisture values and gives accurate estimates of the monthly mean. In this case the sensitivity to the precise local time of the day for the acquisition is shown to be in the range of 1 %.
However, the satellite remote sensing of the surface soil moisture does not allows such a high repeat time. At most one observation every two days will be possible. The theoretical case of two acquisitions every two days is analyzed here from the GCM outputs. It shows that the strong day to day variability of the measured soil moisture leads to a drastic increase in the errors of the resulting monthly mean estimates of the soil moisture when the frequency of acquisition decreases. For sparser observations, the local time for the observation is shown to have a very small impact compared to the revisit time (Figure 5).

The results presented in this paper must be taken with care because of the large uncertainties associated to the simulated climate by GCMs. In particular, the deep convection simulated in climate models is shown to occur several hours too early in most of GCMs (Guichard and Petch 2001; Redelsperger 2001). However, the quality and relevance of the GCM were strongly improved in the last decade. Today most GCMs are recognized to be able to capture the main feature of the climate system. Despite some uncertainties, the diurnal to inter-seasonal and inter-annual variabilities are represented (Taylor and Clark 2001; Beljaars et al. 1996; Harzallah et al. 1996; Vinnikov et al. 1996; Koster and Suarez 1995; Delworth and Manabe 1988). Moreover despite some uncertainties in their simulated climate, GCMs are the only tool which allows us to study the time sampling experiments at the global scale.

The analysis conducted in this paper may underestimate the errors on the monthly mean estimates since at least two observations every two days are considered. The real satellite measurement, with two days as repeat time (ascending one day, descending two days after...) may be affected by larger time sampling uncertainties because only one observation will be available every two days. The present study considers the case of a perfect measurement of the soil moisture. The real satellite remote sensing of soil moisture will be affected by instrumental errors (expected to be low), and the soil moisture retrieval will be affected by uncertainties of surface temperature, vegetation and soil characteristics. The strong heterogeneity of the measured surface soil moisture will also make the remote sensing of soil moisture difficult at a spatial scale of several kilometers. Thus the soil moisture remote sensing is very complex and this paper only addresses the question of the impact of the time sampling on the estimated monthly mean soil moisture.

This theoretical global study shows that the high time variability of the surface soil moisture, that will be remotely sensed from space, causes problem in the estimation of the monthly mean estimates of soil moisture. For every second day revist time, the time sampling error is more than twice the time sampling error resulting for daily observations. An approach to access the soil water dynamics at smaller time scales than the space remotely sensed data of soil moisture, is to develop the use of assimilation methods in land surface schemes. This ensemble of methods consists of updating the land surface schemes by assimilating data, to minimize the effect of models and data errors. It is well adapted to the remote sensing of the variable with higher time variability by allowing independence of the time sampling. Several studies show that the development of assimilation methods of L-band brightness temperature for soil moisture retrieval is as suitable for hourly revisit time as for three days interval (Galantowitcz et al. 1999; Entekhabi et al. 1994). Assimilation of near surface soil moisture with a Kalman scheme is also shown to be relevant for the soil moisture profile retrieval with a 5 day revisit time (Walker et al. 2001). Moreover assimilation methods will allow us to account for the short time scale processes that would influence the measurement of the microwave brightness temperature (e.g. the dew deposition). It is also relevant to be used for climate and hydrological studies as it affords a link between surface (observed) and root zone soil moisture.

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