Global Soil Wetness Project: Forecast and Assimilation Experiments Performed at Météo-France

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Abstract

Global soil moisture data of high quality and resolution are not available by direct observation, but are useful as boundary and initial conditions in comprehensive climate models. In the framework of the Global Soil Wetness Project (GSWP), the ISBA land-surface scheme of Météo-France has been forced with meteorological observations and analyses in order to study the feasibility of producing a global soil wetness climatology at a $1^\circ \times 1^\circ$ horizontal resolution between January 1987 and December 1988. A control experiment and several sensitivity tests have been performed, suggesting that soil moisture remains one of the most difficult climatological parameters to model and that any computed climatology must be considered with great caution. The prescription of the soil depth is particularly critical, showing the relevance of the absolute value of the soil water content and the interest for land surface schemes to include a deep layer beyond the rooting depth. Compared to a river flow climatology, the runoff simulated over large river basins seems to be underestimated because of deficiencies in both the ISBA scheme and the GSWP experiment design. In order to obtain a more reliable climatology, a global reanalysis of soil moisture has been attempted, using a sequential optimal interpolation technique, in which soil moisture is corrected by iterative comparison between simulated and observed near-surface air temperature and relative humidity. Preliminary tests have been performed for July 1987, showing the potential of this method in idealized conditions. In practice, many uncertainties, either in the observations, the land surface properties or the atmospheric forcing, are liable to jeopardize the quality of the reanalysis, suggesting the need for more consistent data within the GSWP framework. Some outlooks are presented for improving the robustness of the assimilation technique, which lead to encouraging results.

1. Introduction

Water is a finite resource essential for all forms of life. How water is distributed over the continental surfaces and how it is exchanged with the atmosphere is a crucial issue for understanding and predicting climate variability and evolution. Global Circulation Models (GCMs), including more and more sophisticated land surface schemes, have been frequently used to investigate this question. In particular, the climate sensitivity to soil water content has been widely investigated. However, the global distribution of soil moisture is still poorly known, due to the lack of observations of high quality and resolution. Therefore, the validation of the GCMs' hydrology is a difficult task, and the numerical studies investigating the climatic role of soil moisture

remain inconclusive.

The aim of the Global Soil Wetness Project (GSWP) is to produce a high resolution soil wetness climatology, using state-of-the-art land surface models driven by meteorological observations and 6-hourly analyses. Météo-France proposed an original twofold participation in this project. First, the global distribution of soil wetness has been computed in a control simulation, and additional experiments have been performed in order to know whether the results are robust or sensitive to changes in the intensity of the precipitation forcing, the surface runoff scheme, and the soil depth. Second, the feasibility of a global reanalysis of soil moisture over the same period has been investigated using a sequential optimal interpolation technique, in which soil moisture is corrected by iterative comparison between simulated and observed near-surface air temperature and humidity (Mahfouf, 1991; Giard and Bazile, 1996, 1997). The aim is to provide a

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global validation product, since the standard GSWP products show a large spread between the various land surface schemes, which is not surprising given the conclusions of similar offline experiments performed on the local scale within the PILPS project (Henderson-Sellers *et al.*, 1993).

In the following section, the ISBA land-surface scheme of Météo-France is briefly described, as well as the assimilation technique. The control simulation and the sensitivity studies without assimilation are summarized in Section 3. More details about the results are available in Douville (1998). Section 4 shows the preliminary results of the assimilation tests, and the conclusions are drawn in Section 5.

2. Land surface and assimilation schemes

2.1 Land-surface scheme

The ISBA land-surface scheme has been developed at Météo-France by Noilhan and Planton (1989), and then modified by Douville *et al.* (1995) and Mahfouf and Noilhan (1996). Heat transfer in the ground is based on the force-restore method (Deardorff, 1977). The treatment of the canopy layer has been simplified to avoid the numerical resolution of a specific foliage temperature. A single surface temperature is computed, which is representative of the whole soil-snow-and-canopy system. Besides the reservoir of rain intercepted by the canopy, the scheme includes two reservoirs in the soil and a single snow layer. Additional prognostic variables have been introduced for snow density and snow albedo to represent the snow aging processes (Douville, *et al.*, 1995).

The ISBA hydrology uses the same type of force-restore method for water in the soil as for heat conduction, namely a diffusive exchange between the two soil layers (Deardorff, 1978). Therefore, the scheme behaves like a bucket model for the representation of runoff. But the surface runoff only happens for high intensity rainfall, since the recent introduction of a deep drainage as a relaxation to the water content at field capacity (Mahfouf and Noilhan, 1996). A more sophisticated runoff scheme derived from catchment considerations has also been tested (Dümenil and Todini, 1992). It takes into account the heterogeneous distribution of soil water capacity within a grid box, thereby allowing the surface runoff to appear before the complete saturation of the mesh (see Douville, 1998, for more details). The degree of heterogeneity is represented by an empirical parameter, b , whose typical average value would be 0.2 for a catchment. In the present study, a global distribution of b (values between 0.01 and 0.5) was obtained through a linear dependency on the average surface slope available in the ISLSCP soil dataset.

In the following, the total soil water content will be normalized by the difference between w_{fc} and

w_{wilt} , which represent the water contents at the field capacity (potential transpiration) and at the wilting point (no transpiration). This allows to take account of spatial variability of the soil depth and textural properties. However, this is not a universal index, since w_{fc} and w_{wilt} may be computed in several ways, either numerically or empirically. In the present study, the calculation is based on the empirical equations of Clapp and Hornberger (1978). The soil wetness index (SWI) equals 0 at the wilting point and 1 at the field capacity:

$$SWI = \frac{w_p - w_{wilt}}{w_{fc} - w_{wilt}}.$$

2.2 Assimilation technique

The principle of the soil moisture analysis has been defined by Mahfouf (1991). Besides a variational technique, the paper describes an alternative and less computationally expensive method based on sequential optimal interpolation (O.I.). A multiple linear regression is assumed to relate the prediction errors of temperature and humidity to the corrections of soil wetness:

$$\delta W_g = \alpha_1 \Delta T_{2m} + \alpha_2 \Delta H_{2m}, \quad (1)$$

$$\delta W_p = \beta_1 \Delta T_{2m} + \beta_2 \Delta H_{2m}, \quad (2)$$

where W_g and W_p are the surface and deep soil water contents, T_{2m} and H_{2m} are the near-surface temperature and relative humidity, and α_1 , α_2 , β_1 , β_2 are the O.I. coefficients.

Some knowledge about the statistics of observational and prediction errors is required, which can be obtained through a Monte Carlo method (Mahfouf, 1991). From these values, Bouttier *et al.* (1993) proposed an analytical formulation. The O.I. coefficients were expressed as a function of the local solar time, the fraction of vegetation cover, the ratio of leaf area index to minimum surface resistance, and the soil texture. Bouttier *et al.* (1993) also emphasized the importance of observation errors for the assimilation procedure. The observation error statistics must be used to selectively filter out the meteorological situations in which the boundary layer contains little information about soil moisture (rain, cloud, strong wind...). Even in suitable conditions (basically strong solar radiation), the near surface parameters are not only influenced by errors in soil moisture, but also by errors in both the ISBA model and the atmospheric forcing. Though not negligible, these additional errors are assumed to be small enough not to mask the soil moisture signal. This strong assumption will be further discussed in Section 4.

Giard and Bazile (1997) have implemented the method in the operational assimilation suite of Météo-France based on the O.I. procedure CANARI. The upper air analysis is performed every

Table 1. Summary of the simulations without assimilation: IS1 is the control experiment, NP89 refers to Noilhan and Planton (1989) and DT92 refers to Dümenil and Todini (1992).

Experiment	IS1	IS3	IS2	IS4
Boundary conditions	ISLSCP	ISLSCP	ISLSCP	ISLSCP
Rainfall intensity	low	high	high	high
Surface runoff scheme	NP89	NP89	DT92	DT92
Prescribed soil depth	total	total	total	rooting

6 hours. The analysis of T_{2m} and H_{2m} follows and the resulting increments are used as input for the soil moisture analysis. The formulation is derived from Bouttier *et al.* (1993), but the O.I. coefficients have been recalibrated and fitted onto a sine function in order to correct errors related to the range of forecast and ensure 24-hour periodicity. This updated routine has been used in the present study. The analysis of T_{2m} and H_{2m} has been adapted from the operational O.I. analysis, but the error statistics have not been modified. In particular, the standard deviation of observation errors have been set to $\sigma_{T_{2m}}^o = 1$ degree and $\sigma_{H_{2m}}^o = 10$ %.

3. Forecast mode

3.1 Experiment design

In this part, ISBA is used in forecast mode only and driven by the atmospheric and radiative forcing provided on a 6-hourly basis by the ISLSCP I CD-ROM (Fig. 2). It includes a hybrid precipitation product (GPCP data and NMC analysis), a hybrid radiative product (ISCCP data and ECMWF analyses) and near-surface parameters from the ECMWF analyses. The CD-ROM also contains all the data for prescribing the land surface boundary conditions, the strict use of common conditions being fundamental to the GSWP project (Douville, 1998). After a six-year spin-up allowing most of the grid points to reach an equilibrium, a two-year simulation was performed between January 1987 and December 1988, which will be hereafter referred to as IS1.

Besides this control run, several sensitivity tests have been conducted for 1987 which are summarized in Table 1. These additional experiments were designed to explain the weak runoff ratio simulated in the control case (see Section 3.2). Several reasons were proposed for this deficiency, which were related to approximations in both the ISBA scheme and the GSWP experiment design. The aim of the first test is to explore the effect of the temporal rainfall variability. In the GSWP project, the hourly precipitation rates are obtained by linear interpolation between 6-hourly values. The rainy periods last at least for 6 hours, and the interception loss (evaporation from the wet part of the vegetation) can be

very high. In the sensitivity experiments, the total accumulation over 6 hours is concentrated during the first 2 hours of each 6-hour period. This modification is tested alone in IS3, and together with the runoff scheme of Dümenil and Todini (1992) in IS2. Finally, IS4 is performed with both the alternative precipitation and surface runoff (like IS2), but with decreased soil depths. ISBA does not distinguish between the rooting depth and the total soil depth that are provided by the ISLSCP data set. In IS4, the use of the rooting depth instead of the total soil depth is expected to significantly affect the hydrologic budget.

3.2 Global water balance

Like most assimilation techniques, the soil moisture analysis presented in Section 2.2 does not conserve water, since soil moisture corrections are applied from time to time with no change in precipitation, snowmelt, evaporation, or runoff. It is actually very difficult to know which of these processes contributes to the errors. The O.I. assimilation is only able to provide a better soil moisture climatology and an idea of the accuracy of the simulated evaporation and runoff. The larger is the magnitude of the increments, the less reliable are the water fluxes.

In simulations IS1 to IS4, no soil moisture correction is applied and it is possible to analyse the global water budget at the Earth's surface. Table 2 gives the annual mean runoff and evaporation, as well as the corresponding SWI, for all the simulations. The results can be compared to previous climatologies based on a similar approach, but with an atmospheric forcing provided on a monthly time scale. These climatologies give a global runoff ratio between 31 and 38 %, while it does not exceed 27–28 % in our control experiment IS1. As shown by Douville (1998), this low value is probably unrealistic. The comparison between the runoffs given by the simulation and the Global Runoff Data Center climatology for the world's largest river basins indicates that the simulated runoff is generally underestimated (Fig. 1). The partition of total evaporation into its various components suggests that the low runoff is partly due to an overestimation of the interception loss. With shorter duration rainfall of

Table 2. Annual and global mean hydrologic budget averaged over all continental surfaces (except Antarctic in BR75, UN78 and WI85, as well as Greenland in our simulations and in LE96); the global averages are normalized according to land area. *BR75: Baumgartner and Reichel (1975); UN78: UNESCO (1978); WI85: Willmott *et al.* (1985); LE96: Levis *et al.* (1996).

Source	IS1	IS1	IS3	IS2	IS4	BR75	UN78	WI85	LE96
Period	1987	1988	1987	1987	1987	clim	clim	clim	clim
P (mm/year)	720	758	720	720	720	806	864	822	818
E (mm/year)	526	543	512	499	482	527	535	568	544
E/P (%)	73	72	71	69	67	65	62	69	67
R (mm/year)	194	215	208	221	238	279	329	254	274
R/P (%)	27	28	29	31	33	35	38	31	33
SWI	0.60	0.60	0.60	0.57	0.52				

higher intensity, there is less interception and more runoff, especially in forested areas. Comparing the runoff ratios simulated in all the sensitivity tests indicates that the higher rainfall intensity (IS3) leads to a slight increase in the runoff ratio in the high latitude river basins, while the increase is more obvious in the wet tropics. In IS2, this tendency is reinforced almost everywhere by the runoff scheme of Dümenil and Todini (1992). In IS4, the runoff increases mainly in the tropics and the midlatitudes, in areas where the soil is much deeper than the rooting layer. This last change has also a strong impact on the amplitude of the SWI annual cycle (Douville, 1998).

Coming back to Table 2, the annual mean runoff ratio increases by 2 % using a more intermittent precipitation forcing (IS3). Changing the runoff scheme (IS2) induces the same relative increase. Finally, replacing the total soil depth with the rooting depth (IS4) causes the runoff ratio to increase by a further 2 %, thus reaching 33 % instead of 27 % in the control simulation. These sensitivity tests suggest that the GSWP project does not necessarily provide a more realistic global water balance than previous estimations at lower spatial and temporal resolution. Experiments IS2 and IS4 may be closer to reality than the control simulation. The annual and global mean runoff ratio might lie between 31 and 33 %, in keeping with the results of Willmott (1985) and Levis *et al.* (1996). It seems more difficult to give an accurate estimation of the mean SWI, which is very sensitive to the soil depth (0.57 in IS2 against 0.52 in IS4). The prescription of soil depth is crucial for land surface schemes like ISBA, which do not include a recharge layer (*i.e.*, the soil depth is implicitly equal to the depth of the root zone). The present study indicates the interest for such schemes to include a third layer to improve the boundary conditions, assuming it is then possible to get reliable global information on the depth of the bedrock or of the water table.

4. Assimilation mode

4.1 Experiment design

The ISLSCP I CD-ROM directly provided T_{2m} and H_{2m} for driving the land surface scheme in Section 3. It is necessary to compute these 2 m parameters from the surface variables in order to implement the assimilation technique (Fig. 2). For this purpose, the screen-level meteorological forcing (temperature, humidity and wind) is replaced by the forcing from the lowest level of the ECMWF model from either the reanalysis (ERA) or the analysis (ANA). The interpolation between the surface and the model's level is based on a Monin-Obukhov type flux calculation (Geleyn, 1988). The same analytical technique is applied in the operational weather forecast model of Météo-France, both for verification of forecasts and determination of "observation minus guess" increments in data assimilation. In the present study, the lowest model level lies around 30 m above the surface and is not influenced by the surface evolution (prescribed forcing). The first assimilation tests have been performed for July 1987, when a large fraction of the continents receive strong solar radiation, so that the surface evaporation may significantly influence T_{2m} and H_{2m} . The various experiments are summarized in Table 3.

As far as the observations of T_{2m} and H_{2m} are concerned, two types of data have been used. In a first step, the assimilation scheme has been validated with pseudo-observations provided at each model grid point by a reference simulation without assimilation. In this theoretical and idealized framework, the land surface model and its forcing are considered as perfect and all the errors in the screen-level parameters are related to soil moisture. At the beginning of July, the surface and deep soil water contents have been modified in order to demonstrate that the assimilation scheme allows them to converge towards the values of the reference simulation, following the methodology applied by Bouttier *et al.* (1993). In a second step, the assimilation scheme

Fig. 1. Top: annual evaporation and runoff simulated in 1987 over the world's 17 largest river basins in the control experiment IS1 and climatological annual mean runoff estimated from the Global Runoff Data Center river flow measurements; Bottom: comparison of the 1987 annual mean runoff ratios simulated in IS1, IS2, IS3 and IS4.

has been tested in the framework of GSWP with real SYNOP observations randomly distributed around the world. In this case, the prediction errors are not only due to soil moisture errors, but also to uncertainties in the observations, the atmospheric forcing, and the land surface properties.

4.2 Results

For the assimilation tests with pseudo-observations, it was first necessary to perform a reference simulation JU0 without assimilation using the ERA

lowest level instead of the ISLSCP screen level as meteorological forcing. The radiative and precipitation forcing were not modified, and this July reference simulation was very close to the control experiment IS1 discussed in Section 3. Besides the reference, two assimilation tests have been performed, JW2 and JF2, starting, respectively, with water content values at the wilting point ($SWI = 0$) and the field capacity ($SWI = 1$). Figure 3 shows the 6-hourly evolution of the total soil water content for

Fig. 2. Schematic diagram describing the experiment design of the forecast and assimilation experiments.

Table 3. Summary of the assimilation tests: JW2 and JF2 use pseudo-observations provided by a reference simulation without assimilation (JU0); JU4 to JU7 use real observations of the SYNOP network and are forced by either the reanalysis (ERA) or the analyses (ANA) from ECMWF.

Assimilation test	JU4	JU5	JU6	JU7	JW2	JF2
Observations	Synop	Synop	Synop	Synop	JU0	JU0
ECMWF forcing	ERA	ERA	ANA	ANA	ERA	ERA
Filtering of ΔT_{2m}	No	Yes	No	Yes	No	No
Initial SWI	JU0	JU0	JU0	JU0	SWI=0	SWI=0

two specific grid points during the month of July, as well as the corresponding prediction errors of T_{2m} and H_{2m} . These two grid points have been selected because they are close to the sites where the FIFE and ABRACOS field experiments were organized. The results demonstrate the ability of the assimilation routine to converge towards the reference soil moisture. The convergence is quicker for ABRACOS than for FIFE, due to the influence of the higher vegetation density on the O.I. coefficients in Eqs. (1) and (2) (Giard and Bazile, 1997).

Moving to the tests with SYNOP observations, it must be emphasized that the spatial coverage of the SYNOP network is quite irregular. Globally, the number of 6-hourly SYNOP data varies between 2500 and 3500, while there are 14637 land grid points in the model at the $1^\circ \times 1^\circ$ horizontal resolution. In some areas, the network is so poor that it may jeopardize the results of the assimilation. Uncertainties in the atmospheric forcing represent another source of difficulty. First, the

6-hourly distribution of radiative fluxes is derived from the ECMWF analyses, while the 6-hourly distribution of precipitation is derived from the NMC analyses, which may contribute to inconsistencies in the forcing. Second, the meteorological parameters (temperature, humidity, and wind) differ somewhat between the ERA and ANA products, and these differences are liable to influence the assimilation's quality. Finally, the ISLSCP land surface properties (vegetation density, albedo, etc...) may also generate some biases in the forecast and assimilation results.

It is therefore particularly important to correct soil moisture only when the prediction errors of temperature and humidity are meaningful; namely, they are related to a bad estimation of surface evaporation. The analysis does not allow any positive/negative correction if the predicted value is above the field capacity/below the wilting point. According to the rules laid down by Giard and Bazile (1997), the soil moisture analysis is also

Fig. 3. Total SWI evolution obtained in forecast (JU0) and assimilation mode (JW2 and JF2) for selected grid points in July 1987; JW2 is initialized at the wilting point and JF2 at the field capacity and both experiments use pseudo-observations provided by the reference simulation JU0; on the abscissa, time is displayed every six hours.

switched off if: 1) the wind speed exceeds 10 ms^{-1} ; 2) the day length is less than 6 hours; 3) the last 6-hour precipitation exceeds 0.6 mm; 4) snow lies on the ground; 5) the instantaneous latent heat flux indicates condensation. In the present study, this last rule has been reinforced because the analysis is performed only if the last 6-hour potential evaporation is more than 0.12 mm. Despite these precautionary measures, the results of the analysis remain quite chaotic and differ significantly according to the choice of the meteorological forcing (ERA in experiment JU4 versus ANA in experiment JU6). This is shown in Fig. 4 through a few examples of the SWI evolution obtained in July for the grid points close to the sites of the FIFE (U.S.), ABRACOS (Brazil), HAPEX-MOBILHY (France) and EFEDA (Spain) field experiments.

An additional modification has been introduced

in experiments JU5 and JU7, using respectively the ERA and ANA forcings. To avoid spurious corrections due to systematic biases in either the ISBA model or in the GSWP atmospheric forcing, the instantaneous increments ΔT_{2m} and ΔH_{2m} have been replaced in Eqs. (1) and (2) by filtered increments in which an average error is subtracted. As expected, the SWI evolution is less noisy than in the previous tests. The SWI predicted in JU6 (JU7) are sometimes very different than in JU4 (JU5), despite the use of the same atmospheric forcing. This confirms that the guess of T_{2m} and H_{2m} may be affected by systematic errors, either in the forcing itself or in the land surface properties. The filtering allows the soil moisture analysis to be less sensitive to the uncertainties in the meteorological forcing, which is particularly clear for the “EFEDA” grid point.

Figure 5 shows the global distribution of the

Fig. 4. Total SWI evolution obtained in forecast (JU0) and assimilation mode (JU4, JU5, JU6, JU7) for selected grid points in July 1987; JU0, JU4 and JU5: ERA meteorological forcing; JU6 and JU7: ANA meteorological forcing; JU5 and JU7 with filtered increments; on the abscissa, time is displayed every six hours.

Fig. 5. Global monthly mean distribution of SWI in July 1987 for the reference experiment without assimilation (JU0) as well as for the assimilation test with filtered increments (JU5).

monthly mean SWI in July 1987 for the reference experiment without assimilation (JU0), as well as for JU5. Though it is not yet possible to consider that the assimilation product is better than the mere forecast, some results are noticeable. Globally averaged, JU5 is drier than JU0, which is probably too wet according to the discussion in Section 3 (remember that JU0 is nearly identical to the 2-year control simulation IS1 which is much wetter than IS4). This drying is seen in all areas where the mean soil water content exceeds the field capacity ($SWI > 1$), as well as in other areas where dry conditions are generally observed in July (Central Asia, Mauritania, Namibia). On the other hand, JU5 is wetter than JU0 over South Amazonia, equatorial Africa and around Mongolia, where the normalized vege-

tation index observed by satellite indicates a high density vegetation in July 1987.

5. Summary and conclusions

The global-scale surface water budget has been computed with the ISBA land surface scheme on a $1^\circ \times 1^\circ$ grid over the period 1987–1988. Particular attention has been paid to the simulated annual runoff which has been compared to observed river flows over large river basins. The results indicate that the regional runoff is generally underestimated, which may be related to the lack of intermittency in the GSWP precipitation forcing, the lack of sub-grid heterogeneity in the ISBA scheme, but also to the use of soil depths which are greater than the rooting depth in a scheme that does not include a

deep layer below the rooting zone. These three factors have a similar impact on the global and annual mean runoff, but they show regional and seasonal variations and they do not affect the soil water content in the same way.

In the framework of GSWP, there has been a debate about the relevance of the absolute soil water content versus the normalized soil wetness as the ultimate product of the project. Obviously, the absolute soil water content is strongly dependent on the soil depth that is considered, but our study indicates that it is also true for the normalized index. Moreover, it is very difficult to compare the results of various land surface schemes, when they do not all distinguish between the rooting depth and the total soil depth and they do not define the wilting point and the field capacity in the same way. For these reasons, we believe that the absolute soil water content in the total soil depth is a more meaningful product, not only for the sake of comparison, but also for the use in climate studies in which the atmosphere will be influenced by the total storage of water in the soil.

Given the spread between the GSWP products derived from various land surface schemes, it seems difficult for GSWP to fulfill its main goal, namely to provide a reliable global soil moisture climatology. It is therefore crucial to develop efficient tools for validating the model outputs. In situ observations are unsuitable because of the inherent spatial variability of soil properties and hydrology. Remote sensing does not give a direct access to the deep soil water content. It is therefore crucial to collect more and more river flow measurements for validating the simulated partition of precipitation between evaporation and runoff. Another promising validation means is by inverse or assimilation techniques, which are liable to provide objective corrections of soil moisture fields predicted by imperfect land surface models driven by imperfect boundary conditions.

Such an assimilation technique has been developed at Météo-France, in which the soil moisture field is inferred by iterative comparison between simulated and observed near-surface air temperature and humidity. This technique has been successfully tested in a theoretical framework, but is difficult to implement in practice. Its efficiency depends on the accuracy of the atmospheric forcing and of the soil and vegetation parameters, a condition which is not fully satisfied by the ISLSCP Initiative I dataset. More consistency between the radiative (ECMWF analyses) and precipitation forcings (NMC analyses) and less uncertainty in the meteorological low-level parameters would probably help to improve the results. Nevertheless, the assimilation produces promising results if enough precaution is taken when doing the soil moisture corrections.

Further works are needed to test the efficiency and the robustness of the method. Validation experiments using single column models and local field measurements already have been undertaken, both at Météo-France and ECMWF. Encouraging results have been obtained, showing that the optimum interpolation technique is a powerful tool for initializing soil moisture, even in the presence of strong biases in the precipitation forcing. It was also shown that the method is robust enough to resist large mis-specifications of the vegetation properties. However, the technique remains rather sensitive to strong biases in the radiation forcing and therefore requires a reasonable estimation of the net solar radiation. These results suggest that there is still some hope for producing a global soil wetness climatology through the assimilation technique presented in the present study.

The implementation in a global numerical weather prediction model would be probably more efficient than the offline implementation attempted in the framework of GSWP. In a global model, the land surface is able to feedback onto the atmospheric boundary layer so that the $2m$ parameters are more sensitive to any error in soil moisture. A global soil moisture analysis could be performed every 6 hours at the same time as the atmospheric analysis, and provide reasonable estimates of both surface evaporation and soil moisture. Since the focus of the assimilation technique is on evaporation (through the $2m$ parameters), the analysis will not necessarily produce a reasonable runoff climatology, if the land surface model does not simulate a realistic ratio between runoff and evaporation. Finally, the implementation of the OI soil moisture analysis requires an accurate $2m$ analysis. In some specific areas (along the coasts and in mountainous regions), it might be wise to limit the soil moisture corrections, as long as the $2m$ analysis is not able to deal with the land-sea contrasts and with the uncertainties related to orography.

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全球土壌水分プロジェクト：フランス気象局における予報と同化実験

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高品質、高解像度の全球土壌水分量データは直接観測によっては得にくい、複雑な気候モデルの境界条件、初期条件として有用である。1度×1度の水平解像度全球土壌水分気候値を作り出す可能性を求める研究のために、全球土壌水分プロジェクト (GSWP; Global Soil Wetness Project) のフレームワーク内で、1987年1月から1988年12月までの間、気象観測値と解析値を強制力としてフランス気象局のISBA地表面スキームを用いた実験を行った。コントロール実験といくつかの感度実験を行い、土壌水分はモデルにとって最も難しい気候パラメータであると共に、計算された気候値はどのようなものでも十分注意を要しなければならないことが示唆された。土壌含水率の絶対値の関連や根の深さに及ぶ深い層を含む地表面スキームを考えると、従来からの土壌層厚は殊に危険をはらむものである。河川流量気候値の比較では、大河川の盆地で計算された流出量はISBAスキームとGSWP実験のデザインに含まれる不足量のために少なく評価されているように見える。更に信頼性のある気候値を得るために、土壌水分量の全球再解析を試みた。それには地表面近傍の気温と相対湿度の計算値と観測値の間を繰り返し比較することにより修正された土壌水分量を使う連続最適内挿法を用いた。1987年7月について予備実験を実施し、理想的な状態でこの方法の可能性が示された。観測値、地表面特性、大気強制力などの不確実性が再解析の質を悪くしやすく、GSWPフレームワークではデータの更なる一貫性が必要であることが示唆された。また、同化手法の偏りを改善した、いくつかの良い結果を示した。