Sensitivity Analysis of TSEB Model

by One-Factor-At-A-Time in irrigated olive orchard

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Abstract

The aim objective of this present study is to identify the most influencing constant parameters of Two Source Energy Balance (TSEB) Model over irrigated olive orchard in semi-arid area. TSEB (Norman et al. 1995) has been based on surface radiometric temperature, Priestley-Taylor estimation of canopy latent heat, climatic forcing and partitioning energy to double sources (canopy and soil) according parallel resistances network. Sensitivity analysis by approach One-Factor-At-A-Time (OAT) was been studied using Eddy Covariance ground measurements data collected during SUDMED Project in Agdal site, Marrakech, Morocco (2003). Data include surface energy fluxes, meteorological inputs and vegetation parameters related to olive orchard. OAT consists in modifying each input parameters of the model by ±10% around its initial value. The effect of each operated modification is analyzed on four outputs of the model (i.e: Net radiation, latent heat, sensible heat and soil heat), using variation rate and sensitivity index. The input parameters data such as Leaf Area Index (LAI), Priestley-Taylor constant (αp), and fraction of LAI that is green (fg) have successively a percentage variation of 18.4%, 15.1%, and 15.1% shown to have the greatest impact on the TSEB estimate of the fluxes.
Thus, the results obtained give a fairly clear idea of the most important entrances of TSEB. They can guide the user through the calibration process and also in collecting experimental data.

Keywords: TSEB Model, Sensitivity analysis, One-Factor-At-A-Time, Sensitivity index, percentage of variation.

1. Introduction

All models describing biophysical phenomenon depending on two kind of uncertainty: First one is due to a system description and second is due to model parameters which estimated through experimental data (Ratto et al., 1996). The values of parameters influence seriously prediction even correct biophysical description (Ratto et al., 1996). The coherence between model and its biophysical system is essential and is evaluated by sensitivity analysis (Saltelli et al., 1999). The sensitivity and the variation level of output versus constant uncertainties are must be known. Sensitivity analysis permit us to evaluate all constant parameter effect on model result to classify them according to their sensitivity level (Saltelli et al., 2000), and to tune parameters at the time of determination on experiment (Jolicoeur, 2002). This paper highlight the model description used for this study in section 2, while section 3 describe the sensitivity analysis method, and section 4 presents results of sensitivity analysis. Conclusion and perspectives are presented in section 5.

2. Brief description of TSEB Model

TSEB Model is based on energy balance closure using surface radiometric temperature, vegetation parameters and climatic data. TSEB outputs surface turbulent fluxes, and temperatures of canopy and soil. The version implemented in this study basically follows what is described in appendix A as the “parallel resistance network”. As such, the model implemented is described in detail in (Norman et al. 1995, Kustas et al. 1999).

3. Sensitivity analysis Method

The main goal of this study is to identify among input parameters the most sensitive to model outputs; (i.e: those for which a little variation may involve a great change in model result, (Saltelli et al., 2000b). Screening Designs method of sensitive analysis is utilized here under technique of OAT (Rody Félix, Dimitri Xanthoulis; 2005), which identify among input parameters whose contribute more to variability of 4 output model: Net radiation, latent heat, sensible and soil heat.

3.1 One-Factor-At-A-Time (OAT) method

OAT is the simple technique of Screening Designs (SD) method to carry out a sensitivity analysis. It consists to identify most sensitive parameter among those may be affecting model output (Nearing et al., 1990). SD is efficient when a model has several input parameter (Jolicoeur, 2002). To assess the impact of errors or variation
±10% around base input value, a sensitivity analysis of TSEB model was performed by computing relative variation rate Vr(p) and sensitivity index SI(p). The effect of each operated modification is analyzed on 4 outputs of the model (i.e: Net radiation, latent heat, sensible heat and soil heat), using variation rate and sensitivity index.
The relative variation rate Vr(p), and sensitivity index, SI(p) of a model flux estimate, in a parameter p, can be expressed as

$$Vr(p) = \left|\frac{S_2 - S_1}{S_1}\right| .100$$

$$SI(p) = \frac{\frac{S_2 - S_1}{S_{moy}}}{\frac{E_2 - E_1}{E_{moy}}}$$

where SI is the sensitivity index of model output ; E1 the initial input parameter ; E2 the tested input value (e.g :±10% modification lag); Emoy average between E1 and E2; S1, S2 are respectively the outputs corresponding to E1 and E2; Smoy is the average between S1 and S2.

This index provides a quantitative basis for expressing the sensitivity of model outputs versus the input variables. A sensitivity index equal to unity indicates that the rate of variation of a given parameter causes the same rate at the outputs, but a negative value indicates that the inputs and outputs vary in opposite directions. The index in absolute value is greater then its impact of a given parameter which might have on a specific output.
The model outputs are treated as follows:
1- In fact, the change of each input variable by ±10% produces two values for each selected outputs. From these two introduced input values, the greatest variation at a given output is used to calculate its sensitivity index (SI).
2- A percentage change (Favis-Mortlock, Smith, 1990) and a sensitivity index (Jolicoeur, 2002) are calculated for each output selected above by previous formulas:
Generally, factors screening may be useful as a first step when dealing with a model containing several no identified parameters. These parameters have often a significant effect on the model output. Screening experiment are used to identify the subset of factors that controls most of the output variability with a relatively low computational effort. This economical method tends to provide qualitative sensitivity measures, (i.e: it ranks the input factors in order of importance, but do not quantify how much a given factor is more important than another.

4. Results and discussion

4.1 Overview

The input parameters used in this sensitivity analysis are the Priestly-Taylor constant (αp), the leaf area index (LAI), the fraction of the LAI that is green (fg), the fraction of the soil net radiation (cg), the canopy height (h), the mean leaf size (s) is given by four times the leaf area divided by the perimeter, the surface emissivity (ε), and the surface albedo (α). After modifying alternately each model input of datasets mentioned above by -10% and+10% around its initial value, we analysis only percentage greater than 0.5%. Such inaccuracies can be derived either from some variability inherent in any consideration or measurement on field. A total of 6983 simulation is performed on the semi-hourly data set obtained from SUDMED Project (The fall year 2003). Each simulation performed here takes into account the change only one input relative to the overall model parameters. The effect of each change made is analyzed in the four model outputs (i.e: Sensible heat (H), Latent heat (LE), Net radiation (Rn) and Ground conduction heat (G)).

4.2 Sensitivity of sensible heat (H)

Input parameters modification produce variation rate from 0.7% to 32.6% on sensible heat. LAI, αp and fg are the most sensitive parameter on this output (fig.1). They produce variation respectively of 32.59%, 23.55% and 23.55%. Sensible heat accuse sensitivity index respectively of -3.4 to -2. It is most sensitive to LAI with -3.4 as negative sensitivity index. This analysis indicates that high uncertainties on these inputs may falsify seriously results of sensible heat. Indeed, it's clear that when vegetation is developing then LAI is increasing and the sensible heat is decreasing (i.e: negative sensitivity index) because vegetation play a role of shock-absorber. Therefore vegetation play a role of shock-absorber, then reduce considerably soil sensible heat with variation rate 100% (SI=-21) and also soil heat stock (14.4% with SI=-1.28 (fig.1)). However, this case is occurred during development phase of olive trees (e.g: during July, August, and September). That is why LAI is related strongly to development phase and has an important influencing in sensible heat especially its soil component.

For the case of the olive, LAI don't vary too much during seasons. Sensible heat is also sensitive to fg and αp with 23.59% of variation (SI=-2). These parameters reduce considerably canopy sensible heat. fg represents the green fraction of vegetation and it's increasing play in the opposite direction to total sensible heat especially in the soil contribution.

4.3 Sensitivity of sensible heat (LE)

Figure 2 indicate that LAI, fg, and αp are the important input for latent heat. LAI produce a variation rate of 8.13%, fg and αp are 6.67% with sensitivity index respectively of 0.74 and 0.65 for input. We observe that sensitivity index is negative for emissivity, albedo, cg and s. It means that these parameters vary inversely to total latent heat input. Note well that LAI is also the most sensitive factor on output. We have the same ascertainment then for total sensible heat varies inversely. On TSEB, LAI play an important role in fractional cover vegetation. It's sensitivity index is positive then it confirm a good influence in evapotranspiration and evolves both in the same direction. However, any doubt measurements or uncertainties in LAI index cause some errors in latent heat. Moreover, fg and αp are the same influencing in evapotranspiration like LAI.

4.4 Sensitivity of net radiation (Rn)

Net radiation undergoes only the both influence of surface emissivity and albedo having variation rate respectively of 2.9% and 1.6% with negative sensitivity as -0.29 and -0.15. It indicates that these parameters evolve inversely effect to net radiation. Net radiation depends also on climatic variables as long wave, short wave and radiometric temperature. However, inaccuracies intricate always on this output, cause errors can occur on these two parameters. In effect an uncertainty of 10% on albedo and emissivity cause only a variation of 1 to 3% at the outlet (Fig.3).

4.5 Sensitivity of soil conduction heat (G)

Entries LAI, α and ε affect G respectively with a variation rate of 14.4%, 2.9% and 1.6% with negative sensitivity indices as respectively -1.28, -0.29 and -0.16 (Fig.4). LAI is the most influential parameter on G as it is normal and consistent with what we saw previously, because the index indicates the leaf area cover and play a role of shock-absorber. The sensitivity is negative, then it means more vegetation is growing the radiation received by the ground is lower and the higher the ground stock heat decreases. In fact, it seems natural that the LAI has this influence on the stock to heat in the soil because it is one of the main parameters that control the level of heat storage in the soil. Uncertainty on this entry could have some imprecision on G which unfortunately is poorly estimated by the model.

4.6 Comparison of changes in TSEB surface fluxes

An average variation determined for the 4 outputs considered and for each entry shows that LAI is the most important parameter with an average change produced approximately 18.4%. It is followed by αp and fg whose variations are 15.1%. Globally changes in other inputs have little influence on model outputs (Fig. 5). Comparing the results of the sensitivity analysis obtained shows a certain similarity in the sensitivity of the four outputs selected with the variation of model inputs of ± 10% from their initial value.

5. Conclusions and perspectives

The sensitivity analysis of TSEB model has been applied using One-Factor-At-A-Time (OAT) which is a typical screening designs to assess all constant parameter effect on model result and to classify them according to their sensitivity level. Although simple, easy to implement and computationally cheap, the OAT methods have a limitation in that they do not enable estimation of interactions among factors and usually provide a sensitivity measure that is local. Input parameters used in this sensitivity analysis are the Priestly-Taylor constant (αp), the leaf area index (LAI), the fraction of the LAI that is green (fg), the fraction of the soil net radiation (cg), the canopy height (h), the mean leaf size (s), the surface emissivity (ε), and the surface albedo (α). The input parameters data such as LAI, αp, and fg are successively (18.4%, 15.1%, and 15.1%) shown to have the greatest impact on the TSEB estimate of the fluxes.

As a result, the sensitivity of the TSEB model output in H to uncertainties in LAI, αp and fg don't exceeded 33% of its reference value. On the other hand, sensitivity of the TSEB model output in LE to these parameters uncertainties was generally less than 8% and not influencing Rn and G except for LAI which have 14% of uncertainties to G.

The results of a sensitivity analysis should be handled with care, since the apparent sensitivity of a model for a given parameter depends on the importance, during the chosen period, the process that affects this parameter, itself linked to environmental constraints and to the initial conditions. Thus, in this study, the results obtained give a fairly clear idea of the most important entrances of TSEB. They can guide the user through the calibration process and also in collecting experimental data.

Appendix A

TSEB Equations

Soil and vegetation temperature contribute to the radiometric surface temperature in proportion to the fraction of the radiometer view that is occupied by each component along with the component temperature. In particular, assuming that the observed radiometric temperature, (Trad) is the combination of soil and canopy temperatures, the TSEB model adds the following relationship (Becker and Li, 1990) to the set of (Eqs 12 and 13):

$$Trad(\theta) = [f(\theta).\ Tc^4 + (1-f(\theta))\ .\ Ts^4]^{1/4} \qquad (A.1)$$

where Tc and Ts are vegetation and soil surface temperatures, and f(θ) is the vegetation directional fractional cover (Campbell and Norman, 1998).

$$f(\theta) = 1 - \exp(-0.5\ LAI / \cos(\theta)) \qquad (A.2)$$

The simple fractional cover (fc) is as follows:

$$fc = 1 - \exp(-0.5\ LAI) \qquad (A.3)$$

LAI is the leaf area index, and the fraction of LAI that is green (fg) is required as an input and may be obtained from knowledge of the phenology of the vegetation.

The total net radiation Rn (Wm^{-2}) is

$$Rn = H + LE + G \qquad (A.4)$$

where H (Wm^{-2}) is the sensible heat flux, LE (Wm^{-2}) is the latent heat, and G (Wm^{-2}) is the soil heat flux. The estimation of total net radiation, Rn can be obtained by computing the net available energy considering the rate lost by surface reflection in the short wave (0.3/2.5µm) and emitted in the long wave (6/100µm):

$$Rn = (1-\alpha s).SW + \varepsilon s.LW - \varepsilon s.\sigma.Trad4 \qquad (A.5)$$

where SW (Wm^{-2}) is the global incoming solar radiation, LW (Wm^{-2}) is the terrestrial infrared radiation, αs is the surface albedo, εs is the surface emissivity, σ is the Stefan-Boltzmann constant, Trad (°K) is the radiometric surface temperature.

The estimation of soil net radiation, Rns can be obtained by

$$Rns = Rn \exp(-Ks\ LAI / \sqrt{2.\cos(\theta)}) \qquad (A.6)$$

where ks is a constant ranging between 0.4 to 0.6 and is the zenithal solar angle.

The Rnc is the canopy net radiation as

$$Rnc = Rn - Rns \qquad (A.7)$$

where Rn is obtained using (A.4-5) and is the solar zenith angle. The soil heat flux, G (Wm^{-2}) can be expressed as a constant fraction cg (≈0.35) of the net radiation at the soil surface by

$$G = cg\ Rns \qquad (A.8)$$

The constant of cg (≈0.35) is midway between its likely limits of 0.2 and 0.5 (Choudhury et al 1987). The canopy latent heat LEc is given by Priestly-Taylor approximation (Priestly-Taylor. 1972).

$$LEc = Rnc.\alpha p\ .fg.\frac{\Delta}{\Delta+\Gamma} \qquad (A.9)$$

where αp is the Priestly-Taylor constant, which is initially set to 1.26 (Norman et al 1995; Agam et al 2010), fg is the fraction of the LAI that is green, Δ is the slope of saturation vapor pressure versus temperature curve, Γ is the psychrometer constant (e.g: 0.066 kPa C^{-1}). If no information is available on fg, then it is assumed to be near unity. As will become apparent later (A.9) is only an initial approximation of canopy latent heat.

If in any case LEc ≤ 0, then LEc is set to zero (i.e: no condensation under daytime convective conditions)

The sum of the contribution of the soil and canopy net radiation, total latent and sensible heat is according to the following equations

$$Rns = Hs + LEs + G \qquad (A.10)$$

$$Rnc = Hc + LEc \qquad (A.11)$$

$$LEt = LEc + LEs \qquad (A.12)$$

Where the subscript s and c designs soil and canopy.

The TSEB model considers also the contributions from the soil and canopy separately and it uses a few additional parameters to solve for the total sensible heat Ht which is the sum of the contribution of the soil Hs and of the canopy Hc according to the following equations

$$H_t = Hs + Hc \qquad (A.13)$$

$$Hc = \rho\, Cp \left[\frac{Tc - Ta}{Ra}\right] \qquad (A.14)$$

$$Hs = \rho\, Cp \left[\frac{Ts - Ta}{Rs + Ra}\right] \qquad (A.15)$$

Where ρ (Kg.m^{-3}) is the air density, Cp is the specific heat of air (JKg-1 K-1), Ta (°K) is the air temperature at certain reference height, which satisfies the bulk resistance formulation for sensible heat transport (Kustas et al, 2007). Ra (sm-¹) is the aerodynamic resistance to heat transport across the temperature difference that can be evaluated by the following equation (Brutsaert, 1982):

$$Ra = \frac{\ln\left[\frac{(Zu - d_0)}{Z_{0,H}} - \Psi H\right]}{k.U*} \qquad (A.16)$$

Where Z_u is the height of air wind measurements, $U*$ is the wind friction velocity, do (m) is the displacement height, Z0,H is a roughness parameter (m) that can be evaluated as function of the canopy height (Shuttleworth and Wallace, 1985), k is the von Karman's constant (≈0.4), ΨH is the diabatic correction factor for heat is computed (Paulson, 1970):

$$\Psi H = 2.\ln\left[\frac{1 + \emptyset_h^2}{2}\right] \qquad (A.17)$$

Where is a universal function for heat defined by: (Brutsaert, 1982; Paulson, 1970)

$$\emptyset_h = (1 - 16.\xi)^{1/4} \qquad (A.18)$$

The term ξ is dimensionless variable relating observation height Z, to Monin-Obukhov stability Lmo.

Lmo is approximately the height at which aerodynamic shear, or mechanical, energy is equal to buoyancy energy (i.e: convection caused by an air density gradient). It is determined from

$$Lmo = -\rho \frac{u*^3}{k.g.\left(\frac{H}{\rho C_p T_a} + 0.61\frac{LE}{\lambda}\right)} \qquad (A.19)$$

Where ρ (Kgm^{-3}) is the air density, Cp is the specific heat of air (JKg^{-1} K^{-1}), Ta (°K) is the air temperature at certain reference height, H is a sensible heat flux, LE is a latent heat flux, and λ is the latent heat.

Friction velocity is a measure of shear stress at the surface, and can be found from the logarithmic wind profile relationship:

$$U* = \frac{k.Ua}{\ln\left[\frac{Z_u - d_0}{Z_{0,M}} - \Psi M\right]} \qquad (A.20)$$

Where Ua is the wind speed and ΨM is the diabatic correction for momentum.

The Rs (sm^{-1}) is the soil resistance to the heat transfer (Goudrian, 1977; Norman et al 1995; Sauer et al 1995; Kustas et al, 1999), between the soil surface and a height representing the canopy, and then a reasonable simplified equation is:

$$Rs = \frac{1}{a' + b'.U_s} \qquad (A.21)$$

Where a' = 0.004 (ms^{-1}), b' = 0.012 and Us is the wind speed in (ms^{-1}) at a height above the soil surface where the effect of the soil surface roughness is minimal; typically 0.05 to 0.2 m. These coefficients depend on turbulent length scale in the canopy, soil surface roughness and turbulence intensity in the canopy and are discussed by (Sauer et al. 1995). If soil temperature is great than air temperature the constant a' becomes a'=c .(Ts-Tc)$^{(1/3)}$ with c=0.004

Us is the wind speed just above the soil surface as described by (Goudriaan 1977):

$$U_s = Uc.\exp\left[-a\left(1 - \frac{0.05}{hc}\right)\right] \qquad (A.22)$$

Where the factor (a) is given by (Goudriaan 1977) as

$$a = 0.28 .\, F^{2/3} .\, h_c^{1/3} .\, s^{-1/3} \qquad (A.23)$$

The mean leaf size (s) is given by four times the leaf area divided by the perimeter.

U_c is the wind speed at the top of the canopy, given by:

$$U_c = Ua.\frac{\ln\left(\frac{h_c - d}{Z_M}\right)}{\ln\left(\frac{Z_u - d}{Z_M}\right) - \Psi M} \qquad (A.24)$$

Where Ua is the wind speed above the canopy at height Zu and the stability correction at the top of the canopy is assumed negligible due to roughness sublayer effects (Garratt, 1980; Cellier et al, 1992).

TSEB implementation and algorithm

The TSEB model is run with the use of ground thermal remote sensing and meteorological data of Agdal site during 2003. Some model constant parameters are supposed invariable along time such as the Priestly-Taylor constant αp, albedo, emissivity, leaf area index (LAI), the fraction of the LAI that is green (fg) , leaf size (s), the vegetation height and a constant fraction (cg) of the net radiation at the soil surface. These considerations are certainly some consequences on model results according to seasons. The Priestly-Taylor constant αp is fixed to 1.26 (McNaughton and Spriggs 1987). The albedo, value of 0.11 is an annual averaged measured with CNR1, and a surface emissivity of 0.98, the leaf area index (LAI) is equal to 3 (Ezzahar et al, 2007). The fraction of LAI (fg) that is green is fixed to 90% of vegetation (i.e: 10% of vegetation could be considered no active). The mean leaf size (s), is given by four times the leaf area divided by the perimeter (s=0.01). The average height of the olive trees is 6 meters. The fraction of the net radiation at the soil surface is fixed to cg=0.35.

Sensible and latent heat flux components for soil and vegetation are computed by TSEB , only in the atmospheric surface layer instability. Note that the storage of heat within the canopy and energy for photosynthesis are considered negligible for the instantaneous measurements. The total computed heat flux components are then from equations (A.5-8).

The canopy heat fluxes are solved by first estimating the canopy latent heat flux from the Priestley-Taylor relation (A.9), which provides an initial estimation of the canopy fluxes, and can be overridden if vegetation is under stress (Norman et al., 1995). Outside the positive latent heat situation, two cases of stress occur, when the computed value for canopy (LEc) or soil (LEs) latent heat become negative which are an unrealistic conditions.

In the first case, the normal evaluation procedure is overridden by setting (LEc) to zero and the remaining flux components are balanced by (A. 1-10-11-13-15). But in the second case, (LEs) is recomputed by using specific soil Bowen Ratio determined by □=Hs/LEs and flux components are next balanced by (A.1-10-11-13-15).

In order to solve (A.15) additional computations are needed to determine soil temperature, and the resistance terms Rah and Rs but as will become apparent, they must be solved iteratively. Soil temperature is determined from two equations: one to relate the observed radiometric temperature to the soil and vegetation canopy temperature, and another to determine the vegetation canopy temperature. The composite temperature is related to soil and canopy temperatures by (A.1). The resistance components are determined from (A.16), for Rah and the following equation (Sauer et al., 1995) for Rs (A.18).

To complete the solution of the soil heat flux components, the ground stock heat flux can be computed as a fraction of net radiation at the soil surface (A.8).

Applying energy balance for the two source flux components resolves the surface fluxes, which cannot be reached directly because of the interdependence between atmospheric stability corrections, near surface wind speeds, and surface resistances (A.16-17). In these equations, the stability correction factors ΨM and ΨH depend upon the surface energy flux components H and LE via the Monin-Obukhov roughness length Lmo.

TSEB computation for solving the surface energy balance by ten primary unknowns and ten associated equations (Table.1), needs an iterative solution process by setting a large negative value to Lmo (i.e: in highly unstable atmospheric conditions). This permits an initial set of stability correction factors ΨM and ΨH to be computed. Computed iteration is repeated until Lmo converges.

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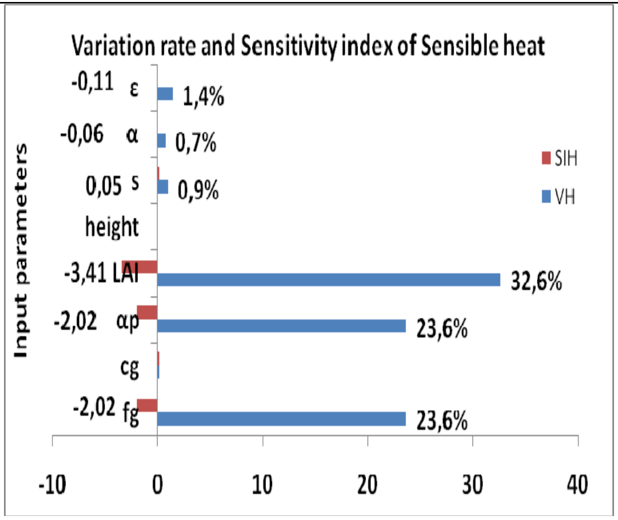
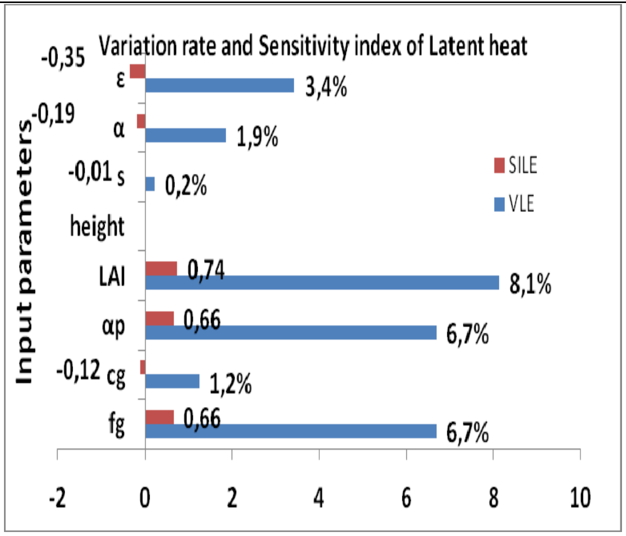
Figures

Fig.1: Parameters influencing on Sensible heat



Legend :	Cg: Fraction of the soil net radiation
SIH: Sensitivity Index of sensible heat	Height: Canopy height
VH: Variation rate of sensible heat	S: Mean leaf size
αp: Priestly-Taylor constant	ε : Surface emissivity
LAI: Leaf area index	α : Surface albedo
fg: Fraction of the LAI that is green	

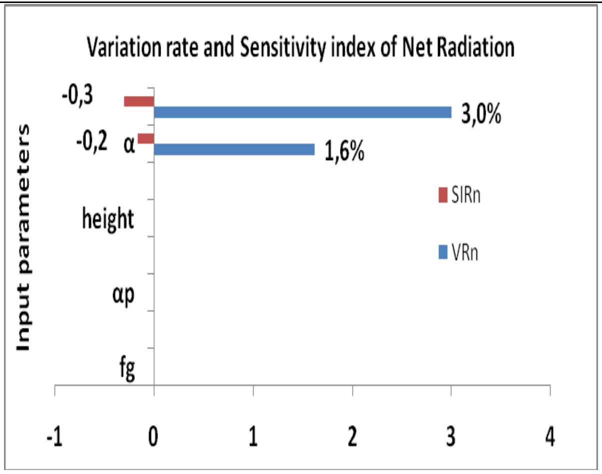
Fig.2: Parameters influencing on Latent heat



Legend :
SILE: Sensitivity Index on Latent heat
VLE: Variation rate on Latent heat
αp: Priestly-Taylor constant
LAI: Leaf area index
fg: Fraction of the LAI that is green

Cg: Fraction of the soil net radiation
Height: Canopy height
S: Mean leaf size
ε : Surface emissivity
α : Surface albedo

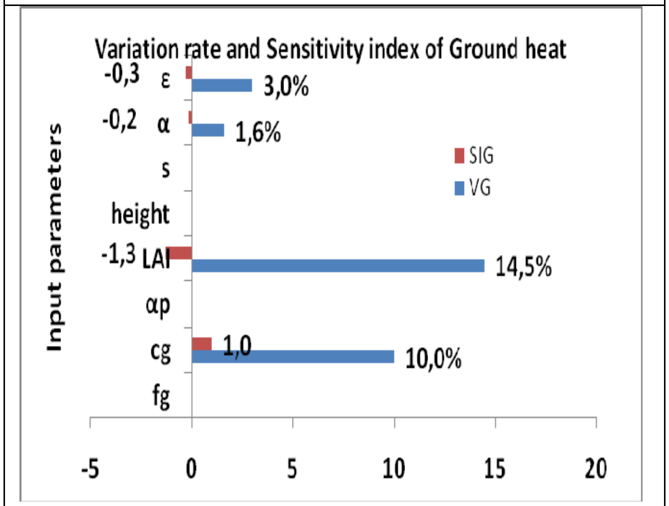
Fig.3: Parameters influencing on Net Radiation



Legend :
SIRn: Sensitivity Index on Net Radiation
VRn: Variation rate on Net Radiation
αp: Priestly-Taylor constant
LAI: Leaf area index
fg: Fraction of the LAI that is green

Cg: Fraction of the soil net radiation
Height: Canopy height
S: Mean leaf size
ε : Surface emissivity
α : Surface albedo

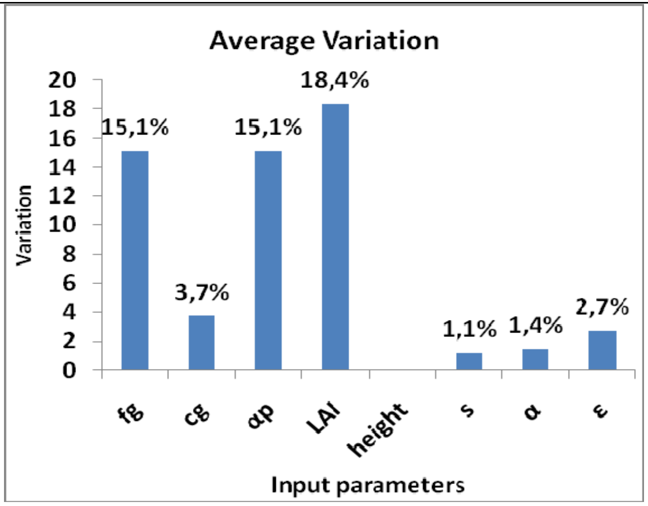
Fig.4: Parameters influencing on soil conduction heat



Legend :
SIG: Sensitivity Index on soil conduction heat
VG: Variation rate on soil conduction heat
αp: Priestly-Taylor constant
LAI: Leaf area index
fg: Fraction of the LAI that is green

Cg: Fraction of the soil net radiation
Height: Canopy height
S: Mean leaf size
ε : Surface emissivity
α : Surface albedo

Fig.5: Global average variation of TSEB outputs



Legend :
αp: Priestly-Taylor constant
LAI: Leaf area index
fg: Fraction of the LAI that is green
Cg: Fraction of the soil net radiation
Height: Canopy height
S: Mean leaf size
ε : Surface emissivity
α : Surface albedo

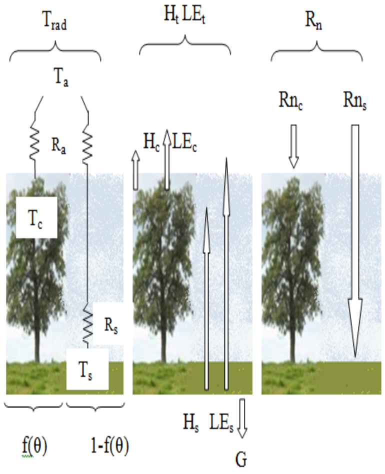


Fig.6: Scheme of resistances and flux partitioning between soil and canopy, corresponding to the TSEB parallel network

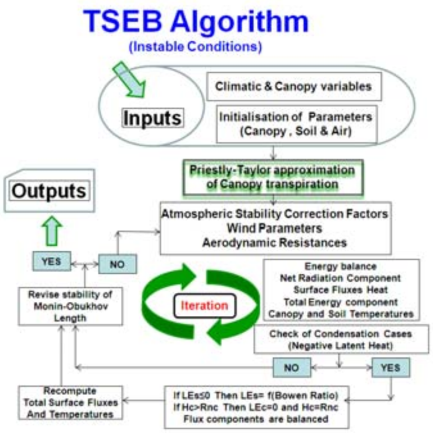


Fig.7: Algorithm of TSEB Model

Table.1: 11 Unknowns Variables of TSEB Model and associated formulae

Unknown variable	Formula
Rn	Rn = (1- αs).SW + εs.LW – εs.σ.Trad4
Rns	Rns = Rn exp(0.9 ln(1-fc))
Rnc	Rnc= Rn- Rns
G	G = cg Rns
Hc	Hc = Rnc - LEc
Hs	$Hs = \rho\ Cp\ [\frac{Ts - Ta}{Rs + Ra}]$
LEc	$LEc = Rnc.\alpha p\ .fg.\frac{\Delta}{\Delta + \gamma}$
LEs	LEs = Rns -Hs -G
Tc	$Hc = \rho\ Cp\ [\frac{Tc - Ta}{Ra}]$
Ts	Trad (θ) = [f(θ) . Tc4 + (1-f(θ)) . Ts4]1/4
fc	fc = 1 – exp (-0.5 LAI)