REVIEWER 2:

We thank Reviewer#2 for the detailed comments. Please find the responses below.

RC 1: The manuscript focusses on arid and semi-arid ecosystems where G can be a large component of the surface energy balance. Further, the authors have reported that the LE and G is sensitive to the LST observations. Over such arid or semi-arid ecosystems, it has been reported that the MYD21 LST (based on the Temperature Emissivity Separation algorithm) product might work better than the MYD11 product. May I suggest the authors to test if MYD21 product is better suited than the MYD 11 product for this coupled model?

AC: We have carried out the sensitivity analysis of the new coupled model (STIC-TI). It showed that Both LEi and Hi were sensitive to T_S to the order of 2 – 29% (LEi) and 5 – 35% (Hi) for T_S uncertainty of ±0.5 – 2.5 K from its mean values (Table 3). This provides a quantification of improvement of flux estimates with better accuracy of Ts. Therefore, the answer to reviewer's suggestion is already built-in the sensitivity analysis. However, in subsection 5.2 we will mention about better expected accuracy of Ts from MYD21 over arid and semi-arid ecosystems that can lead to little higher accuracy in LEi.

In the revised version, we will incorporate model results by using MYD21 product particularly over the arid and semi-arid sites.

RC 2: Among the different components of surface energy fluxes, the in-situ observations of G and soil temperature are indeed strictly point observations when compared with LE, H or even Rn. In Equation 12, I think the ground observed soil temperature amplitude and satellite LST are combined towards developing the regression relationship. Is this valid considering that there can be varying soil conditions that can affect the amplitude of the soil temperature in a pixel?

AC: Soil temperature amplitude and noon-night LST as well as noontime surface albedo are taken from soils over varying soil types of Northern hemisphere (Indian site) and Southern hemisphere (Australian site), respectively. Based on the soil temperature amplitude model, STIC-TI estimate of G is independently validated over several US sites having varying soil types and vegetation cover for multiple years. This showed a good accuracy of G estimates. Therefore, we conclude that the proposed approach is valid for a wide range of soil, plant, and climate types.

RC 3: Further, satellite LST can represent soil temperature only over bare surface. Till what level of fraction vegetation cover, can we use LST to estimate the amplitude of soil temperature? Can the results in Section 4.1 be separated in terms of fc to see if there is any decrease in accuracy in estimating A with increasing vegetation cover?

AC: The present soil temperature amplitude model has been developed from noon-night LST difference as well as surface albedo for mean vegetation fraction around 0.5. In the revised version, **we will segregate the temperature amplitude evaluation and mention the results for both fc <0.5 and fc >0.5.**

RC 4: The STIC-TI model uses difference in LST between day and night. MODIS observations of LST can vary significantly in terms of viewing angle or increase in GIFOV due to the ground point being away from the nadir between day and night observations. Is this taken into consideration? Can the results be separated for LST observations made with similar viewing angles and different viewing angles during day and night?

AC: This is an excellent suggestion. In the revised version, we will mention the errors in LE and H with respect to the view zenith angle.

RC 5: As mentioned clearly, the method by Bastiaanssen (1998) was able to retrieve G with accuracy closer to that of the STIC-TI model. Is this due to the fact that both the models use LST, NDVI and albedo as key inputs to the 'G' model? Also, what benefit does the STIC-TI brings over the model by Bastiaanssen? We can look at the diurnal variation of LST to get more information about the ecosystem processes than the soil temperature amplitude, I think.

AC: This is a very good observation by the Reviewer followed by suggestion. The modelled soil temperature amplitude can be used to quantify diurnal variation of soil temperature and G fluxes which in turn can help to quantify diurnal latent heat fluxes and plant water stress. Although Bastiaanssen (1998) G model uses similar inputs and provides comparable accuracy of G estimates as STIC-TI, the former is not applicable for diurnal G, LE and water stress simulations. Although diurnal simulation of fluxes from STIC-TI is not within the scope of this paper, we will include the above future scope of STIC-TI in the sub-section 5.2.

RC 6: There can be a considerable difference between the diurnal behavior of soil temperature at the surface (skin temperature) and soil temperature at 10 cm depth. Further, for modelling G, the soil skin temperature is the actual boundary condition. Can the authors please explain the reason for using soil temperature measured over 10 cm depth as the boundary condition rather than the skin temperature?

AC: Soil temperature measured at different depths within top 10 com soil layer was averaged and considered as representative surface soil temperature (0 – 10 cm). Studies also showed that LST carries some signal beneath the skin of the surface. We will clarify this in section 3.1.1.1 of the revised version of the manuscript.

RC 7: In addition, over two sites (Ind-Dha and AUS-Ade), soil temperature observations are done at or below 10 cm depth. How this has been used in the study in place of soil temperature up to 10 cm depth? When there are more than one soil temperature observations within 10 cm depth (AU-ASM, US-Ton and US-Var) were they averaged?

AC: Soil temperature observations at different depths within 10 cm were averaged (AU-ASM, US-Ton and US-Var). For Ind-Dha and AUS-Ade, single-depth (10 cm) soil temperature observation was used. We will state this explicitly in section 3.1.1.1 of the revised version.

OTHER COMMENTS:

RC: Lines 103-104, Please mention the key conclusions of the studies that you are referring to and explain why this study is needed.

AC: We will modify this portion in the revised manuscript mentioning the key conclusions from the previous studies and explain why the present study is needed

RC: Lines 181-182 The fetch ratio of …90% of fetch area: This sentence is not clear. Are the authors trying to say that the assumed fetch area around the towers accounted for 90% of the energy fluxes? Figure 1 caption can be shortened and made precise.

AC: The flux footprint for EC towers in India varied from 500m-1km (Bhat et al. 2019). In present study, about 90% of fluxes came from an area within 500 m to 1 km from the EC tower. This represents that relative contribution of the vegetated land surface area to the flux is close to 90% (Schmid, 2002; Vesala et al, 2008). The remaining few percentage of flux is coming from an area beyond flux footprint.

We will shorten the Figure 1 caption by removing the text '(Supplement) map in PDF (Institute for Veterinary Public Health)' in the revised version.

RC: Lines 237-238: Non-availability of G over Indian sites is an issue. The authors have explained about the this at the end of the discussions section. But any studies supporting the use of unclosed energy budget from EC observations and lack of G observations will be helpful here.

AC: In the micrometeorological research, it is well known that the turbulent fluxes (H + LE) measured with eddy covariance (EC) systems do not usually equal the available energy (Rn-G) on instantaneous, hourly, daily time scale. However, it tends to be show closure at longer time scales such as weekly, monthly and season. Hence, qualitative knowledge of the impact of different vegetation types, and climatic variables on this 'non-closure' on shorter time scale is essential. The study by Dare-Idowu et al. (2021) analyzed a unique database of EC flux measurements covering 8 growing seasons of 3 crops (maize, wheat, and rapeseed) cultivated over two close agricultural sites (FR-Lam and FR-Aur) in southwestern France. For data analysis, some dry and wet cropping seasons of the same crop type were selected; then, their phenological stages were identified to investigate their effect on the energy balance closure (EBC), and flux partitioning. The results showed that the systematic effect of each site on the EBC was stronger than the influence of crop type and stage, as EBC was generally higher at FR-Aur (82%) than at FR-Lam (67%), even for the same crop type. The assessed effect of rainfall, and phenological stages on energy partitioning revealed that during the wet seasons, over 42% of the net radiation (Rn) was accounted for by the latent heat flux (LE), which was 9% higher than the recorded LE in the dry year during the active vegetation period. Similarly, the ground heat flux (G) was observed to be very sensitive to vegetation; G accounted for 30% of Rn when vegetation was low, whereas at the peak of vegetation, it fell below 16% due to canopy shading. Closure was also assessed under various atmospheric stability conditions and wind sectors, and it was observed to be higher under unstable conditions, and in prevailing wind directions. Analysis of the sensible heat advection (AH) revealed that AH accounts for more than half of the imbalance at both sites.

The unclosed energy budget from EC observations is helpful to model flux partitioning (LE/Rn, H/Rn, G/Rn) with respect to vegetation/crop growth characteristics or biophysical properties for a given crop type at local scale. Especially, where G observations are lacking such as in many Indian sites, the TI-based G model can be used to fill up the gaps of G observations and estimate noontime G/Rn to simulate vegetation / crop growth characteristics.

Though the use of unclosed energy balance is not the main emphasis of this paper, we will mention the above findings and conclusions of Dare-Idowu et al (2021) briefly in section 5.3 where SEB closure is discussed.

RC: Lines 268-269: The land surface emissivity was estimated from land cover types, atmospheric water vapour and …retrieval': I think MODIS emissivity is estimated from land cover type and anisotropy factor. The other variables mentioned here are used in the retrieval of LST with the split window algorithm. Please rewrite the sentence.

AC: Yes, we will rewrite the sentence as suggested by the reviewer.

RC: Lines 271-272: How albedo was estimated from the white sky and black sky albedo available in the MCD43 product?

AC: Actual albedo is a value which is interpolated between white-sky and black-sky albedo as a function of the fraction of diffuse skylight which is itself a function of the aerosol optical depth.

We will add this text in the new sub-section (in section 3.1) on input data generation (as also suggested by R1)

RC: Line 273-274: The line 'eight-day compositing … (MYD11A2)' appears little confusing. Do you mean that the compositing dates were obtained from MYD11 product? Please rewrite clearly.

AC: The 8-day average values of clear-sky LSTs retrieved from MYD11A2 data were used (Source: https://vip.arizona.edu/documents/viplab/MYD11A2.pdf). We will clarify this in L273 – 274 of the revised manuscript.

RC: Lines 295-296: Is point (4) a contribution of this study? I think that is the nature of the TI model selected for coupling. Also, what is meant by 'moisture constants'?

AC: We agree that point (4) is not a contribution of this study but is a feature of STIC-TI. We will delete this point to remove confusion.

We mean soil moisture characteristic limits. We will modify the text accordingly.

RC: Lines 303 – 304: Will the amplitude vary with each harmonic component? If yes, the A has to be replaced with An.

AC: In the present study, we have considered a single pair (noon-night corresponding to 1:30 pm and 1:30 am) of MODIS aqua LST data for amplitude. Therefore, 'A' is appropriate here. If we take multiple (n) LST pairs within a day, then 'An' will be appropriate.

RC: Lines 310-312: How φn' can be taken as zero and k can be assumed to be one when noon-night data is considered? Please explain clearly. In equation (2), the first term in the inner bracket of sin term is 'nωt'. However, this becomes ωt' in eqn. (3). Are the symbols consistent here?

AC: Since we have considered a single pair (noon-night corresponding to 1:30 pm and 1:30 am) of MODIS aqua LST data for amplitude in the present study, the phase shift (ϕ'_n) is taken as zero and number of harmonics is taken as one (k=1) for estimating noontime G_i. We are not doing it here diurnally. **The explanation will be given in Line 310 – 312.**

The symbols are consistent between Eq. (2) and (3).

RC: Lines 331-332: It is mentioned that figure 2 contains theoretical and observed trajectories of soil temperature. However, only one curve is seen in the figure and I am not sure if it is theoretical or observed. Please check.

AC: This curve is based on observed soil temperature variation. We will clarify it in the revised manuscript.

RC: Lines 339-340: How TSTmin can be assumed to be closer top deep soil temperature as well as minimum soil temperature of other layers? Any data/studies to show this?

AC: This sentence will be deleted in the revised version to remove confusion.

RC: Lines 342-344: Have you used the OzFlux sites data to create Figure 2 or for the entire analysis?

AC: We have used OzFlux sites data to create Figure 2 to show example of diurnal variation of surface soil temperature.

RC: Line 438: 1.5 K repeats twice. Please check.

AC: The sensitivity was assessed by varying noon-time T_S by ±0.5 K, ±1.0 K and ±1.5 K (keeping nighttime T_S constant so that amplitude can vary automatically). We will modify accordingly in the revised version.

RC: Line 579: What is 'clothesline effect'?

AC: The 'clothesline effect' is the effect on soil moisture when warm, dry air moves by advection through vegetation (e.g. field crops or forest). Close to the point of entry the warm air warms the soil-canopy system thus increasing the rate of evapotranspiration and drying the soil. Deeper into the vegetation canopy the temperature of moving air falls.

We will revise the text in the line 579 in the following way:

The intermittent EF spikes in the soil moisture dry down phase could be due to enhanced latent heat fluxes through evapotranspiration due to passage of warm air transported by micro-advection from surrounding vegetation causing additional evaporation than expected. This is known as the 'clothesline effect' which frequently occurs in semi-arid and arid ecosystems.

RC: Figure 12: Expect the relationship between M and thermal inertia in the first plot, there seem to be no direct link between other variables in the other plots. What is the key take home message from this figure?

AC: We will modify Figure 12 in the revised version considering comments from Reviewer 1 also. The revision will be as follows:

(i) We will merge Fig. 12 (a) and (b): thermal inertia in y-axis and noontime Ts in x-axis with color segregation according to M. The plot of thermal inertia versus Ts is flattening due to the effects of M and we see so much scatter due to different soil types across the sites.

(ii) We will merge Fig. 12 (c) and (d): G in y-axis and Amplitude (A) in x-axis with color segregation according to the thermal inertia.

The description in the text will be modified accordingly**.**

RC: Line 627: …'range of 2-3 K with a standard deviation of 0.009'. I think the 0.009 corresponds to the standard deviation in surface emissivity in MODIS product. Please check.

AC: The standard deviations of errors in retrieved emissivity in bands 31 and 32 are 0.009, and the maximum error in retrieved LST values falls within 2-3 K. We will correct this in the revised version.

Reference:

Dare-Idowu, O., Brut, A., Cuxart, J., Tallec, T., Rivalland, V., Zawilski, B., Ceschia, E. and Jarlan, L. (2021). Surface energy balance and flux partitioning of annual crops in southwestern France. Agricultural and Forest Meteorology, 308 – 309, 108529, https://doi.org/10.1016/j.agrformet.2021.108529.

Schmid, H.P. (2002). Footprint modelling for vegetation atmosphere exchange studies: a review and perspective. Agricultural and Forest Meteorology 113, 159-183.

Vesala, T., Kljun, N., Rannik, U., Rinne, A. Sogachev, Markkanen, T., Sabelfeld, K., Foken, T. and Leclerc, M.Y. (2008). Flux and concentration footprint modelling: State of the art. Environmental Pollution, 152, 653-666.