

Interactive comment on “An Ensemble Square Root Filter for the joint assimilation of surface soil moisture and leaf area index within LDAS-Monde: application over the Euro-Mediterranean region” by Bertrand Bonan et al.

Anonymous Referee #1

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The paper by Bonan et al., describes the application of an ensemble Kalman filter (EnKF) for the joint assimilation of surface soil moisture and leaf area index over the Euro-Mediterranean region using the LDAS-Monde land surface data assimilation framework. The authors compare the skill of the EnKF with the skill of the well-tested simplified extended Kalman filter (SEKF). This is done by assimilating surface soil moisture and leaf area index, and compare the corresponding effect of the analysis on unobserved variables, such as evapotranspiration (from GLEAM) and gross primary production (from FLUXCOM). In addition, the authors investigate how the ensemble from

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the EnKF can transfer information between variables by the ensemble covariances and compare this to the SEKF Jacobians. The paper provides a good starting point for future work on joint assimilation of surface soil moisture and leaf area index. The paper is well organized and it discusses the current difficulties in assimilating leaf area index using the EnKF. It would have been interesting to see if the joint assimilation (using the EnKF) could have improved over the open loop when compared to in situ soil moisture data, however, I leave this for the authors to include in future work. I recommend that the paper is published in HESS after a careful proofread by the authors and after taking care of the following minor comments:

Minor comments:

Title: “moiture” to “moisture”

L1: Skip “a deterministic ensemble Kalman filter”

L7: Missing “filter”

L7: Unclear sentence, suggested change: “, which has been well studied within the LDAS-Monde framework over the Euro-Med. region, see for example...”

L9: “The SEKF”

L11: How is this assessed, there is no validation of the root-zone analysis?

L14: Please change wording “exhibited” to “is found” or something along those lines.

L15: Is this correlation/anti-correlation seasonally dependent?

L18-19: Please change wording “and GPP, but a highly positive...”. Also what skill metric is considered for the river discharge.

L23: “.. the earth’s water and carbon cycles”

L26: Please specify what goals?

L28: “initialization” and please find other wording than “misspecified” forcing.

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L30: "Generally provide sparse spatial coverage..."
L31: "ranging from the km scale to the meter scale"
L32: Please specify why this is the case.
L33: "flaws in both approaches"
L35: "passive microwave brightness temperatures, microwave backscatter coeff..." and "obtained from the aforementioned satellite observations".
L39: "systems of both the and the UK Met office".
L41: "rapidly extended"? Please clarify. It has undergone development from assimilating SSM only to now also include LAI assimilation.
L42: "the SEKF approach..."
L43-44: Please clarify this sentence, "thus limited their number"?
L45: "..., such as"
L47: In what context?
L49: "Recently, ..."
L50: Please rephrase, "LAI is a key land biophysical variable, it is defined."
L51: Please rephrase, "One way to monitor LAI is to assimilate observations indirectly linked to LAI, such as"
L56: Please rephrase: "Another way to constrain LAI is through the assimilation of direct LAI observations."
L56-57: "...products benefit from..."
L58: "and at high-res..."
L58: Please rephrase: "...other studies have assimilated LAI in crop models and at a

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more local scale.."
L60: "Succeeded in introducing such an approach. ..."
L64: CNRM is already introduced.
L65: "allows for..."
L65: "Building on that work..."
L66: Remove "have"
L67: On a site? Please specify
L67: "Their study..."
L68: "Leading to the development of LDAS-Monde."
L68-69: "The LDAS-Monde is available through the CNRM modelling platform. . . and it has been successfully..."
L72: "For example, ..."
L72: Drop "has"
L73-74: "while Ling et al (2019) compared..."
L74: Drop "has"
L76: Drop "water and carbon cycles".
L77-78: Rephrase: "These studies did not update both SM and LAI, as we will do in this study".
L79: "in the LDAS-Monde..."
L79-82: Very long sentence, please consider to rephrase.
L82: Please make it clear that this is not the current study but the study of Fairbairn et

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al. (2015).

L85: “used”

L85: SMAP acronym not defined.

L89: “the LDAS-Monde...”

L89: Replace “to” with “on”.

L90: “..and its ability to..”

L90: “To achieve these...”

L105: “such as”

L105: “or for evaluation”? Please rephrase.

L106: “Finally,...”

L107: “...prospects for future work.”

L110: “by the Meteo-France research centre CNRM”.

L110-L113: Very long sentence, please rephrase.

L114: Replace “conduct” with “in”

L119-L121: Please consider to rephrase to make this sentence easier to read. For example: “In this paper we use the ISBA multilayer diffusion scheme (ref) which solves Richards equations (ref) for water transport and the one-dimensional Fourier equation for heat. The soil is discretized in 14 layers over a depth of 12 m.”

L123: “..minimize the errors from the numerical approximation of the diffusion equations”.

L124: “the water and carbon...”

L141: “simulated runoff into simulated river discharge”.

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L144: “The coupling between ISBA...”

L145: “groudwater” to “groundwater”

L146 “to CTRIP, while the...”

L149: “...assimilation system with a 24 h assimilation window”.

L155: “...covariances are considered).”

L156: “..from a time t to t + 24 h.”

L156-L157: Please rephrase, maybe: “The update of patch p is denoted...”

L161-L162: Please describe what y0 is, and also what you mean by available at the grid cell level (instead of at the individual patches?).

L162: Suggested change: “.., we first calculate model equivalents of the observations. This is done separately for each individual grid cell.”

L168: “.., it replaces the forecast error covariance matrix (B) with a fixed error covariance matrix.” Please rephrase from “and uses as...” Product of what? The model state evolution and?

L170: “..that there are no covariances between the patches.”

L177: “column of can...” of what?

L182: “The EnKF approximates the classical Kalman Filter equations using the...”

L187: “..where $X_p = []$ is the ensemble perturbation matrix.”

L188: Please change “The forecast step is simple...” to “In the forecast step we propagate...” and “...from time t to t + 24 h using the ISBA LSM.”

L189: “The analysis step then updates...”

L190: “of the observations...”

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Equation (8): Missing punctuation.

L193-194: Given certain conditions?

L195: "We choose to neglect the ensemble. . ."

L195-L196: "This assumption is in line with the SEKF method and it ensures a fair comparison between the two approaches."

L196-L198: Please rephrase from "It also allows. . .". This is already given since you are working on a 1D EnKF. Maybe change to: "The approach outlined here is in line with other studies (ref) showing that the 1D-EnKF can achieve promising results with around 20 ensemble members."

L201: "..patch p.."

Equation (11): is subscript k defined?

L210: Please rephrase, maybe: "This ensures that information from the analysis is stored in the ensemble and is propagated forward in time."

L213-L214: This should be placed in the "Experimental setup" section.

L218-L219: "The ERA-5. . ." and ". . . 31 km horizontal spatial resolution."

L219: Please change "To be used,..."

L221: "or wind speed" is wind speed optional? "...interpolated to the ISBA 0.25 spatial resolution using bilinear interpolation."

L222-L223: Please rephrase this sentence "...reanalysis improves the quality of LSVs reanalyses."

L226: Remove space between end of sentence and punctuation.

L226: "These satellite-derived products have already been successfully assimilated in the LDAS-Monde..."

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L230: "...in order to measure.."? Please clarify what you mean by "measure" in this context.

L232: "Prior to the assimilation, the SWI. . ."

L234: "...the soil..."

L235: Please clarify, you say that you use a linear rescaling but you also use a CDF method? The linear rescaling corrects the mean and variance while the CDF matching corrects all modes of the distribution?

L238: Please define GEOV1.

L239: "10 days.. with the finest spatial resolution being 1 km."

L251: Please define GPP at first occurrence (L245).

L252: "...from eddy-covariance flux towers..."

L253: "The FLUXCOM data are available. . ."

L256: Please make clear that this is model output data. "River discharge output from the CTRIP is. . ." and "data obtained from the Global. . ."

L261: Change "efficiency" to "skill"?

L269: "...for the soil moisture variable." Who are "They", the perturbations?

L270: Please consider moving this sentence for after the SM perturbations.

L271: "covariance ," remove space

L272: "...dynamic range of soil moisture."

L274: Drop "successful"

L276: "...and using B for the covariance matrix." What does this mean?

L276: What do you mean by "underestimate ensembles" ensemble spread?

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L277: “..artificially small ensemble spread...”
L278: “have”?
L280: White noise of what?
L281: Please define and use the SM acronym earlier.
L283: White noise of what?
L284: “This is similar to the work of. . .”
L287: Reference to these studies?
L290: Please drop “sanity”
L290: “open loop counterparts”
L291: Please clarify, what is “those two LSVs”?
L295: “the ensemble...”
L299: “response to SM6”? Do you mean they have the same behavior?
L300: “Potential improvements in EnSRF and SEKF estimates of evapotranspiration. . .”
L307: What do you mean by “accuracy”?
L308: “open loop run”
L312: Suggest you change this to something like this: “Figure 2 displays the open loop, SEKF, EnSRF and observed LAI 10-day time series...”
L319: Please use “open loop” for the rest of the text.
L319-L320: The numbers show that the SEKF is closer than the EnSRF, this is the opposite of what you say in L317?

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L320: Please make it clear that this is no longer independent validation data, as you compute the skill between the analyses and the observations assimilated in the analyses.
Figure 3: Please provide masked regions with different color coding than zero values.
L344: “Strongest” to “Largest”, “...occur for both cases. . .”
Figure 6: Does this figure not also show the spatial std, since it is averaged over the whole domain?
L355: Linear rescaling not CDF matching?
L362: “southeast” and “northern”
Figure 7 (a), change title to “RMSD open loop”.
L369: Note that this is for a single open loop run? An ensemble open loop run might improve more?
Figure 8: Please provide different color coding for masked regions vs zero value regions.
L376: “..the Jacobian is replaced by correlations sampled. . .”
L382: “..and correlations with SM2.”?
L283: “extend” to “extent”
L385: “western”, “spring” and “summer”. Please double check this spelling throughout the text e.g., L396-L398.
L402: “Nevertheless we discern seasonal tendencies”? Please explain this sentence.
L402: What about SM6 and the abrupt change close to the Arctic circle?
L403: “...increments in SM4...”

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L404: “tends” to “tend”

L406: “..disparity over arid regions is...”

L408: “estimates” to “increments”?

L410: Please rephrase this sentence, start with: “The SM4 estimates and analyses increments for the SEKF and EnSRF tend to be similar, except for arid regions.”

L413-L418: Please rephrase this paragraph. What do you mean by “cycling”? “...does not modify directly estimates as correlations. . .” estimates of what?

L423: Please define ET acronym earlier and GPP is already defined.

L428-L429: “..for almost all grid cells.”

L436: “best” to “biggest” or “largest” and remove “on”

L441: Please rephrase “. . ., thus validating our approach.”

L445: How do you decide on this 3% limit?

L446: Maybe state that the rest of the stations (20) showed a neutral impact?

L457: What are these favorable atmospheric conditions?

L461: “on” to “in” and what do you mean by “LAI dynamics is weak in those places”?

L464: “.., model perturbations can introduce. . .” remove “thus showing its influence.”

L469: Please rephrase, for example: “Model perturbations can lead to LAI values below this threshold...”

L470: “when this is the case it can lead to. . .”

L475-L478: What does “more uncertainty in the additive model error” mean? It increases the size of the increments and therefore the EnSRF is closer to the observations than the SEKF? Please clarify this section.

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L479: “CDF match” to “CDF matching”, are you sure that this is the approach you are using?

L479: “This shows that the short-term variability of the observations is different from what we model with ISBA in this region.”

L480: Check CDF matching.

L482: Maybe change to: “Further studies of such aspects are beyond the scope of this paper.”

L483: “...both DA approaches...”

L484: “model error” to “model perturbations”

L486: Change “fatally” to “could potentially...”

L488: “..by the model perturbations...”

L491: “summer”

L493: “southwest”

L494: Please rephrase to make it clear that covariances between the ensemble members explain the relationship between e.g., soil moisture in different soil layers in ISBA.

L494: Maybe change to: “Another type of model error...” and “...different characteristics of the covariances between the ISBA variables. ”

L496: “also provides”

L497: “their” to “the”?

L500: Remove “Considered out of scope for this paper.”

L501: “...dams, . . .) can potentially modify soil moisture, streamflow and river discharge.” Maybe provide a reference for this?

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L506: "more physical states"? Do you mean "...ensemble of land surface states"?

L514: "the model error."

L517: Include a reference to the original Desroziers paper.

L521: "...processes, etc)."

L524: "such ideas have"

L526: Please simplify section heading. For example, "The question of 1D or 3D filtering"

L529: "to" to "in correlated..."

L530: Provide reference for this statement. Same for line L531.

L532: I don't understand, could you please clarify this section? You say that the SEKF cannot include covariances, but it relies on ISBA to calculate covariances. Why does the SEKF need covariances from ISBA when it cannot include them?

L537: "...12 times the size...?"

L549: Please rephrase, for example: "approach, because of the 1D nature of the ISBA LSM."

L550: "applications"

L553: "based on spatial characteristics and it..."

L559: "Results show"

L563: "...the model error perturbations."

L565 "surface. The EnSRF..." Please rephrase after this, what are those estimates and what are those layers?

L569: "for the two previous"? Please make it clear what the two previous are.

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L569: Please clarify "While involving a crude model error", the sentence feels a bit out of context.

L572: Maybe change to: "(for CGLS products). This only allows for an update of LAI every 10-days, as the assimilation of surface soil moisture is found to have negligible impact on the LAI analyses."

L573: "for the radar backscatter..."

L574: What do Livens (2017) and Shamambo (2019) show?

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