Item-by-item Reply to referee #3

Original Referee comments appear in yellow
Authors' reply follows in normal text

This paper applies a Kalman Filter (KF) approach for temporally successive point retrievals of surface emissivities and temperature from infrared measurements at 8.7, 10.8, and 12 micrometers of the SEVIRI geostationary satellite instrument at intervals usually of 15 minutes (and for up to one month); the exception for the latter is the consequence of the presence of clouds. This is followed by an evaluation of its results. The retrieval (and data assimilation) of surface emissivities and temperature has been, and stills remains, an active area of research and the application of KF to this problem is certainly relevant and worth exploring - especially considering the increasing use of KF approaches in weather prediction data assimilation. The 'novel' aspect of the paper is, for me, the application of KF for the retrieval of surface emissivities and temperature. As such, this work does contribute to the advancement in this area and merits publication. The presentation of the material and its orientation is lacking in a few ways (most being minor).
We really appreciated this in depth review, we acknowledge the highly competence and expertise of the referee and would like to thank him for its patience and effort in revising the paper.

Some, if not most, of the related issues are identified under the following section. As initial example, the paper seems to suggest that the general application of KF to geostationary satellite measurements is a/the novel aspect of this paper - the application to surface emissivities and temperature being just the example used. Different KF approaches are already applied in assimilation of such data sources (for retrieving atmospheric temperatures for example), simultaneously to multiple others, in numerical weather prediction (NWP). The KF setup applied here can take advantage of the a priori when the diurnal variations are weak (this essentially since H is set to the identify matrix) and the forecast error covariances are set accordingly. It would have been useful to identify the impact of temporal information propagation from the KF versus the case without this propagation, this to better justify the merit of the KF application for this problem. Significant improvements to grammar and composition would be beneficial in various parts of the text. These are not identified in this review (except for a few lines at the beginning of the paper) considering the large number of such occurences. Major revisions are recommended to encourage improving the grammar and composition and to allow sufficient some time in addressing points in the following section.
We have rewritten abstract and introduction to better describe the objective of the study. The referee is right when he says that KF has widespread applications, however the idea to use KF to convey temporal continuity for the retrieval of surface emissivity and temperature is unique, e.g., see the recent review by Li et al 2013. Here and later in his review the referee suggests that we should explore also the case **H**=0 to identify the impact of temporal information propagation from the KF versus the case without this propagation. This example has been worked out and is now shown in section 3.3. The comparison with **H**=**Identity** leads us to conclude that the temporal constraint allows us to have an effective retrieval. In the case **H=0**, we show that the inherent anti-correlation between temperature and emissivity tends to bias the final estimate and the simultaneous retrieval of emissivity and temperature becomes unpractical.

Specific Comments

Title: Considering some of the above and following statements, a title such as "Kalman filter retrieval of surface emissivities and temperature from geostationary infrared radiances" might possibly be more appropriate.
We agree with the referee to revise the title as suggested. We have left *physical* in the title to stress that until now algorithms for the retrieval of emissivity and temperature have been largely based on statistical approach: split window algorithms and similar.

Abstract: The suggested changes in the abstract provides some insight on the need for a more careful presentation of the context of the material. First sentence: "which could be suitably used" might suggest to

some/many that such data (and capability) have not been previously applied (and made use of) in retrievals – which may not be entirely correct. A suggested alternative is "The high temporal resolution of the data acquisition by geostationary satellites and their capability to resolve the diurnal cycle are a valuable source of information in retrieving geophysical parameters." Second sentence: The intended meaning of the second sentence needs to be in accordance to the third sentence. As such, "is for the most part considered uncorrelated" does hold when considering data assimilation applied in numerical weather prediction. The latter, which uses such data, applies spatial constraints through the background error covariances. Time constraints are additionally imposed with the 4DVar and the Ensemble KF (if not other KF approaches). An alternative sentence(s) to precede the remainder of the abstract is needed. A suggestion is to focus on the retrieval of surface emissivities and temperature being an active area of research. Third and fourth sentence: The KF implementation applied as is in this paper does not apply spatial constraints. Also, as KF approaches have been used, and are being used, with radiance measurements, the emphasis here should be on its application to the retrieval of surface emissivities and temperature. As example "In this paper, we implement a Kalman filter approach for applying temporal constraints on the retrieval of surface emissivities and temperature from radiance measurements made from geostationary platforms. This is applied to SEVIRI ...." The abstract could/should include a short summary of the results.
We have rewritten the abstract as suggested. However, we have also stressed that the methodology is presented in its general 4-D formulation. We think that this is important in perspective of the extension of the application to include spatial constraints, as well.

Introduction: Considering above comments, it is suggested that the introduction (and the way the material is presented/introduced for some of the other sections) revolve on the retrieval of surface emissivities and temperature (with reference to other works in that area) for which a KF approach was implemented to introduce temporal correlation as oppose to this being a paper on the KF approach itself. The introduction does not mention other KF uses/applications in retrievals and, particularly, NWP data assimilation, Note that some have referred to KF-type applications in atmospheric remote sensing as sequential estimation (e.g., as with MLS-UARS in the 1990s).
We have rewritten the introduction as suggested. We have revolved the presentation on the retrieval of surface emissivity and temperature. We think that now the introduction clarifies that we are neither addressing the problem of how to improve the Kalman filter, nor to assimilate satellite data within a NWP models. We aim at implementing a retrieval strategy for surface emissivity and temperature, which allows us to get better insight into understanding how we can have a better exploitation of satellite data per se, in other words the analysis moves within a context, which envisages an almost entirely data-driven system.

P3, lines 5-6: Temporal continuity/constraints are part of the 4D-Var (within each window) and of Ensemble KF used in NWP data assimilation. This contradicts somewhat the first of these two sentences.
Introduction has been rewritten and the part the referee is referring to has been cancelled.

P3, lines 15-20: Shouldn't this information instead be mentioned in the results section and not the introduction?
We have moved this information in the results section.

Section 2.1 P4, lines 10-11: "The KF methodology will be applied, in this paper, for the retrieval of surface emissivities and surface temperature from ..."
We have changed as suggested.

P7, lines 7-11: There is mention of the background vector and its related covariance matrix without any explanation or reference of what is meant by "background vector". It might be worth adding something here. It might be worth mentioning, in some cases, in which sections some additional details of some data are given (e.g., section 3 for the background vector and covariance matrix)
We have rephrased this part.

Section 2.2 P10: Including equation (3) is not essential (but it's ok) – as long as the averaging is mentioned since it is not referred anywhere else in the paper except for section 2.2. By the way, some re-phrasing is needed with "In the following of this section the angular brackets, ,<.> will ..". Maybe something like this would help: "Considering the larger channel bandwidths of the SEVIRI measurements, averaging is applied over the spectral wavenumber band of each channel. This averaging is identified by the angular brackets <.>." P10: The left-hand side of equation (4) is not really needed.
Eq, (4) has been shortened. We have re-worded as suggested.

Section 3 The definition of data assimilation used in Wikle and Berliner (2007) is very broad and not what may be usually implied in NWP. It would be worth mentioning the definition used in that paper - and in this application. In NWP data assimilation (referring here to improving temporally successive short-term forecasts at the model grid points using information from observations), KF and its variants are considered as one/some of the different approaches used in data assimilation. And so, KF is not distinct from data assimilation but a method available for data assimilation, just as KF is considered an approached using in retrievals. Might the same be said of the Wikle and Berliner definition? The position taken on this may affect text in following subsections. Note that many readers will come from an NWP data assimilation background where the notation is a bit different than in Rodgers (i.e., M instead of H; H instead K: xa instead of x-hat; Sb instead of Sa; ....). Using the notation in Rodgers is still per fectly fine.
For Data Assimilation we have expanded references to include Lorenc, Talagrand, Nychka and Anderson and Rodgers, as well. We prefer Rodgers notation because, in our intention, the paper is much more intended for satellite retrieval people than for the NWP assimilation community. This is why the title of this section reads *The retrieval framework.* Throughout the introduction we have now clarified that we want to address a retrieval problem and not an assimilation problem according to its common definition of *combining numerical and statistical models with observations*.

Section 3.2.1 P13: Equation (13) is not really needed since it is the same (10) - but it depends on author's preferences. The equivalence could just be said in words. There is one equation is missing. Sa(t+1)=HShat(t)HˆT + S_eta combined with xa(t+1)=Hxhat(t), which reduces to Sa(t+1)=Shat(t)+S_eta since H=I in this paper. This is important.
The *missing equation* is indeed displayed as Eq. (18). As now stressed in the revised paper at the very beginning of section 3, the KF methodology is presented in its general form, therefore **H** is not identified with the identity operator until section 3.3 where we deal with the case study of temperature-emissivity. See Eq. (25) and the sentence which follows this equation: <<... *and H is the identity operator*>>.

Section 3.3 P19, line 16: As set of only ten samples is used to derive the starting covariances, this implies an uncertainty of 30% for the covariances in addition to any uncertainties of the UW/BDEMIS database content. This should be mentioned/discussed.
This reflects our present knowledge of emissivity and is the reason why algorithms as that presented in this paper should urgently become operational. We have commented on this in the conclusion section.

P19, line 22: Tables 1 and 2 imply that element (5,5) is for the channel at 9.7 microns (not 8.7). This mismatch is also found in the caption of Table 2,
The apparent mismatch is only due to the fact that the referee has read the table according to the wavelength order, instead of the wave number order as explicitly said in the caption of Tab. 2. The element (1,1) corresponds to the wave number 746.30 cm^{-1} and so on, therefore the element (5,5) corresponds to the window channel at 1149.90 cm^{-1} (8.7 micron), as correctly identified within the text and the caption of Table 2.

P20, lines 1-3: The 'down-scaling' (of line 4) is said to be being done to "take correctly into account the expected variation of emissivity on a time scale comparable to the SEVIRI repeat time". This statement is unclear when it comes to justifying a 'down-scaling'. The variances from the sample set of 10 cases would/may (?) give variability variances – which would be expected to be larger than 15 min forecast error variances given accurate start values hence serving as justification for a down-scaling to estimate S_eta. The

down-scaling was ultimately needed to get S_eta so that results obtained were more acceptable (i.e., the tuning referred in lines 12-13) - this refers to the application of Sa(t+1)=Sa(t)+S_eta with the KF.
The referee is right. We have rephrased this part.

P20, Equations 28 and 29 could be combined into a single equation: S_eta_e(i,j)=S_e(i,j)/fˆ2 There is also no need for Sˆ{s)_e.
We have rewritten this part. Our intention is to deal with the general case of a scaling vector ***f.***

P21: line 1: As will be suggested later, this choice of 1K (over land) implies very little impact by the a priori temperature. Smaller values would have been possible if H would have been chosen to be able to reflect the diurnal variation.
The referee understood well. The problem of more complex **H** has been studied in Serio et al 2013. We have commented on this point in section 3.3 and in the conclusions.

P21: It would help if some estimate of the error std dev implied from the measurements for emissivities and temperature were provided. For temperature, this appears to be 0.2K based on the results section. It might be useful to know the equivalent brightness temperature error std. dev. associated to S_epsilon for example.
The precision of the retrieval (error bars obtained on the basis of the square root of the diagonal of the a-posteriori covariance matrix) has been presented in section 3.3, e.g., Fig. 5 and 6. This is ≈ ±0.2 K for temperature and ≈ ±0.005 for emissivity. We have stressed this result in the abstract, section 3.3 and section 4.1, as well. NEDT which applies to S_epsilon has been already shown in Tab. 1 (last column).

P22: lines 5-6: The comparison of the time of the maximum temperature with ECMWF (max at 12 UTC) is not valid as the ECMWF fields are only available here at 00, 06, 12, and 18UTC. While mentioning that daytime ECMWF temperatures are larger is fine, the mention of the time of max temperature from ECMWF should be removed.
We have removed the sentence regarding ECMWF.

P24: lines 17-18: What does the following mean: ", if not that considered through the ECMWF reference state.".
We have rephrased to clarify meaning.

P24: lines 19-22: Is this statement relevant here? If so, how is this connected to the previous statements? It may just be that the statement may need to be made clearer in the context that it is presented.
There may be concurrent schemes based on different kind of regularization, e.g., simple ridge regression, which could be much more sensitive to interfering factors. We want to caution the reader that the conclusion achieved in this section could well be not general, but only applies to the present analysis. We have clarified the sentence in the revision.

Section 4.1 P25, line 19: A resulting temperature precision of 0.2K or better (variance of 0.04 or less) implies that a priori xa for temperature has little to no impact since S_eta=1Kˆ2 for points over land. This and its implications should discussed (and mentioned also in the Conclusions section).
We have already stressed this point in section 3.3, maybe with different words. Throughout this section we say that surface temperature is strongly constrained by the data, which allows us to relax our confidence on the adequacy of the state model. In the revision we have clarified this aspect and also mentioned it in the conclusion section.

Missing results: (statement also found in the "General comments" section above) The KF setup applied here can take advantage of the a priori when the diurnal variations are weak (this essentially since H is set to the identify matrix) and the forecast error covariances are set accordingly. It would be useful to identify the impact of temporal information propagation from the KF versus the case without this propagation, this to better justify the merit of the KF application for this problem.
As said before (our reply to the General Comments above) this exercise has been worked out and is now presented in section 3.3

Conclusions P31: See earlier comments regarding suggested focus of the paper which would impact on how parts of the conclusions section are presented. This work would benefit from quantitatively showing how much benefit the temporal information propagation component of KF contributes to the retrieval solutions. (see comment on missing results above). This benefit could be shown via the increase in the precision and also the differences in solutions (to see both random and bias impact).
Conclusions have been rewritten according to the many suggestions of the reviewer.

Technical Corrections Only occasional typographical, grammatical, and composition, corrections in the introduction (and figure captions) are pointed out below. One frequent issue is the placement of commas (not always at the correct places or missing).
The revised version has been checked by a native English speaker.

A review by the authors for the purpose of making other similar improvements in all sections is recommended. Different sections seem to require different levels of corrections. Introduction: The following corrections may be irrelevant if this section is re-structured. The text of the introduction is often laborious to read
P2, line 19: "Currently" instead of "However".
P2, line 19: "for the Meteosat .... (MSG) satellite (or mission)"
P2, line 20: “on board" not needed.
P2, line 21: "...point and 16 channels (8 in the thermal band), and..."
P2, line 24: "The IRS will have ..." (if that is the correct one) since the previous sentence refers to two instruments.
P3, lines 3-4: "cycle, and hence to .... of observations, is ..." (added commas)
P3, line 21: "calls for".
P3, line 25: "a time constraint" or "time constraints"
P3, line 27: "to convey" what? The sentence may need re-phrasing.
P3, lines 4-5: Re-phrasing needed. Example: "the precise form of the evolutionary equation is not important for the estimation problem as long as the error covariance appropriately reflects the uncertainty of the current state estimate."
P3, lines 6-10:
P3, line 18: "agree within 1K"
P3, line 19: "with differences normally of"
P4, lines 5 and 7: "section 4" and "section 5"

Section 2.1:
P6, line 15: ", the Sahara desert, and"
P6, line 16: "which have a size of"
P6, line18: "(e.g., see Fig. 3)"
P7, line 20: "analyses" for the plural form (since one analysis per day is used) .....

Tables:
Table 2: caption: "(5,5) corresponds to the channel at 9.7 microns"
Table 2: Extra commas after two elements, (1,4) and (4,5), in the table should be removed.
Figures:
Legends and or axes labels are too small for some of the figures.
Figure 5: caption: "Retrieval exercise using simulations..."
Figure 6: caption: "is shown by the +/-...."
Figure 7: caption: "of the stochastic term Ts is"
Figure 9: caption: "pair" instead of "couple"
Figure 12: caption: "to identify the times of the emissivity minima as compared to noon."
Figures 13-14: caption: "The retrievals included are only those which correspond to"
Figure 15: caption: "retrievals have been" (plural)
Figure 18: caption: " according to this work:

We have reviewed the paper for the purpose to improve presentation and English where needed. The above corrections have been applied where applicable after the revision. Labels and legends of Figures have been re-sized with a Font size 12.