The sensitivity of land emissivity estimates from AMSR-E at C and X bands to surface properties

By Norouzi et al, 2011

Response to reviewer comments

First, we would like to thank two reviewers for their time and efforts.
The comments of the reviewers are very relevant and they greatly contributed to the improvement of the quality of our paper. We would like to submit our revised paper later.

Referee 1:
This paper presents microwave land surface emissivity estimates calculated globally from AMSR-E observations over more than 6 years. The study analyzes the sensitivity of the estimates to the vegetation, and to some extent to the soil moisture. The paper is well structured and clearly written. However it does not bring significant new information, as compared to the existing literature on the subject. Before being published, the following comments have to be taken into account.

Authors answer:
This paper introduces a new land emissivity product that is determined from AMSR-E. The paper tries to introduce this emissivity retrieval that mostly has been adopted from Prigent et al studies. Due to lack of the "ground truth observations", validations of estimated emissivity especially in global scale sounds difficult. This new information gives a better opportunity to investigate temporal, spatial, and spectral characteristics of emissivity along with other available products.
Recently, there is a Land Surface Working Group (LSWG), which specifically works to find an accurate estimation of microwave land surface emissivity for the Global Precipitation Measurement (GPM) mission (Dr. Prigent and authors of this manuscript are active members of this working group). Microwave emissivity is needed to improve the development of physically based precipitation retrievals over land under all weather conditions such as clear, cloudy and precipitating sky from 10 – 190 GHz. The primary results of this working group shows that significant differences exist among different available products, and more information spectrally and temporally are needed to obtain a reliable surface contribution over land.
We added following in introduction section to clarify this in our paper:

"Microwave emissivity is needed to improve the development of physically based precipitation retrievals over land under all weather conditions such as clear, cloudy and precipitating sky from 10 – 190 GHz. Related studies suggest that significant differences

exist among different available products, and more information spectrally and temporally are needed to obtain a reliable surface contribution over land in passive microwave observations (Tian 2011, personal communication)."

This study also highlights the potential of using lower frequencies in different geophysical studies and the issue of using infrared observations in emissivity retrieval. At these low frequencies an accurate assessment of the discrepancy introduced in the determination of land emissivity because of the difference is sensitivity between thermal and microwave temperatures was possible. We found that this issue is worse for AMSR-E observations because of its unique overpass time at early morning and maximum temperature of the day. However, the other sensors are providing "more" consistent results (they still have this issue) than AMSR-E in this respect, even though they show larger emissivity variability. Therefore, mitigating these discrepancies for AMSR-E emissivity estimates sounds necessary. Several adjustment and changes were made through the manuscript to address this comment and highlight this worse situation in AMSR-E emissivities than other products. Some of the changes through the paper are as following:

In abstract, we added:
"Significant greater standard deviation of estimated emissivity over desert regions were found compared to previous retrieved emissivity from SSM/I observations."

Also, we added:

"The mismatch between day and night AMSR-E emissivities is greater than ascending and descending differences of SSM/I emissivity. This is because of unique orbit time of AMSR-E (1:30 A.M. / P/M.) while other microwave sensors have orbit time of 6:00 to 9:00 (A.M. / P.M.). This highlights significance of the penetration-diurnal temperature effects for AMSR-E observations than for SSM/I. This issue must be addressed in future studies to improve the accuracy of the emissivity estimates especially at AMSR-E lower frequencies."

At the end of section 1 (Introduction), we add:

"It explores the differences between day and night retrieved emissivities from AMSR-E and compares the differences to SSM/I estimates."

In section 4.2, the following is added:

"These differences are more than 0.1 in some regions such as North Africa, and are much larger than emissivity variability in available SSM/I product with standard deviation of about 0.02. This larger systematic difference than seen in SSM/I results can be explained by the timing of the overpass: since the daytime overpass is closer to the daily maximum temperature but the nighttime pass is not near to the daily minimum temperature."

Also, we mentioned that:

"A map that shows the effect of penetration depth at North Africa and Arabian Peninsula was produced by prigent et al (1999). The comparison between this map and the emissivity difference map during day and night (Fig. 8) reveals an overall consistency, despite some differences noticed in Western part of Sahara desert. These discrepancies will be carefully examined in subsequent studies, but we would expect to see some penetration effect over a wider area because the diurnal temperature contrasts are larger for the AMSR-E overpass times than for the SSM/I overpass times."

Detailed comments:

Referee Comment:
- p. 5669. line 6. 'appropriate … for snow cover detection'. This is to be proved. Actually, low frequencies are likely to be insensitive to most snow cover. Even at 19 GHz, the sensitivity to snow is weak (Cordisco et a., JGR, 2006).
Authors answer:
This snow detection was suppressed from manuscript.

Referee Comment:
- P. 5670. Line 6, line 26 '(19GHz >)'. This is a confusing notation.
Authors answer:
The notation was changed to *"(higher than 19 GHz)"* throughout the manuscript.

Referee Comment:
- P. 5671. Line 3, line 7. 'First is to …'. 'Second is to…'. These expressions should be verified by a native English speaking person.
Authors answer:

We rephrased this expressions to *"The first objective is to … . The second objective is to … ."*.

Referee Comment:
- P. 5674. Lines 25-27. The use of TOVS daily resolution product is dangerous, not only because of the lack of intra-diurnal variability but mostly because to my knowledge this data set often contains climatological values, when the TOVS data are not available for a day. This can introduce significant spurious patterns in the atmospheric correction for the emissivities.

Authors answer:
A discussion is added to "Ancillary data sets" section as following to address the limitations of TOVS data set:
"The uncertainties in atmospheric information especially TOVS data set are 2-4 K for air temperature and 20-25% for atmospheric column precipitable water below the 300 hPa level (Zhang et al, 2006). TOVS data may include climatological values when actual measures are missing which can introduce an error in the atmospheric corrections (Prigent et al, 1998). TOVS data were selected in this study to be consistent with ISCCP products such as skin temperature which is also based on TOVS data (See Zhang et al. (2006) for comparisons of the TOVS product with other atmospheric datasets)."

Referee Comment:
- P. 5675. Line 3. '30 d' to be changed in 30 days.

Authors answer:
The journal format for "day" is "d". Our original was "day"!

Referee Comment:
- P.5675. Line 10. 'As much as 10%'. This is likely an underestimation of the uncertainty when climatological values are used in case of missing TOVS data.

Authors answer:
This is changed to "20-25%" with corresponding reference. However, our error analysis has been done up to "25%" uncertainty in TOVS data.

Referee Comment:
- P. 5676. Line 5-8. The ISCCP Ts does not necessarily show systematic bias, but we observed an uncertainty that tends to increase with increasing temperature, as compared to other estimates (AIRS, MODIS, or in situ CEOP observations).

Authors answer:
There is no global product that could be claimed as best product. However, in this study we used ISCCP-DX product as it has a fine temporal resolution (3 hourly). This allows us to better characterize the diurnal cycle and address the differences between day and night estimated emissivities which one of the main goal of this study. This fact was highlighted in the paper:

"ISCCP skin temperature has some uncertainties that tend to increase as temperature increases. The recent study shows that differences between ISCCP and MODIS skin temperature could be 5 K and 2.5 K for day and night, respectively (Moncet et al, 2011). However, in this study the ISCCP-DX product was used because it has a fine temporal resolution (3 hourly). This allows us to better characterize the diurnal cycle and address the differences between day and night estimated emissivities which one of the main goal of this study."

Referee Comment:
- P. 5676. Line 20. 'incidence angle'. Suppress the 'on'.

Authors answer:
Done.

Referee Comment:
- P. 5676. Line 23. 'Eddington's radiative transfer'. This type of method is adapted to the radiative transfer calculation in presence of scattering. A simple radiative transfer equation would do. Suppress the mention to the Eddington method. You used a radiative transfer code to calculate the emisivities (equ. 2-3-4). Why don't you use the same one for this sensitivity analysis???

Authors answer:
Eddington's radiative transfer model was suppressed, and Liebe's model was tested. Similar results to what we had found before were obtained.

Referee Comment:
- P.5676. line 26. 'with the 2 degree difference'?? What do you mean??

Authors answer:
This 2 dgree difference" is the difference between incidence of angles for AMSR-E and SSM/I. "(550 for SSM/I and 530 for AMSR-E incident angle)" was added to clarify this expression.

Referee Comment:
- P.5677. line 6. Line 13. Which polarization?

Authors answer:
The corresponding polarizations are added in the text.

Referee Comment:
- P.5677. Line 17. For the mountainous locations, the two major differences in emissivities are likely due to spatial resolution difference, and to differences in the atmospheric correction related to the altitude. In your retrieval, is there any correction on the profiles for the altitude?

Authors answer:
To address this, we have included the following in section 3.2:

"The largest differences appear in arid and mountainous locations. The differences in mountainous locations could be attributed to differences in spatial resolution of two sensors, given the small-scale changes of temperature with topographic height. The TOVS profiles are properly terminated over high terrain but only approximately as the topographic variability is smaller scale that the available surface pressure information; nevertheless, there is much less atmospheric effect over high terrain because the column water vapor amounts are much smaller. No adjustment has been done for atmospheric corrections in mountainous regions to account for the altitude and its effect on temperature and water vapor profiles. The differences in arid regions may be caused by the difference in overpass times and the difference of the diurnal temperature cycle amplitude at the surface and at deeper layer below surface (Prigent et al., 1999)."

Referee Comment:
- P.5677. line 27. We actually tried to use the TOVS atmospheric profiles (Prigent et al., JGR, 1997), but we abandon the idea, based on large spurious patterns in the data, especially over desert.

Authors answer:
We added the following statement to address this comment in section 3.2:
"The SSM/I based emissivity made used of the TOVS data set as atmospheric information in its first version to correct for the atmospheric effect (Prigent et al., 1997). NCEP reanalysis atmospheric profiles were used in subsequent version because of some flaws that had seen in TOVS data especially over deserts (Prigent et al, 1998), where the TOVS product is generally missing and climatology is used."

Referee Comment:
- Figure 4. When analyzing the seasonal cycle, the two hemispheres should be separated. Although most continental surfaces are located in the North, considering the two hemispheres at the same time makes the seasonal cycle less clear.

Authors answer:
Figure 4 is changed to new figure that analyzes the seasonal cycle of polarization differences in Northern and Southern hemisphere separately. The corresponding text and figure caption is changed accordingly.

Referee Comment:
- Figure 4. Over the cold deciduous forest, snow presence should interfere with the

vegetation signal. This has to be discussed. The higher the frequency, the higher the sensitivity to the snow (Cordisco et al., JGR, 2007).

Authors answer:
In new figure 4, we have used "deciduous woodland" areas that are less affected by snow interference to highlight the effect of vegetation seasonal variation.

Referee Comment:
- P. 5680 and figure 5. The analysis of the emissivity with respect to the soil moisture is problematic, both variables being retrieved from AMSR-E. Part of the correlation between the two variable is likely artificial. An external soil moisture variable has to be used, or you have to show that the AMSR-E soil moisture and the emissivity difference you show are independent.

Authors answer:
To avoid the mentioned issue, instead of AMSR-E soil moisture, we used ASCAT soil moisture product. The results are depicted in new figure 5 with contour lines. The figure caption and text are revised accordingly. The following is added to section 4.1:
"Figure 5c-d illustrates the emissivity polarization differences at 6.9 and 10.7 GHz versus the soil moisture product from the Advanced Scatterometer (ASCAT) provided by the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) (Bartalis et al., 2008). The correlation between emissivity polarization differences at 10.7 GHz and soil moisture content is less than 70 % and is 71 % at 6.9 GHz. Weaker correlations (between 65% to 70%) were found at higher frequencies (higher than 19 GHz) (not displayed)."

Referee Comment:
- Figure 5. The two different structures in the populations (for NDVI below 0.5 and above 0.5) should be interpreted.

Authors answer:
We investigated this structure and found that these regions correspond to regions that are flooded. We also found that this structure has seasonal variations. The comment is addressed as following in section 4.1:
"The regions with NDVI greater than 0.6 with different structure than NDVI less than 0.6 were investigated and found to belong to regions that are flooded or in coastal regions. These regions also showed significant seasonal variation."

Referee Comment:
- P. 5680. Line 27. No discussion needed on the relation with the NDVI in desert regions.

Authors answer:
This part is suppressed.

Referee Comment:
- P. 5681. Line 4. More information on the relationship between vegetation / soil moisture and emissivity in Prigent et al., JGR, 2005 and Aires et al., JGR, 2005.

Authors answer:
The citations of these studies were added to section 4.1.

Referee Comment:
- P. 5681. NDVI in tropical forest is to be considered with caution. Its variability is often related to cloud clearing problems in these regions that are rarely cloud clear.

Authors answer:
The reviewer's comment is true, as any misidentification of cloud in densely vegetated regions could affect the analysis. We tried to address and discuss this possibility in the paper section 4.1 as following:
"It is also worth noting that NDVI in Tropical regions could have some cloud contaminations, as the chance of having clear sky situation in these regions is very small. Therefore, low correlation between NDVI and emissivity polarization difference could be because of this issue."

Referee Comment:
- Figure 7. Specify the vegetation type on the figure or in the caption.

Authors answer:
The vegetation types are added to the figure caption.

Referee Comment:
- P. 5682. Line 7. 'The frequency dependence of this variability … desert area…'. This contradicts what is said later (line 29). Be consistent.

Authors answer:
The manuscript is revised as following:
" In desert regions, the day-to-day variability mostly decreases, while in densely vegetated areas the standard deviation increases as the frequency increases."

Referee Comment:
- Figure 8. The difference in the ascending and descending orbits are not clearly related to

the sandy deserts. This is surprising. In our analysis (Prigent et al., JGR, 1999), it was much clearer, although the overpassing times were less favorable. To be discussed.

Authors answer:
The over pass time of SSM/I and AMSR-E are not matching. We plan to discuss the effect of penetration depth in our later publication more carefully. we are also referring in our paper to previous attempts to investigate the difference between ascending and descending orbits. the following statement was inserted:
"A map that shows the effect of penetration depth at North Africa and Arabian Peninsula was produced by prigent et al (1999). The comparison between this map and the emissivity difference map during day and night (Fig. 8) reveals an overall consistency, despite some differences noticed in Western part of Sahara desert. These discrepancies will be carefully examined in subsequent studies, but we would expect to see some penetration effect over a wider area because the diurnal temperature contrasts are larger for the AMSR-E overpass times than for the SSM/I overpass times."

Anonymous Referee #2

The paper by Norouzi et al. describes the development of a global land emissivity product using AMSR-E observations, and an investigation of the sensitivity of this product to land surface properties. The focus is on the C and X bands of AMSR-E. The emissivity product is reasonably consistent with a similar product based on SSM/I observations.
The surface emissivities showed expected behavior with changing surface properties (soil moisture, vegetation density, surface roughness) in most areas. However, the authors found quite large differences in emissivity between ascending and descending (day and nighttime) overpasses. This was a result of the use of skin temperature in the emissivity retrievals, as this temperature does not always correspond well to the temperature at penetration depth for these lower frequencies.

In my opinion the paper is well written, quite clearly structured, and the scientific methodology seems sound. However, I find the results average and rather general, even taking the global scale of the study into account. It does not become clear to me what the benefits of using this product would be to users. The product does not seem to bring any new insights in itself, as the emissivity behavior is all 'as expected', and neither do the authors succeed in making it clear how it could improve existing applications.

Authors answer:
As mentioned to respond to the first reviewer, we have made several changes in the paper to highlight the results of this study. This paper aims to add new emissivity retrieval from AMSR-E observation and give an introduction to our emissivity estimates. Due to lack of "ground truth observations", validation of estimated emissivity especially in global scale is not straightforward. In this paper, we added new estimates of land emissivity by using observation from AMSR-E. These new estimates that we are proposing in this paper give the scientific community a better opportunity to investigate temporal, spatial, and spectral characteristics of emissivity because of the uniqueness of the overpass time of AMSR-E as well as its higher spatial resolution with respect to similar sensors such as SSM/I. Moreover, land emissivity estimates from AMSR-E should complement existing studies and allow for better interpolation of emissivity between frequencies and angles as it provides estimates at two low frequencies that are not available on SSM/I at constant angle, which may add information on the angular dependence of land emissivity.

The paper includes also an in-depth analysis of land emissivity spatial and temporal variation with relevant comparison to existing land emissivity products and surface parameters. The agreement between our findings and those obtained from other sensors is in itself a relevant result that is worth to be communicated. So our work corroborates the results of previous studies and complements them by proposing new product and new land emissivity estimates and lower frequencies which penetrate deeper into the soil layer and provide us with further information on key subsurface parameters.

More explanation of changes regarding this comment has been reported in first reviewer general comment answer

Referee Comment:
Only some vague ideas are given for the latter (e.g. "[it] can be used as additional indicators of land cover or vegetation type variation at global scales." (Ch.5 Conclusions)). But the results are not specific enough to convince or inspire.

Authors answer:
This paper didn't aim to characterize the land cover and vegetation type variation. In figure 4, we showed that as vegetation increases the polarization differences (V-H) of emissivity decrease. This polarization difference potentially can be quantified to be an indicator of land cover or vegetation type variation at global scale. To address this comment we added the following in section 4.1:

"This polarization difference can be considered as an indicator of land cover and vegetation type, as the polarization difference decreases with increasing vegetation."

Referee Comment:
No temporal analyses (e.g. of emissivity and surface characteristics) were presented although the product covers a six-year period.

Authors answer:
The temporal analysis was addressed, as we dedicated most of this paper to investigate the emissivity variation through the time. Some of related studies are shown in table 2, figure 4, figure 6, and figure 7.

Referee Comment:
And finally, if the skin temperatures do not work well enough, why not try to improve the product by using more in-depth temperatures from some other source?

Authors answer:
As discussed in our response for the first comment, we have done several adjustments through the paper to address this comment. This paper aimed to address the difficulties of using infrared skin temperature in emissivity retrieval especially at lower frequencies.

This problem is unavoidable as there is no measure of physical surface temperature "profile" at global scale. The paper shows that the problem, pointed out previously by Prigent et al is even worse and more extensive than for SSM/I because of the AMSR-E orbit at daily minima and maxima compared to other sensors with 6:00 to 9:00 (A.M / P.M) when they miss the extremes temperatures. We are currently working on a manuscript that is continuation of this study and try to resolve this issue by generating an effective temperature that is diurnally consistent with microwave diurnal variation.