We would like to thank both reviewers for their constructive and helpful comments. We greatly appreciate taking your time out for such a comprehensive review and, more importantly, providing concrete suggestions to improve the manuscript. Please find below point-by-point response (in blue coloured text) to your comments.

Reviewer #1

As per both reviewers' suggestion, the entire methodology and results sections are revised and re-written to help improve clarity of the methodology.

Specific Comments:
Page 3878
L2: Shouldn't use abbreviation in abstract. Write out AVHRRs and NOAA in full.
- corrected.
L4: 'during the life span of sensors' → 'during the life span of the sensors'
- corrected.
L5: 'Depending on'!'Depending upon' and 'amplitude of a diurnal cycle' → 'amplitude of the diurnal cycle'
- corrected.
L7: 'to bracket' is awkward. Perhaps 'to estimate'?
- changed.
L7-8: 'a rotated empirical orthogonal function analysis' → 'a rotated empirical orthogonal
function analysis (REOF)'
- changed.
L10: 'correcting' doesn't seem quite right : : : separating? subtracting?
- The word subtracting is now used instead of correcting.
L14: 'and their rigorous testing before' → 'and rigorous testing thereof before'
- corrected.
L16: write out 'year'
- corrected.
L18/20/21: I would hyphenate 'space-based', 'process-based' and 'climate-monitoring'
- corrected.
L19: 'resolutions' – are there more than one spatial resolution?
- corrected.
L20-24: It might be helpful to create a table showing the different spectral channels, and the meteorological products you get from each one. In this table you might also link to show how you detect and type clouds in the measurements, which you briefly discuss later.
- There are many meteorological products derived from the AVHRRs over the last three decades and each one of them often uses measurements from more than one channel and combines them in a complex way to produce final meteorological product. Hence, it is not practical (and beyond the scope of the present study) to list them. For studying clouds and their properties, the number of channels used depends on the cloud property in question. For example, to compute cloud fraction, often times the data from all channels

are used, while for estimating optical depth the data from few channels in the visible wavelength spectrum are sufficient. For our specific study, we focused only on correcting cloud fraction time series of deep convective clouds since the literature shows that they have strongest diurnal cycle among all cloud types. For detecting these specific clouds, we used the channel 4 brightness temperature threshold of 220K. Over the Indian subcontinent, only deep convective clouds and optically thick cirrus clouds associated with deep convection can produce such low temperatures (except few pixels covering Himalayan mountain peaks) and hence this simple threshold works.

Page 3879

L1: I think you should start a new paragraph with the sentence starting with 'However'.

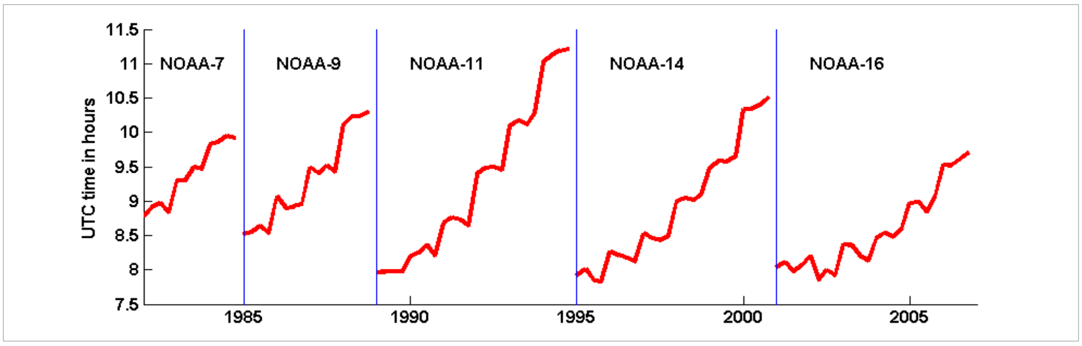
- corrected.

I also think that after this first sentence you need to give a description of what 'drift' is. Are we talking about the spatial or temporal aspect here, or both? By how much, in time or space, as appropriate do satellites drift? Is it hours or minutes? (I struggle to see how minutes would greatly affect trends, but hours definitely would) Is it constant over their orbit? Does it increase in time? By what rate? Involving what aspects of the spacecraft's motion? Etc. Perhaps a schematic would help

- We implicitly assumed that the reader will be aware of these facts. This, however, may not be the case and we thus fully agree with the reviewer that this part of the manuscript needs to be clarified to better understand these terms and the nature of the drift. We have, therefore, revised this part and following text is added.

The nature of the drift:

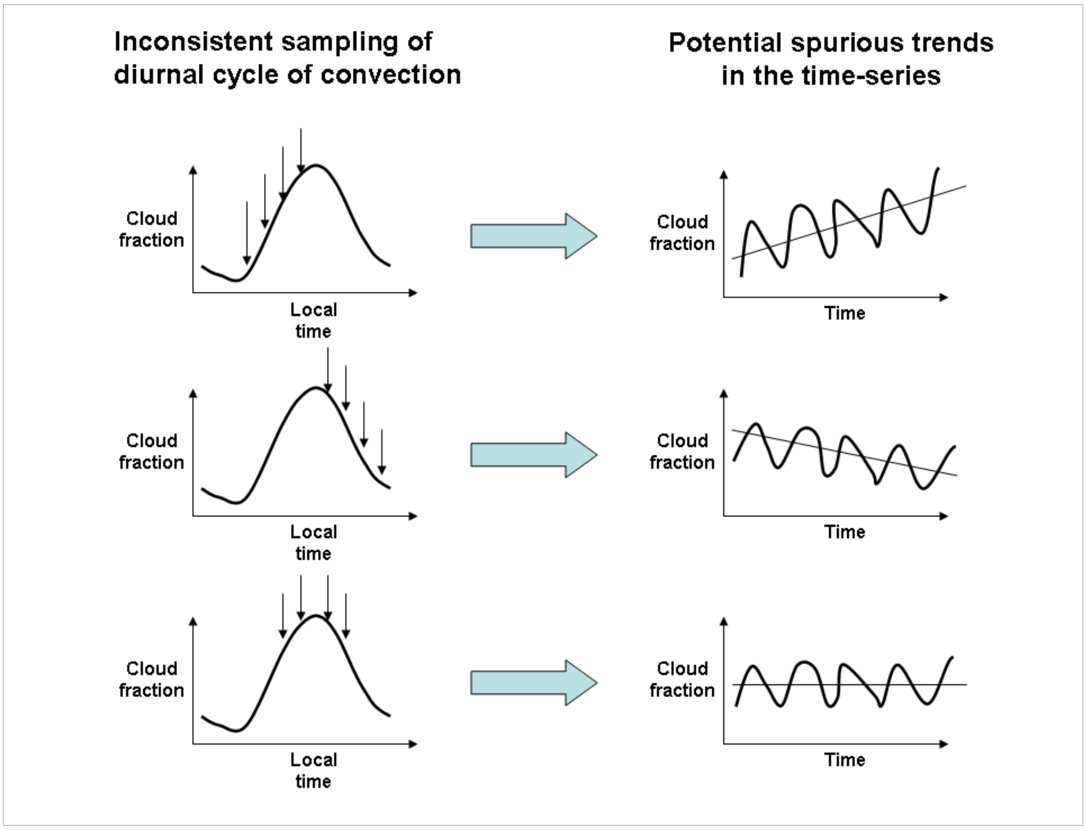
The host NOAA satellites that carry AVHRR instruments are sun-synchronous satellites, meaning that they have fixed equator crossing times. In order to fulfill this condition, it is required that the satellites exactly maintain their altitude, which in practice means that their orbital path is tightly monitored and corrections are periodically applied to maintain this path. If this is not done properly, the satellite will start drifting from its initial orbit (as happened in case of many of the old NOAA satellites up to NOAA-17). This drifting results in a continuous change in equator crossing time. The rate of drift is different for each satellites, and it may not be constant over time. The following figure shows the monthly mean time of observation of NOAA satellites averaged over the entire study area for the summer months and provides a good overview of how different satellites historically have drifted in time.



As can be clearly seen in this figure, depending on the satellite and time period in question, the rate of drift is different. A drift of a few hours is sufficient to produce spurious trends in the time series of convective clouds since the amplitude of their diurnal cycle is quite large. The papers by Ignatov et al (2004) and Devasthale and Grassl (2007) provide useful overview of these aspects. Notice that, in general, in case of the afternoon satellites the drift results in a delay in the equator crossing times, while in case of morning satellites, the drift leads to earlier observations. The most recent satellites (NOAA-19 and MetOP-2, not shown here) have very tightly controlled orbit and thus have shown relatively stable equator crossing times so far.

Potential influence on the time-series:

The following figure shows the conceptual schematic of the potential impact of inconsistent time sampling due to orbital drift on the time-series of convective cloud fraction.



It shows an idealised diurnal cycle of convection over land and presents three scenarios wherein this diurnal cycle is sampled along its ascending or descending branches. In the first scenario, when the diurnal cycle is sampled along its ascending branch due to continuous delay in the time of observation due to orbital drift, we may observe a spurious increase in convective cloud fraction during the life span of a sensor. If the diurnal cycle is, on the other hand, sampled along its descending branch, this may lead to spurious decrease in convective cloud fraction as depicted in the second scenario. However, it may happen that the change in the time of observation is around the peak of the diurnal cycle. In such case, the time series may not show any discernible trend or may be small enough to be masked by the real trend. Notice that the magnitude and sign of the spurious trend will eventually depend upon the scenario in question, which in turn depends upon the type of cloud studied, amplitude of the diurnal cycle, the rate of drift, season and geographical position.

Earlier, L3: 'The drifting leads to the delay' ! 'the drifting leads to delay'
- corrected.
L4: I would hyphenate 'time sampling', and I think it's worth noting that it also results in inconsistent time sampling of other meteorological quantities other than clouds as well
- corrected.
L9: 'other geophysical climate variables' ! 'other geophysical climate variables from AVHRR'
- corrected.
L11: 'satellite platform change related biases' is quite awkward
- rephrased.
L12: Is land surface skin temperature different from land surface temperature?
L15: I wouldn't capitalise Radiation Budget
- corrected.
L20: Would this work for less dynamically extreme regions where the background signal is less strong? How would you differentiate from a long slow trend? (A synthetic example would work wonders here for confidence in method).
- In the present study we presented an extreme example of convective clouds. The methodology is expected to work on other cloud types as well where daily variations in thermodynamics are relatively weaker. The drift signal may not be very important, though, for clouds with a weaker diurnal cycle. There are few studies using this methodology for outgoing longwave radiation data (e.g. Waliser and Zhou, 1997; Lucas et al., 2001), which has a weaker diurnal cycle amplitude. So we can draw only a few parallels from these studies. In both cases (i.e. our study and the Lucas et al 2001 study) the drift signal is visible with the difference that, in the present study, we suspect that the first few modes are affected by drift, while in the Lucas et al (2001) study affected modes were 3rd and 4th.
L23: 'data' ! 'spectra'?
- "data" is the correct term here.
L24: I think you should give the wavelengths of the solar and thermal channels somehow, or point to a table, and I find the use of 'AVHRRs' as an abbreviation rather awkward: perhaps 'AVHRR sensors' would be better?
- The wavelengths for the five channels of AVHRR are added to the revised text. The AVHRR is a five-channel instrument with two channels in the solar spectrum (0.58-0.68µm and 0.725-1.1 µm), two in the thermal infrared spectrum (10.3-11.3 µm and 11.5-12.5 µm) and the third channel falls partly in the solar and in the thermal infrared spectrums (3.55-3.93 µm).
L27: no comma after 'therefore', and 'homogenization' ! 'consistency'
- corrected.

Page 3880
L3: Perhaps a schematic on how you differentiate between cloud types, or at least in the most frequent cloud types?

- As mentioned above, we used only channel 4 brightness temperature threshold of 220 K to define very deep convective clouds. This is mentioned more clearly in Section 2 of the revised manuscript.

L5: I'd hyphenate 'optically-thick'

- corrected.

L6: 'therefore the time series of these clouds most likely shows the spurious' ! 'therefore it is probable the the time series of these clouds shows spurious'

- corrected.

L9 – 21: I think this paragraph is vastly insufficient to describe the methodology used here. This is effectively an algorithm description paper, and yet you don't really describe the algorithm! I think it is important to describe a bit of the theory here, instead of just referring the reader to citations. Describe the difference between rotated and non-rotated EOFs, what a varimax rotation is : : : etc. Then, when it comes to what you've actually done in your algorithm, you really do need to justify why, for instance, you retain only the first 20 modes, and why only the first 7 are rotated and used. Presumably this is to do with total variance captured by the first 20 or first 7 components, but you do have to explicitly state this, and perhaps show a plot of the variance captured by each successive component. How do you identify the modes contaminated with drift signal visually? Is there nothing quantitative? I certainly couldn't reproduce your algorithm given the information you've given – and that's rather the point of an technique paper, right?

If it were me, I would create a synthetic example, to go along with your description of your algorithm. Make it as simple as you like: say sinusoidal, with a period of 24 hrs to represent the diurnal variation in cloud, with an appropriate amplitude. Then impose a simple, but realistic drift on this 'nominal' signal. Go through each of the steps, showing what you do, and why you make the qualitative decisions you do, in terms of number of modes you consider and treat, and describe how you 'visually' can determine which of the REOFs contain variation due to the drift. How can you tell that they aren't trends? Then recombine, and show the drift-removed new dataset compared with the original synthetic signal (without the drift added) – and hopefully these should be about the same – or at least closer than the original and the original+drift-added data. You could also do this for a smaller amplitude signal, so there is some justification for the assertion you make about this working even if you don't have clouds ...

- The methodology section is now completely revised and arranged into three subsections to improve clarity. Please refer to the revised manuscript to see expanded details, few of them are highlighted below.

a) The REOFs were used instead of EOFs because of their distinct advantages: they are more effective in reducing the dimensionality of the data set, insensitive to the size of the chosen study area and, thirdly, easier to physically interpret. The varimax rotation, which is most commonly used rotation method, is explained in the revised manuscript.

b) Only 20 modes are retained because they capture 99% of the total variability in the data set.

c) First 7 modes are rotated because other modes showed extremely weak correlation with equator crossing time ($<\pm0.02$).

d) We identified modes containing orbit drift signal visually because, in this particular study, they have high correlation with equator crossing time (Fig. 4). One could easily do it automatically and quantitatively by examining this correlation and providing a certain threshold on it to select influenced modes in which the drift signal is not so strong (e.g. other cloud types).
e) In order to create a synthetic example, we would need many artificial time-series with different characteristics to demonstrate the effectiveness of the REOF analysis. This would eventually become just as complicated as the study presented here. Instead, we chose to revise the entire methodology and results sections and greatly simplified it providing details on the every aspect of the analysis and introduced five new figures to improve clarity.

Page 3881
L1-6: needs a clearer explanation. Why, for instance, do you say that a strong drift signal is seen only in modes 1 and 3? Without telling us what a drift-signal looks like, we can't judge.
- This statement was made on the basis of following three points.
a) In the REOF case, the correlation of EOF loadings of Modes 1 and 3 with equator crossing times is very strong compared to others (Fig. 1 on page 3886, right panel).
b) Time series of EOF loadings for these two modes clearly show spurious jumps at the start of each new satellite record (even more evident in the synthetic loadings for these modes shown in Fig. 3 on page 3888) and increasing cloud fractions during the life-time of a sensor.
c) The spatial patterns of REOF vectors for Modes 1 and 3 show striking land-sea contrasts which are unrealistic. The distribution of convective clouds over the Indian subcontinent should follow a spatial pattern similar to the one visible in Mode 2 (also seen in Devasthale and Grassl, 2009a; Devasthale and Fueglistaler, 2010).
We have now included this reasoning in the revised draft of the manuscript.
L5: 'The mode 2' ! 'Mode 2'
- corrected.
L8-9: 'compute new synthetic loadings. They are shown in Fig. 3 in red color.' ! 'compute new synthetic loadings (Fig. 3).' Does this mean that the synthetic loadings effectively interpolate the signal back to what if would be if there was no drift? It is awkward how you describe this.
L14: I don't agree that 60% correlation is 'very high'
- This correlation relatively speaking very high. Please note that only a few percent changes in cloud fraction could mask or exacerbate warming effects of CO_2 and other greenhouse gases. So if we are potentially searching a very small trend signal in the time-series of cloud fraction, even the low correlations in the order of 10-20% could spuriously mask or exacerbate such climate change signal in clouds. Therefore, we mentioned that the correlations of 40-60% are very high.
L16: Give a reference for this statement about the amplitude of diurnal variation of clouds.
- References are given in the revised version of the manuscript.
L19: take out word 'artificial'
- corrected.

L23: ’is not removed at the same time. Thus the remaining question is whether the natural’ → ’is not removed at the same time – that is, whether the natural’
- corrected.
L25: Reference for MODIS?
- given.
L28: Time of overpass? Surely you can do better than ’afternoon’ : : : and there must be an estimate of what time the NOAA satellite generally makes its overpass.
- When discussing sun-synchronous meteorological satellites, it is in fact quite common to use this terminology. Broadly speaking, these satellites usually have either early morning (around 6 to 7 AM, e.g. as in case of NOAA-7, -10 satellites), mid-morning (around 10:00 to 11:00 AM, e.g. MetOP-2 and Terra satellites) or afternoon overpasses (around 1:30 to 2:20 PM, e.g. the satellites considered in this study). In case of afternoon satellites, some of them have equator crossing times of 1:30 PM, while others have 2:30 PM, and therefore, the term “afternoon satellite” is often used to collectively represent them.
L29: ’Therefore the REOF analysis’ ! ’The REOF analysis’
- corrected.
Page 3882
L1: stay in the present tense. ’Was’ should be ’is’. And I’m not sure I understand how you’ve done this : : : are you correlating 5 years of data against only 1 year of data? This doesn’t seem right : : : Perhaps more explanation of what you’ve actually done would clarify.
- The reason for using MODIS data for JJAS 2006 is that during the time period of 2001-2006, the highest drift in NOAA-16 orbit occurred in 2006. So, the idea was to use this “worst case year” to do comparison of uncorrected and corrected AVHRR data sets with MODIS for this year.
L9-10: ’drift signal from the dataset. Our comparison results support their argument.’ ! ’drift signal from the dataset: our comparison supports their argument.’
- corrected.
L12: ’We demonstrate that the REOFs efficiently’ ! ’We demonstrate that REOF analysis efficiently’
- corrected.
L13: ’series of convective cloud fraction’ ! ’series of convective cloud fraction for the example of the Indian Monsoon’
- corrected.
L13-14: You haven’t really shown this : : : for instance you haven’t given magnitudes of the difference in trends you’d attribute – you’ve just said that it is important. Back it up with something quantitative to show the ramifications of leaving the drift signal in the data.
L16-17: remove ’which can be used for climate studies with emphasis on essential climate variables like clouds’ – redundant.
- corrected.
L17: ’An accurate intercalibration of AVHRR sensors and the removal of orbital drift signal are the two issues that need to be addressed’ → ’However, the two key issues of accurate intercalibration of AVHRR sensors and removal of orbital drift signal need to be addressed’

- corrected.
L22: ’the other important issue’ → ’the orbital drift issue’
- corrected.
L24: Have you actually given the upper limit? I don’t remember a number : : : or do you mean that monitoring of big convective clouds will be more impacted by drift than other meterological variables, like water vapour concentration or atmospheric temperature? How do you justify this?
- Yes. We are indirectly referring to other cloud types, which have weaker diurnal cycles than deep convective clouds. This is clarified in the revised manuscript.
Page 3883
L2-6: An expanded version of this should rather be in the results section, surely?
- This is now elaborately discussed in the revised draft.
Fig. 2 What are the units of the colours in the plots? This should be on the plot somewhere
Fig. 3 Again, units of y-axis?
- corrected.
Fig. 4 Units for colour again!
- corrected.
Fig. 5 Label for y-axis, and units, please
- corrected.
Technical Comments:
Generally: I think you ought to change written-out-units to just units: ie. Micrometers ! m and degrees !
Also, there is quite a lot of inconsistency in hyphenisation: in phrases like ’time series’, ’long term’, ’life span’ and the like – some of the time you have them hyphenated and other times you don’t ...
- Inconsistency corrected.

Reviewer #2

General remarks: The authors deal with a basic topic which is handled very compendiously. I suggest further data analysis to be finally more conclusive.

- As per both reviewers' suggestion, the entire methodology and results sections are revised and re-written to help improve clarity of the methodology and more discussion is added in the analysis part. Please note that some of the comments of reviewer #2 were also directly/indirectly raised by reviewer #1. Therefore we kindly request the reviewer #2 to refer to our replies above to the comments by reviewer #1.

Remarks on section 2 (Data and methodology): Many details are missing in order to follow the logic. The methods of EOF and REOF condignly have to be specified and explained or at least advantages and disadvantages of both methods should be discussed.

- This section is structured into three subsections in the revised manuscript that provide details of the methodology, the description of REOFs and their advantages. For example, the use of REOFs analysis offers a few distinct advantages mentioned below over EOFs, which are especially relevant for the present study.
1) The REOF analysis reduces dimensionality of the data set even more effectively. This has been shown in the works by Waliser and Zhou (1998) and Lucas et al. (2001) and also in the present study. This allows relatively easy identification and delineation of orbital drift signal in the data.
2) The REOFs are independent of the domain size. This entails that although we successfully applied this analysis over the Indian monsoon region, it can be spatially extended and/or applied to other domains without significant changes in the application method.
3) It is relatively easy to interpret physically. For example, by reducing dimensionality and aggregating the drift signal only in few modes, one can compare spatial patterns of modes that are or aren't, respectively, affected by the drift signal in a more physical way.

Remarks on section 3 (Results of the REOF analysis): I am not convinced that the REOFs shown in figure 1 disentangle the orbital drift signals better than the first EOF modes. The correlation for REOF modes 1 and 3 is higher than for the EOF modes 1 and 3. The second REOF mode seems to be slightly lower than the second EOF mode. On the contrary mode 4 shows reduced correlation. This needs more explanation. Moreover, I am interested to see results for clouds with BT<230 K and BT<240 K. What are the differences? Please indicate in captions of figures 1, 2, 3 and 4 which years were analyzed (2001-2006?). Definitely the frequency distribution of the cloud fraction shown in figure 5 reveals agreement between MODIS and corrected AVHRR data. The result is a requisite. In my opinion this alone is not sufficient for the conclusions presented. A detailed comparison of cloud brightness temperature is needed. Statistical analysis (not just basic statistics) could prove that the new AVHRR results significantly agree with MODIS data or not. Frequency distributions as in figure 5 should be compared for cloud brightness temperature (different years might give important hints if the correction procedure works out).

a) The Fig. 1 in the discussion paper is in fact showing the effectiveness of the REOF analysis in aggregating the drift signal only in a few modes compared to more in the EOF case. For example, in the REOF case there are only two modes that show correlation with the time of observation > ±0.2, while in the EOF case, the four modes are likely contaminated by the signal making it more difficult for the interpretation.
b) The warmer BT threshold is, the flatter the amplitude of diurnal cycle of cloudiness is. This means that the drift signal will be weaker and weaker and may not be dominant enough to be visible in the first few modes. Apart from this, we expect no significant difference if we used different BT threshold to define convection.
c) For all results presented in the figures 1 to 7, the data from 1982 to 2000 is used (NOAA-7, -9, -11, and -14).
d) The comparison with MODIS is performed in order to demonstrate that the methodology is working is further supported by introducing two new figures. The first figure below shows the spatial distribution of uncorrected (original) AVHRR convective cloud fraction, corrected AVHRR cloud fraction after removing the drift signal, MODIS cloud fraction and the difference of uncorrected AVHRR and corrected AVHRR convective cloud fractions for the JJAS months of 2006. The difference image shows large spatial variability. A careful investigation shows that the correction reduces convective cloud fraction over areas where the diurnal cycle is sampled along its ascending branch during the life span of the sensor, while the cloud fraction is slightly increased over areas where the cycle is sampled along its descending branch. This is physically consistent.

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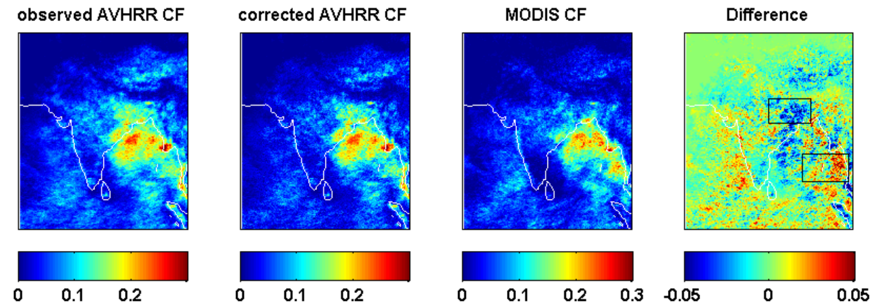
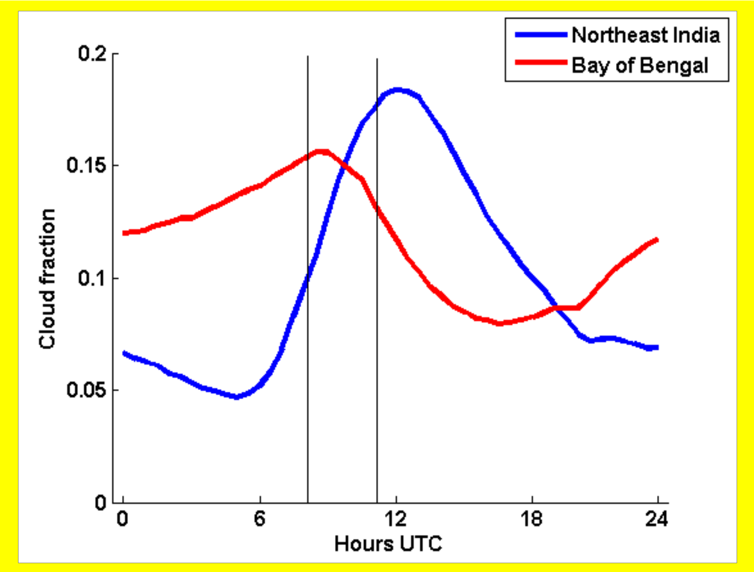


The figure below shows the shows the diurnal cycle of convection derived, for the same time period (JJAS 2006), over two areas (marked in rectangles in the figure above) using Meteosat Visible and Infrared Imager (MVIRI) onboard Meteosat-5 geostationary satellite providing images at every 30 minutes. This figure demonstrates that, over the first area over the northeast India where the diurnal cycle is sampled along its ascending branch, the cloud fraction is reduced in the corrected AVHRR data, while the opposite is true for the area over the Bay of Bengal. These two regions are in fact good realizations of the first two scenarios described in the conceptual schematic presented above in the response to reviewer #1.



Remarks on section 4 (Conclusions and discussions): The technical issue of the work is the removal of orbital drift signal in 'Nearly 30 yr of data from the Advanced Very High Resolution Radiometers (AVHRRs) onboard the National Oceanic and Atmospheric Administration (NOAA) satellite series'. In the manuscript a more detailed discussion is just presented for 2006. Why? The comparison with MODIS data for other years, specification of the orbital drift and overpass times (2001-2006) is inevitable. I would like to see much deeper discussion with regard to such an important issue.

- The reason for performing the comparison for year 2006 is that during this year the absolute drift and its rate was maximum for NOAA-16 between 2001 to 2006. Therefore, we wanted to examine if the cloud fraction for this "worst case year" could be corrected. The other years, e.g. 2001 and 2002, have smaller drift rates and, therefore, may not have detectable influence on the time-series. The ideal scenario would be to carry out comparison of the last few yeas of corrected and uncorrected data from each historical satellite with independent data set, but, unfortunately, the reference data sets do not exist. All other sensors which are capable of providing the long-term convection climatology (e.g. HIRS, TOVS, AMSU) have been on the same NOAA satellites which drifted in time.

References

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Hannachi, A., T. Jolliffe, and D. B. Stephenson, Empirical orthogonal functions and related techniques in atmospheric science: A review, Int. J. Clim., 27(9), 1119–1152, 2007.

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