June 16, 2016

Authors reply to the Anonymous Referee #3 comment posted on May 28, 2016.

Interactive comment on "Pivotal role of the North African Dipole Intensity (NAFDI) on alternate Saharan dust export over the North Atlantic and the Mediterranean, and relationship with the Saharan Heat Low and mid-latitude Rossby waves" by E. Cuevas et al.

We thank Referee #3 for his/her report. We appreciate his/her constructive critical comments and some interesting suggestions that are helping us to improve substantially the way in which the results are presented in the manuscript.

General Comments:

The study analyses the role of the NAFTI on the dust transport and the potential relationship with the Saharan Heat Low and the mid latitude circulation. Even if this paper shows some interesting it is absolutely necessary to make substantive changes before acceptation. So I would recommend major revisions.

We are about to complete major revisions in the manuscript drafting, detailed below.

MAJOR COMMENTS (MC)

MC1. The paper is too long and needs to be drastically reduced. I especially suggest to remove a lot of descriptive comments or too speculative conclusions proposed by the authors in section 3.2, 3.3 and 3.4. For instance L11 end of paragraph 2 p13 (too descriptive), p17 second paragraph (too speculative), p19 first paragraph (too long and not clear), p21 beginning of the 3rd paragraph (too speculative and out of the scope).

We agree the paper is too long. We have almost finished a new version of the manuscript shortened substantially: we have moved some detailed analysis and secondary results of sections 3.1, 3.2., 3.3 and 3.4 to the Supplement material, removed some no necessary material and redundancies, shortened considerably the conclusions, and rewriting completely the abstract and the introduction. We recognize the level of detail and the large extension of the manuscript had blurred the objectives and very relevant results we think the paper contains. The new version will be uploaded next week.

Concerning the specific comments:

L11 end of paragraph 2 p13 (too descriptive)

In the new version of the manuscript, this information has been moved to the Supplement material since this is not core information.

p17 second paragraph (too speculative)

Probably the information of page number and paragraph given by the Referee#3 is not correct, since we do not find here any possible speculative argument.

p19 first paragraph (too long and not clear)

We have re-written this paragraph adding information concerning the statistical significance.

p21 beginning of the 3rd paragraph (too speculative and out of the scope)

We think the discussion presented in this paragraph is not speculative, but based on solid physical arguments. However, the purpose there was not to provide a final explanation, but to present arguments that might stimulate new studies to be performed by other research groups (e.g., groups working on the West African Monsoon). Anyway, since this discussion represents a secondary observation/assessment of the main line of argument in our study, the full page has been moved to Supplement for the sake of brevity.

MC2. There is a big confusion associated with daily and monthly correlations and daily or monthly values. The authors should clarify how they perform the calculation.

We appreciate the Referee comment.

We have eliminated this confusion in the new version of the manuscript. First, the former section 3.1 has been moved to the Supplement. Second, in the new section 3.1 (old 3.2) we work with NAFDI monthly values as Rodriguez et al. (2015), who used only August months, extending the study period to the whole summer and other geographical regions. Third, in the new section 3.2 (old 3.3), when we investigate the connection between the NAFDI and the SHL, quantifying their relationship, we need to introduce a daily NAFDI index along with another daily index that accounts for variations in the position of the SHL. In the new section 3.3 we also work with the daily NAFDI index in order to know its relationship with the daily variability of mid-latitude Rossby waves. Anyway, the terms "monthly" and "daily" are always explicitly stated to avoid any confusion.

MC3. All the results are presented without significance tests.

We agree with the Referee. This point had been raised by Referee 1 too, and we provide here the same arguments (already presented in our reply to Referee 1) and detail of changes are going to be implemented.

Concerning the statistical results of the NAFDI-SHL and Rossby Waves-NAFDI daily relationships addressed in Sections 3.3. and 3.4 for the summers of the period 1980-2013, we assumed that the fairly good Pearson correlations obtained using more than 3,000 pair-data implied a high statistical significance to "the naked eye". Given the great length of the paper (addressed by the three Referees), we focused efforts in describing the physical mechanisms behind these relationships and document the statistical results. However, we agree with the Referee. A complete assessment of statistical significance is presented here for the main results of the paper. Please, indicate if you require specific additional minor results.

a) Concerning the correlation plots, the following sentence will be added in the manuscript (Section 3.1):

"The correlation plots shown in this paper are computed using monthly means (only one month per year, e.g., August) of the period 1980-2013 (i.e., 34 years), except for Fig. S5 (2 monthly means per year). Therefore, the critical value for having a significant Pearson´s correlation coefficient (*R*) with a 95% confidence level is 0.34 (i.e., the correlation is significant if $|R|$>0.34)."

Correlation plots are shown in Figs. 1, 11, S5, S6 and S11. The following sentence will be included in the caption of all these plots: "Correlations greater (in absolute value) than 0.34 are significant with a 95% confidence level", except in Fig. S5, for which the critical value is 0.24. All the correlation plots shown have large regions where the correlation is well above this threshold.

b) Concerning the correlations between the two NAFDI index versions and the monthly total dust concentration measured at Izaña Observatory for August months (presented in Section 3.1), the number of elements in the time series is 26, and therefore, the critical value for having a significant Pearson´s correlation coefficient (*R*) with a 95% confidence level is 0.39 (i.e., the correlation is significant if $|R|$>0.39).

The correlation of the dust at Izaña Observatory with the old version of the NAFDI index is 0.67 (r_1; this value is significant with a 99.98% confidence level), whereas with the new version of the NAFDI index is 0.72 (r_2; this value is significant with a 99.997% confidence level). There is a confidence level of 63% about the fact that r_2 is significantly larger than r_1 .Some details about this confidence level computation will be presented in the Supplement, including the corresponding references; i.e., Fisher transformation, computation of the difference... However, the decision of providing an improved version of the NAFDI index is not based on the improvement of this correlation.

These three confidence levels will be provided in the main text of the manuscript.

c) Concerning the correlations between the daily index time series (3,060 values per time series):

Assuming that there is no time-lag autocorrelation in any of the time series, the critical value for having a significant Pearson´s correlation coefficient (*R*) with a 95% confidence level is 0.036 (i.e., the correlation is significant if $|R|>0.036$).

However, indeed, there is time-lag autocorrelation in the time series. We have used the method exposed below to establish an upper bound for the critical value of the Pearson's correlation coefficient. In the four time series (NAFDI, SHLWEDI, O500 and ZWA300) the autocorrelation decreases when increasing the time-lag. The maximum time-lag (MTL) in which there is still a significant autocorrelation (larger than 0.036) is: 22 days for the NAFDI time series, 23 days for the SHLWEDI time series, 7 days for the O500 time series, and 15 days for the ZWA300 time series. Then, to establish an upper bound to the critical value, we consider a lower bound of the number of independent values (LBNIV) in the time series, computed as the ratio between 3060 and MTL. Note that this is a very conservative estimation of the lower bound. For correlations including the SHLWEDI, LBNIV is 133, and the upper bound to the 95%-confidence-level critical values is 0.17. For correlations including NAFDI but not including SHLWEDI, LBNIV is 139, and the upper bound to the 95%-confidence-level critical values is 0.166. However, for correlations not including the former time series but ZW300, LBNIV is 204, and the upper bound to the 95%-confidence-level critical values is 0.137. These explanations will be included in the Supplementary Material.

The correlation (r_2) between the 1-day time-lagged SHLWEDI and the daily NAFDI is 0.770 (this value is significant with a 99.999% confidence level) whereas the non-lagged correlation (r_1) is 0.688 (this value is significant with a 99.999% confidence level). There is a confidence level of 92.2% about the fact that r_2 is significantly larger than r_1. Some details about this confidence level computation will be presented in the Supplement, including the corresponding references; i.e., Fisher transformation, computation of the difference…

These three confidence levels will be provided in the main text of the manuscript.

The paragraph starting in line 26 of page 26 will be rewritten as follows (the new text is highlighted here using bold face letter):

"*Table 4 shows the Pearson correlation coefficient between the daily ZWA300, O500 and NAFDI (also for some time lags as well as 5-day running means* ***-5drm-****). The results led to the following conclusions: 1) the correlation of both ZWA300 and O500 with NAFDI is significant* ***(with a confidence level larger than 99.999%)****; 2) the correlation between ZWA300 and O500 is low but not negligible* ***(with a confidence level larger than 86.5%, and 99.7% in case a 5drm is previously applied);*** *these two facts together indicate that ZWA300 and O500 are quasi-independent indexes that take into account different aspects of the Rossby wave in agreement with our previous discussion); 3) it seems that ZWA300 drives almost one day in advance the value of NAFDI (* ***the correlation with NAFDI lagged 1 day is larger than the correlation without any time lag, with a confidence level larger than 58.7%; the correlation with NAFDI lagged 1 day is larger than the correlation with NAFDI lagged -1 day, with a confidence level larger than 72.9%****), whereas O500 might be ahead respect to NAFDI less than 12 hours* ***(the correlation with NAFDI lagged 1 day is significantly larger than the correlation with NAFDI lagged -1 day, with a confidence level larger than 79.1%)****, which agrees what is shown in Figures 5 and 7 of Chauvin et al. (2010): a Rossby wave-packet comes from the Northwest Atlantic and approaches Northern Africa days before a maximum in the SHL displacement is achieved, reaching the centre of the wave-packet Northern Africa when that maximum is achieved ; 4) when applying 5-day running means to the time series before computing the correlation coefficients, they increase significantly (because of the removal of part of the "noise" due to synoptic signal). When performing a multilinear least-square regression of daily*

NAFDI as function of ZWA300 and O500, a linear correlation of 0.533 is obtained (0.656 for 5-day running means; ***in both cases, the correlation is significant with a confidence level larger than 99.999%****). Supplement S13 provides more details about these regressions*."

MC-4. The definition of the NAFTI is justified with the August correlation. Why June/July and September are not taken into account?

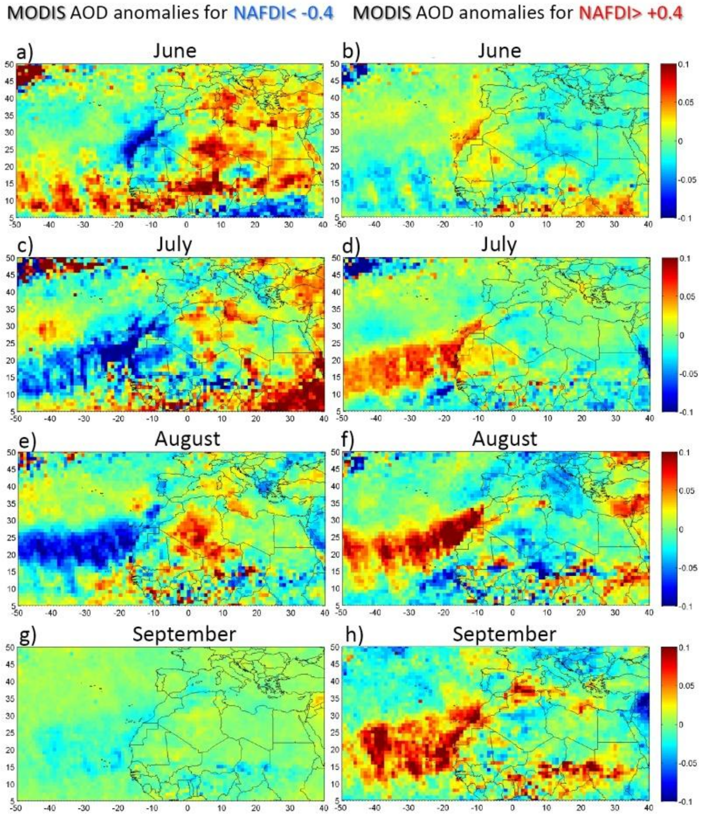
The reason is that the concept of NAFDI was introduced and used by Rodríguez et al. (2105) for August months. This is one of the central months of summer. So, in order to compare with previous results, we justify the slight change in the NAFDI index definition using only August months. In the new manuscript version, this change of the NAFDI index is presented not in the main paper but in the Supplement. We guess that the solid arguments we present are valid for the rest of the months of the summer period. The analysis for each month of the summer period would require an unnecessary (an unwanted) extension of the paper.

MC-5. September month is not provided in Fig. 2 to Fig. 9. But the authors discussed the link with the SHL that is defined for the entire rainy season over the Sahel from 20 June to 17 September. Why the NAFTI is studied only from June to August ? is there a scientific reason ? I agree that is this is the common definition of summer, but in a science point of view this is not necessary robust due to the seasonal cycle of the West African Monsoon.

We appreciate this suggestion and agree with Referee#3. The only reason for analyzing the period June-August is that this is the considered standard summer period, used in most papers. However, we agree that September is also a "summer month" to be account for in the study region. So we have included September in all our monthly analysis. Please, notice that September had been already considered on daily analysis.

The Referee will see in the results how the patterns found in AOD and meteorology for the two NAFDI phases in September are quite similar to those observed in July and August confirming the results found.

This is an example plot: AOD anomalies for negative and positive NAFDI phases.



MC-6. There is a constant back and forth between ERAI and NCEP reanalysis. I would suggest to use only one set of data to be consistent. These two reanalysis are relatively closed but difference are still present.

As we had already replied to the same comment posted by Referee#1, at synoptic scale, the scale at which we are working in this study, both ERA-Interim (ECMWF) and NCEP/NCAR reanalysis provide the same patterns. We decided to use ERA-Interim in some plots of limited geographical domain (new sections 3.1. and 3.2) because of its higher spatial resolution compared with NCEP/NCAR. On the contrary we found more practical to use NCEP/NCAR reanalysis for correlation and regression plots (with NAFDI) in larger geographical domains.

On the other hand, the use of two independent reanalysis has been carried out in other studies. For example, Knippertz and Todd (2010) used simultaneously ERA-Interim and NCEP/NCAR reanalysis. Chauvin et al. (2010) reported that no fundamental differences were found in their analysis of the intra-seasonal variability of the SHL and its link with mid-latitudes, when considering the 1948-2007 period of the NCEP-NCAR Reanalysis or the 1979-2001 period of ERA-40, even using different time periods.

Anyway, and in order that readers can verify that both reanalysis show the same large-scale patterns, the new Figures 4, 5, 6, 7, 8, 9 of the manuscript plotted using ERA-Interim (which now also include September months) have been also plotted using NCEP/NCAR reanalysis and shown in the Supplement.

MC-7. The role of the African Easterly Waves, one of the most important component of the west african monsoon that can modulate the wind and temperature fields at 700hPa is not mentioned.

The West African Monsoon (WAM) is out of the scope of our study, and therefore it is very briefly mentioned in our manuscript. African Easterly Waves (AEWs) do play an important role modulating the precipitation in the WAM in their time scale (3-5 days; e.g., Holton, 1992). Moreover, due to their relatively short period (3-5 days), their imprint is not seen in monthly mean meteorological plots. Anyway, AEWs are not expected to have any significant impact on the SHL position as argued below.

The African Easterly Jet (AEJ) is the thermal wind associated to the strong temperature gradient between the equator and the SHL over West Africa. AEJ has its maximum wind speed near 650 hPa. AEWs form and propagate in the AEJ, obtaining their energy by barotropic and baroclinic conversions of energy from the AEJ (Holton, 1992). Therefore, the position of the SHL determines where the AEWs are formed. The SHL is the northern flank of the background state that determines the AEJ, being the AEWs perturbations to such background state. Then, the AEWs cannot produce a significant impact into the SHL, because for that it would be necessary the AEWs become highly no linear and a subsequent strong no linear interaction between these waves and the background state.

Lavaysse et al. (2010) showed empirically that AEWs have no significant impact on the SHL (see their Figure 12).

Since the manuscript contains already a lot of relevant material and it is rather long, we think it is better not including any mention to the AEWs. However, if the referee insisted again that the AEWs must be (extensively) mentioned in the manuscript, we would include the above arguments at the end of the new section 3.3.

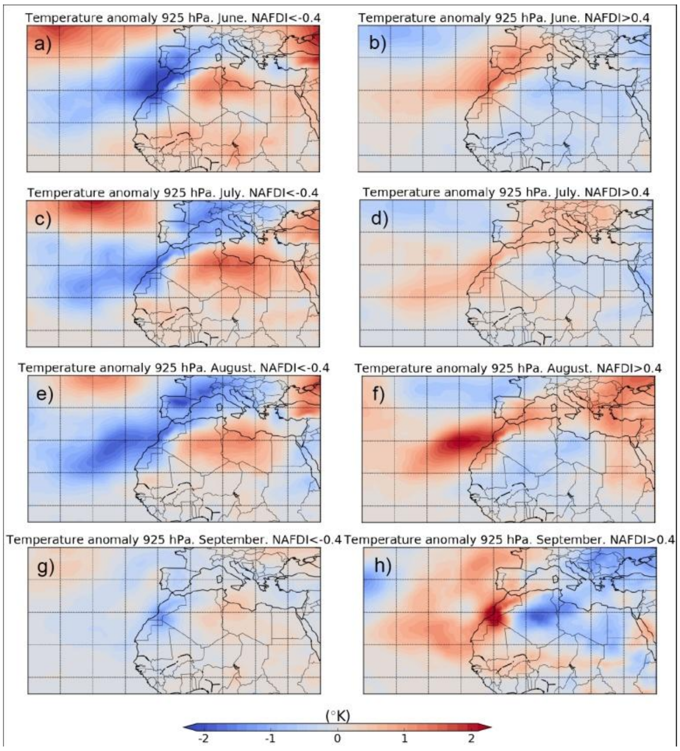
References:

Holton, J. R.: An introduction to dynamic meteorology, Third edition, International Geophysics Series, vol. 48, Academic Press, San Diego, California, 1992.

Lavaysse, C., Flamant, C., Janicot, S., and Knippertz, P: Links between African easterly waves, mid-latitude circulation and the intra seasonal pulsations of the West African Heat Low, Quart. J. Roy. Meteor. Soc., 136, 141 – 158, DOI: 10.1002/qj.555, 2010b.

MC-8. The use of the geopotential at 1000 hPa should be used with a lot of caution due to the topography of the region. The value is provide by using an linear interpolation technique that can influence the results.

We only used the 1000 hPa level for temperature anomalies analysis. We have replaced 1000 hPa by 925 hPa, the lowest level considered no very affected by the topography, in the new manuscript version. As the Referee can see, the results are quite similar in both levels.


Temperature anomaly 925 hPa. June. NAFDI<-0.4
a)
Temperature anomaly 925 hPa. June. NAFDI>0.4
b)
Temperature anomaly 925 hPa. July. NAFDI<-0.4
c)
Temperature anomaly 925 hPa. July. NAFDI>0.4
d)
Temperature anomaly 925 hPa. August. NAFDI<-0.4
e)
Temperature anomaly 925 hPa. August. NAFDI>0.4
f)
Temperature anomaly 925 hPa. September. NAFDI<-0.4
g)
Temperature anomaly 925 hPa. September. NAFDI>0.4
h)
(°K)
-2
-1
0
1
2