A study of the influence of the Saharan Air Layer on tropical cyclones using TOMS data

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1. Introduction

Saharan dust that crosses periodically the North Atlantic in the air layer between 1000 and 5000 meters (Saharan Air Layer (SAL)) may play a role in the genesis and the evolution of tropical cyclones (TCs). The SAL constitutes a dry air region and its presence usually coincides with the presence of a mid-level jet, which enhances vertical shear. Further, it modifies the radiation amount at surface level by reflecting and absorbing a part of the incident solar radiation and also induces a strong temperature inversion, thus inhibiting convection. These air mass characteristics should tend to inhibit cyclogenesis and cyclone intensification (Dunion and Velden, 2004; Evan et al., 2006; Wu et al., 2006; Niscovic et al., 2008).

In contrast, other studies (Karyampudi and Carlson, 1988; Shu and Wu, 2009; Braun and Shie, 2008; Tripoli et al., 2007) suggest a rather positive SAL influence on the transformation process of easterly waves into tropical cyclones.

Further, SAL could also supply the deep convective TC regions in additional CCN. In this case, under certain conditions, the resulting increase in droplet concentration could induce an inhibition of the warm rain production process, a redistribution of momentum, vertical velocity and liquid water content (Molinié and Pontikis, 1995; 1996; Pontikis et al., 2004) in these regions, thus strengthening convection and influencing the TC evolution. The microphysical Saharan dust effect on TCs has been investigated by Cotton et al. (2007; 2008) and Zhang (2007). The results of these studies seem to support a rather negative influence of SAL on TCs. Note however that, because of the lack of data, the properties of Saharan dust acting as CCN are not well known and consequently not accurately represented in these model studies, thus strongly limiting the corresponding conclusions.

This paper presents some preliminary results of an attempt to check the role of the SAL on cyclogenesis and cyclonic evolution by using TOMS aerosol index values and corresponding TC observations for the 1979-2007 period.

2. Data and methodology

A tropical North Atlantic box within 0-30N latitude and 15W-60W longitude limits has been defined. This box delimits the area for which dust and TC activity have been considered. Two indicators have been used as dust indicators: the mean TOMS absorbing aerosol index AI for a given time laps and the total number P of TOMS boxes (1°latitude x1.25°longitude) corresponding to a positive AI value for the same time laps (dust covered boxes). The AI values are available for the following time lapses: 1979-1993 (TOMS -Nimbus 7 (N7t)), 1996-2005 (TOMS-EP-PEGASUS-XL (EP)) and 2005-today (OMI-Aura (OMI)) at TOMS' web site (http://toms.gsfc.nasa.gov/aerosols). The data for the time laps 1993-1996 are missing or partially missing. From 2002 to 2004, the AI and P values appear to be abnormally high compared to the values obtained during the previous years. The overestimation has been confirmed by comparing the EP and OMI P values for the time period during which EP and OMI measurements overlapped

(09/09/2004-31/12/2004). Thus, the data considered in this study cover the following periods: 1979-1992, 1997-2001, 2005-2006.

Usually, the cyclonic activity may be represented by using either the tropical cyclone day number (CD), as in Evan et al. (2006), or directly by using the number of named cyclonic perturbations (C) that crossed the Atlantic box in the considered time period. By defining CD as the number of days during which at least one named cyclonic perturbation was present in the above mentioned box and plotting C versus CD (Figure 1) for the 20 August to 30 September time laps (during which more than half of the yearly tropical cyclones occur), a strong linear correlation (correlation coefficient = 0.91) appears. Thus, in this work, the C number has been directly used to represent cyclonic activity.

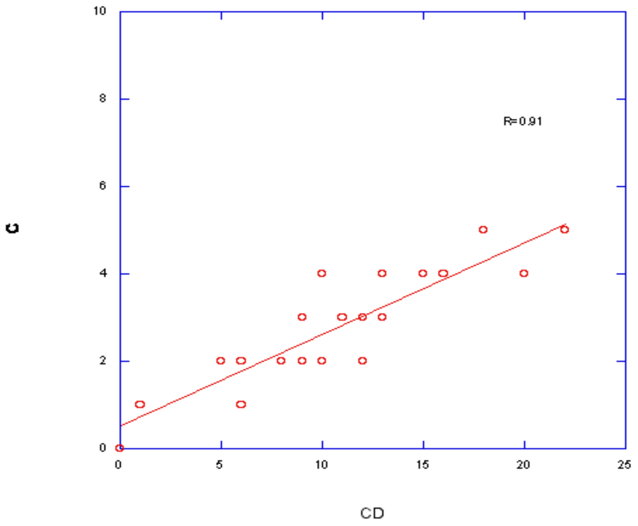

Figure 1 : Number of named cyclonic perturbations (C) present in the 0°-30° N/15°-60° W box versus the corresponding cyclonic days (CD), in the time lapse 20 August-30 September, between 1979 and 2006.

The behaviors of AI, P and C have been simultaneously studied in order to determine the possible correlations between these parameters and also the conditions under which dust may act or not act favorably on cyclonic genesis and evolution. Further, the spectral distribution of the TOMS elementary boxes (1°x1.25°) has been studied as a function of AI. This distribution may be defined as $\Delta P = F(AI).\Delta(AI)$, whereby ΔP and $\Delta(AI)$ represent respectively the number of elementary boxes containing dust with AI indices between AI and $AI+\Delta(AI)$.

3. "Dusty" and less "dusty" years, cyclogenesis and cyclonic evolution as related to SAL

The mean P yearly value (P_{mean}) has first been calculated for the studied period (roughly 1979-2006). Then, the years for which data was available have been classified according to their P number as “above normal” for $P>P_{mean}(1+0.05)$, “normal” for $P_{mean}(1-0.05)<P<P_{mean}(1+0.05)$ and “below normal” for $P<P_{mean}(1-0.05)$. Table 1 presents this classification. The latter is in good agreement with the classification made by Chiapello et al. (2005) on the basis of the TOMS optical thickness values.

A similar classification is presented in Table 2, whereby the yearly P values and the P_{mean} value have been determined for the time lapse between August, 20 and September, 30. The red and blue color used in this table, indicates respectively years with C numbers above and below the mean C value

(C_{mean}=2.9). It appears that high and low C values may correspond to years with high, moderate and low dust surface extent. This conclusion does not support the idea of a physical correlation between the dust covered area and the cyclonic activity in the considered North Atlantic box.

Table 1. Years corresponding to above normal, normal and below normal yearly P values.

above normal	**1983**, **1984**,**1987**, **1992**
normal	**1981**, **1982**, **1985**, **1986**, **1988**, **1989**, **1990**, **1991**, **1998**, **1999**, **2000**, **2001**
below normal	**1979**, **1980**, **1997**, **2005**, **2006**

Table 2. Years corresponding to above normal, normal and below normal P values corresponding to the time period between August, 20 and September, 30. In red (blue), the years with a C value above (below) the mean C value (Cmean=2.9) for the same time period.

above normal	**1982**, **1983**, **1984**, **1985**, **1986**, **1987**, **1988**, **1989**, **1990**, **1992**
normal	**1981**, **1991**, **1998**, **1999**, **2000**, **2006**
below normal	**1979**, **1980**, **1996**, **1997**, **2001**, **2005**, **2007**

For the studied period, between 20 August and 30 September, 78 TCs were named in the chosen Atlantic box. As from the day it was named and for the days it remained in the Atlantic box, the position of each TC was projected on the corresponding TOMS aerosol index map. The analysis revealed that 18% of the TCs were named, with certainty, in a dusty region. There is a high probability that 35% more tropical cyclones were named in a dusty region, since dust was present in the region surrounding the TC but the absence of data on the TC coordinates, possibly due to cloud contamination, limits this assumption. However, it appears that cyclogenesis is not systematically inhibited by the presence of dust.

Further, for the same studied period and between 20 August and 30 September, the AI values have been used to establish a climatological mean dust distribution map. On this map, presented in Figure 2, the mean AI values range from 0 to 3 and the positions of all considered TCs on the day they were named, have also been plotted. It appears that all but one TC have been named in regions where the mean AI values range between 0.5 and 1.5 and tend to be positioned all around the outline of the 1-1.5 mean AI zone. This behavior suggests the existence of an AI cut-off value (1.5) above which cyclogenesis is impossible. Most probably, above this cut-off value, the dynamic and thermodynamic characteristics of the SAL (shear, temperature inversion, dry air masses etc.) are sufficiently intense to inhibit the evolution of tropical depressions towards the hurricane stage.

The behavior of TCs, when they develop close to SAL dust, may be very different. For example, Figs. 3(a, b, c, d) and 4(a, b, c, d) show respectively the positions of TC Debby between the 22 and 25 August 2006 and the positions of TC Hugo between the 11 and 14 September 1989 projected on the corresponding TOMS AI maps.

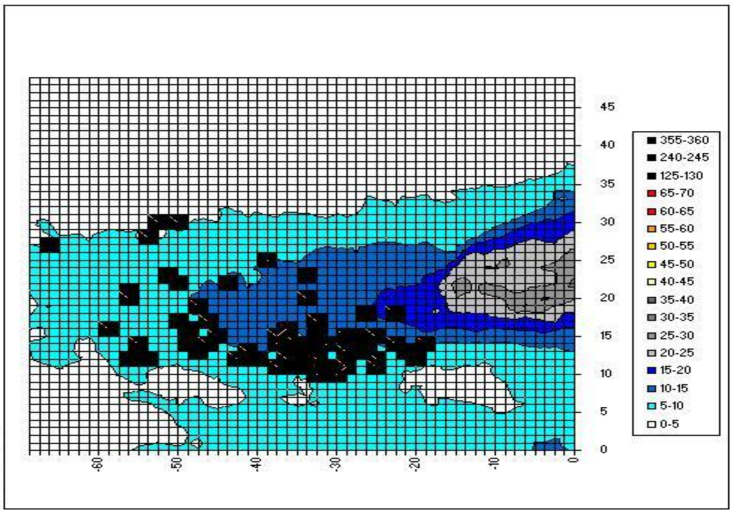

Figure 2 : Mean TOMS aerosol index map corresponding to the 20 August-30 September period from 1979 to 2006 on which the geographical location of all the corresponding TCs, on the day they were named, have been plotted.

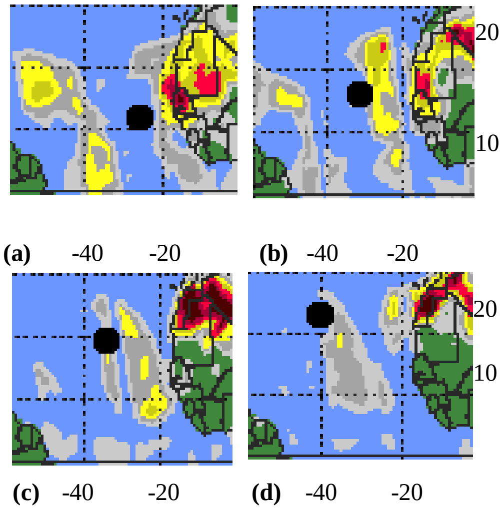

Figure 3 (a,b,c,d) : Tropical storm Debby (2006) 's successive positions (22 (a), 23 (b), 24 (c) and 25 August (d)) plotted on the corresponding daily TOMS AI map (AI=1-1.5 (light grey), 1.5-2 (dark grey), 2-2.5 (yellow), 2.5-3.0 (dark yellow), 3.0-3.5 (red)).

Debby crossed regions with AI values larger than the cut-off value mentioned above. This TC, after a first increasing intensity phase (21-24 August) during which it became a tropical storm started declining and decayed 4 days later (28 August) without reaching the hurricane level. This behavior could suggest that SAL played an inhibitive role in the development of this TC.

Hugo developed at first in the midst of a dusty region and as it moved westwards, it crossed several SAL regions with AI values larger than the AI cut-off value. In contrast to Debby, the intensity of this TC increased continuously and reached the intensity of a class 5 hurricane. Consequently, in the case of Hugo, the presence of SAL dust does not seem to inhibit the TC development. This behavior is in agreement with previous results (Hicks et al., 2008) indicating that although dust seems to affect cyclogenesis, once the TC is formed, the presence of dust doesn't seem to play an inhibitive role any more. In most cases, the cyclone remains at the same intensity and the cases of intensification in presence of dust are more frequent than the weakening cases. Most probably, the microphysical dust properties play an important role in the evolution of tropical depressions.

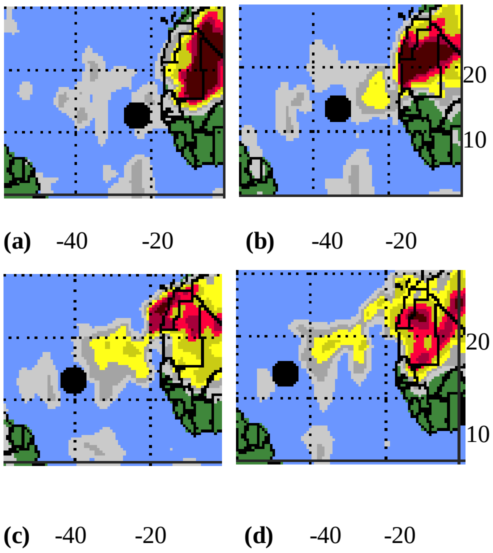

Figure 4 (a,b,c,d): As in Figure 3 (a,b,c,d) for TC Hugo (1989)'s successive positions (11 (a), 12 (b), 13 (c) and 14 September (d)).

4. Microphysical interaction between dusts and cyclones

The AI values are related to the microphysical dust characteristics (radii and concentration). The latter may also influence the TC genesis and evolution since they may act on the vertical velocity and latent heat distribution in the deep convective clouds developing in tropical depressions ((Molinié and Pontikis, 1995; 1996, Pontikis et al., 2004). As a consequence, a given range of sizes of dust particles could influence cyclogenesis and cyclonic evolution. In order to investigate the possible influence of the microphysical dust characteristics, the daily spectral distribution of the TOMS elementary boxes (1°x1.25°) has been studied as a function of AI.

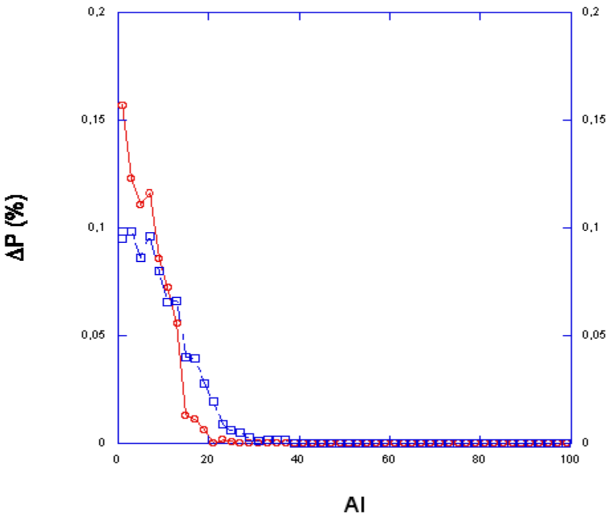

Figure 5 : Example of two daily spectral distributions of TOMS elementary boxes ΔP (x0.01) as a function of Δ(AI) (x10) characterizing days with high (red) and low (blue) AI values<1.

This distribution may be defined as $\Delta P = F(AI)\Delta(AI)$, whereby ΔP and $\Delta(AI)$ represent respectively the number of elementary boxes containing dust with AI indices between AI and $AI+\Delta(AI)$.

Figure 5 presents two different daily P distributions, with respectively high and low percentages of low AI values ($AI<1$) and an inverse behavior in the tail of the spectrum ($AI>1$). A first rough analysis of such distributions reveals that high percentages of low AI values are observed during years characterized by low C values. This trend may be seen in Fig. 6 that presents the C values plotted against the corresponding mean number of elementary boxes containing dust with AI indices between 0.1 and 0.9 ($P_{1\text{-}9}$ values), for the time lapse 1 July - 30 September.

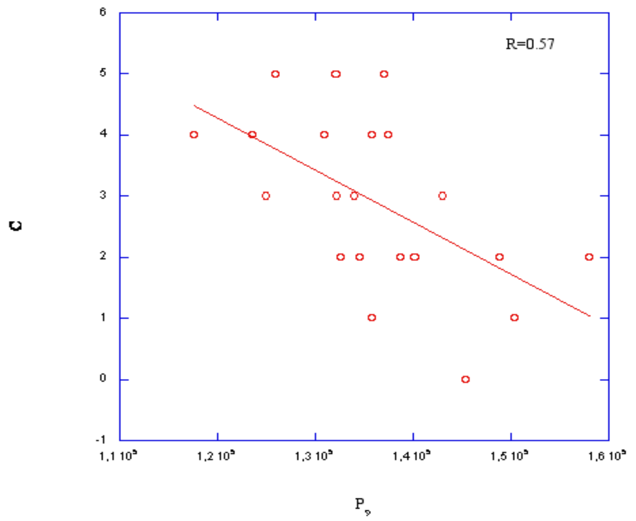

Figure 6. C values plotted against the corresponding mean $P_{1\text{-}9}$ values for the time lapse 1 July to 30 September (correlation coefficient : 0.57).

The inverse relation between C and $P_{1\text{-}9}$ suggests an interaction between the dynamic, thermodynamic and microphysical characteristics in the convective regions of the cyclonic system.

5. Conclusion

In this work, the role of the SAL and associated dust on the genesis and the evolution of tropical cyclones in the tropical North Atlantic basin have been studied by using TOMS data.

The relative absence of cyclogenesis in the Atlantic regions where the TOMS aerosol index value is high ($AI>1.5$), shows that SAL acts as an inhibitor of cyclogenesis in the North Atlantic regions where its dynamic and thermodynamic characteristics are intense.

The behavior of the tropical cyclone number as a function of the dust cover reveals that the influence (if there is one) of the SAL dust on tropical cyclones may be sometimes negative, thus decreasing the number of observed storms and sometimes null or positive.

This ambiguous behavior could result from the combined action of SAL's dynamic and thermodynamic characteristics and the corresponding chemical and physical dust characteristics. The latter could drive the microphysical properties of the cyclonic system. Indeed, the presence of dust entrained inside the cyclonic system and acting as CCN may influence the convective development at appropriate regions of the system, thus enhancing or inhibiting the cyclonic intensity. Note however that the CCN efficiency of Saharan dust is still not clear. Further studies are necessary in order to confirm or to infirm such speculations.

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