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# Effect of Sea Salt AOT on Precipitation Processes Associated with Red Sea Moisture Flux on Iraq, a Case Study

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## ABSTRACT

Sea salt acquires importance in the process of precipitation formation through its hygroscopic nature. and its role in accelerating the droplet formation process within a moisture saturation less than if it was not present. In this work, the maps of precipitation distribution with sea salt aerosol optical thickness (AOT) as well as moisture flux and wind at an altitude of 50 meters were compared. The data of Three rainy cases, characterized by heavy rains and moisture feeding from the Red Sea were selected. They are respectively 13 to 15 November 2018, 1 December 2018, and 27 to 29 January 2019. Cloud top temperature (CTT) data were obtained from Meteosat satellites (Meteosat 9, and 10). Total Precipitable water (TPW) and sea salt (AOT) were obtained from Model projects: a modern-era retrospective analysis for research and applications 2 (MERRA-2). the correlation coefficient (R) was used to test the relation between the variables like Total Precipitable water (TPW), Cloud top temperature (CTT), precipitation, and Sea Salt AOT. The results showed that there is a good correlation between the sea salt AOT and the amount of precipitation. The work also showed the roles that other variables play in the precipitation process. Where the relationships showed values of correlation coefficients about 0,6 to 0,7 between the variables, leading to the enhancement of precipitation.

**KEYWORDS**: Sea salt AOT; precipitation; Total Precipitable water TPW; Cloud top temperature CTT.

الخلاصة

يكتسب ملح البحر اهمية في عملية تشكل الهطول من خلال طبيعته الميالة الى الاتحاد بالماء Hygroscopic ، ودوره في تسريع عملية تشكل القطيرات ضمن اشباع رطوبي اقل من ما لو لم يكن موجودا.في هذا العمل تم مقارنة خرائط توزيع الامطار وخرائط توزيع تركيز ملح البحر وكذلك فيض الرطوبة وحركة الرياح على ارتفاع 50 متر. لقد تم اختيار ثلاث حالات مطرية اثرت على العراق تميزت بغزارة الامطار و فيض رطوبي مصدره البحرالأحمر, وهذه الحالات هي : 13 الى 15 تشرين الثاني 2018, 1 كانون الأول 2018, 27 الى 29 كانون الثاني. لقد تم الحصول على بيانات درجة حرارة قمة الغيمة CTT من بيانات الأقمار الصناعية متيوسات (متيوسات 9 و متيوسات 10). اما بيانات المحتوى المائي الكلي TPWواملاح البحر فقد حصلت من مشروع نموذج (MERRA-2). لقد استخدم معامل الارتباط R لاختبار مدى العلاقة بين المتغيرات مثل المحتوى المائي الكلي TPW ودرجة حرارة قمة الغيمة CTT و كميات الهطول. بشكل عام بينت النتائج ان هنالك ارتباطا جيدا بين قيم الهطول واملاح البحر. كذلك بين العمل الدور الذي تضطلع به المتغيرات الأخرى في عملية الهطول. حيث بينت معاملات الارتباط بين المتغيرات قيما بين 0.6 و 0.7 وصولا الى تعزيز عملية الهطول.

## INTRODUCTION

In previous years, there was a noticeable increase in the incidence of torrential rains, which are caused by heavy rains around the world. Extreme weather events are likely to become more intense and More repeat as the climate warms, threatening populations and making environments more dangerous [1].

Cloud condensation nuclei CCN define as a particle that can nucleic the cloud droplet, it is a solid or liquid aerosols particle that has the ability to water solubility, such as salt particles [2]. Sea salt conceded as a Hygroscopic. It is naturally present in the air [3]. Sea salt is the main source of cloud condensation nuclei CCN [4]. Sea salt is produced by breaking waves at oceans coastal [4]. Many works have dealt with this topic, Yang and other 2019 [6] tray to assess Sea Salt and Non-Sea Salt (marine and continental) aerosols in rainwater and their source pathways. over the western Ghats in the

Indian peninsula. Where the air masses were classified into two distinct groups (oceanic and continental) during the summer monsoon period. they suggest that aloft dust and sea salt forms a perfect sandwich to provides favorable conditions to the formation of precipitation. Horowitz and others 2020 [7] studied the effects of sea salt aerosol emissions for marine cloud brightening. The work is considered as one of the suggested solutions for global warming, by emitting sea salt aerosols to the tropical marine boundary layer, which increases aerosol and cloud albedo. Dadashazar and others 2016 [8] uses aircraft information from multiple regions campaigns, off the California coast to understand the relationships between giant sea salt particles and clouds inferred, and measurement the effect of sea salt particles, on marine stratocumulus cloud properties. Chieh Chen. et. all [9] studied the impact of aerosols on warm cloud microphysics and they suggested that the presence of aerosols enhances the concentration of condensation nuclei under the quantitative water content, this increases the number of droplets in the cloud, and these changes subsequently alter the cloud age and precipitation process. This work aims to assess how sea salt particles affect the heavy rainfall cases in Iraq due to Red sea moister fluxes. The importance of this work lies in the limited studies of the impact of sea salt on the precipitation in Iraq.

## MATERIAL AND METHODOLOGY

Cloud top temperature CTT image view shows the temperature of whatever the satellite is looking at, including clouds, land or water. The temperature is displayed on a chromatic scale with red and yellow indicating very cold cloud tops and therefore very strong storms reaching into the stratosphere. Gray and white indicate warmer clouds as well as clear weather with no clouds at all. Because this view uses infrared radiation to produce its images instead of the sun's radiation, it can be seen both day and night. The increased aerosol loading, to the deepening of the clouding systems [10]. Under higher aerosol loading, the liquid water content increased especially supercooled liquid droplets above the freezing level [10]. Total precipitable water TPW is derived by integrating atmospheric column moisture [11]. The sea salt AOT, precipitation, and total precipitable water TPW can be obtained from Model projects: Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA -2) [10]. TPW represents the mass of water (kg) in one cubic meter. Moisture and wind distribution maps were used to trace the source of sea salts. While other maps were used to examine the extent of congruence between the temporal and spatial distribution of sea salts and the distribution of other variables such as precipitation. Cases were identified as shown in Table (1) then maps of TPW, sea salt AOT, and precipitation were extracted from MERRA -2 and compared with CTT image. Thus, it is possible to follow the scattered relationships between the variables and the extent to which they are related to each other. The correlation coefficient R can be used to measure the relationship between variables.

### Dataset

Modern-Era Retrospective analysis for Research and Applications, Version 2 (MERRA-2) provides data from 1980 [12]. MERRA-2 aerosol reanalysis attempts to take advantage of the best features of both models and observations to produce Four-dimension grid output, that combines model continuity with real observations, which look different from each other and/or far apart temporally and spatially. The aerosol information consists of the split analysis technique that uses AOD information at 550 nm considering the following sources:

(1) Data from the Advanced Very-High-Resolution Radiometer (AVHRR) sensor (1979–2002); (2) Data from the MODIS on Terra (2000–present) and Aqua (2002–present); (3) AOD retrievals from MISR (2000–2014); and (iv) AOD measurements from AERONET (1999–2014) [12]. Aerosols, optically characterized at eight wavelengths (340, 380, 440, 500, 675, 870, 940, and 1020 nm) were used for satellite validation and large-scale models. AERONET solar photometers use spectral ranges of 340–1020 nm and 440–1020 nm for direct sunlight and diffuse skylight, respectively. AERONET can Measures AOT values at wavelength >440 nm with uncertainty about ±0.01, and ±0.02 for shorter wavelengths [13]. AERONET algorithms were recently updated to version 3, with real-time quality checks for clouds, and faster AOT data processing. Daily

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MODIS Level 2 AOT data are also produced with a spatial resolution of 10 km × 10 km [14]. To maximize monitoring coverage, AOT retrievals on land and sea are derived from the dark target algorithm and the deep blue algorithm (measurements on bright surfaces such as deserts and urban areas), respectively. On Earth, the MODIS uncertainty at AOT is 0.05 ± 0.15 [13].

Cloud top temperature CTT is obtained from Meteosat satellites (Meteosat 9, and 10). Meteosat 9 provides a quick 5-minute image scan of Europe, and Meteosat 10 provides a broader view of all of Europe and Africa with images available every 15 minutes [10]. Three rainy cases were used as shown in Table 1:

**Table 1.** Cases locations and moisture feeding.

| Date | Location effect | Moisture feeding |
|---|---|---|
| 13 to15 NOV 2018 | Middle and south Iraq | Red sea basin |
| 1 DEC. 2018 | north and middle of Iraq | Red sea basin |
| 27 to 29 JAN 2019 | Over all of Iraq | Red sea basin and West Africa |

## RESULTS AND DISCUSSION

According to cases from 13 to 15 NOV 2018 two rainy days affect southern Iraq. The accumulated amount of precipitation reaches 50 mm as shown in Figures 1, 2. an increase in sea salt AOT can be seen at the same location where precipitation formed. At 12 Z on November 14, 2018, the precipitation focused on the areas of southern and southwestern Iraq, as shown in Figure 1, where the area was colored greenish-blue and violet, indicating heavy rain. At the same time, Figure 2 shows that the concentration of sea salt AOT increased in the same precipitation areas, where the areas of southern and southwestern Iraq were colored blue-green, which indicates the high concentration of sea salt AOT, and these colors extended to the Red Sea Basin.

Figure 3, shows the transfer of moisture flux from the Red Sea region towards the precipitation areas in Iraq. Figure 4, shows the wind direction at a height of 50 meters, showing the south and southwest winds blowing from the Red Sea region to the precipitation areas over Iraq. It seems that the source of sea salt AOT comes from east of Africa where the red sea is located as in Figures 3 and 4.

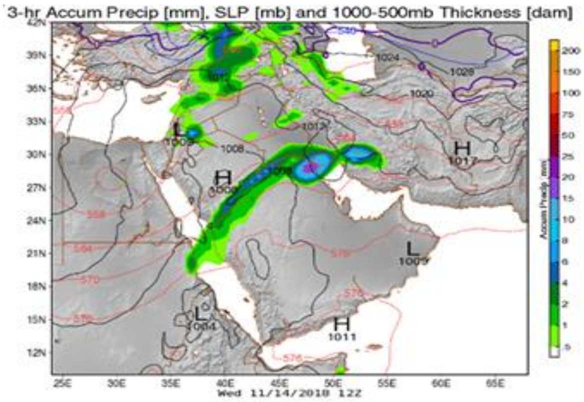


**Figure 1.** Distribution of precipitation mm/3h 14NOV.2018 12Z.

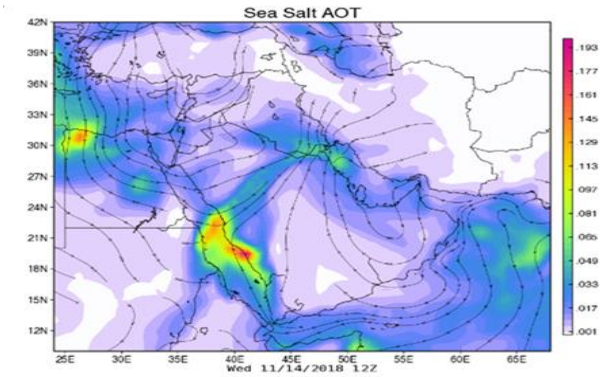


**Figure 2.** Sea salt AOT 14 NOV.2018 12Z.

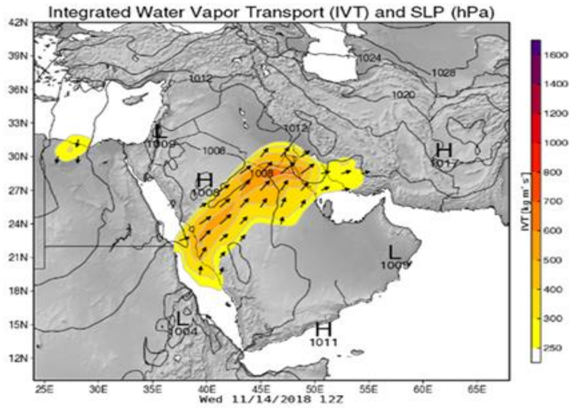


**Figure 3.** Integrated water vapor transport (IVT) 14 NOV.2018 12Z.

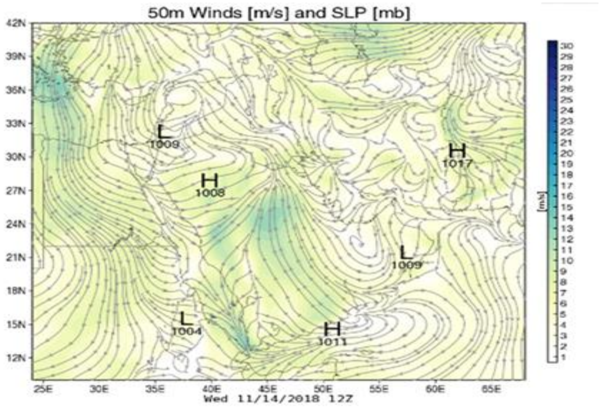


**Figure 4.** 50 m winds [m/s] 14NOV.2018 12Z.

Figure 5, shows a case of heavy precipitation in the 1st of DEC. 2018 effect on north and middle of Iraq. Where the areas marked in violet and blue in northwestern Iraq are the areas that are exposed to heavy precipitation at 03 Z. The amount of rain reaches more than 50 mm per 24 hours. At the same time, an increase in sea salt AOT can be seen in the same location where precipitation formed as shown in figure6. Where it is clear that a belt of air carrying relatively large quantities of sea salt extends from the Red Sea region to the region of heavy precipitation in northwestern Iraq. It is marked in greenish-blue as well as yellow to indicate the high concentration of sea salt.

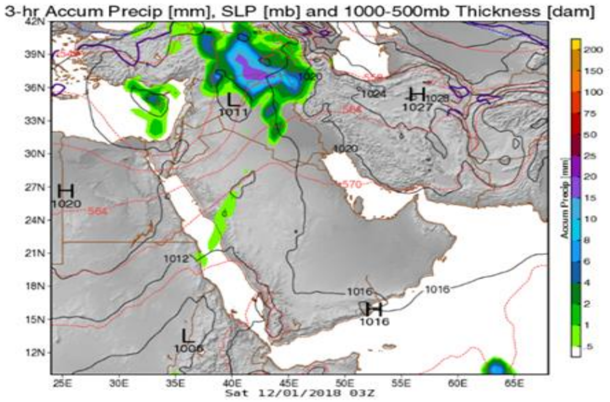


**Figure 5.** Distribution of precipitation mm/3h, 1 DEC. 2018 03Z.

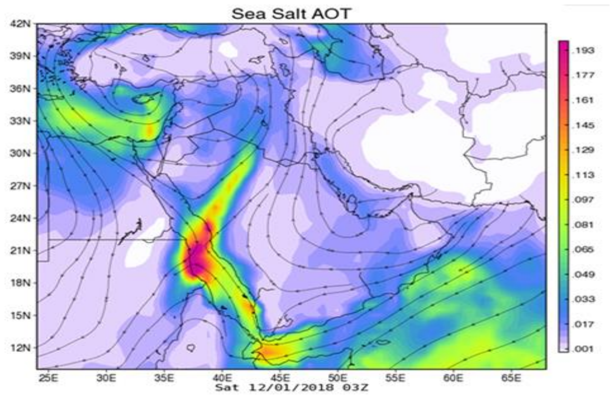


**Figure 6.** Sea salt AOT 1 DEC. 2018 03Z.

Figure 7 show that: the source of feeding the moisture flux is from Red sea basin. The wind direction at a height of 50 meters (Figure 8), which blows from the coast of the Red Sea towards the precipitation areas over Iraq, reinforces the belief that the source of sea salt is from the Red Sea Basin.

In the case from Jan. 27 to 29 2019 the accumulated amount of precipitation reaches more than 50 mm. The same phenomenon has occurred when the sea salt AOT increased where precipitation was formed especially in southwestern Iraq as shown in Figure 9, which Shows areas of heavy rain in southern Iraq. While Figure 10 shows the sea salts AOT that appear on the map in the form of a belt loaded with sea salt extending from the Red Sea region towards the precipitation areas in Iraq.

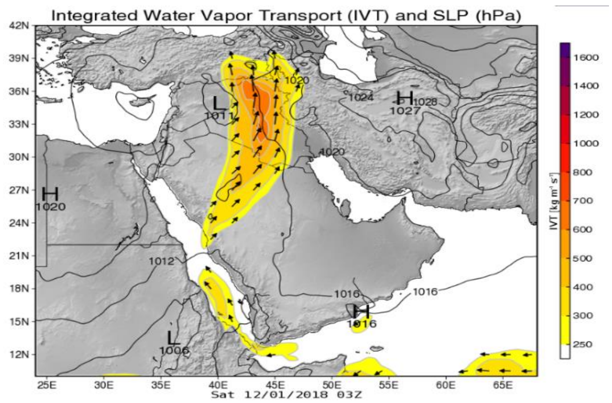


**Figure 7.** Integrated water vapor transport (IVT) 1 DEC. 2018 03Z.

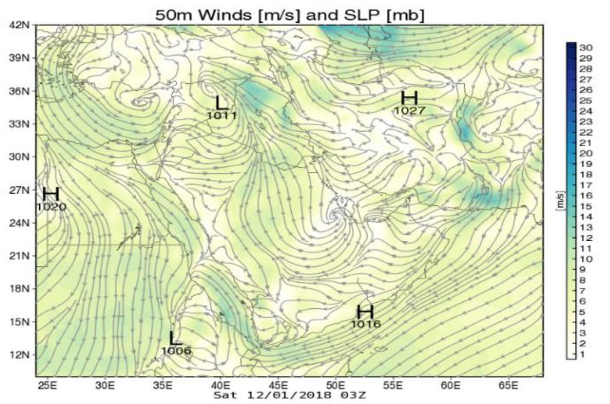


**Figure 8.** 50 m winds [m/s] 1 DEC. 2018 03Z.

According to the moisture flux map Figure 11, show that is coming from the Red sea basin. winds map in Figure 12, showed that the winds were blowing from the Red Sea region towards the precipitation areas in Iraq. So, most of sea salt AOT is coming from the southwest where the red sea is located.

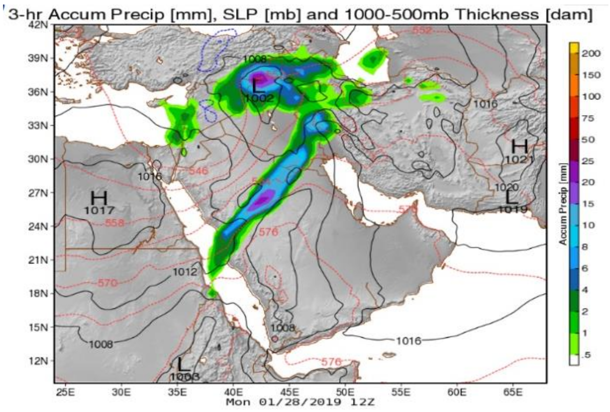

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**Figure 9.** Distribution of precipitation mm/3h, 28 JAN. 2018 12Z.

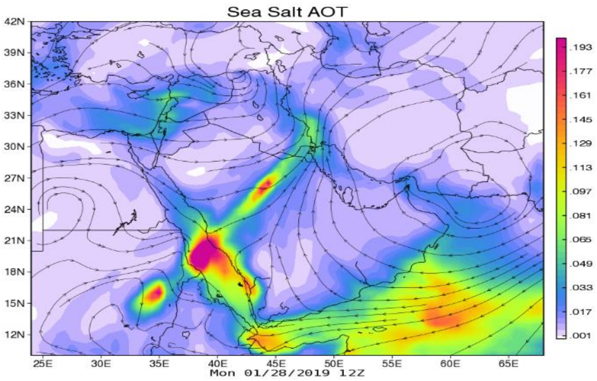


**Figure 10.** Sea salt AOT 28 JAN. 2019 12Z.

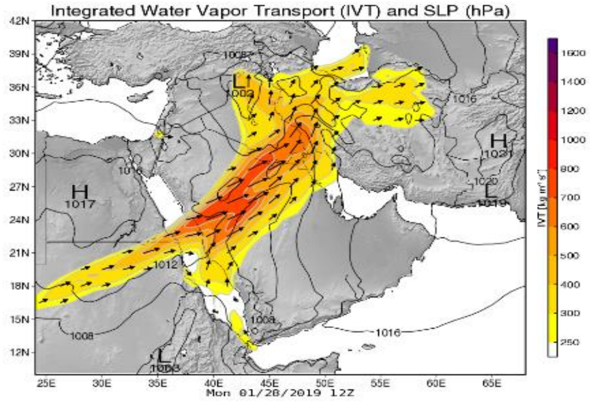


**Figure 11.** Integrated water vapor transport (IVT) 28 JAN. 2019 12Z.

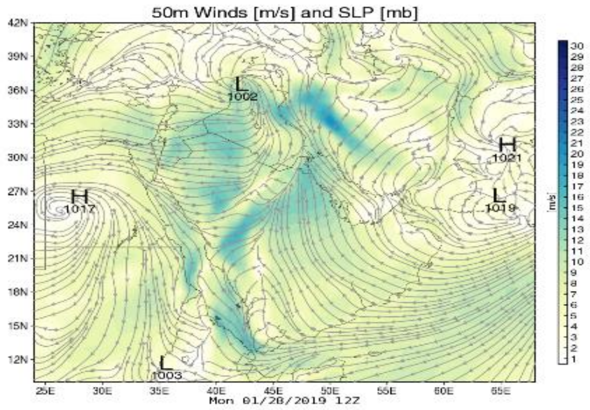


**Figure 12.** 50 m winds [m/s] 28 JAN. 2019 12Z.

The association between the amounts of precipitation and the concentration of sea salts in the three cases encourages the study of the statistical correlation of this phenomenon. Simple linear regression and the correlation coefficient were chosen to evaluate the relationships between the variables according to an acceptable physical interpretation, as follows: In general, the relationship between precipitation values and sea salt AOT (S.S) tends to be directly proportional as shown in Figure 13. The correlation coefficient for this relation is about 0.7 The scattering of the values led to a decrease in the value of the correlation coefficient. This indicates that sea salt is not the only variable affecting the precipitation process, but it is one of the important factors.

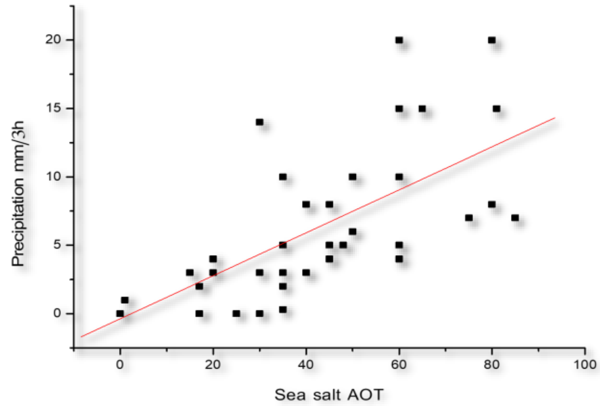


**Figure 13.** The relation between Precipitation and Sea salt AOT.

The relation can be represented by equation (1) which is considered as an empirical equation, with correlation coefficient about R = 0.7

$$\text{Precipitation} = -0.36 + 0.16\ \text{S.S} \qquad (1)$$

It is appropriate to explain the sequence of processes related to the development of condensation nuclei and the formation of clouds, to the formation of precipitation. The effect of sea salt AOT (S.S) on cloud stricture is showing in Figure 14. when the sea salt AOT increasing the cloud top temperature (CTT) will be decreased, it works as condensation nuclei that increase the condensation processes and release latent heat, which leads to an increase in the convective inside the cloud and increases in cloud top height. this is mean deep cloud will form.

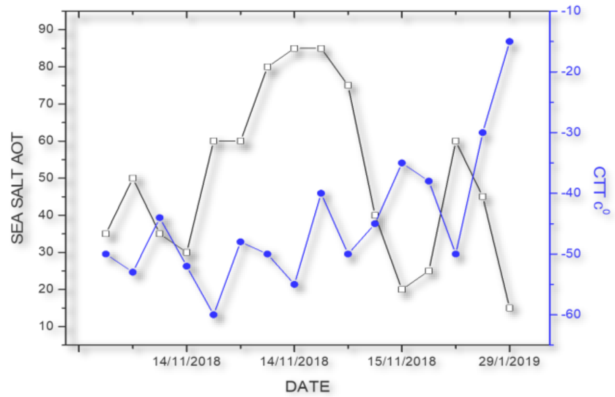


**Figure 14.** The form of the change of CTT and Sea Salt AOT values for the three cases understudy.

The relationship between CTT and sea salt AOT can be explained in Figure 15 which is showing the inverse proportion between two variables.

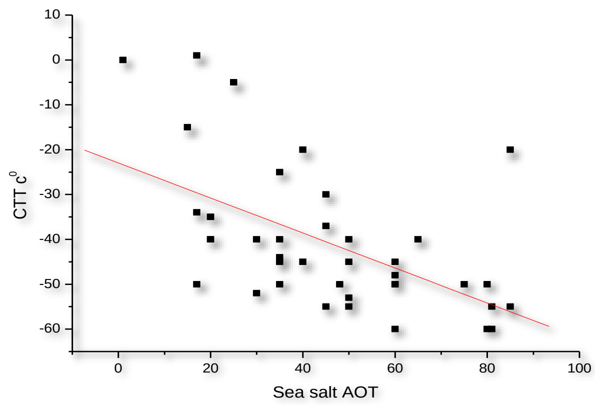


**Figure 15.** The relation between Sea Salt AOT and CTT.

The relationship can be represented by equation (2) with a correlation coefficient about R = - o.6

$$CTT = -23 + (-0.4)\ S.S \quad (2)$$

Low CTT and deep cloud lead to ice crystal formed which enhances the seeder feeder process in the cloud where leads to more condensation and droplet growth inside the cloud. So, the total perceptible water TPW will be increased at the same time as showing in Figure 16.

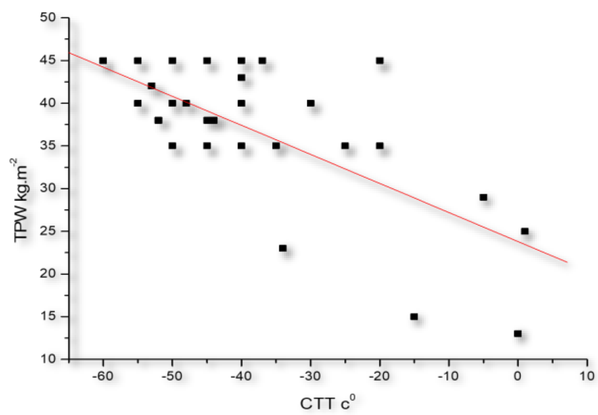


**Figure 16.** The relation between CTT and TPW.

Equation (3) explains the relation above with a correlation coefficient about R = -0.7

$$TPW = 23.8 + (-0.35)\ .\ CTT \quad (3)$$

It is also possible to represent the direct relationship between sea salt AOT and TPW as in Figure 17. The increase in Total Precipitable Water TPW activates and enhances the processes of collision and coalescence between droplets within the clouds, thus increasing the amounts of precipitation.

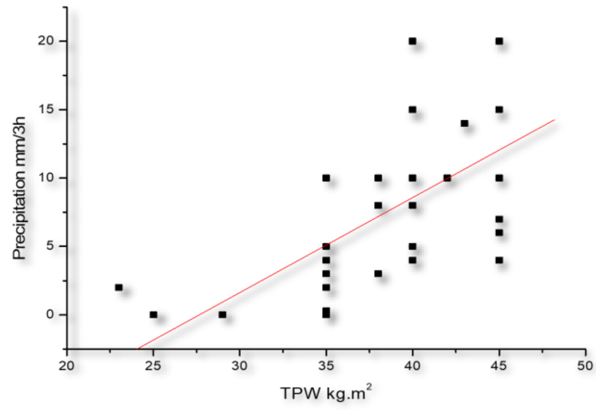


**Figure 17.** The relation between TPW and Precipitation.

The relationship can be represented by an empirical equation (4) as follow:

$$Precipitation = -19.2 + 0.7\ TPW \quad (4)$$

The correlation coefficient for this relation is about R = 0.7.

## CONCLUSIONS:

By following the maps and charts above, It can be concluded that the source of sea salts in the three cases is: The Red Sea Basin region.

Sea salts affect the region of southern and central Iraq, and even the areas of northern Iraq, as in the case of 1 December 2018, where the sea salt reached northwestern Iraq from the Red Sea.

it becomes clear that there is an undoubted relationship between the amount of precipitation and sea salt AOT.This relationship is not direct, it depends on the relationship of sea salt with other variables, such as its relationship with the cloud top temperature CTT, which represents an inversely proportional.

It is expected that there is an effect of other types of aerosols on precipitation processes that were not addressed in this work, such as dust and organic carbon.

It is assumed that attention should be paid to it in similar works to complete the overall conception of the effect of aerosols on precipitation processes.

The decrease in the value of CTT has an effect on the increase in the value of TPW which increases the precipitation finally

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