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Spectral analysis of salt clouds originated at Mar Chiquita lake using remote sensing

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ABSTRACT

Laguna Mar Chiquita, is a permanent saltwater lagoon located in the Argentine province of Cordoba. The extent of the water surface of the Mar Chiquita lagoon has experienced increases and decreases over the years. However, since 2003 the lagoon began a period of regression, exposing large areas of land covered with salt. Since 2006, observations from space with different satellites allowed to document the presence of very white salt clouds originated when fine sediments around the lake perimeter are easily lofted into the air by winds. In this study some examples of salt storms are documented using satellite images captured by MODIS sensor on board of Aqua and Terra satellites and AVHRR sensor on NOAA 18 and 19 satellites. The salt event on 8 July 2012 and 29 July 2012 were investigated with two reflective and two infrared thermal AVHRR bands. It is found that salt clouds are more reflective than the background soil, but less reflective than water or ice clouds, probably because salt clouds have less thickness. Other characteristics of these clouds are that the observed 11µm minus 12µm brightness temperature difference is always negative. Then it could be used for the identification of salt storm outbreak and for the estimation of the spatial extent developed. It can be used in both daytime and night time conditions for automatic identifying of the salt storm. The variation of the temperature difference is also associated with the dust concentration.

INTRODUCTION

Salt clouds or salt storms are a particular case of dust storms. They are commonly observed in arid regions and arise when the wind exceeds a value that allows dust particles to be removed from the surface. Salt storms usually occur in places with large aboveground deposits of salt like Aral Sea and Uyuni salt flat. Salt storms are different from dust or sand storms not only for its origin, but also by their composition and particle size. In addition, they are difficult to predict and control and can contaminate the air, soil, water, food, and cause illness by producing a harmful alteration of ecosystems and the natural environment, and damage to equipment or machinery. By producing a decrease in visibility they are also a problem for transport. As dust storms, they interact with the incident solar radiation, reflecting, absorbing and emitting at a time, thus intervening in the radiative balance and hence on climate. Up to now, studies on the occurrence of salt storms are rare and their distribution and frequency is unknown on a global scale. Since 2006 several salt plumes that blew from Argentina's Laguna Mar Chiquita were captured by NOAA and Aqua and Terra satellites.

Laguna Mar Chiquita is a permanent saltwater lagoon in the Argentine province of Cordoba, north-central Argentina (Fig. 1). To the north are vast expanses of saline marshes. Driven by varying levels of moisture, the shallow lake Mar Chiquita expands and shrinks, reaching about 5,770 square kilometers at its maximum extent, and about 1,960 square kilometers at its minimum and 4 meters deep. For years, too much water has been diverted from the greatest in-flow of the lake, the river Dulce for the industry and the livestock farming in the province of Santiago del Estero. Because of climate changes, the rainfall has diminished and the natural evaporation of the lakes increased. The salt content fluctuates from 25 to 290 g/l depending on the water level (Fig. 2). In periods of extended drought, when the water level drops, fine sediments around the lake perimeter are easily lofted into the air by winds, reducing visibility (Fig. 3) and producing salt clouds which are dispersed in the form of elongated plumes (Fig. 4).

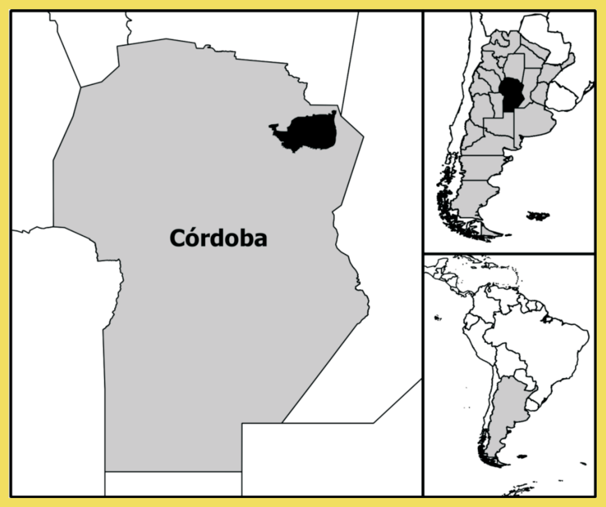


Fig. 1 Geographical location of Mar Chiquita lagoon

Fig. 3 Visibility reduced by the presence of salt dust in the air

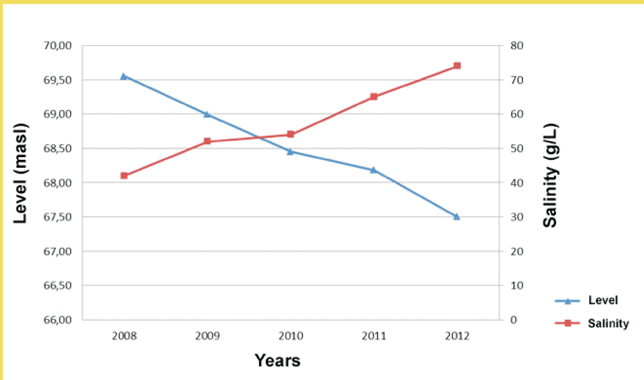


Fig. 2 Variation in the level and salinity of the lagoon

Fig. 4 Natural-color image captured by MODIS sensor on board Aqua satellite, on September 4, 2011. Source: NASA

OBSERVED CHANGES IN THE LAGOON AND EXAMPLES OF CAPTURED SALT PLUMES BY SATELLITE SENSORS AVHRR AND MODIS

The Mar Chiquita lake level shows great variations by year, with its surface area and salinity changing a great deal depending on the weather. Two extreme conditions in the extent of the lagoon can be seen in Fig. 5, a) and b).

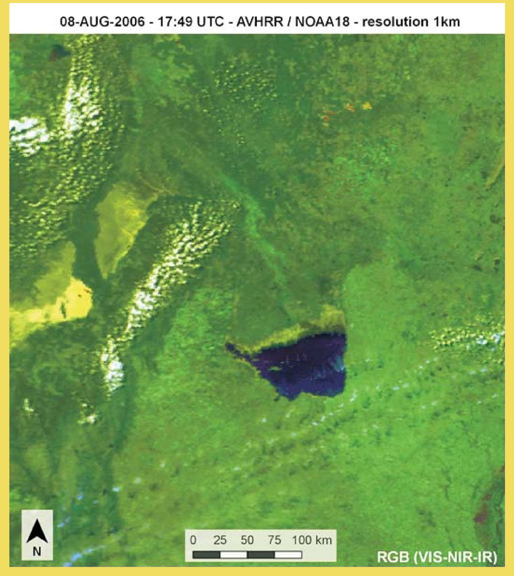


Fig. 5 a)

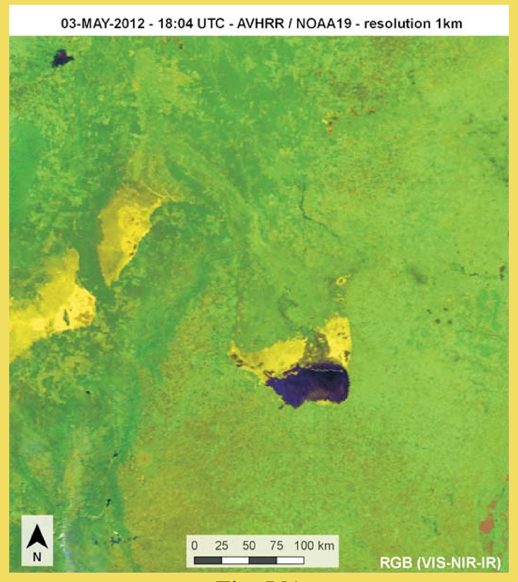


Fig. 5 b)

During this period (2006-2012) several salt storms were captured by the Advanced Very High Resolution (AVHRR) sensor on the NOAA satellites and the Moderate Resolution Imaging Spectroradiometer (MODIS) flying onboard NASA's AQUA and TERRA satellites. Most of salt storms reviewed for this study occurred in conditions of strong southerly winds, with the passage of cold fronts, which are more common in winter, as are most of the documented salt storms. However, some also were observed with strong northerly winds. Two examples are shown in Figures 6 a) and b) and 7 a) and b).

Fig. 6a)

Fig. 6b)

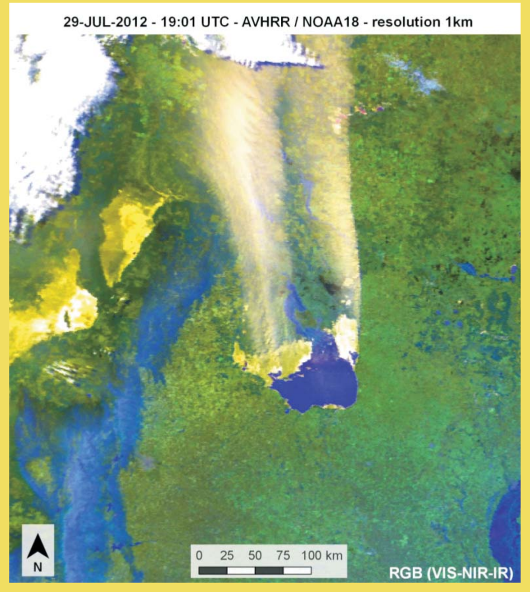


Fig. 7a)

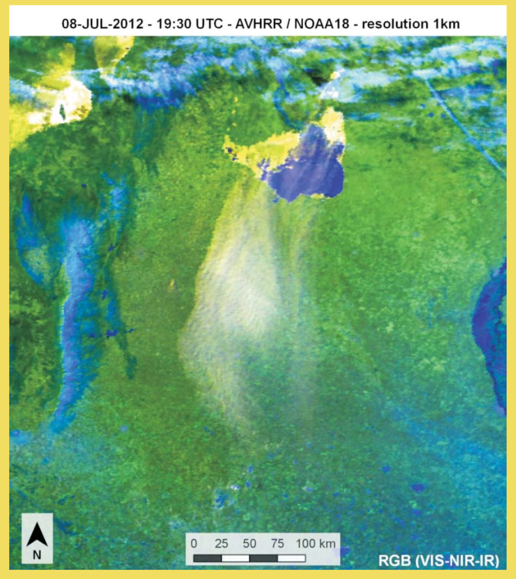
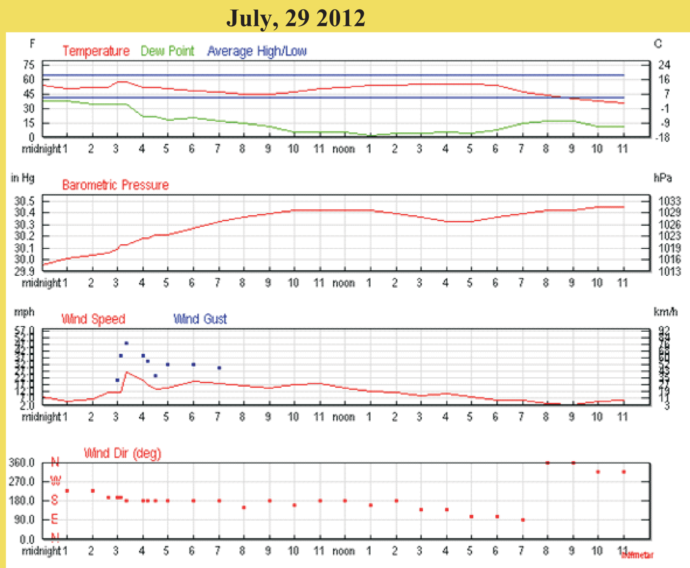


Fig. 7b)

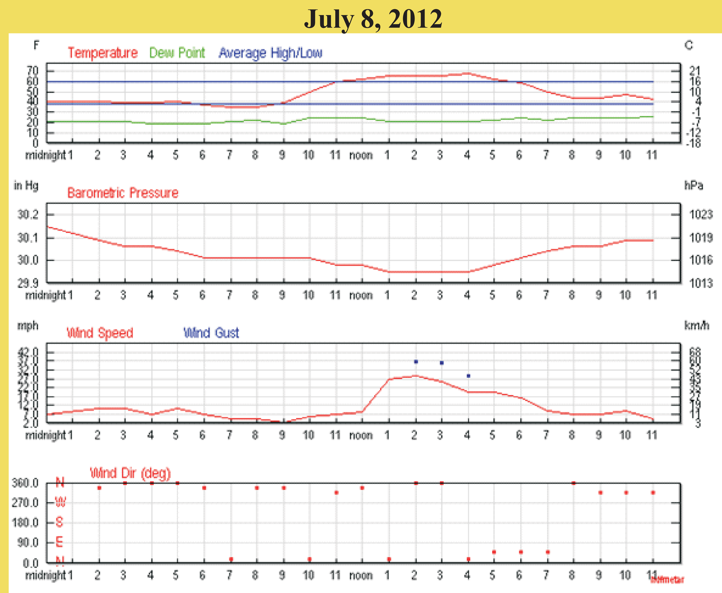
WEATHER CONDITIONS

Weather conditions that prevailed prior to both storms, with high temperatures, low rainfall and high winds favored the evaporation process, being also reinforced by the possible deviations of water from the rivers that feed the lake. In these conditions, winds from certain intensity lift off small particles from the beaches and crawl long distances depending on its intensity, and the conditions of thermodynamic instability that they cooperate to move to greater heights.

July, 29 2012



July 8, 2012



SOURCE: WHEATHER UNDERGROUND

ANALYSIS OF TWO SALT STORMS

On July 8 and 29, 2012 two salt storms were observed by the NOAA-18 AVHRR satellite. The bands used for the analyses are shown in Table 1.

Tabla 1: NOAA AVHRR

Band	Δλ (µm)
B1 (VIS)	0.58 - 0.68
B2 (NIR)	0.72 - 1.10
B4 (IR)	10.30 - 11.30
B5 (IR)	11.50 - 12.50

July 29, 2012

Two plumes of dust blew northward from Laguna Mar Chiquita in Argentina on July 29, 2012. Both are clearly distinguished in the RGB (VIS, NIR, IR) image, in the two reflective images (VIS and NIR) and in (TB4-TB5) image (Fig. 8 a, b and c).

The yellow and yellowish colors in the RGB image is due to the high response of clouds in the reflective bands while white indicates high reflectance and high temperature, as can be observed over the Ambargasta salt flat (Fig.8 a)) In the reflective image (Fig. 8 b)) water or ice clouds, salt flats and beaches, appear brighter than salt plumes, while in the image (TB4-TB5) clouds and salt pans still appear bright but the salt plumes appear dark (Fig. 8 c)). This indicates that the difference image gives additional information to clearly distinguish the two types of cloud. Furthermore, as can be observed, the two plumes are not uniform along its path. A more detailed analysis is shown in Fig. 9, 10 and 11.

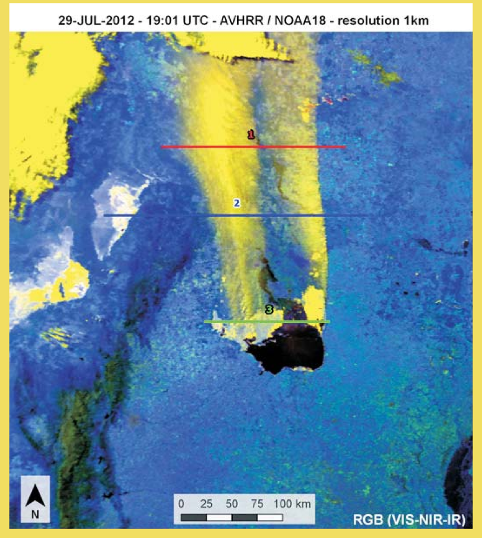


Fig. 8a)

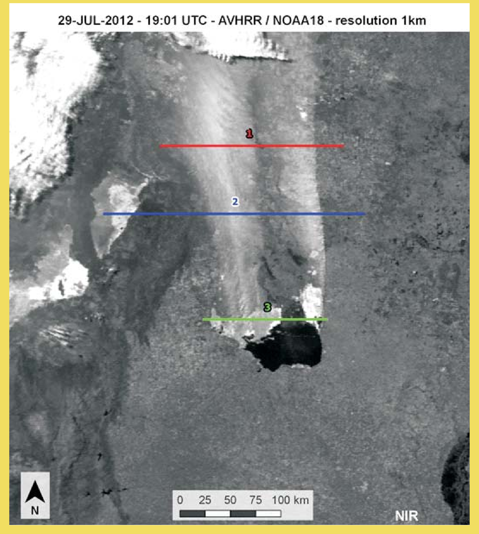


Fig. 8b)

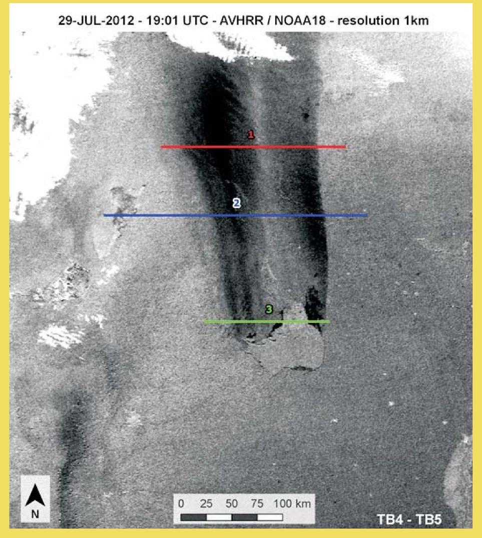


Fig. 8c)

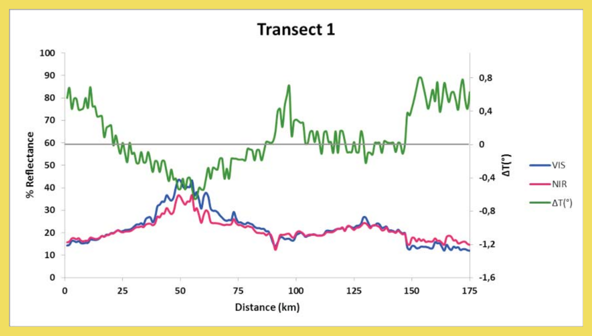


Fig.9 Reflectance (VIS and NIR) and (TB4-TB5) across the red transect in **Fig. 8 b) y c)**

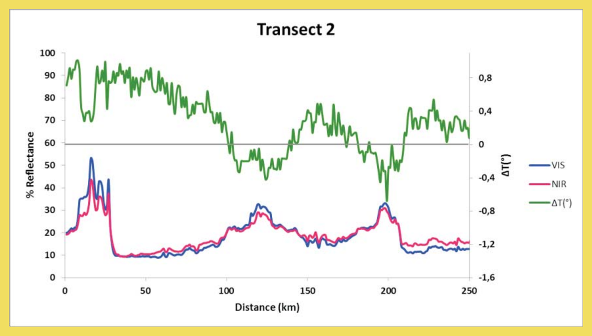


Fig. 10 Reflectance (VIS and NIR) and (TB4-TB5) across the blue transect in **Fig. 8 b) y c)**

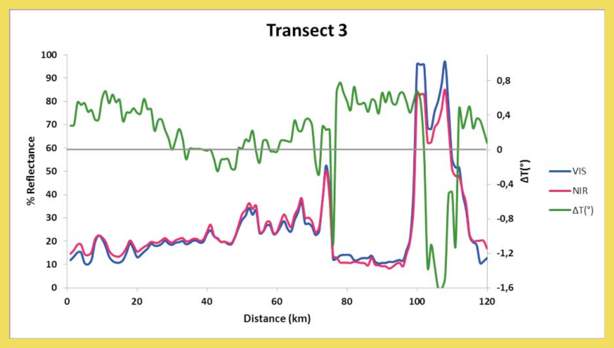


Fig. 11 Reflectance (VIS and NIR) and (TB4-TB5) across the green transect in **Fig. 8 b) y c)**

July 8, 2012

In this date the salt clouds form under conditions of prevailing NNE wind, as opposed to the previous case when wind was blowing from south. Imagery and analysis for this storm is show n in Fig. 12 a), b) and c) and Fig. 13.

Fig. 13) Reflectance (VIS and NIR) and (TB4-TB5) across the red transect in **Fig. 12 b) y c)**

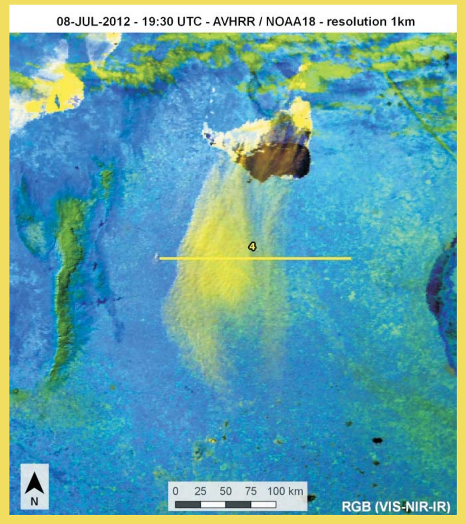


Fig. 12a)

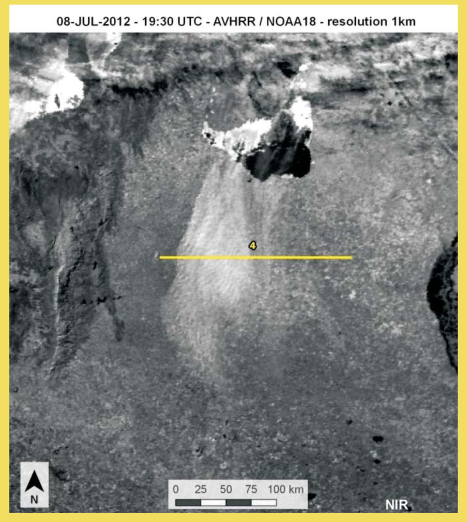


Fig. 12b)

Fig. 12c)

CONCLUSIONS

Salt storms are different from dust or sand storms not only for its origin, but also by their composition and particle size. In addition, they are difficult to predict and control and can contaminate the air, soil, water, food, and cause illness by producing a harmful alteration of ecosystems and the natural environment, and damage to equipment or machinery. By producing a decrease in visibility they are also a problem for transport. As dust storms they interact with the incident solar radiation, reflecting, absorbing and emitting at a time, thus intervening in the radiative balance and hence on climate. Up to now, studies on the occurrence of salt storms are rare and their distribution and frequency is unknown on a global scale.

In this study the use of MODIS and AVHRR images allowed documenting the occurrence of salt clouds near the Laguna Mar Chiquita in the province of Córdoba, Argentina.

The analysis of the spectral responses with AVHRR data allowed us to differentiate the behavior of these clouds with respect to cloud water and / or ice and with respect to saline soils. The salt clouds are characterized by their plume shape and generally have lower reflectance than the other clouds. Obviously, the reflectance value depends on the thickness of the cloud whether they be water, ice or salt. Also, their temperature does not reach as low values as those reached at common clouds, since they have little vertical development.

In some cases it was possible to observe the formation of water clouds along the plumes, depending on the moisture content of the atmosphere and the size of salt particles.

A remarkable behavior founded is related to the temperature difference (TB4 - TB5). This value is negative in the presence of salt clouds, contrary to what is observed on the clouds of water or ice and salt surfaces, forming a suitable index to distinguish salt clouds from other clouds. These negative values were also observed in volcanic plumes, but these differences were an order of magnitude higher.

The salt clouds identification using satellite imagery could be very useful to establish their temporal and spatial distribution, since on this subject there is little information to the present, not only nationally, but also globally.

The difference (TB4 –TB5) is useful too, for the generation of cloud masks, particularly, to calculate land variables, such as vegetation indices.

Analysis of a larger number of cases is necessary to investigate the relationship between the values of the temperature difference (TB4, TB5) and the thickness of the cloud, using this parameter together with some other.

Moreover, it is advisable to investigate whether this phenomenon occurs in another region of the country, in which time of year, and how often they occur.

THANK ENOUGH to Facundo Facio for the help.