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Characteristics of detected salt storms by AVHRR sensor on NOAA satellites from 2006 to 2014 in Argentina

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ABSTRACT

Salt storms only happen in places where there are large deposits of salt on the ground, like those around the Aral Sea in Central Asia, the Great Salt Lake in the United States of America and in the Mar Chiquita Lake, Argentina. These storms are low clouds whose development is similar to dust storms, except for the characteristics of the soil where they originate. Since 2003 the Laguna Mar Chiquita began a period of regression, exposing large areas of land covered with salt. The 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. The occurrence of salt storms near Mar Chiquita from 2006 to 2014 was documented using satellite images captured by sensor AVHRR on NOAA 17, 18 and 19 satellites and downloaded by the receiving station at the Argentina´s Meteorological Service. The observed clouds have different levels of development, from a weak plume to a thick cloud of great extent. The number of observed events varies from year to year and also during the year. Most of the observed storms occurred in the winter months with the winds blowing almost exclusively from the north or south. A number of salt events were analyzed using data from two reflective and two infrared thermal AVHRR bands. Some results for the event on July 8, 2012 are presented. 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 optical thickness and brightness temperature difference (BTD) (11µm minus 12µm) is always negative. Then it could be used for the identification of salt storm outbreak and for the estimation of the spatial extent developed and also for automatic salt storm identification in daytime and night time conditions.

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 satellites.

The 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, of about 4 meters deep, expands and shrinks, reaching about 5,770 km^2 at its maximum extent, and about 1,960 km^2 at its minimum. 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 lagoon´s water level (Fig. 2). In periods of extended drought, when the water level drops, fine sediments around the lake perimeter are easily lifted into the air by winds, reducing visibility (Fig. 3) and producing salt clouds which are dispersed in the form of elongated plumes (Fig. 4). They generally extend from its point of origin (source), directed mainly towards the north or south.

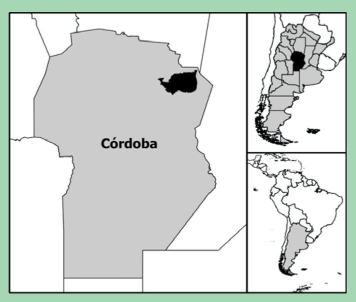


Fig. 1 Geographical location of Mar Chiquita lagoon

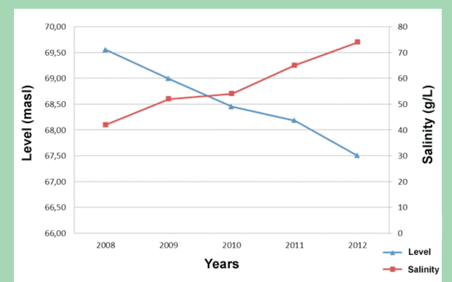


Fig. 2 Variation of the lagoon´s water level and salinity

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

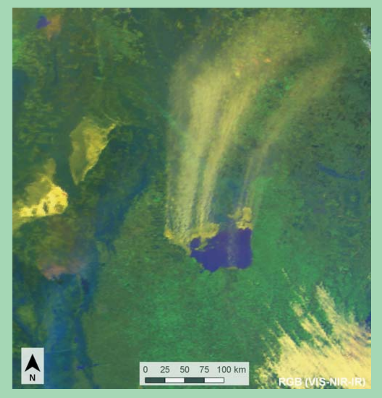


Fig. 4 RGB (VIS-NIR-IR) image capture by AVHRR on board NOAA-18 satellite on September 4, 2011

OBSERVED CHANGES IN THE LAGOON AND EXAMPLES OF CAPTURED SALT PLUMES BY SENSOR AVHRR

The water level of Mar Chiquita shows great variations along the years. Particularly, since 2006, the water level is descending and consequently there are increases on the beaches in their environment, mainly in the northern part of the lagoon, as shown in Figure 5.

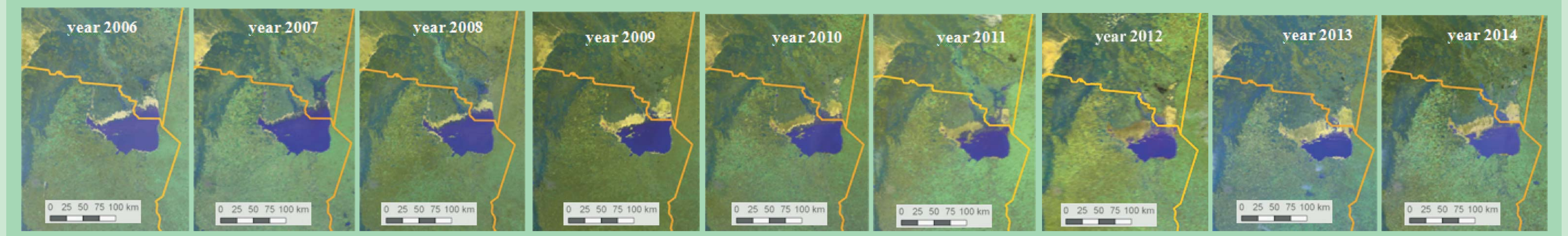


Fig. 5 Changes of Laguna Mar Chiquita water level, 2006-2014. RGB images (VIS-NIR-IR).

During the period (2006-2014) several salt storms were captured by the Advanced Very High Resolution (AVHRR) sensor on the NOAA satellites with spatial resolution of 1.1 km. Most of the salt storms occurred in conditions of northerly or southerly winds. Two examples are shown in Figures 6a) y 6b).

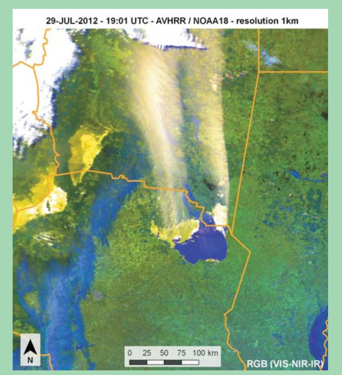


Fig. 6 a) A large salt storm blew northward from the Laguna Mar Chiquita on July 29, 2012

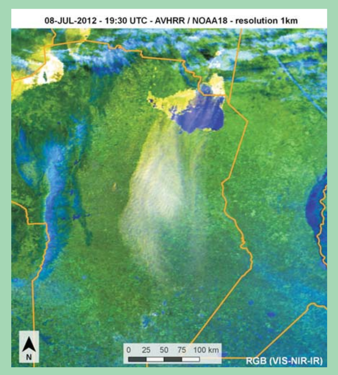


Fig. 6 b) Example of a salt storm blowing southward from the lake on July 8, 2012

DATA AND ANALYSES

Since 1995, NOAA AVHRR images are regularly received, calibrated and archived at the Department of Remote Sensing and Environmental Applications National Weather Service of Argentina. In addition, images are processed to generate products such as vegetation index (NDVI), soil moisture index (NDWI) and other products that may be required from different areas of the Service or from other domestic or foreign Institutions. However, the presence of very white dust clouds began to be seen from 2006.

All images of days with salt clouds observed between the years 2006-2014, captured by NOAA 17, 18, 19 satellites, were calibrated and converted to reflectance or temperatures according to the spectral band (Table I). These images were used to obtain RGB images and also images of temperature difference BTD (TB4-TB5). It has been tested in previous works that the difference is useful for detecting salt clouds and differentiates them from dust clouds or water clouds.

From the analysis of images reflective, RGB and BTD, it was observed that some salt clouds could be distinguished only in the reflective bands or RGB images, while others appeared clearly in all of them (VIS, NIR, RGB, BTD). The first ones, are weak or wispy clouds, while the second ones, could be considered as really salt storms, since they were very thick and extended and some of them for hundreds of kilometers.

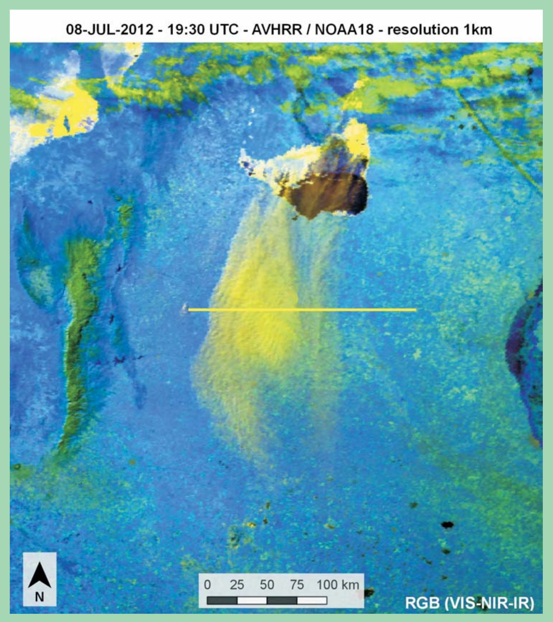
Table I. NOAA AVHRR BANDS.

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

CASE EXAMPLE: July 8, 2012

Prevailing weather conditions for this date were high temperatures, low humidity and strong NNE winds with gusts.

The salt plum is clearly distinguished in the RGB (VIS, NIR, IR) image (Fig. 7a) and in (TB4-TB5) image (Fig.7b.). 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 low temperature, while in the image (TB4-TB5) water or ice clouds still appear bright but the salt plumes appear dark (Fig.7b). This indicates that the difference image gives additional information to clearly distinguish the two types of cloud.



a) RGB (VIS-NIR-IR)

b) TB4-TB5

Fig. 7 July 8, 2012. Image captured by the sensor AVHRR on NOAA 18

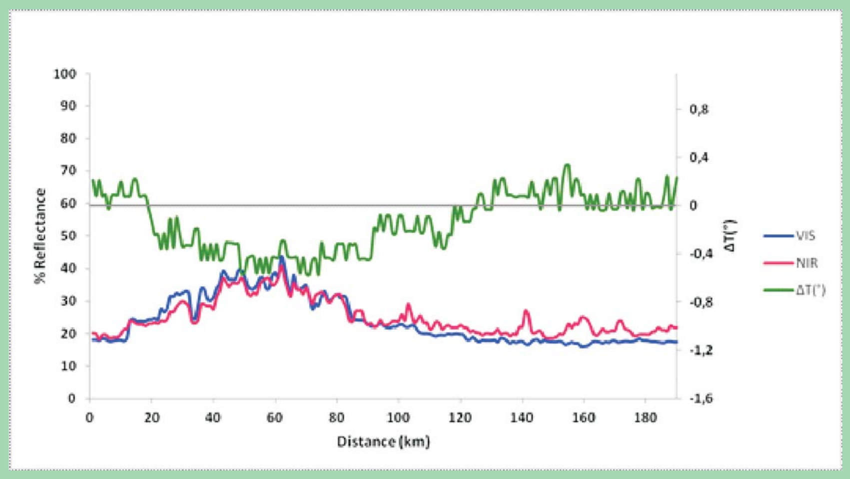


Fig 8 Values of reflectance (VIS and NIR) and (TB4-TB5) along the transect on Fig. 7.

In Figure 8, it is possible to see the variation of reflectance (VIS and NIR) and (TB4-TB5) across the plume and on part of the background. While reflectance values are high across the cloud, the temperature difference is negative.

ANNUAL AND MONTHLY VARIATION

While the archives of received images start in 1995, salt clouds only start to be distinguished in 2006. Since 2006 until 2014, salt clouds were observed in 279 days in images captured by NOAA AVHRR sensor. On some dates, they were captured by more than one satellite.

Clouds were classified as weak or thick, and also they were separated according to the prevailing wind direction (Fig. 9).

The number of days when salt clouds were observed varies from year to year.

The higher frequency of days with intense salt plumes occurred in 2009 and 2013, 29 and 44 days respectively. In those two years in particular, the extent of the water body had fluctuations, leading to increased salt deposit on the shore by retreating water, which partly could explain the high number of events.

The highest frequency of salt thick plumes or salt storms is observed between July and September (Fig. 10), with a prevalence of these events under northern wind conditions, as it is in the case of weak plumes.

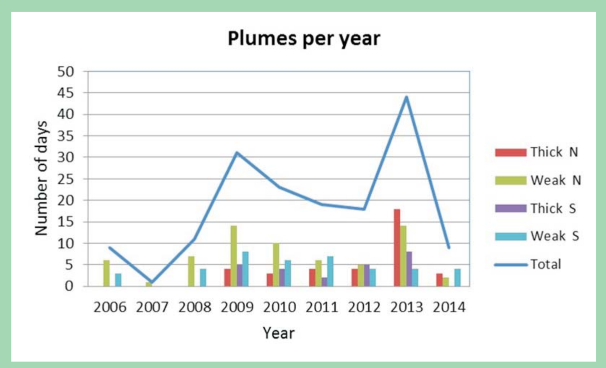


Fig. 9 Number of days with plums per year.

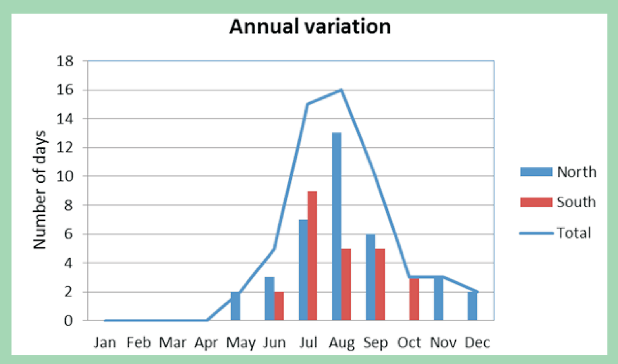


Fig. 10 Monthly variation of number of days with thick plumes (2006-2014).

The most frequent winds in the area of Mar Chiquita come from the northern sector, (N: 25 %, NE: 16%, NW: 12% of the time, respectively), see Fig. 11. Strong southerly winds are observed only with the passage of cold fronts that are more common in winter and early spring.

About 60% of days with salt clouds, prevailing winds were from north, which is the prevailing wind direction in Mar Chiquita, and almost 40% of the salt plumes detected were thick and extended; they were really strong salt storms (Fig. 12).

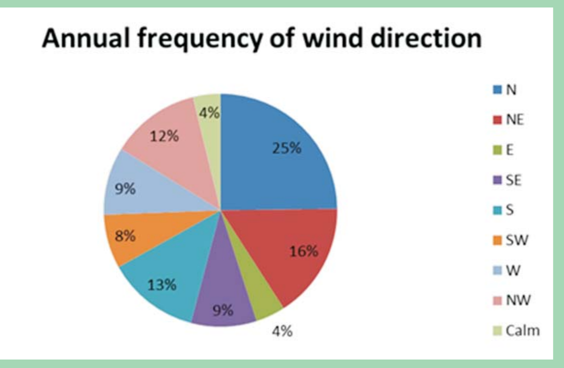


Fig. 11 Frequency of wind directions during the year.

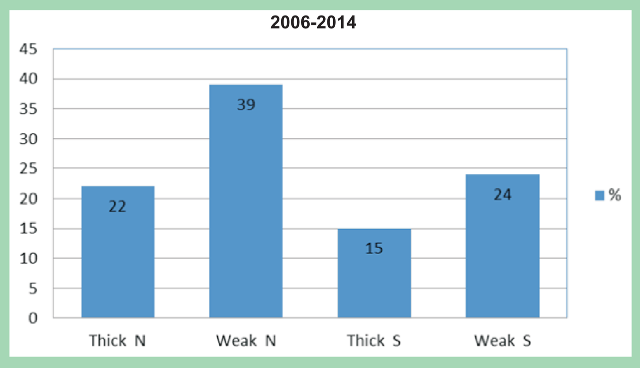


Fig. 12 Frequency of thick and weak salt clouds according to the direction of the prevailing wind.

CONCLUSIONS

This paper documents a meteorological phenomenon that can be called salt cloud and / or salt storm, which has been observed in Argentina since 2006. These events originated exclusively near Laguna Mar Chiquita (Córdoba).

The decline in the water level of the lake left exposed large beaches of salt powder. When there are winds of certain intensity, salt powder is introduced into the atmosphere and form salt clouds.

Then, depending on the air flow, the salt can be transported over long distances and be deposited far from their region of origin. In some of the cases recorded, salt plumes spread north or south for more than 400 km coinciding with the passage of frontal systems.

The number of events varies from year to year depending on meteorological and hydrological factors. In turn, also these vary throughout the year, with the greatest frequency of cases in the winter and an almost complete absence in the summer.

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