CLOUD AND PRECIPITATION FORMATION AND MODIFICATION BY REFINERIES AND POWER PLANTS

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Refinery and power plant emissions (heat, water vapor, and hygroscopic nuclei) can trigger or enhance clouds. These processes have been observed, photographed, and studied. The purpose of this paper is to present a small part of the photographic documentation of these cloud impacts and to illustrate some of the cloud forms produced and their interactions with other clouds. Other papers in this subject area will document the direct linkage of power plant emissions to clouds and to ultimate precipitation and the uses of man-made clouds for rainfall enhancement, pollution clean up, and energy production.

California State College, Dominguez Hills (CSCDH) is strategically located to allow full view of clouds from refineries in Carson, Wilmington, Harbor City/Lomita, Torrance, and a distant view of those from the refinery in El Segundo (Figure 1).

The campus also allows a distant view of clouds from the Redondo Beach Power Plant. Photographic data, showing direct connections between refinery and power plant sources and clouds on a variety of scales, have been accumulated.

The present study is based on photographic evidences. Prior to the beginning of the photographic study, refinery clouds had been studied visually over a period of several years. The photographic study of refinery and power plant clouds began in February 1975.

Heat, water vapor, and condensation nuclei are the three refinery and power plant emissions affecting clouds and precipitation. Each of the refineries which have been the principal emphasis of this study emit heat, water vapor, and hygroscopic nuclei. The observed emissions from the power plants show less water vapor emissions. Other pollutants and water vapor may be entrained into the plumes from refineries or power plants to help initiate or intensify the cloud activity.

Observed refinery and power plant clouds show a relationship with sub-cloud (i.e., between the cloud base and the ground) relative humidity. On dry, stable days, refinery plumes disappear quickly from the visual range, indicating evaporation of the water borne in the plume causing cooling and quick dissipation of the plume through sinking.

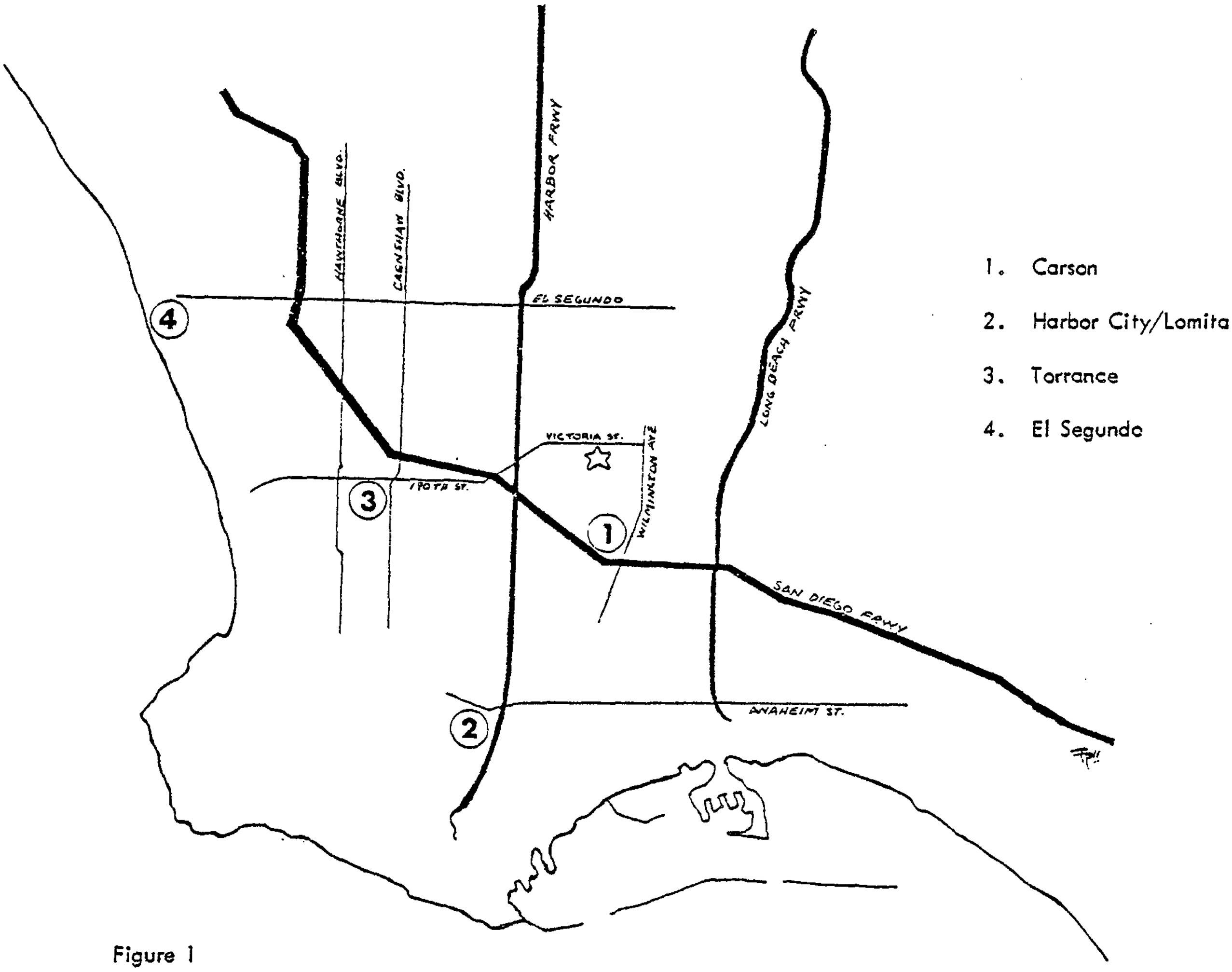

Figure 1

On relatively unstable days with high humidity, refinery plumes retain sufficient amounts of their original water in the early stages, and then take on new water through condensation at higher levels, allowing them to remain visible through the sub-cloud layer. The visible plume throughout the sub-cloud layer is strong evidence of the presence of hygroscopic nuclei in the plume condensing out water at relative humidities less than 100 percent.

If the plume is able to rise to the natural condensation level through its internal buoyancy, clouds begin to develop. The cloud is formed from both the plume and the entrained air from the outside environment. Refinery clouds frequently have a funnel-shaped base with a dark gray coloring. The coloring suggests larger than normal initial water drops. Buoyancy produced in the cloud may cause it to grow, even though it breaks away from its plume source. When the moist air becomes saturated by cooling through lifting, a larger cloud may develop. If there is insufficient buoyancy in a cloud, due to stability, the cloud may turn horizontally and be more characteristic of stratocumulus, altocumulus, or nimbostratus clouds.

In the case of natural orographic clouds (in the observed cases, from the Palos Verdes Hills), the refinery cloud may be drawn into or connect with the orographic clouds and seed them to augment or trigger rainfall or hail.

It has been observed that refinery clouds are frequently the first observed buoyant clouds (other than orographic), and in many cases are the only buoyant clouds in the sky. When refinery effects are weak or poorly organized because of strong winds, minimally effective relative humidity, or minimal instability, the plume may not be visible all the way from the ground to the cloud. A funnel-shaped downward portion of the cloud base may sometimes still be identified by its shape and color. Grayer and lower clouds may be observed in the wake of the refineries, even when heavy natural cloud formations are present.

On the basis of the observed data, it is concluded that refinery-initiated clouds studied have unique characteristics, as compared to natural clouds. They are most commonly observed to be directly connected with the refinery plumes in the early morning or evening when natural cloud formations are developing and the relative humidity is high. The connector plumes tend to become invisible when the sun heats the atmosphere, causing a decrease in sub-cloud relative humidity. These clouds have also been observed at night, but not photographed.

Figure 2 shows unique refinery clouds from each of the refineries on the same day (February 5, 1975). The Carson cloud (Figure 2-A) is dark and gray with a cumuloform top. The Harbor City/Lomita cloud (Figure 2-B) has a cumuloform top with refinery-type funnel-shaped base. The Torrance cloud (Figure 2-C) is less developed and is composed of a sequence of cells which have broken off over a period of time. The El Segundo cloud (Figure 2-D) is more stratocumulus in form, indicating a less buoyant internal structure.

Figure 3 is part of a sequence of photographs taken April 16, 1975, of a cumulus cloud sequence. At 9:00 a.m., the Torrance refinery cloud is visible along with the cumulonimbus cloud. A connector tube between the Torrance cloud and the cumulonimbus cloud is visible. Fragments of former refinery clouds can be seen in the foreground. These features and their history are depicted in other photgraphs which are not included in this paper.

Refinery clouds have been observed in all seasons and are generally more intense than unaffected natural clouds in all seasons. The refinery plumes and associated clouds affect the organization of clouds over all of the visible sky.

The first rains, and the hardest rains in the vicinity, may be associated with refinery clouds. Two (2) cases of hail and strong winds, in 1975, though associated with orographic clouds, were significantly affected by refinery clouds.

Since refinery and power plant emissions (heat, water vapor, and hygroscopic nuclei) can cause clouds to form and can significantly modify natural clouds, it is logical to assume that with proper cloud engineering, cloud control is possible, at least on a local scale.

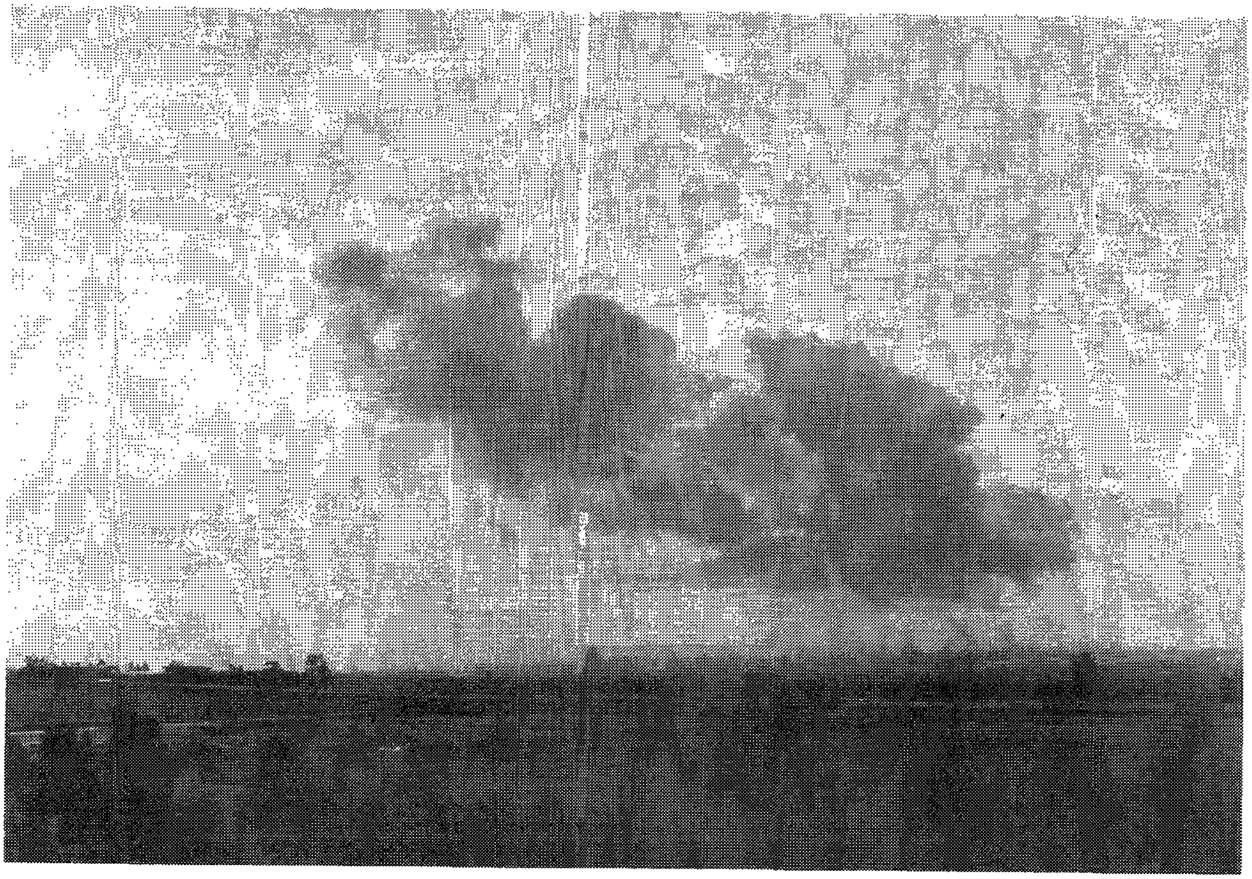

Figure 2-A

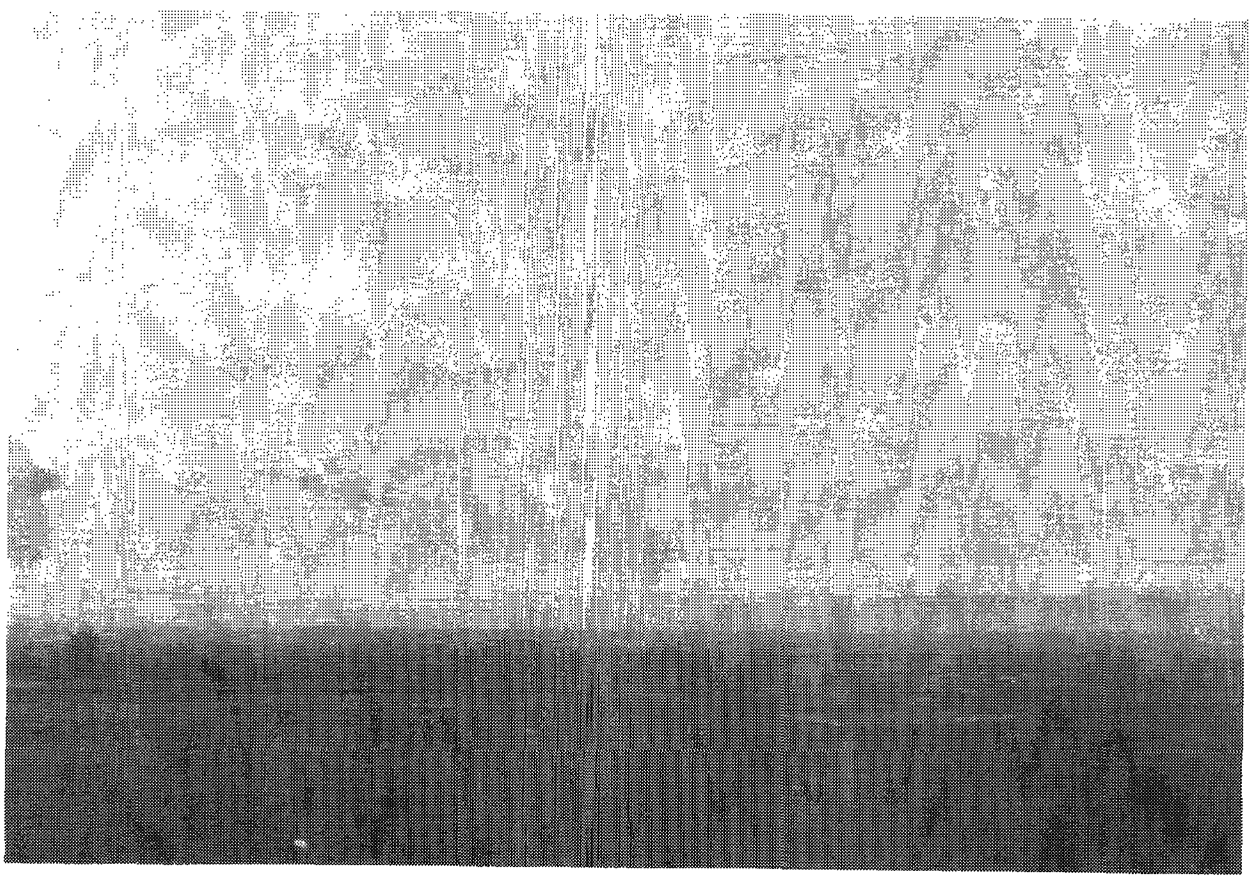

Figure 2-B

Figure 2-C

Figure 2-D

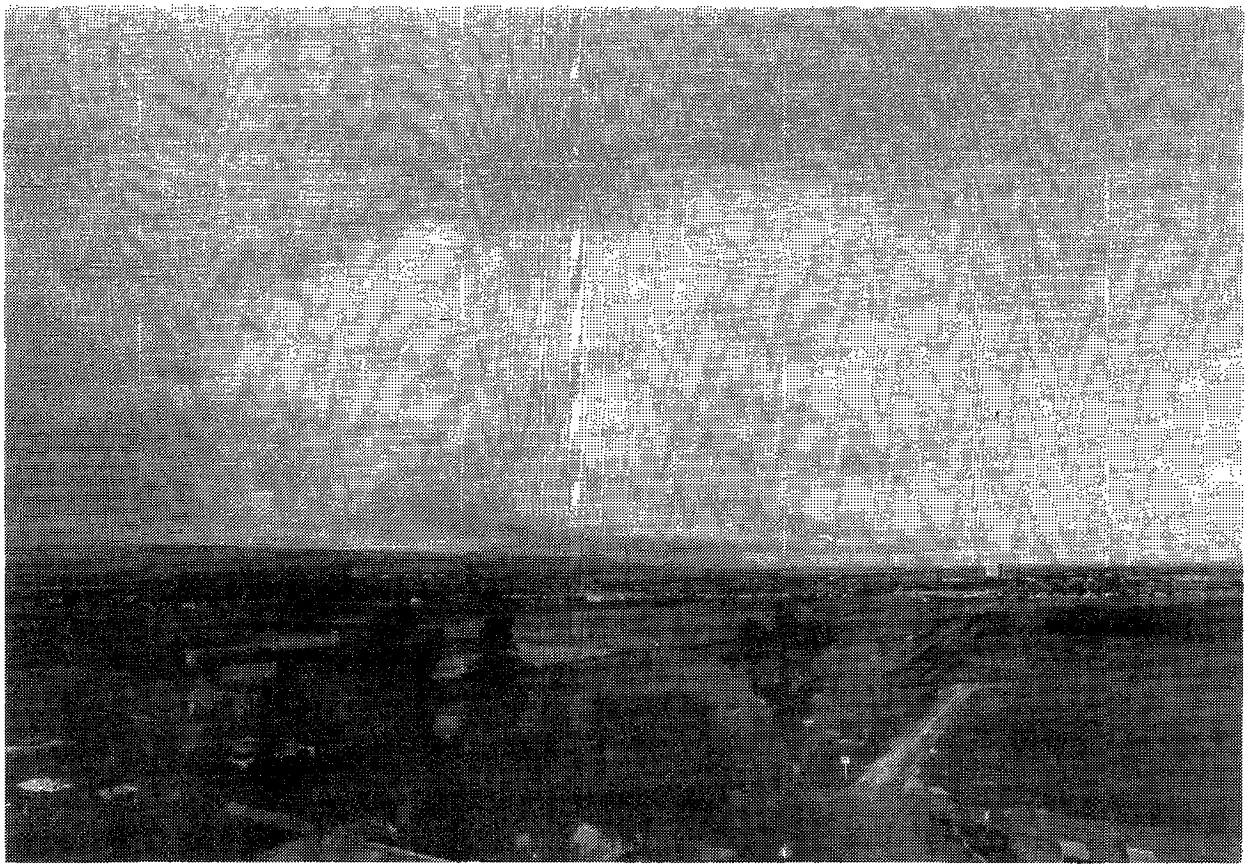

Figure 3

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