Satellite Observations of Wake Formation Beneath an Inversion[1]

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ABSTRACT

TIROS I photographs reveal striking wake patterns in low clouds to the lee of small islands in the eastern Pacific. These patterns are indicative of standing long gravity waves and provide a means of estimating the wind velocity beneath an inversion using a simple one-layer model.

1. Introduction

An extended wake pattern has been observed on several occasions by TIROS I to the lee of an island, which acted as the disturbing influence. The flow pattern is made visible because of the existence of a stratiform cloud deck in the free stream below an inversion. One such wake, originating from Guadalupe Island off lower California on 18 May 1960, has been selected for the purpose of illustration.

2. Synoptic

Fig. 1 shows the 19 May 1960 sea-level map for 0000Z, three hours after the wake observation discussed below. The familiar summertime thermal low over southern Nevada and the California desert is noted, with a low pressure trough extending southward into Mexico. To the west is a portion of the eastern cell of the Pacific high. Jointly, these systems give rise to northwesterly flow in the vicinity of lower California and Guadalupe Island. A similar wind pattern is indicated on the 850-mb contour chart (not shown). Nearby pilot balloon observations show the northwesterly flow extending to about the 3-km level. Fig. 2, a radiosonde from a ship north of Guadalupe (see Fig. 1 for location), indicates a strong subsidence inversion at about 450 m, with extremely dry air above.

3. Cloud pattern

Evidence of the wake phenomenon, i.e., the cloud banding observed by TIROS I, is shown in Figs. 3a and 3b (arrows). These are wide-angle photographs taken at approximately 2100Z on 18 May 1960. Rectification of this pattern onto a base map containing geographic features is depicted in Fig. 4. Of note is the coincidence of the wake origin with Guadalupe Island, which has a mountain extending to 1600 m above sea level. Guadalupe is invisible in these photographs; even under ideal cloudless conditions the island is infrequently seen because of its small size and low reflectivity.

In the wake of the island, extending at least 385 km downstream, is an unusual disturbed zone of rather diffuse cloud with superimposed oblique bands spaced at 55 km intervals. The breadth of the disturbance is of the order of 60 km, while the band dimensions are about 55 km by 9 km.

A narrow-angle photograph, Fig. 5, shows the clear area adjacent to Guadalupe within a field of broken clouds, apparently low stratiform as indicated by surface observations at Guadalupe and the sharp inversion of the ship sounding. A portion of the first cloud band is visible at the lower right (arrow); it is seen to be a smooth band, differing sharply from the broken banded clouds in the region.

4. Discussion

An examination of the available photographs suggests that the pattern represents standing waves. The wavelength is so long (55 km) that they must be long gravity waves. A wave disturbance along an internal boundary such as a sharp inversion with denser air below may be treated by using a simple single layer model for an incompressible fluid but modifying the gravitational constant g by the formula

$$g' = (\Delta T/T)g \qquad (1)$$

where ΔT is the difference between the temperatures above and below a sharp inversion, and T the temperature above (assumed here to be 300K).

Long waves must propagate with respect to the fluid at a speed

$$c = (g'h)^{\frac{1}{2}} \qquad (2)$$

where h is the depth of the lower layer. Data from the

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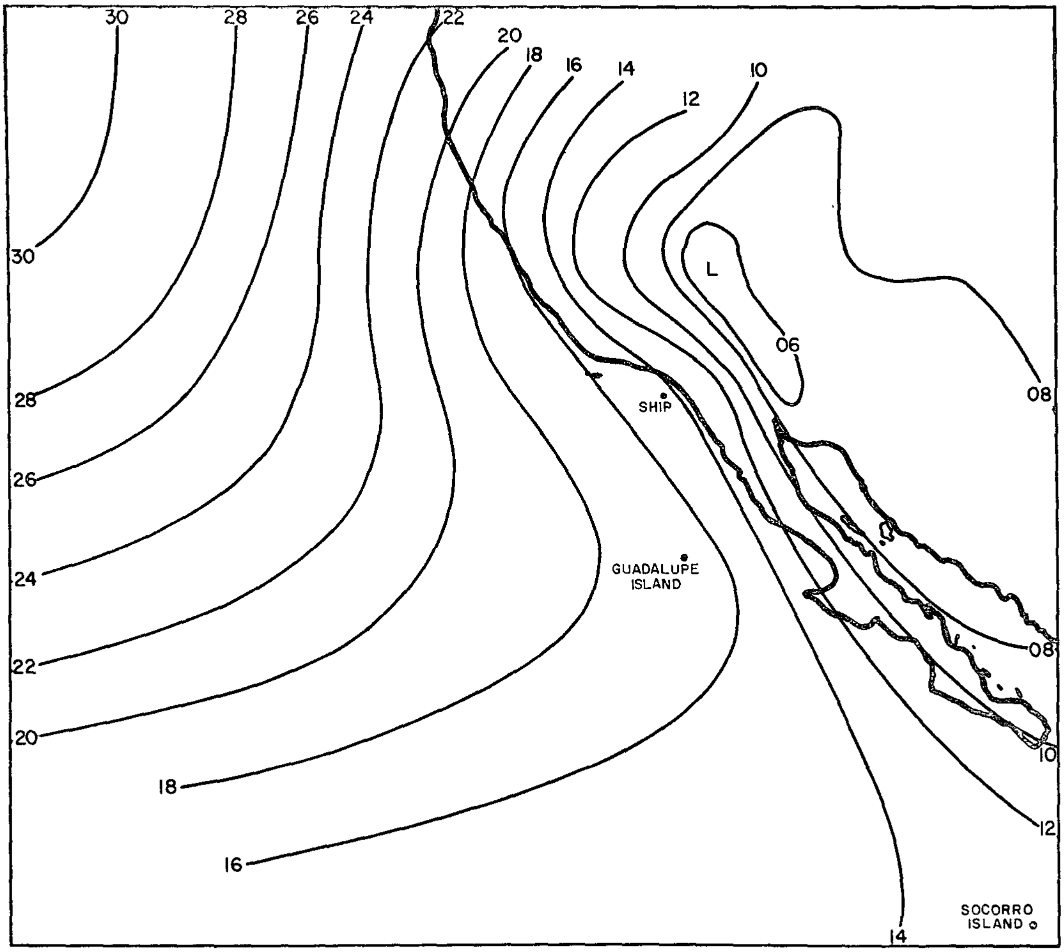

FIG. 1. Sea level map for 0000Z, 19 May 1960. Isobars are shown at 2-mb intervals.

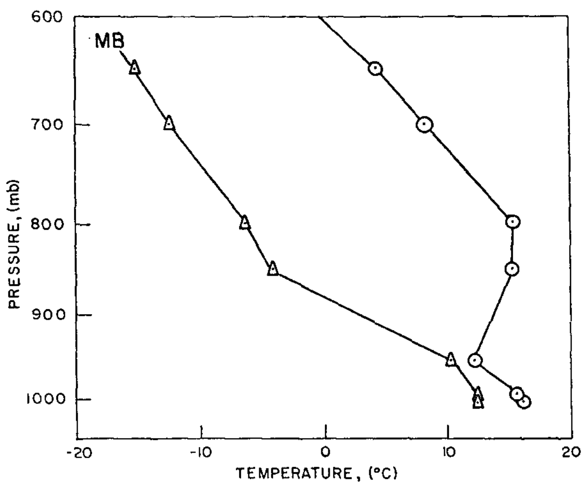

FIG. 2. Plotted sounding (temperature and dewpoint) from ship located at 33.1N 118.3W for 0000Z, 19 May 1960.

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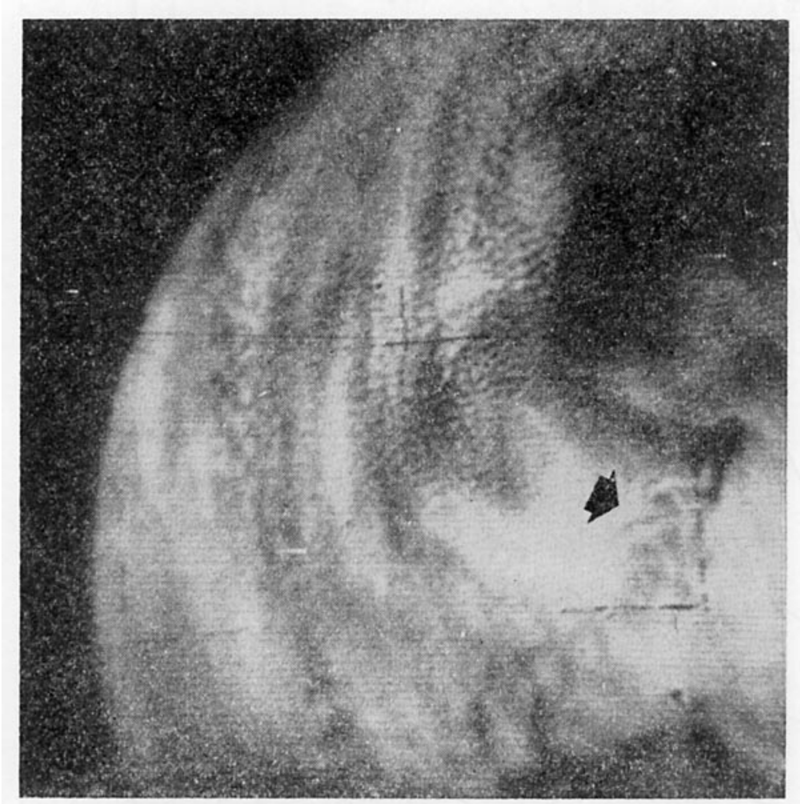

FIG. 3a. Wake pattern at about 2100Z from TIROS I Orbit 688.

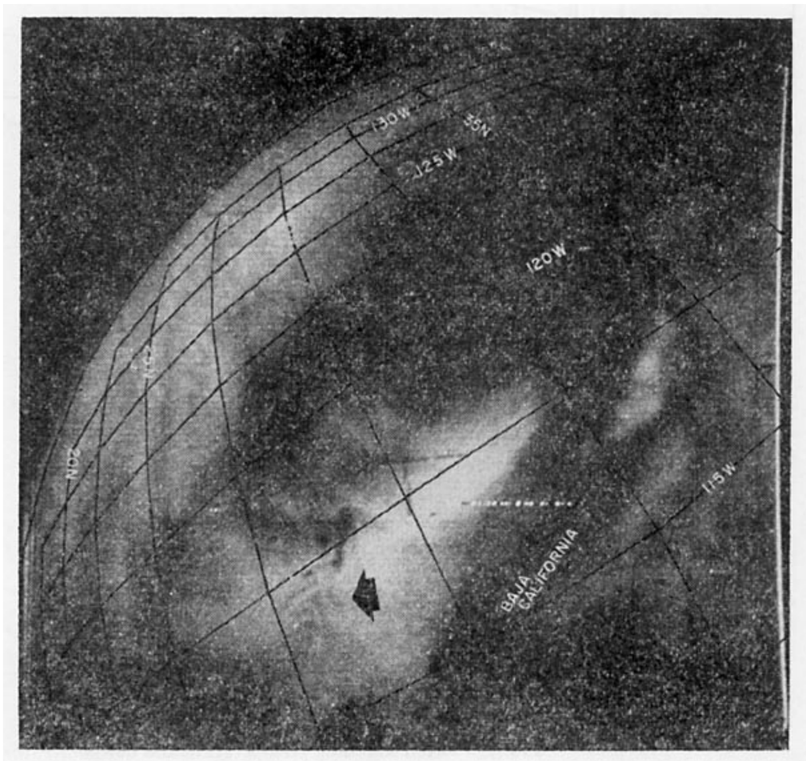

FIG. 3b. Wake pattern one minute after (a) with superimposed computer-drawn 2.5 deg latitude-longitude grid.

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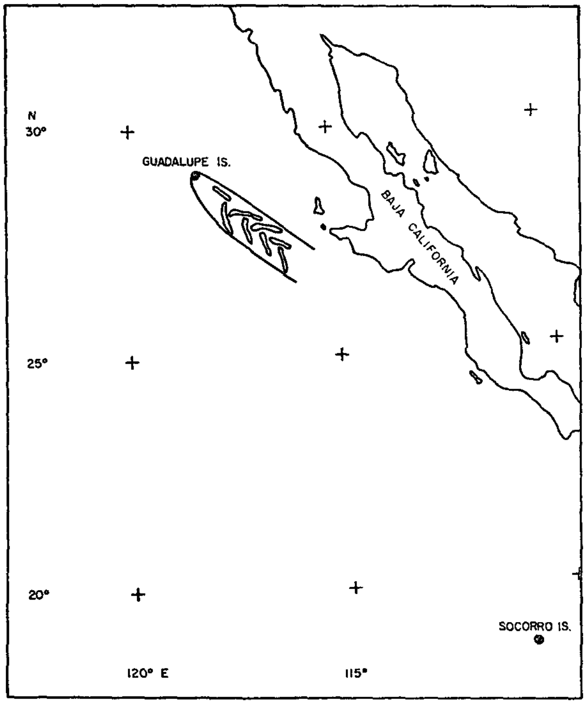

FIG. 4. Map rectification of wake pattern.

ship radiosonde north of Guadalupe give the inversion base to be 450 m with ΔT about 3C (Fig. 2). From Eq (1) and (2) this corresponds to $c=6.7$ m sec^{-1}.

If the waves are at an angle θ from the undisturbed wind flow of velocity v and remain stationary then the wind component perpendicular to the wave front must oppose the speed of propagation of the wave

$$v \sin\theta = c. \qquad (3)$$

By measuring the angle between the waves on opposite sides of the wake, the angle θ between undisturbed wind and waves was found to be 32 deg with an accuracy of ± 3 deg From (3) the wind speed v is computed to be between 12 and 14 m sec^{-1}.

Wind speeds observed at Point Arguello, California, below the inversion at 0000Z 19 May were about 14 m sec^{-1} from the north-northwest, which is in good agreement with the computed speed. The geostrophic winds in the vicinity of Guadalupe were estimated to be of that order, but the sparsity of data precludes a good estimate. Winds below the inversion at San Diego were evidently subject to local effects since they were light southwesterly.

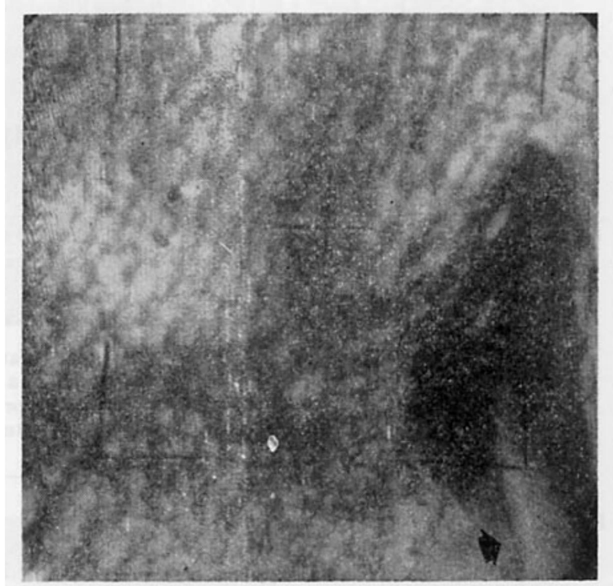

FIG. 5. Narrow-angle photo of clouds in the vicinity of Guadalupe.

5. Conclusions

The TIROS photographs of the wave pattern in stratocumulus clouds off the California coast indicate that relatively small islands may cause a visibly disturbed wake for distances of several hundred kilometers downstream.

The wake pattern is probably not an unusual phenomenon in stratiform clouds; it was observed on five successive days at Guadalupe Island and it has been observed twice at Socorro Island, also off the lower California coast, some 1370 km to the southeast of Guadalupe (see Fig. 3 for location).

The observation of this phenomenon from TIROS photographs enabled the determination of the approximate wind flow over a large area in the Pacific. While this is an unusual situation, it points to the potential of satellite cloud photographs in observing and interpreting atmospheric flow patterns.

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