LEE WAVE CLOUDS PHOTOGRAPHED OVER THE APPALACHIANS BY TIROS V AND VI

by SIGMUND FRITZ *and* CHARLES V. LINDSAY
U.S. Weather Bureau, Washington, D.C.

1. INTRODUCTION

From observations taken at the ground alone, it is difficult, if not impossible, to observe organized *patterns* of clouds which cover over 100 miles in horizontal extent. But now with the advent of the TIROS satellite, photographs of entire cloud *patterns* have been obtained. Among these, and of special interest to soaring pilots, are photographs of lee-wave clouds (mountain waves). TIROS photographs of lee-waves have been obtained from several mountain areas of the world. For example, waves in the Andes Mountains (Doos, 1962) and over Northern Mexico and Southwestern United States (Fritz, 1963) have been photographed by TIROS I and VI, respectively.

More recently, on April 18, 1963, at 1300 EST, TIROS V passed over the Appalachian area of West Virginia, Virginia and Pennsylvania and photographed the striking, well-formed wave cloud pattern shown in figure 1. About two hours earlier at 1110 EST a different satellite (TIROS VI) photographed the same lee wave system with the results shown in fig. 2. Those wave patterns are the subject of this paper.

2. THEORETICAL BASIS OF LEE WAVES

Waves in the lee of the mountains have been studied theoretically and empirically for a long time (Alaka, 1960). These results show that, in order for wave clouds to form, the following criteria must be fulfilled: (a) the wind direction must be more or less perpendicular to the mountains through a deep layer of the atmosphere, (b) winds at the mountain top level should have a minimum speed of about 20 knots, (c) the wind should increase rapidly with height, and (d) the atmosphere should be stable for vertical displacements. Criterion (d) requires that the temperature should not fall too rapidly with height. Often the temperature even increases with height; that is, a temperature inversion is often observed when mountain wave clouds exist. Many of these criteria are embodied in Scorer's (1953) requirement that the parameter, $F_{(z)} = L^2$, should decrease with height. Here L^2 is defined by

$$L^2 = \frac{g\beta}{U^2} \quad ; \quad \beta = \frac{1}{\theta}\frac{\partial\theta}{\partial z} \qquad (1)$$

The symbols in eq. (1) have the following definitions:

g = the acceleration of gravity
θ = potential temperature
z = height
U = horizontal wind speed

Thus β expresses the thermal stability for variations of temperature with height. It is evident that if the wind increases rapidly with height, L^2 will ordinarily decrease with height, and waves will appear. The appearance of waves under these circumsances is also in agreement with empirical results (Alaska, 1960).

In the waves, the air moves up on one side of the wave and down the other. And if enough water vapor is present in the air, the water will condense in the upward moving part of the wave and appear white in reflected sunlight as seen from a satellite.

All the criteria mentioned above were realized in the case of the Washington wind and temperature soundings which were associated with the lee-wave cloud pattern portrayed in figs. 1 and 2.

3. THE SATELLITE WAVE PATTERN AS RELATED TO THE TOPOGRAPHY OF THE MOUNTAINS

The main features of the wave pattern seen in fig. 1 have been sketched in fig. 3, together with weather observations taken by pilots flying over the area. Fig. 3 indicates that the wave pattern begins near the ridge of higher mountain elevations in West Virginia, and extends into southwestern Virginia. The wave pattern in fig. 1 extended over 100 miles downwind from the first organized wave, and

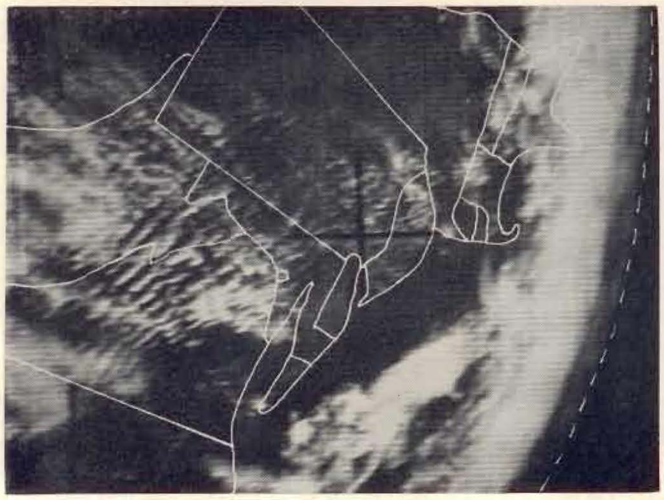

Figure 1. Wave cloud pattern to the lee of the Appalachians, as photographed by TIROS V at 1300 EST on April 18, 1963.

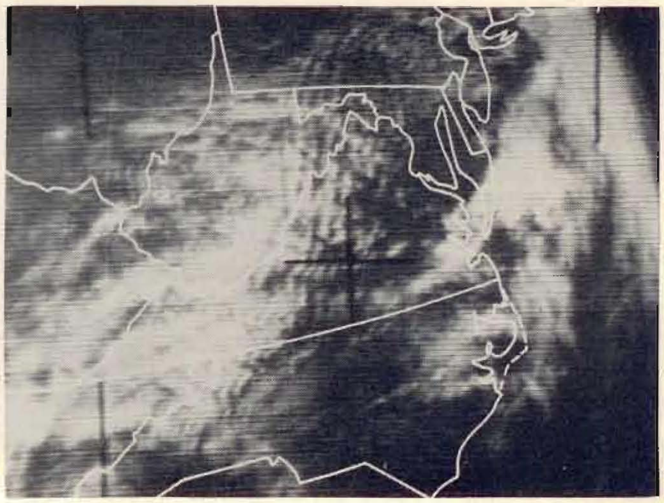

Figure 2. Wave cloud pattern to the lee of the Appalachians, as photographed by TIROS VI at 1110 EST on April 18, 1963.