

# Small Scale Disturbances as Observed by Tiros Satellites

By D.G.James. Presented at the 10th OSTIV Congress, South Cerney, England, June 1965

## Introduction

The first Tiros satellite was launched on 1st April 1960. At the time of writing a further eight have been launched which have differed in orbital inclinations and in their instrumentation. However, the primary object of these satellites has been to report on meteorological activity on a synoptic scale that is of the order of a 1,000 miles so that the recording of any small scale features is somewhat fortuitous. This has been largely our own fault. Tiros I carried a narrow angle camera which viewed an area of 75 by 75 miles, a hundred times less than that viewed by the usual wide angle cameras, but these photographs were not found to be as useful to the operational meteorologist as were photographs of synoptic scale features. Consequently the subsequent satellites carried only cameras which viewed areas of  $10^5$  to  $10^6$  square miles. (Tiros 2 also carried a narrow angle camera, but this soon stopped working.) Thus the only photographs available for analysis of small scale meteorological features are those from the narrow angle camera on Tiros I. But let me first define what I mean by small scale features.

The resolution of the photographs obtained from the Tiros satellites is determined not only by the optical system of the cameras but also by the raster width of the electronic beam with which the vidicon tube face is scanned. For the wide angle cameras, the resolution has been about 2 miles but was about a quarter mile for the narrow angle camera of Tiros I. This means that fair weather cumulus of dimensions of the order of a half mile would be resolved by one camera but would only appear as a grey haze on the other provided there were sufficient number of them. I would define a small scale feature in this context as a cloud pattern or formation which, although itself perhaps of dimensions of

a 100 miles is composed of clouds substantially smaller than this. Thus the individual cloud elements would be observed from the ground, but the patterns which they form would not.

Before proceeding with a review of photographic research on this type of feature I would mention the radiation measurements which are also made from some of the Tiros satellites, though not in fact from Tiros I.

A five channel radiometer carried on about half of the Tiros series measures reflected solar and emitted infra-red radiation at five different spectral intervals. Radiances from opposite directions are reflected from opposite faces of a right prism and are allowed to fall in turn onto the five sensors of the radiometer via a mechanical chopper which determines the time each beam is viewed. Five lensfilter combinations define the spectral intervals examined. Although the field of view of this instrument is about  $5^\circ$ , which means a viewing area of about 40 by 40 miles, it is possible to obtain a finer structure from an overlapping sample. For our purposes the only channel of interest will be channel 2 with a spectral response of 8 to 12 microns. This is almost an atmospheric window through which the radiation from ground or cloud can pass freely. I will describe later the uses to which this channel can be put; but let us return to the satellite photographs.

## Cellular Clouds

All the Tiros satellites have produced photographs showing extensive areas of the sea covered by a layer of low cellular cloud. These areas in general cover  $10^5$  to  $10^6$  square miles and it is somewhat surprising that their presence was not discovered before. From my own experience at Christmas Island I had observed apparent curvature in the roll like

cumulus clouds but I was quite unaware that these clouds formed cells and that indeed they were part of a very much bigger pattern. This extensive area is composed of cells or sections of cells either in ring or U shaped elements of horizontal dimensions 30 to 50 miles across the cell, but the cloud itself being 10 to 15 miles across. The associated meteorological parameters have been examined for some examples by several authors, for instance Kruger and Fritz. They first of all determined what conditions were common on the occasions when these patterns were observed. These were 4:

1. Large anticyclones with little wind.
2. Dry type inversion at low levels with close to a dry adiabatic lapse rate below.
3. Sea temperature slightly warmer than air temperature, usually about 2° or 3° C.
4. Little vertical shear.

In one of the cases analysed by them they found that the variation of height at the inversion level with latitude was accompanied by a change in cell size. They made estimates of vertical cloud thickness and concluded that the horizontal dimensions of the pattern were about 30 times as great as the vertical dimensions.

The configurations of each cell suggest that there is upward motion at the periphery and descent at the centre. This is not then a simple Benard cell which requires upward motion at the centre and descent at the edges. Some 30 years ago laboratory experiments by Chandra and by Graham, using smoky air heated from below, showed that the mixture formed a pattern of polygonal cells provided that there was no vertical shear. The pattern was not stable; there was a tendency for the cells to join together into long rolls and then for the rolls themselves to break up and form new cells. Increasing the depth of the tank used in the experiments increased the size of the cells, but the ratio cell width to tank depth was relatively constant at about 2 or 3 to 1. This is a factor of 10 less than the measurements of Kruger and Fritz in the atmosphere!

There is also another significant difference between the laboratory produced and the observed atmospheric cells. The narrow angle camera of Tiros I shows that the cell walls themselves are composed of small cumulus elements suggesting that more than one scale of motion is present in the pattern, whereas in the laboratory, the flow in the cells is more nearly smooth. Various explanations have been offered by several authors including Professor Scorer to explain this apparent difference in scale. I am not sure that the matter is yet fully resolved. However, operationally, we may use the presence of such extensive patterns to tell us something of the low level conditions at the places where the clouds are formed, namely that the cloud top will be bounded by a dry inversion, below which the flow will be anticyclonic with little vertical shear.

### Cloud Streets

It is well known that under certain conditions cumulus clouds tend to form in lines known as cloud streets. This is a comparatively common phenomena and, as may be expected, has been photographed on numerous occasions by Tiros satellites. As we know, Dr. Kuettner has written an extremely

comprehensive paper on the band structure of the atmosphere, and we may use his conclusions to obtain winds and air mass information from photographs showing cloud streets. Thus, for example, in areas where cloud streets are



Fig. 1

Tiros IV, 13 April 1962  
UK & Ireland, Orbit 920,  $\approx$  1500 z

well marked we would deduce a low level wind roughly parallel to the streets, rather stronger than usual, with little change of direction with height, but with a maximum within the convective layer. Also we would expect that the air temperature at the surface would be rather colder than the surface temperature, and that the clouds themselves would be limited by a rather stable layer or inversion. Schuetz and Fritz examined a mosaic of Tiros photographs showing cloud streets in the Caribbean. They used the local radiosonde soundings of temperature and wind to confirm Dr. Kuettner's conclusions based on aircraft and surface observations. One surprising detail emerged however and this was concerned with the spacing of the clouds. Over land the spacing of the cells in streets was 3 to 4 miles in agreement with Kuettner's observations, but over the sea spacing is more like 20 to 30 miles. The difference is accounted for by the greater instability over the land—it was in fact Cuba—so that possibly the cloud spacing may give us the air-surface temperature difference also. Fig. 1 to 3 show cloud streets close to the British Isles on quite separate occasions. Fig. 1 is a well known example of small cumulus clouds covering the whole of Britain but not Ireland. Also streets are very evident over France. Figs. 2 and 3 are of one occasion August 31st 1964 taken by the Nimbus satellite during its short lifetime, Fig. 2 being of an APT transmission received in France and showing the broad scale pattern of clouds over south western Europe—note that the cloud streets over the North Sea and possibly eastern England are quite well marked—while Fig. 3 shows an AVCS picture at the same time. Now we clearly see that there are indeed cloud streets also over Northern Ireland and north east England with a

much smaller spacing. Note too the better resolution of these Nimbus pictures as compared with the Tiros IV pictures shown before.

*Orographic Disturbances*

Perhaps some of the most impressive satellite photographs have been of distortions in the low level flow produced by mountains and islands. The theory of the formation of mountain waves is now quite well known thanks to people such as Dr. Scorer and G.A. Corby. Briefly, stable air is forced upwards by a mountain ridge and, if sufficiently moist, forms rolls of cloud parallel to the ridge. Fig. 4 shows

Fig. 2 Nimbus I, 31 August 1964  
A. P. T. Reproduction

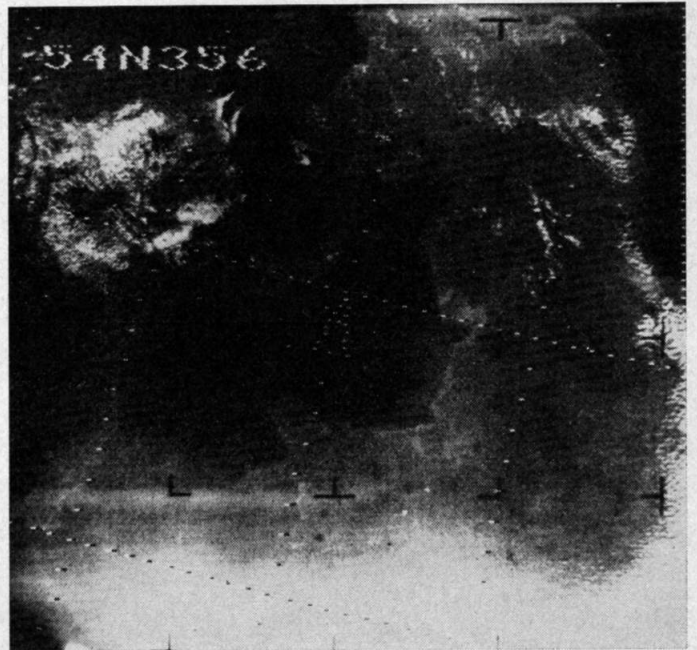
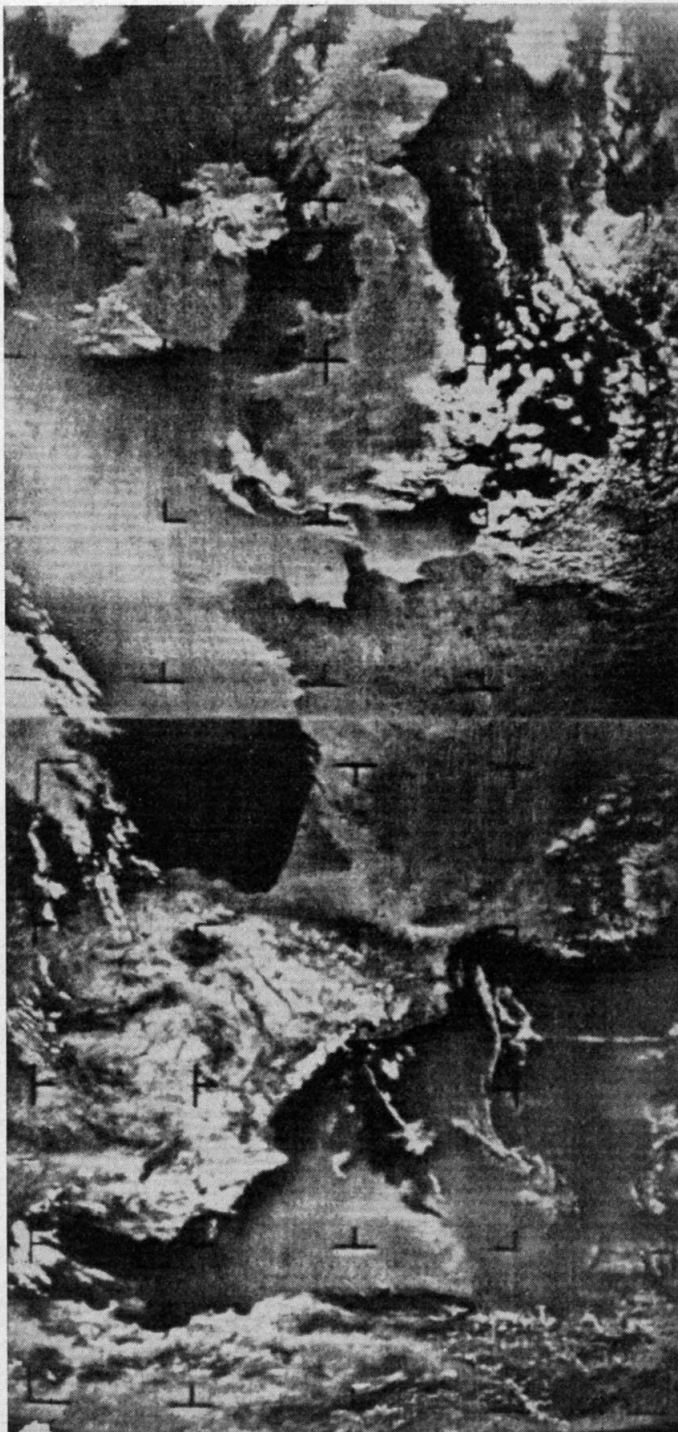
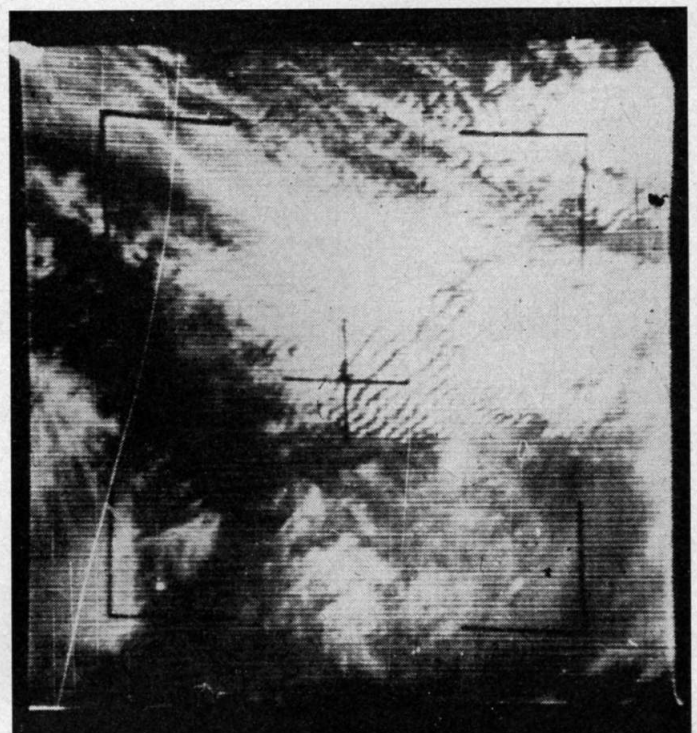


Fig. 3 A. V. C. S photograph  
Nimbus I, 31 August 1964

some wave clouds over the Sierra Madre in Mexico. Fritz analysed several such examples and estimated the mean tropospheric winds from the spacing of the waves. He found that in general these values agreed well with the winds recorded from routine radiosonde soundings, but that on occasions there were marked differences which could be attributed to variations in the stability of the air masses. Even so, given photographs of mountain waves evenly spaced and parallel to the mountains one could conclude that the winds were perpendicular to the ridge, that they increased with height with little change in direction and that the wavelength of the oscillations gave the relation between stability and mean tropospheric wind.

Fig. 4



The mountain ridge is an example of a long obstacle which, when roughly normal to the airstream forces it upwards to produce oscillations. Some satellite photographs have indicated that *horizontal* displacements too can sometimes be important in producing patterns in an otherwise uniform cloud sheet. A long sea track frequently ensures that an air mass becomes stably stratified with smooth laminar flow at low levels. The presence of an island or

The viscous forces would have damped them out long before. Fritz however points out that their estimates of the eddy coefficient of viscosity might have been in error by factor 2 or 3 in which case no additional destabilising mechanism would be required. To my knowledge there is as yet no complete explanation of these patterns. Therefore the existence of such patterns on satellite photographs does not allow us to deduce very much quantitative information about the low level flow.

#### Radiation Data

I do not wish to end this talk without mentioning the radiation data obtained from some of the Tiros satellites. At the beginning I described briefly the instrumentation used aboard the satellites to measure reflected and emitted radiation, and in particular I mentioned that the 8 to 12 micron radiances may be used to provide fine scale structure of cloud top. This spectral interval is erroneously called the "atmospheric window" and receives most energy from the ground or cloud in the field of view. A correction has to be applied for ozone and water vapour in the beam thus reducing the absolute accuracy, but the relative accuracy is better than  $\pm 2^\circ \text{C}$ . The field of view of the radiometer is  $5^\circ$  which means that at any instant radiation is received from an area of roughly 40 by 40 miles. At first sight this appears far too crude a resolution to obtain finer detail but in Fig. 5 we see an analysis by Professor Fujita of the detail in cloud top temperatures above a hurricane. Obtaining this sort of resolution involves hand analysis of the original analogue tapes, rather than computer processing, involving much lengthy and painstaking work.

There have been a few cases of small scale features shown by satellite observations. Since the launch of the first Tiros in 1960 work has proceeded to improve not only the availability of the data for operational usage but also the quality of the measurements. With a new Vidicon camera, resolutions down to half a mile or less are possible in the visible and one and half to two miles by the high resolution infrared. Furthermore, as this technology progresses we can expect more and more information on small scale features to be available regularly all over the globe at day and night. This does not make life any easier, but it does at least give us a more complete picture of where these patterns form and how they are associated with the general synoptic picture.

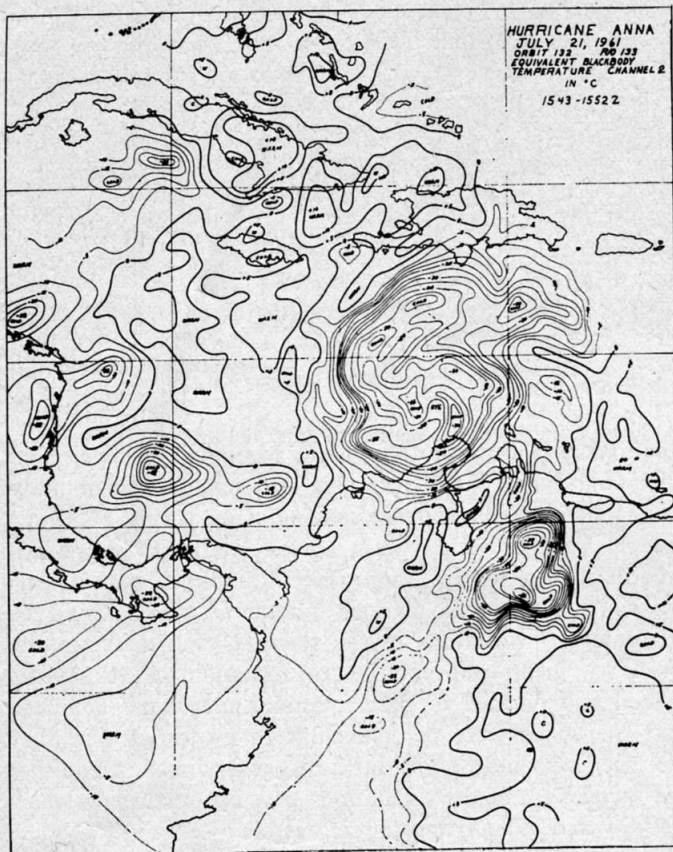


Fig. 5

peninsula in this flow causes disturbances which, if conditions are favourable, produces variations in the low level cloud cover. One of these cases has been analysed by Hubert and Kruger who thought that the patterns were too far downstream from the island to be Von Karman vortices.

## Perturbations à petite échelle observées à l'aide de satellites Tiros

Alors que l'auteur écrivait ce rapport, neuf satellites Tiros avaient été lancés dans le but d'observer principalement les phénomènes météorologiques à une échelle synoptique, couvrant environ 1500 km, opération pour laquelle des caméras à grand angle ont été utilisées. Malgré cela, Tiros I emportait une caméra à petite ouverture, couvrant une zone de 120 km<sup>2</sup> et dont les images permettent de mettre en évidence des phénomènes de faibles dimensions, tels que des systèmes nuageux d'une extension d'environ 150 km, mais qui se composent d'éléments nettement plus petits. Le pouvoir de résolution se monte à un demi-kilomètre.

Les radiomètres emportés par quelques satellites couvrent une surface de 65 km<sup>2</sup>, chaque canal correspondant à une zone du spectre de 8 à 12 microns, permettant de déceler aisément la radiation du sol ou des nuages.

Beaucoup des photographies permettent d'observer des zones océaniques étendues (jusqu'à 3x10<sup>6</sup> km<sup>2</sup>) couvertes d'une couche de nuages bas à structure cellulaire. Les cellules ont la forme d'anneaux ou de U, d'une longueur de 50 à 80 km et larges de 15 à 25 km. Kruger et Fritz ont observé que cela se produit dans le cas de vastes anticyclones, avec peu de vent, des inversions sèches à basse altitude, la

mer étant de 2 à 3° C plus chaude que l'air, et peu de variation verticale.

Les systèmes étaient environ 30 fois plus larges que haut, ce qui est 10 fois plus que ce qu'ont obtenu Chandra et Graham en laboratoire, il y a environ 30 ans. On n'a pas éclairci les raisons de cette différence.

Un grand nombre de photographies font voir des routes de nuages. Un détail intéressant qui en ressort est l'espacement des cellules, de 5 à 7 km sur terre ferme, comme dans les observations faites par Kuettner, mais de 30 à 50 km sur mer. Cela est dû au fait que l'instabilité est plus élevée sur la terre ferme.

La figure 1 (Tiros IV) montre de petits cumulus couvrant toute la Grande-Bretagne, mais pas l'Irlande, et des routes de nuages sur la France. La figure 2 (Nimbus 1) est une transmission APT et montre, à grande échelle, un système de nuages sur l'Europe occidentale; les routes de nuages sur la mer du Nord sont nettement marquées. La figure 3 est une image AVCS prise au même moment et montrant

nettement des routes de nuages sur le nord de l'Irlande et le nord-est de l'Angleterre. Les images de Nimbus ont un pouvoir de résolution supérieur à celles de Tiros IV.

La figure 4 montre des nuages d'ondes sur la Sierra Madre au Mexique. De l'espacement des ondes, Fritz a déduit les vents moyens troposphériques et trouvé une bonne concordance avec les mesures faites par radiosondes, malgré quelques notables différences occasionnelles, attribuées à des variations dans la stabilité de la masse d'air.

Quelques photographies ont montré qu'un déplacement horizontal peut, dans certaines conditions, produire des changements de structure dans une couche nuageuse.

En ce qui concerne les données fournies par les radiations, celles de 8 à 12 microns peuvent servir à déterminer la structure à petite échelle des sommets nuageux. La température peut être déterminée avec précision supérieure à  $\pm 2^{\circ}$  C. La figure 5 montre l'analyse, faite par le professeur Fujita de la température des sommets nuageux surplombant le cyclone Anna (1961). Des résolutions de cette précision exigent une analyse individuelle laborieuse.

(Swiss Aero-Revue 9/1967)