A TIROS IV INTERPRETATION EXERCISE OVER SOUTHERN AUSTRALIA

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Abstract: Observations obtained from ground stations and from aircraft and rocket photography are compared with TIROS IV pictures of a cold front situation. Features of the satellite pictures are interpreted in relation to the synoptic situation and the observations, and attention is drawn to the importance of familiarity with terrain.

1. INTRODUCTION

Effective use of cloud pictures from meteorological satellites depends primarily on the accuracy with which cloud types can be determined. Their significance both as separate elements and in organised patterns can then be more readily interpreted in terms of synoptic processes.

Identification of cloud types can be achieved with comparative ease from the earth's surface according to well recognised criteria. These criteria are less effective when observation is made by camera from aircraft above the cloud layer and the difficulty increases with altitude of observation. At satellite levels familiarity must be acquired with an entirely new set of criteria based on the resolution of the television system and on the characteristic appearance in satellite photographs of clouds of known type.

The paper describes an exercise conducted on 30 May 1962 in which sky conditions known from ground observations, aircraft observations and photography from 45,000 feet, and photography by a 'Long Tom' rocket from altitudes up to 85 miles are directly compared with satellite pictures from TIROS IV.

2. OBSERVATIONS

Reports from the ground observational network were obtained for the mid-time of satellite pass on orbit 1588 at 0230 GMT, 30 May 1962, from a wide area centred about Woomera in South Australia (Fig. 1).

An adequately dense network could not be established in this thinly populated area. However, the location allowed use of rocket launching facilities of the Weapons Research Establishment and enabled cloud photography from a rocket head at various altitudes and at times centred about 0230 GMT.

The rocket used was a medium altitude vehicle with instrumentation which included two standard electric lloca cameras (focal length 50 mm) set to give continuous operation from 60 sec after launch (at approximately 200,000 ft) at one frame every 0.9 sec. In addition two WREROC were mounted on the head and were switched on to give continuous operation from about 350,000 feet with timing neon pulsed every 2½ sec by telemetry signal. The function of the WREROC cameras was to indicate the rate of roll and the direction of the field of view of the lloca cameras.

A Canberra aircraft carried out a photographic and visual cloud survey on the track shown in Fig. 1 from heights of 35,000 to 47,500 feet. An F-24 5-inch vertical camera took pictures of cloud forms vertically beneath the aircraft, and port and starboard pictures were taken at frequent intervals along track by hand-held 35 mm camera. These photographs were accurately tied to the positions of the aircraft which was tracked by ground based radar.
The track of the satellite on orbit 1587 and the principal points of frames 13 and 15 are also shown. For all frames on this orbit there was a high nadir angle of view to the Woomera area which rather severely restricted the resolution of the cloud elements. This was unavoidable due to circumstances involving availability of the launch vehicle and more particularly the limited period at this time for picture-taking orbits of TIROS IV over Australia.

3. SYNOPSIS SITUATION

A low moved over the south Indian Ocean and intensified as it reached the southwest coast of Western Australia on 27 May. It remained quasi-stationary in this region from 28 to 30 May. A cold front moved rapidly eastward during 30 May and at 0200 GMT was located with NW–SE orientation through the Woomera area. The surface analysis for this time (Fig. 1) shows the front was followed over southern and western Australia by a strong (40 kt) W/NW flow. A new front formed in the frontogenetic area off the Western Australia coast and at 0200 GMT was moving into the extreme southwest of the State followed by a strong southwest flow. The satellite scanned both fronts and the primary low.

Upper air analyses at 2300 GMT 29 May, showed that the low was a typical mature system with a core of cold air extending almost vertically above the M, S, L, centre. Maximum wind analysis indicated a jet in excess of 200 kt over Western Australia with NW/SE orientation.

4. CLOUD DISTRIBUTION

The cloud observations from all sources, including ground stations, aircraft and rocket, are depicted schematically in Fig. 2.

Surface reports indicated that skies were cloudless over the northeast of the continent. In the frontal zone through Central Australia, reported cloud was broken to overcast middle cloud with areas of rain and showers chiefly over southern sections. Showers were heavy at times and sferics activity was reported about lat. 26°S long. 134°E. Scattered small cumulus was reported in the rear of the front along the coastal sector and ships over the Bight reported large cumulus and showers. Further north, in the western desert, no reports were available behind the front but stations on the western border reported cloudless conditions.

Observations from the Canberra aircraft were depicted in the horizontal using techniques described elsewhere (van Dijk and Rutherford 1961). Vertical photographs covered a square on the earth's surface of 8 mi along a side from a viewing height of 8 mi, or a 6 mi coverage on a cloud top surface of 2 mi elevation. Port and starboard 35 mm pictures extended this coverage to about 20 mi. Beyond this distance resolution was too poor to enable satisfactory depiction. The flight of the aircraft lay above the frontal cloud. On the southernmost leg, the overcast and middle cloud broke sharply to a clear zone 10 mi wide followed by fair weather cumulus streets. To the north and visible on all traverses of the box track was a line of large cumulus and cumulonimbus which protruded sheer through the overcast middle cloud deck. This was most clearly visible on the northern leg as a wall of cloud roughly parallel to the track. Clouds in the frontal zone beneath the aircraft were mostly overcast middle with scattered larger protrusions of cumulus tops.

Interpretation of rocket photographs was assisted by identification of the coastline in some areas. The WREROC cameras were not entirely effective in indicating the direction of view of the iloca cameras due to the high rate of roll. Apart from streets of small cumulus along the coastline, there was no locally distinctive cloud pattern in any other known direction which assisted in orientation of the rocket pictures. The rocket pictures disclosed a great deal of cloud organisation in streets and bands on a scale which could not be detected in the wide angle camera pictures of the satellite.
Fig. 2 Schematic depiction of cloud from ground, aircraft, and rocket data.
5. DISCUSSION

(a) Extension of frontal cloud to low latitudes

Satellite pictures of low latitude areas have not infrequently portrayed distinct zones of cloud which appear to have been associated with polar fronts frontolysing as they moved northward. In some cases their frontal origin can still be identified by a low level cyclonic wind shear. In other cases winds are light and variable or apparently anticyclonic, and other conventional data also is inadequate to identify the front. The low latitude bands of cloud which persist in these latter conditions may well represent the final stage of frontal evolution. The original air mass difference has progressively deteriorated to a cyclonic wind shear, a weakly convergent zone and finally to a passive cloud mass which may persist for a considerable period without the assistance of any vertical motion.

Frame 15 (Fig. 3) shows the cloud band at A associated with the primary front through central Australia (Fig. 1). (The cloud system at B at the western end of the well defined southern coastline, represents the secondary front and vortex.) The extension of the frontal cloud at A as far north as 200S and beyond, could not have been anticipated with any confidence from conventional reports and analysis. Nevertheless, this front was well authenticated over southern Australia and it is reasonable to assume that the low latitude extension of the cloud band in Fig. 3 was evidence of some persisting frontal activity.

(b) Indication of large cumuliform cloud and cumulonimbus in satellite pictures

A sferics report at 0600 GMT on 30 May 1962 at 260S 1340E indicated thunderstorm activity in the frontal zone. The aircraft photographs and visual observations indicated a line of cumulonimbus emerging clear of middle level cloud to heights estimated at 25/35,000 feet (Fig. 4). In neither the satellite cloud pictures, of which Frame 15 is typical for this orbit, nor in the rocket pictures was there any graduation of brightness as between the middle level cloud and the line of Cb.

In addition to dimension, form and texture, the degree of brightness of the cloud image is often a useful guide to interpretation of cloud type providing due consideration is given to the factors involved. These are the illumination of the cloud surface, its position in relation to the camera and sun, and its reflectivity.

The illumination on a horizontal surface has been stated by Jones and Condit (1948) to decrease by half with elevation decrease from 900 to 350. The zenith distance of the sun in this exercise was 530 and the illumination should have been adequate for effective photography. A more important factor in this case, however, is the position of the camera in relation to the cloud and sun.

Clouds appear brightest when viewed along the sun path, i.e., in the direction of the sun. In this and all other frames of orbit 1587 the camera was directed away from the sun (bearing 9 degrees from Woomera) and the intensity of reflected light was reduced accordingly.

The reflectivity of clouds is related to their thickness, drop size composition and the solar elevation. Neiberger (1949) has shown that there is little increase in albedo as the thickness of cloud increases beyond 1000 feet. Hewson (1943) found that albedo is more sensitive to cloud thickness for clouds of large drop size, and Fritz (1954) examined the effect of solar elevation and found that at lower elevations the net result of this increased albedo and decreased illumination tended to reduce the variations in reflectivity for different cloud types and thicknesses. In this exercise, identification of the thick middle cloud and Cb as separate features within the frontal cloud mass was hardly to be expected even if the cloud had been viewed along the sun path with high solar elevation.
Fig. 3 Frame 15 orbit 1587 Tiros IV 30 May 1962.
Fig. 4  Aircraft photo of cumulonimbus and middle level cloud (foreground) from 4000 feet. (Courtesy RAAF)

Fig. 5  Frame 15  orbit 398  Tiros III  8 August 1961.
(c) Streaky appearance of the frontal cloud

First impressions of the broad striations in the frontal cloud zone might suggest that some degree of frontolysis or an absence of moisture is responsible for the streaky appearance. This is at variance with aircraft reports of cumuliform cloud and the moist air sounding. The picture in this frame (Fig. 3) nevertheless contrasts rather strongly with that obtained of the frontal cloud photographed over southeast Australia in a previous exercise (Fig. 5). In the latter picture the cold front cloud at B was identified as large cumulus and Cb whose strong vertical cell development gave a scalloped edge appearance. The cloud at C consisted of thick middle and lower level clouds. No striations were evident in these formations.

Examination of the wind flow in the warm air adjacent to the fronts on these two occasions revealed a general similarity of structure with strong vertical shears in the lower troposphere. Hitchfield (1960) and others have shown from radar techniques that the main structure of Cb cloud remains essentially upright even in the presence of severe vertical wind shears. Although the anvil portion is carried downwind its density is not such that it is capable of definition in satellite photographs to the extent of the striated effect in Fig. 3.

The streakiness in this instance arises in all probability from the presence of broken cloud at different levels in a wind field increasing strongly with height. This association of broken low and middle type clouds was reported at all stations within the frontal zone. The absence of streakiness in the earlier case represented by Fig. 5 is consistent with the observation of cloud at A and B as parallel bands of cumuliform cloud, largely unaffected by the vertical shear, and at C of a uniformly overcast middle layer.

(d) Street Formations

The street formations of small fair weather cumulus which formed as the cold air moved over the warmer land surface was observed by aircraft and more clearly in rocket photographs (Fig. 6(a), (b)). The spacing between the streets was about 1.7 mi as measured by vertical aircraft camera, and the streets closely parallel the WNW direction of low level wind flow. The cumulus appeared to be 0.5 mi or less in diameter and of very little vertical development.

Observations by Conover (1962) indicate that the thickness of the convective layer from surface to cloud tops is from 30 to 70 percent of the street spacing. This would give a layer at most 6000 feet thick, which together with reported convective cloud bases within the range 3/5, 000 feet is consistent with their classification as fair weather cumulus.

According to various studies (Kuettner, 1959 and Malkus, 1961) the direction of cloud streets is usually related to the vector of the vertical wind shear. This was supported by the vertical wind profile at Ceduna and Maralinga (Fig. 7) where the shear vector lies along the wind at each station for all wind soundings through a deep layer. Scattered fair weather cumulus was reported from both stations at each time of observation.

Kuettner found that street formations were in most cases accompanied by a negative curvature of the speed profile due to a maximum within the convective layer. In these soundings (Fig. 7) there was no clearly defined speed maximum at low levels but the negative curvature condition was approximated in the layer from the surface to 5000 ft with "maxima" at about 3000 ft. Although clearly visible in the rocket pictures (Fig. 6(b)) these streets were not visible in the wide angle satellite pictures of frame 15 or adjacent frames of this orbit. The cloud was present in the region indicated by the letter C (Fig. 3) and was over 200 mi from the nearest sub-satellite point with a nadir angle of view of about 30°. The raster line width of 2 mi appropriate to this angle (Erickson and Hubert, 1961) obscures the street structure as well as the cloud itself. Other factors are the location of the feature in an area of poor focus distant from the principal point and the restricted illumination due to the direction of view to the southwest, well away from the sun path at 0300 GMT.
(a) from aircraft at 40,000 feet (Courtesy RAAF)

(b) from rocket at about 200,000 feet (Courtesy Department of Supply).

Fig. 6 Cumulus streets - 30 May 1962.
Fig. 7  Vertical wind profiles at 2300 GMT 29 May 1962.
Wind direction also shown.
It has been noted that a greyish haze is contributed by cloud elements of diameter less than the raster line width and therefore too small to be separately distinguished. Any such effect produced by the small cumulus clouds would be masked by the light grey background which is shown extending from C to D on Fig. 3 and due, for the most part, to the comparatively highly reflective surface of the Nullarbor Plain since most stations reported clear skies. This is a limestone - "gilgari" surface, bare except for scrub in "gilghi"* and scanty salt-bush after rain. Survey charts show a well defined boundary between this and the soft sands of the western desert with its characteristic giant west-east ridges. The boundary extends in excess of 200 mi inland in the southwest. The difference in reflectivity is attributable to surface rather than colour since both sands and plain have the same reddish colouration. Survey aircraft pictures taken from 20,000 feet show the nature of the surface in better detail (Fig. 8, 9). On the satellite pictures the limestone surface gives the cirrus-like shadings extending inland about 100 mi from the coast which is clearly defined against the poorly reflective ocean waters.

Frame 15 (Fig. 3) shows a cloudless area which extends about 30 mi to 50 mi southward from the coastline over the Australian Bight. A number of ships south of this area reported large cumulus and showers due to instability arising from the moisture flux over the sea surface and persisting cold temperatures aloft, characteristic of the original southerly outbreak with the stationary West Australian low. The satellite picture indicates at E the street formation of these clusters of large cumulus. The distance from the sub-satellite point of frame 15 and the nadir angle of view give a line width of the television system of about 2.5 mi. Diameters of large cumulus are typically 1 to 4 mi and the clarity of definition of these cloud streets inclines to the view that the cloud dimensions are of the larger size and the street spacing may be 10 mi or more and applicable to a convective layer of the order of 15,000 feet (Conover 1962).

(c) Cold Front Model

The location of the cold front was well defined south of 30°S by both surface and upper air observations (see Fig. 1 for positions of soundings discussed below). The distribution and type of cloud preceding, within and in the rear of the frontal zone, was well documented in the Woomera area by the detailed ground reports, by aircraft reconnaissance and rocket photographs.

Although no idealised model can represent an individual front in detail, the cloud observations in this area were consistent in many respects with major features of a model suggested by Sawyer (1955). The line of cumulonimbus visible from the aircraft (Fig. 4) occurred as pre-front activity in the warm air which is typically represented by the pre-front sounding at Woomera at 2000 GMT 29 May 1962 (Fig. 10a). Characteristics of the model are a high degree of moisture and pronounced ascent in the warm air immediately preceding the front, with dense cloud in a deep layer and often Cb development.

The aircraft photograph (Fig. 4) shows also the uniform upper surface of a band of middle level cloud located in the rear of the Cb formation. In the Sawyer model, cloud of predominantly stratiform type exists in the cold front zone, with vertical development suppressed at mid-troposphere levels 700-600 mb due to a pocket of very dry air found within and preceding the frontal zone at these levels. This may be typified by the soundings at Giles (Fig. 10b) and Adelaide (Fig. 10c). Both soundings were taken just after the frontal passage and intersected its lower surface at 870 mb and 900 mb respectively.

The characteristic clearing behind the front was revealed by photographs from both aircraft and rocket (Fig. 6a, 6b). These convective clouds may be expected to develop in predominantly descending post-front cold air according to time, season and nature of surface. The sounding at Maralinga (Fig. 10d) is typical of this air. Under conditions such as occur over the Australian Bight at D (Fig. 3) where the cold air has accumulated moisture from the relatively warm sea surface, ascending currents have become established through a deep layer to form large cumulus with showers as reported by shipping.

* "gilghi" : aboriginal term for natural water holes
'gilber' : smooth-surface stones
Fig. 8(a) Nullarbor plain from 25,000 feet showing limestone-gibber surface with gilghi.

(Courtesy Department of National Development)

Fig. 8(b) Western Desert from 25,000 feet showing sand ridges aligned with prevailing westerlies.

(Courtesy Department of National Development)
Fig. 9 Boundary region of Nullarbor Plain and Western Desert.
(Courtesy Department of National Mapping)
Fig. 10 Soundings on 29 May 1962

(a) Woomera 2300 GMT in the warm air
(b) Giles 2300 GMT intersecting the frontal zone
(c) Adelaide 2300 GMT intersecting the frontal zone
(d) Maralinga 2300 GMT in the cold air
6. CONCLUSIONS

A not uncommon feature of satellite pictures is the extension of a cloud belt northward along a frontolyzing polar front into low latitudes where the front can no longer be detected by conventional methods.

The relatively streaky rather than cellular appearance in satellite photographs of some frontal bands containing Cb is not necessarily a consequence of a difference in vertical wind shear. The striations can be produced for example by broken cloud at different levels in a wind field increasing strongly with height.

Lines of Cb may be indistinguishable against middle level cloud, chiefly because of insensitivity of photography to cloud thickness. Low solar elevations and unfavourable sun path are contributing factors.

A grey, cirrus-like shading due to reflection from the limestone surface of the Nullarbor Plain evidences the need for familiarity with the terrain when interpreting satellite cloud pictures.

The cloud structure near the frontal zone closely resembled that of a Sawyer cold front model and illustrates the application of such models in interpretation.

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