PICTURES OF THE MONTH
A Tropical Cyclone with an Enormous Central Cold Cover

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1. Introduction

Dvorak (1975) developed a technique for using visible (VIS) satellite imagery to estimate (and forecast) the intensity of tropical cyclones (TCs). The foundation of the technique is a demonstrated relationship between the intensity of a TC and the characteristics of its satellite cloud signature. Further, the rate of change of the satellite intensity estimate (and characteristics of the TC itself) can be used to make 24-h intensity forecasts. The cloud characteristics used to estimate TC intensity on VIS satellite imagery include the size and location (with respect to the low-level circulation center) of persistent deep convection, and the width and azimuthal wrap of the peripheral bands of deep convection. When a TC possesses an eye, the estimate of its intensity depends primarily upon the width of the eyewall cloud, the character (e.g., ragged, cloud filled, sharply delineated) and size of the eye, and the width and azimuthal wrap of peripheral convective bands.

In a later paper, Dvorak (1984) developed a technique for estimating the intensity of TCs from their appearance on infrared (IR) satellite imagery. (Dvorak’s VIS and IR techniques are now used worldwide, and satellite-derived TC intensity estimates are the primary data source of this statistic in most TC basins.) The cloud features that are used to estimate the intensity from IR imagery are physically similar to those used in Dvorak’s VIS techniques; however, when IR imagery is used, the cloud-top temperature (i.e., the IR equivalent blackbody temperature) plays an important role in the intensity diagnosis. For example, when a TC possesses an eye, the intensity estimate is based not only upon the width of the eyewall cloud (the greater the embedded distance of the eye within the eyewall cloud, the higher the intensity), but also upon the cloud-top temperature of the eyewall cloud (the colder the temperature, the higher the intensity) with an adjustment made for the temperature within the eye (the warmer the temperature, the higher the intensity).

For most applications of Dvorak’s techniques, the greater the amount of deep convection near or over the low-level circulation center of the TC, and the colder the cloud-top temperatures of that centrally located deep convection, the higher the diagnosed intensity. Ironically, one of the largest and coldest eruptions of convection near the core of a TC, the central cold cover (CCC), indicates slowed or arrested development (Dvorak 1984).

2. The central cold cover

In his 1984 paper, Dvorak noted that the use of IR imagery required the introduction of a new concept—the CCC—in order to deal with the occurrence of a sudden spreading of cold clouds over the central features of a TC. When a CCC persists, it signals an interruption in the development of the TC. According to Dvorak, the CCC pattern is defined when a more or less round, cold overcast mass of high cloud covers the TC center or comma head obscuring the expected signs of pattern evolution. The outer curved bands and lines usually weaken with the onset of CCC. It is only rarely that the CCC pattern is used with VIS pictures since the central dense overcast (CDO) or curved cloud lines are usually visible through the thin cirrus clouds. The cold cloud shield of a CCC also tends to be much larger than that of most CDOs.

There are major structural differences between a CCC and a CDO. The CCC is a very cold layer of cirrus that spreads over, and obscures, the core and primary rainbands of the TC. It usually begins with an explosive growth of deep convection near the core of the TC with a subsequent spreading of a very large, smooth, and very cold cirrus canopy over the TC. It is a relatively

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Fig. 1. Gloria (with its large CCC) and Herb are developing simultaneously in the western North Pacific. A third TC, Frankie, was developing in the South China Sea and is out of range of this image (1431 UTC 23 July GMS-5 enhanced infrared imagery: enhancement is the “MB” curve). The inner white portion of Gloria’s CCC (surrounded by black and other gray-shade borders of higher temperature thresholds) indicates IR equivalent blackbody temperatures of $-81.2\,^\circ$C or colder. Note the large difference in the amount of cold cloud associated with Gloria versus the amount of cold cloud associated with Herb.
rare phenomenon that is observed in the developmental process of a small fraction of the TCs in each TC basin. The CDO, on the other hand, is a common cloud pattern for a TC at strong tropical storm or minimal typhoon intensity and occurs as the dense cirrus from the central deep convection spreads over the low-level circulation center. An eye and surrounding eyewall cloud is often well formed under the cirrus canopy of a CDO before it appears on satellite imagery. An eye within a CDO often first appears as a relatively warm spot on IR imagery (a warm spot can be defined as an eye when the temperature of the warm spot becomes at least two gray shades warmer than the surrounding wall cloud ring). On VIS imagery, the eye within a CDO usually becomes apparent earlier than on IR imagery, and, for intensifying TCs, becomes better defined as the obscuring cirrus thins. According to R. Zehr (1996, personal communication), the average intensity of a TC at the first appearance of a visible eye within its CDO is 80 kt.

The acquisition of an eye by a TC possessing a CCC, noting that many TCs that exhibit a CCC do not emerge from it with an eye, comes about by way of a completely different sequence of events. All the central features and most of the banding features of a TC are obscured by the very high, cold cirrus of the CCC. Unlike the emergence (on satellite imagery) of an eye within a CDO, the whole TC core with an eye (or other structural pattern) emerges from under the cirrus of the CCC as the cirrus of the CCC dissipates.

3. An enormous CCC during the development of Typhoon Gloria

During late July 1996 the tropical atmosphere of the western North Pacific was dominated by an active monsoon trough. On 23 July, three TCs were developing along the axis of this trough: Frankie (in the South China Sea), Gloria (in the Philippine Sea, east of Luzon), and Herb (northeast of Guam) (Fig. 1). Gloria had been developing as a monsoon depression, defined by the Joint Typhoon Warning Center (JTWC) as a large (but relatively weak) cyclone in the monsoon trough that is composed of an ensemble of mesoscale convective systems (MCSs) (JTWC 1993). During the evening hours of 23 July, a cluster of small cold-topped MCSs began to grow near the estimated center position of Gloria. During a 6-h period, this cluster of MCSs mushroomed into an enormous CCC. By local midnight, the average diameter of the area within which the cloud-top temperature was at or below $-70^\circ$C was approximately 780 km (Fig. 2).

In relation to published statistics of convective cloud sizes, Gloria’s CCC is extraordinarily large. The area of that portion of Gloria’s CCC (see Fig. 2) that is colder than $-70^\circ$C is nearly 500 000 km$^2$. For ease of visualization, one sees from Fig. 3 that this is nearly as large as the state of Texas (which encompasses 692 402 km$^2$). In a study of 43 mesoscale convective complexes (MCCs) occurring over the central United States during 1978, Maddox (1980) measured the areal extent of cloud-top temperatures at, or below, $-52^\circ$C. Only one of these 43 MCCs possessed a cold cloud shield (at, or below, $-52^\circ$C) that was bigger than the portion of Gloria’s CCC that was at, or below, $-70^\circ$C. In a study of winter monsoon cloud clusters in the region of Borneo and surrounding seas, Williams and Houze (1987) found no cluster elements (i.e., an individual cloud mass) meeting the area and temperature thresholds of at least 50 000 km$^2$ of contiguous cloud below $-60^\circ$C with a size greater than 300 000 km$^2$. Mapes and Houze (1993) examined maritime tropical cloud clusters as defined by the very cold threshold of $-65^\circ$C (which matches the instantaneous precipitation area in radar-sampled mature MCSs fairly well). In their study, a cloud cluster was identified on geostationary IR imagery by an algorithm that searched for connected areas of cold cloudiness. This algorithm required horizontal (along the satellite scan line) connectivity as well as a columnar (not merely touching diagonally) connectivity. Less than 0.1% of all cloud clusters at the temperature threshold of $-65^\circ$C had sizes greater than 500 000 km$^2$.

Gloria’s CCC was not only large but also exceptionally cold. Roughly half of the area of Gloria’s CCC was colder than $-90^\circ$C. The coldest IR pixel, with an equivalent blackbody temperature of $-100^\circ$C, was located near the geometric center of the CCC. This is an extremely cold cloud-top temperature that is rarely seen. It is only 2$^\circ$C shy of the record cold cloud-top temperature of $-102^\circ$C reported by Ebert and Holland (1992) in the deep convection associated with a TC near Australia.

By the early daylight hours of 24 July, the periphery of the CCC began to warm on IR imagery, and a new smaller CCC mushroomed into the preexisting cold cirrus canopy. As the day progressed, the underlying structure of Gloria gradually emerged in VIS imagery as the supporting convection of the CCC ended and the large cirrus canopy of the CCC thinned. By midafternoon, the cold cirrus of the CCC became nearly transparent, and a ragged eye accompanied by some peripheral convective cloud bands of the intensifying Gloria was then seen.

That a CCC indicates arrested development is a finding by Dvorak. This is generally accepted as valid and is used in operational application of Dvorak’s techniques. While it is true that there were no in situ measurements of the intensity of Gloria before, during, or after it possessed a CCC, the satellite imagery does provide evidence that little intensification took place. The JTWC best track (largely dependent upon satellite intensity estimates) shows little intensification during this time period. Prior to the formation of Gloria’s CCC, satellite intensity estimates (supported by ship observations) indicated that Gloria’s peak winds had increased to approximately 55 kt. During the afternoon
Fig. 2. Gloria's CCC reaches its maximum areal extent and registers its coldest temperatures. The location of the coldest temperature of ~100°C is indicated by the arrow. Enhancement is the "MB" curve applied to 1431 UTC infrared GMS-5 imagery. The area bounded by the black (~60.2° to ~63.2°C) gray-shade enhancement is approximately 600 000 km²; the area of white (~81.2°C or colder) is approximately 400 000 km².
hours of the following day, as the dense cirrus of Gloria’s CCC thinned to allow a view of the underlying central cloud structure, a very poorly defined eye was observed on VIS imagery, indicating that Gloria had become a minimal typhoon. By the morning hours of the next day, Gloria acquired a well-defined CDO within which there was a small cloud-filled eye. Applications of Dvorak’s techniques to the satellite imagery indicated that Gloria had reached 90 kt (its peak estimated intensity), representing a rise of only 35 kt during the 36-h interval following the onset of its CCC—hardly a remarkable change considering the extreme changes in the cloud pattern. This is consistent with Dvorak’s findings that the appearance of a CCC signals arrested development that is renewed as the eye pattern of the T4 (minimal hurricane) emerges beneath the thinning cirrus. It is an irony that the most significant convective event that may be observed during the life of a TC has little immediate effect upon the intensity.

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REFERENCES


