**Article ID:** 1006-8775(1999) 02-0208-06

# A METHOD FOR DETERMINATION OF GALE REGION OVER OCEAN SURFACE BY TROPICAL CYCLONE USING $T_{BB}$*

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**ABSTRACT:** With black-body temperature ($T_{BB}$) from GMS infrared cloud imagery for 16 tropical cyclones in 1996 – 1997 and domestic and overseas reports of gale by tropical cyclones as well as some conventional and shipboard wind reports, a number of conceptual charts are statistically summarized to determine ranges of gales on near gale and 10 of the storm. A method by which the radius of gale is operationally useful has been tested.

**Key words:** black-body temperature ($T_{BB}$); tropical cyclone; near gale and storm gale

**CLC number:** P457.8 **Document code:** A

## Ⅰ. INTRODUCTION

Tropical cyclone gale is a destructive weather that brings much influence on ocean shipping and fishery industry in addition to occasional serious threats. Hence, it is one of the most important rings in the analysis and forecasting of tropical cyclones to define the distribution of the intensity and regions of gales on various Beauford scales. Due to the facts that air reconnaissance has been stopped over the northwestern Pacific, there has been scarce distribution of conventional oceanic measuring stations and ships take routes off the effects of the tropical cyclone, it is much more difficult to obtain real distribution of gale by the tropical cyclone. Additionally, the problem is aggravated by poor numerical analysis and forecasting over low-latitude ocean surface and high uncertainty in Dvorak's estimation procedure (Guo et al., 1996). It is the pressure near the center that it determines, which is not well correlated with the wind force. It also fails to give additional information on region of gales by the tropical cyclone. It is, therefore, necessary from the viewpoint of operational analysis and forecasting that a method is to be developed that locates the region of tropical cyclone gales based on satellite imagery.

## Ⅱ. DATA AND METHODS

As far back as in the late 1960's and early 1970's, attempts were made both at home and abroad to derive winds at the upper, lower and surface layers using features like the shape of high and low clouds and the axial directions of cloud sectors in satellite imagery (CMO, 1975; API, 1972) and there have been results of useful reference in practice. On the basis of these researches, we try to develop a procedure with which the gale regions by the tropical cyclone are determined by displaying quantitatively cloud patterns and major directions of cloud sector axis based on $T_{BB}$.

* **Received date:** 1998-01-22; **revised date:** 1998-08-24

**Foundation item:** Project of the National Meteorological Center, China (95-02-05)

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The data are selected from 16 tropical cyclones over the northwestern Pacific in 1996–1997 that include infrared cloud imagery, reports issued by the Central Meteorological Observatory of China and weather centers in Japan and Guam as well as some wind measurements on islands stations and shipboard observations, covering a total of 246 time levels in their life cycles. For the subsystem of receiving and processing satellite information, the $T_{BB}$ isolines are analyzed on every time level for the infrared cloud sectors with the domain of value being $T_{BB} \leqslant 0°C$ at $-10°C$ intervals. Analysis charts are output with the same frequency so that regions of near gale and storm gale s are superposed on them as issued in relevant reports by centers at home and abroad, together with wind measurements of conventional means and ships available.

The comprehensive charts thus obtained are divided into two groups according to the intensity of the tropical cyclone, because only regions of near gale and storm gale are issued in the reports. The near gale is analyzed for the tropical storm only but both scales are analyzed for the severe tropical storm and typhoon. For the $T_{BB}$ fields corresponding to individual gale regions located in this way, recognition of statistical patterns and induction are conducted to form schematic conceptual models which are attached with instructions for determining various gale regions.

## III. ANALYSIS AND RESULTS

### 1. *Method determining ⩾Near Gale in Tropical Storm*

Analyzing the comprehensive charts statistically, we have six schematic conceptual models of the $T_{BB}$ fields corresponding to the near gale region in the tropical storm (Fig.1).

It is obvious from the figure that the boundary of the near gale region is consistent with the outer edge of the $T_{BB}$ isolines concentrating at the top of its parent cloud system. For the four $T_{BB}$ fields in Fig.1a – d, the isolines of $T_{BB}$ make a dense appearance at different azimuths relative to the center of the tropical storm, suggesting asymmetric distribution of cloud systems and strong wind shear in the vertical, which is characteristic of the stages of development and decay in a tropical cyclone. On the satellite imagery, however, the outer edge of the dense $T_{BB}$ isolines are shown as cumulus lines at the lower level, which is hard to isolate when they are not dense enough and shaded by clouds at high altitudes. To the scarcest side of distribution of $T_{BB}$ isolines generally correspond a region of cirrus at upper level. The formation of a dense $T_{BB}$ isoline distribution reflects active and intense evolution of convective clouds, implying strong convergence of airflow underneath and appearance of gale over corresponding surface of the ocean further down below.

The gale region of the tropical cyclone, as shown in Fig.1a–d, is defined as a circle that takes the eye as the center and the distance as the radius that measures from the center to the most outward isoline of concentrated $T_{BB}$ area. In Fig.1e & f, however, the vertical wind shear is smaller, which reflects in the satellite imagery as quasi-symmetric distribution of cloud sectors resulting from severe convection. The gale of the storm is a circle that is centered at the eye but falls between it and the $T_{BB}$ isoline closest to it.

The six conceptual models cover nearly 85% of the tropical cyclone cases selected. The exceptions, in their minority, are not generalized in the model because there are substantial differences between the location in the reports and the center of cloud sector in the imagery, or between reports by domestic and overseas centers, or the $T_{BB}$ field is disorganized during rapid maturing and decaying of the storm.

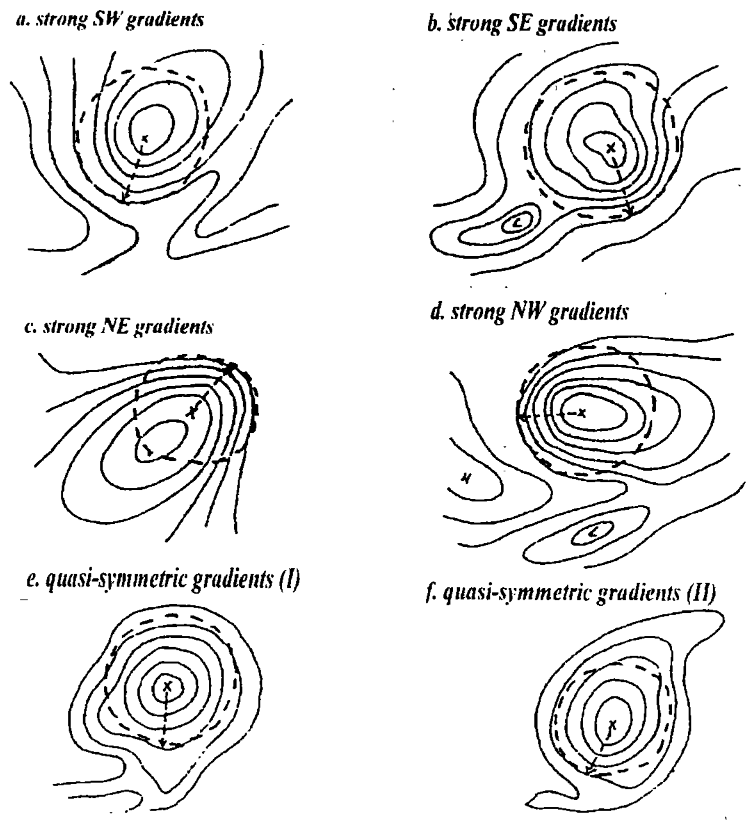



Fig.1 Six conceptual models of $T_{BB}$ field for determining regions ≥near gale in the tropical storm. The "×" sign indicates the center of the tropical cyclone (The heavy dashed line represents the boundary of the near gale region and the thin line the $T_{BB}$ isoline ≤0°C at the interval of −10°C; "W" and "C" are the centers of warm and cool sectors in the cloud bands, respectively)

2. *Method determining Gale in Severe Tropical Storm and Typhoon*

The winds ≥near gale and ≥storm gale are two regions to determine in severe tropical storms and typhoons. Another six conceptual models are also concluded with statistical study of the comprehensive charts (Fig.2). The determination of gale regions using the models turns out far more difficult than in the case of tropical storms. It may attribute to large coverage of cloud systems in severe tropical storms and typhoons which are embedded with a number of severe convective clusters in addition to less concentrated, poorly defined and less compact distribution of $T_{BB}$ isolines. The asymmetry of the gale region is such that the group of conceptual models conclude more than 85% of ≥gale cases but only nearly 80% ≥near gale cases.

Concentrated $T_{BB}$ isolines appear in both Fig.2a & b. The method for determining the ≥ near gale region is the same as we would use for tropical storm, i.e. it is defined as a circle that takes the eye as the center and the distance as the radius that measures from the center of the severe tropical storm or typhoon to the most outward isoline of concentrated $T_{BB}$ area. As for the determination of the ≥gale region, it is a circle that takes the eye as the center and the distance as the radius that measures from the center to the most inward isoline of concentrated $T_{BB}$ area.

the radius that measures from the center to the most inward isoline of concentrated $T_{BB}$ area. Maximum winds appear between the center of the severe tropical storm or typhoon and the eye-wall sector of the cloud, which consists of symmetric or asymmetric $T_{BB}$ concentration due to vigorous development of convective clouds caused by strong convergence of low-tropospheric layers around the center.

The $T_{BB}$ field is quasi-asymmetrically distributed (Fig.2c). It is also observed that a strong cloud band inserts from the southeast with a low-$T_{BB}$ tongue in the shape of a semi-ring south of the center. The ≥near gale region is defined a circle with the radius spanning from the severe storm center to the inner boundary of the inflow cloud band while the ≥gale region a circle with the radius from the center to a half ring around it or to the axis of major severe convection area.

The $T_{BB}$ field of the cloud systems of severe tropical storm or typhoon (Fig.2d) is shaped like a non-typical comma. The determination of ≥gale region is the same as in Fig.2c, but is

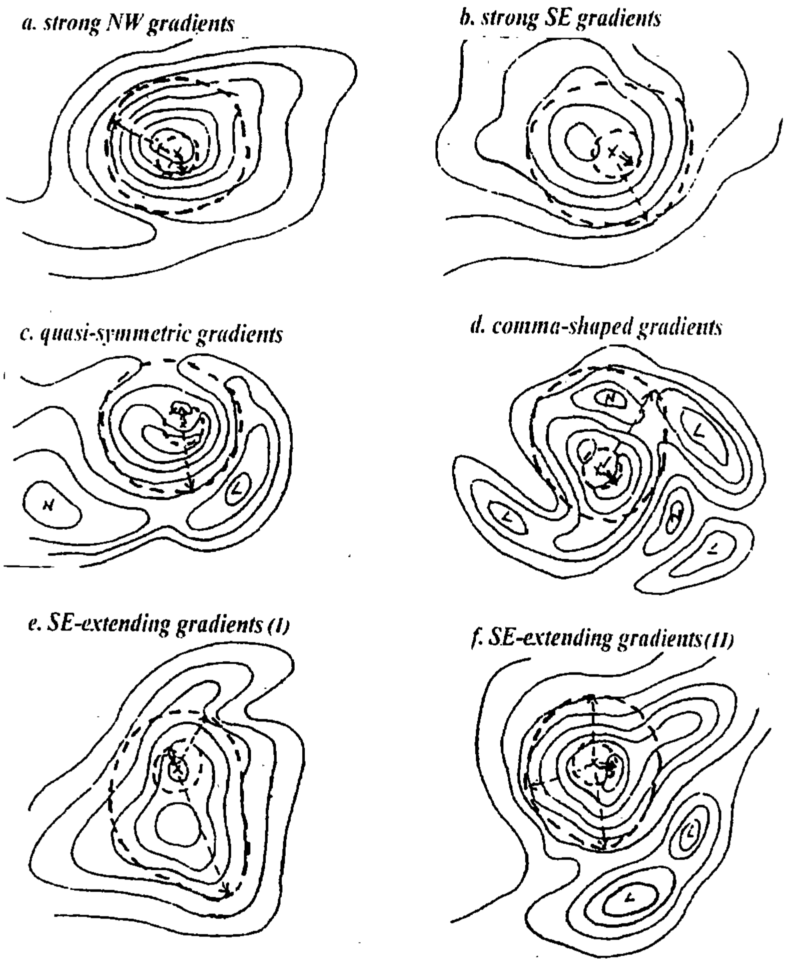


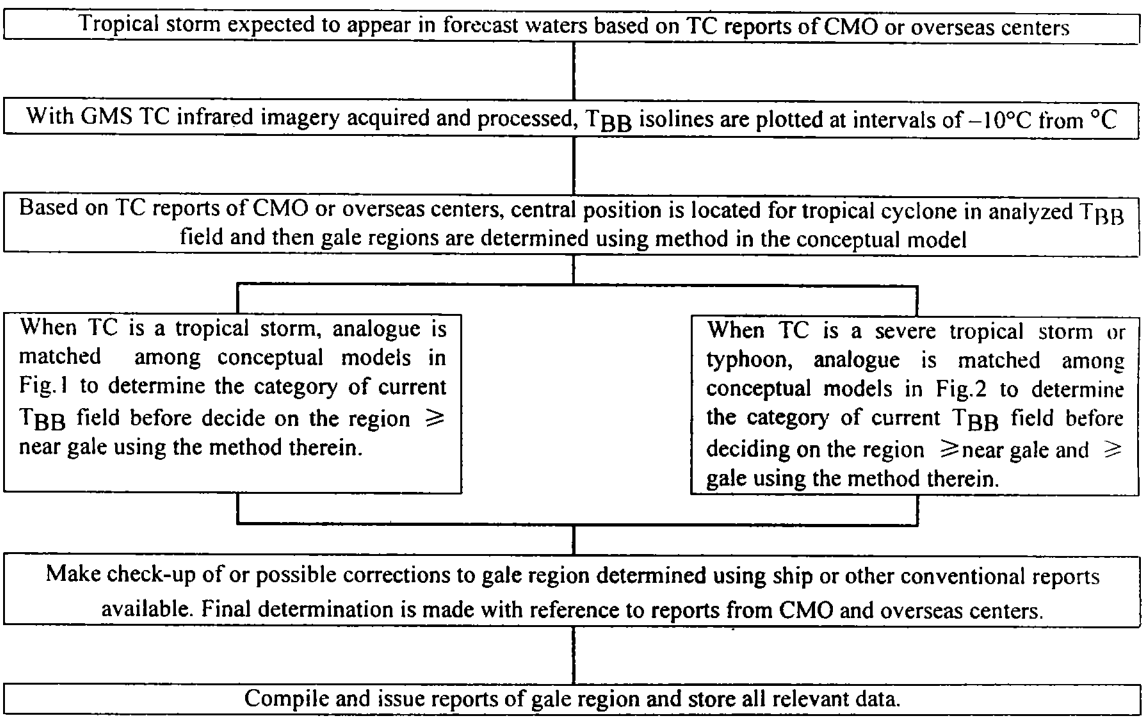

Fig.2 Six conceptual models of $T_{BB}$ field for determining gale regions ≥near gale and ≥gale in the severe tropical storm and typhoon (The solid dashed line is the ≥gale region and the arrow its radius and the rest is the same as Fig.1)

much difficult for the region of ≥near gale because of its asymmetric distribution. The region is larger north of the center, having the cold axis point of the inflow cloud band northeast of the comma. The northern semi-circle with the radius measuring from the point to the center is the region where the ≥near gale prevails. The southern semi-circle, however, is defined when the warm sectors of scattered clouds appear to the southwest or southeast together with the southernmost position the major convection around the center. The distance between the boundary mark above and the severe storm center is just the radius of the semi-circle. Both semi-circles form a whole gale region.

As shown in Fig.2e & f, a larger ≥near gale region appears southeast of severe tropical storm and typhoon. The determination of ≥gale region follows the same procedure as above, i.e. the gale boundary is set at the inner edge of the concentrated $T_{BB}$ isolines in Fig.2e but at both the former and the cold axis of severe convection near the center in Fig.2f. The northern ≥near gale region in Fig.2e is a semi-circle that runs the radius from the ending point of the warm tongue northeast of the center and the center itself while the southern ≥near gale region coincides on the boundary with the outer edge of the concentrated $T_{BB}$ isolines. The near gale region in Fig.2f is also semi-circle that has its boundary to the southeast on the outer edge of the concentrated $T_{BB}$ isolines and its radius to the north and west takes the mean distance from the outer edge of the concentrated $T_{BB}$ isolines to the severe storm center.

## Ⅳ. FLOW CHART DETERMINING TROPICAL CYCLONE GALE

On basis of the preceding research on the relation between the $T_{BB}$ field in the tropical cyclone (TC) and gale regions, an operational working flow chart is designed as below for determination of gale regions over the sea surface.



## V. CONCLUSIONS AND DISCUSSIONS

It is both important and difficult to determine operationally the region of gale in the tropical cyclone over the ocean.

Using GMS cloud imagery of high temporal and spatial resolution, a meaningful attempt has been made in this paper to determine the gale region in the tropical cyclone through schematic conceptual models set up with $T_{BB}$ data quantitatively analyzed. Examining the cases randomly selected, we find that generalizing rate of the conceptual models is between 80% and 85%, indicating close relationship between the $T_{BB}$ field and gale region. It is noted that the current research is only preliminary and more work remains to be done, especially in the aspect of recognizing features of cases uncovered by the conceptual models and improving the objectivity of the latter.

**Acknowledgements:** We are grateful to Mr. CAO Chao-xiong, who works at the Guangzhou Institute of Tropical and Oceanic Meteorology, for his translation of our paper into English.

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