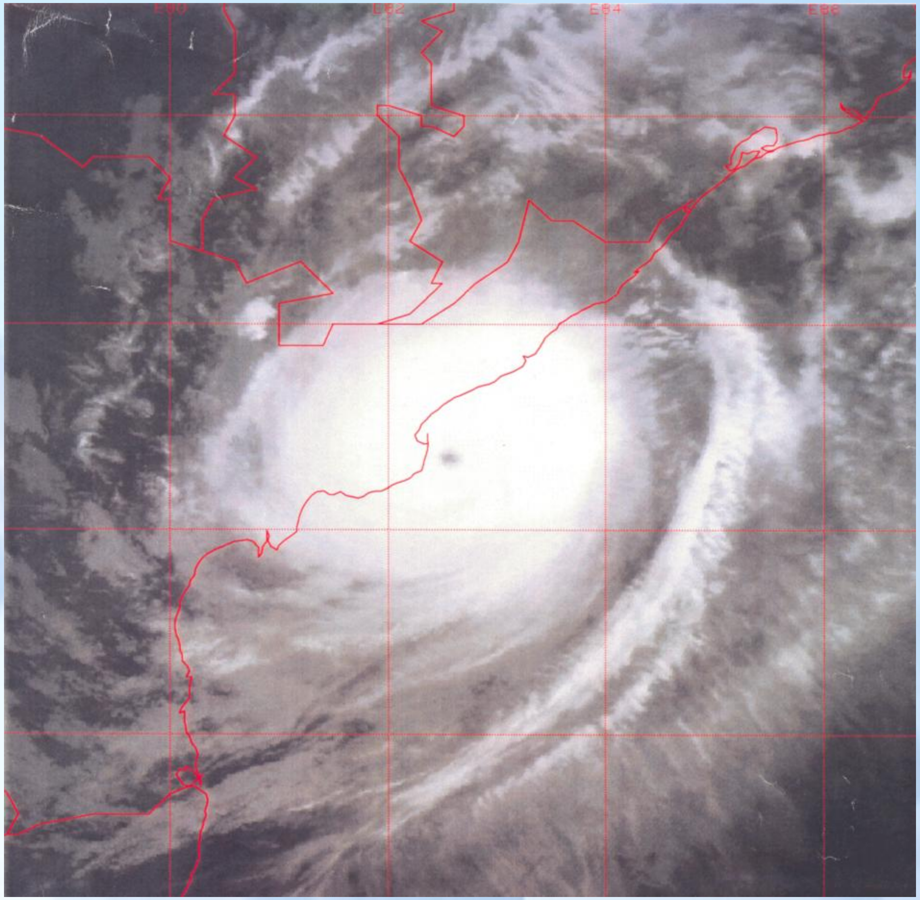
Dvorak Technique -Tropical Cyclone Intensity Analysis

Vernon Dvorak (circa: late 1970s).



Suman Goyal
Scientist-E
Satellite Meteorology Division

Introduction

- For the past three decades, Vernon Dvorak's practical insights and tools for estimating Tropical Cyclone (TC) intensity from satellite data have proven to be invaluable in forecast applications.

- The Dvorak technique's practical appeal and demonstrated skill in the face of tremendous dynamic complexity place it among the great meteorological innovations of our time.

- The technique evolved significantly during 1970 -1984 and matured over an extended period so that there is no single reference that wholly defines the application of the technique. However the document "Workbook on Tropical Cloud Systems.." published in 1990 ; tries to brings together a collection of notes regarding application of the technique as a reference for operational forecasters .

- The future evolution of the Dvorak and similar satellite-based TC intensity estimation methods is of vital interest to the meteorological and coastal communities, and the continued improvement may be a top research priority in the atmospheric sciences.

Past History and Foundation of the Technique

- The first methods for tropical storm analysis using satellite imageries (TIROS 1) were developed and operationally used in early 1960's when only one Picture was available per day (Fett, 1964; Timchalk; et al 1965).

- By the late 1960's, polar orbiting satellites with visible and limited IR capabilities were providing TC forecasters with coarse-resolution imagery several times a day. At this time there were no enhancement or animation capabilities. Early work by Fett (1966), Fritz et al. (1966), and Hubert and Timchalk (1969) was generally unsuccessful in inferring TC intensity from this type of imagery.

Past History and Foundation of the Technique

- In early 1970's number of satellite increased and there their capabilities improved. Dvorak and his colleagues started working to analyse the tropical cyclones using satellite imageries.

- He derived an empirical method relating TC clouds structure to storm intensity using a simple numerical index (CI) corresponding to the maximum sustained wind (MSW) as shown in the Table below (Dvorak 1972, 1973).

CI No	MSW(kt)
1.0	25
1.5	25
2.0	30
2.5	35
3.0	45
3.5	55
4.0	65
4.5	77
5.0	90
5.5	102
6.0	115
6.5	127
7.0	140
7.5	155
8.0	170

vortex	T No
WML	T1.0
D	T1.5
DD	T2.0
CS	T2.5 & T3.0
SCS	T3.5
VSCS	T4.0 to T6.0
SUPER CYCLONIC STORM	T6.5 to T8.0

Basics of Dvorak Technique

The technique relies on four distinct geophysical properties that relate organised cloud patterns to TC intensity.

1. Vorticity,
2. Vertical wind shear,
3. Convection, and
4. Core temperature.

- Vorticity: **The strength and distribution of circular winds (by implication, vorticity) in a TC organises the clouds into patterns that Dvorak relates to the MSW.**

- Vertical wind shear: **The shear is kinematics force that acts distort the vorticity consequently the cloud pattern. Dvorak found that degree distortion was also related to the MSW.**

- Convection: **the convection in the bands of the outer core of the cyclone also figures in the cloud pattern recognisation and scene type assignment.**

- Core Temperature: **Using CTT in the TC inner core the technique relates convective vigor to intensity.**

Evolution of the Technique

- Originally the technique was largely reliant on pattern-matching concepts and the application of Dvorak's development/decay model.

- The significant revisions of 1982 and 1984 shifted the emphasis of the technique toward direct measurement of cloud features.

Details of the Technique

In Dvorak technique following types of satellite imagery are used.

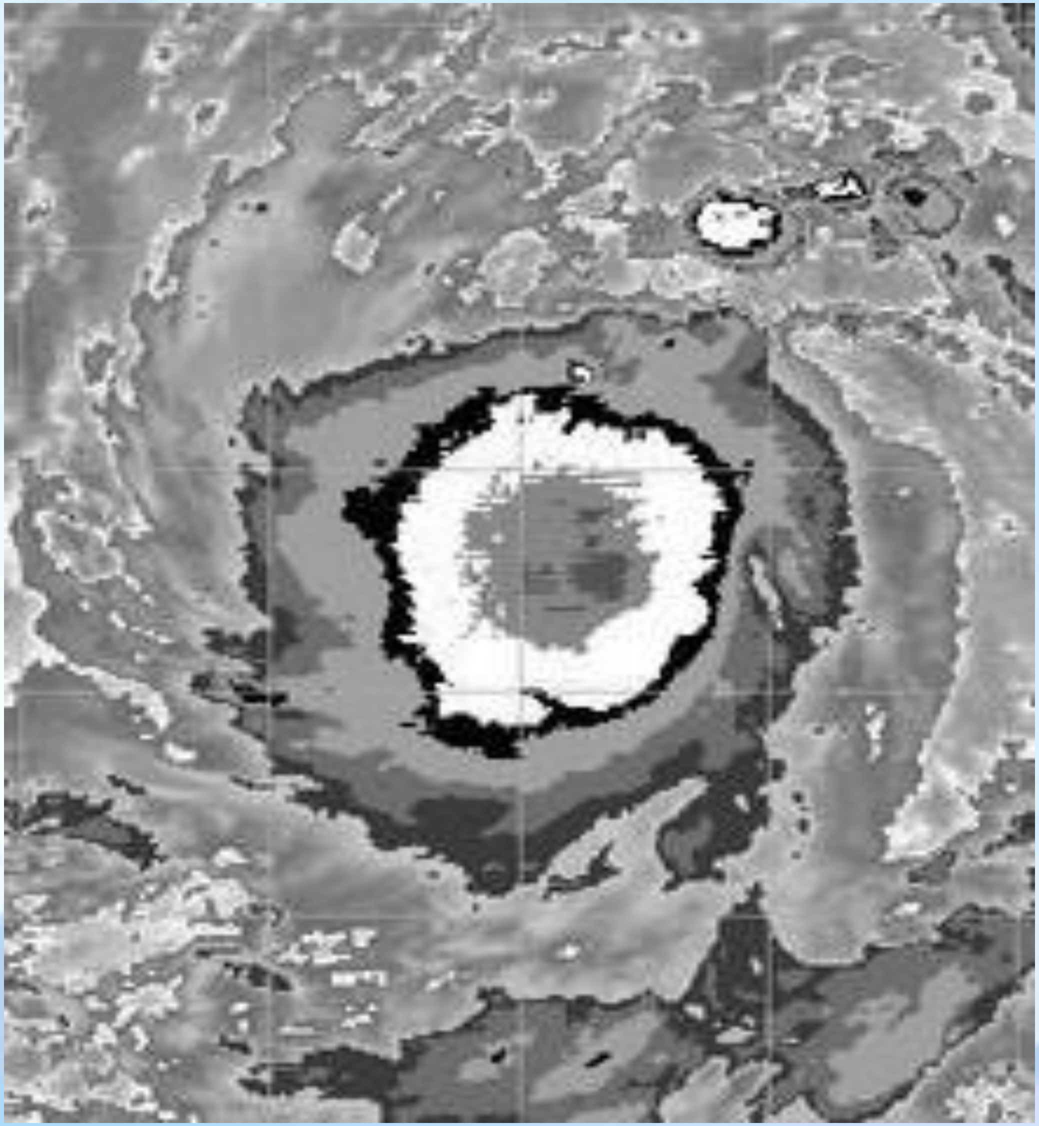
- Visible imagery
- EIR (Enhanced Infrared imagery)
- Digital IR imagery

Enhanced Infrared Imagery (EIR)

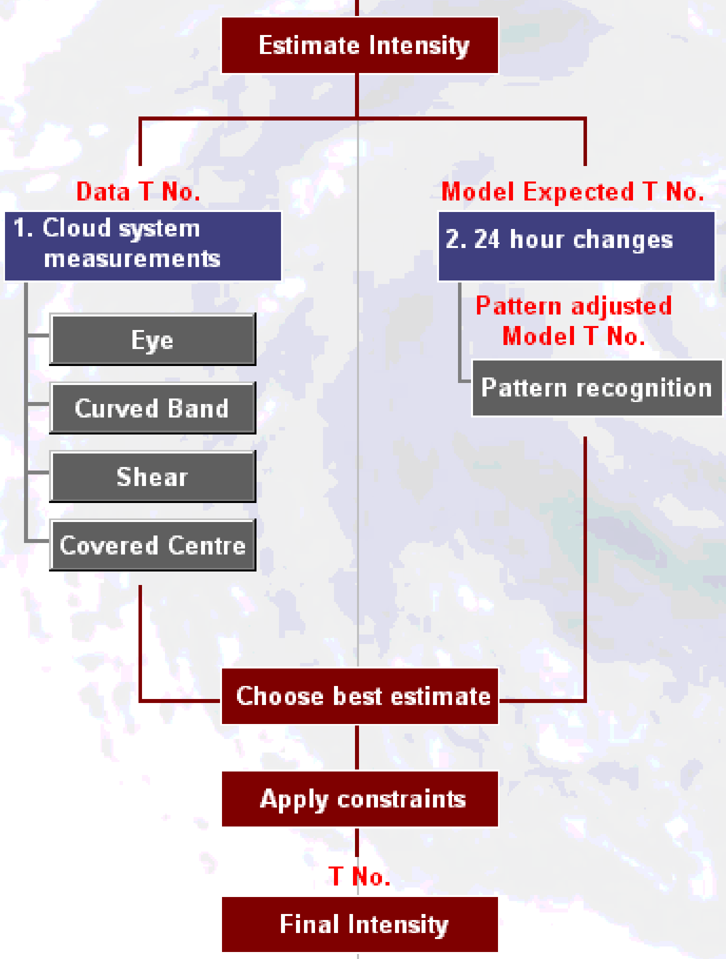
During night time visible imagery is not available and water vapour imagery are not helpful therefore this method was developed by Dvorak and Wright in 1978. In this method we use special lookup table (to highlight the features we use different lookup table in different imageries) . In EIR lookup table different temperature ranges have different gray shades.

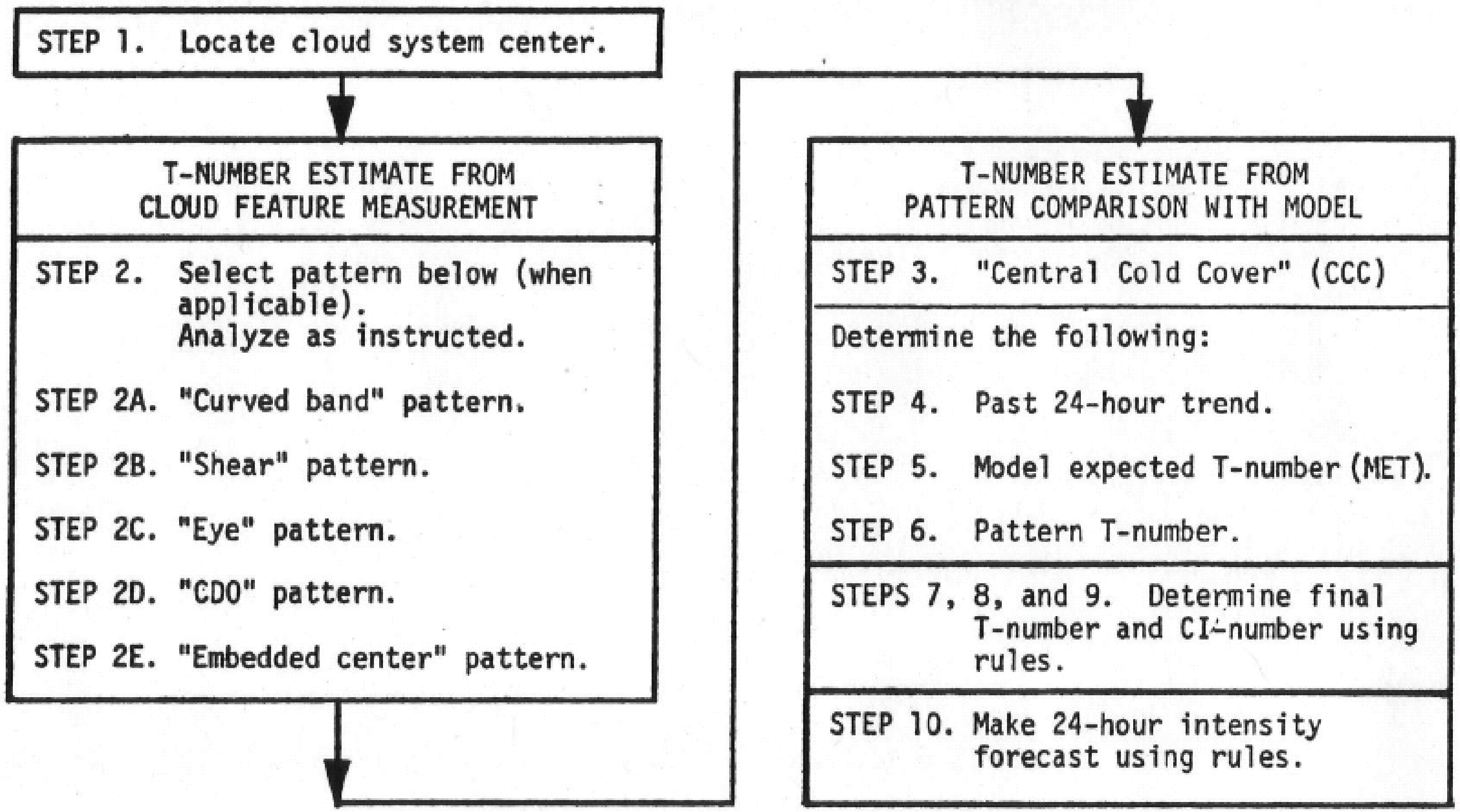
WMG (warm medium gray)	> + 9ºC
OW (off white)	+ 9ºC to - 30ºC
DG (dark gray)	- 31ºC to - 41ºC
MG (medium gray)	- 42ºC to - 53ºC
LG (light gray)	- 54ºC to - 63ºC
B (black)	- 64ºC to - 69ºC
W (white)	-70ºC to -75ºC
CMG (cold medium gray)	-76ºC to - 80ºC
CDG (cold dark gray)	≤ - 81ºC

Enhanced Infrared Imagery

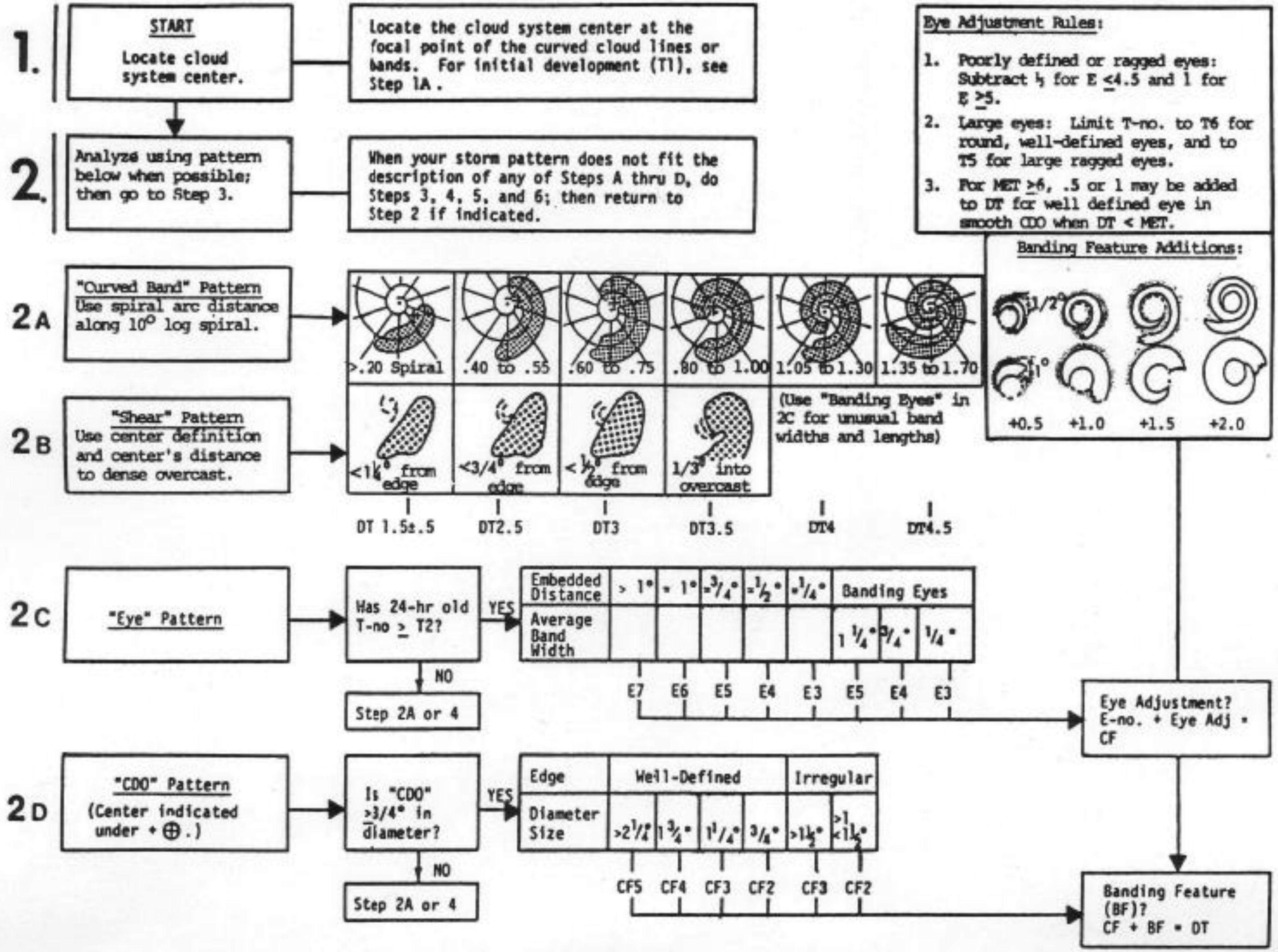


Steps for Intensity Estimation




STEP 1. Locate cloud system center.
T-NUMBER ESTIMATE FROM CLOUD FEATURE MEASUREMENT
STEP 2. Select pattern below (when applicable). Analyze as instructed.
STEP 2A. "Curved band" pattern.
STEP 2B. "Shear" pattern.
STEP 2C. "Eye" pattern.
STEP 2D. "CDO" pattern.
STEP 2E. "Embedded center" pattern.
T-NUMBER ESTIMATE FROM PATTERN COMPARISON WITH MODEL
STEP 3. "Central Cold Cover" (CCC)
Determine the following:
STEP 4. Past 24-hour trend.
STEP 5. Model expected T-number (MET).
STEP 6. Pattern T-number.
STEPS 7, 8, and 9. Determine final T-number and CI-number using rules.
STEP 10. Make 24-hour intensity forecast using rules.

VIS Analysis Diagram-1



VIS Analysis Diagram-2

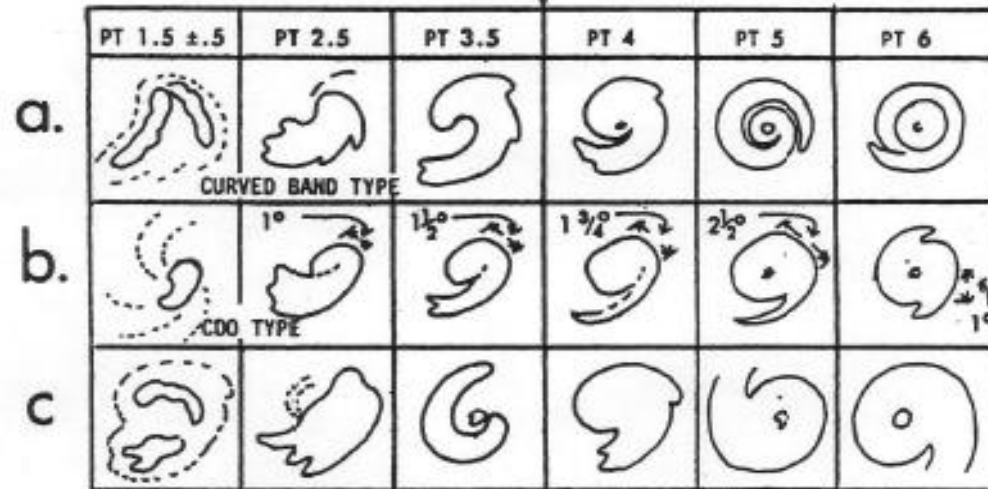
3. "Central Cold (Dense) Cover" Pattern

Rules: When past T-no. ≤T3, maintain model trend for 12 hours; then hold same. When past T-no. ≥T3.5 hold T-no. same. Use as final T-no.; then go to Step 9.

4. Determine past 24-hour trend. Is Development, Weakening, or Same indicated in a change of:
(a) center or eye characteristics, or
(b) center's involvement with dense overcast.

5. Determine Model Expected T-no. (MET).

6. Determine pattern T-no. Select pattern in diagram that best matches your storm picture within one column of the MET. Adjust MET .5 when indicated.



When cloud comma is extremely small (<2½° lat), subtract 1 from pattern number.

7. T-no. Determination:

1. Use data T-no. from Step 2 when cloud features are clear-cut.
2. Use Pattern T-no. when DT is not clear and adjustment to MET is made.
3. For all other cases, use the MET.

8. Final T-number Constraints:

1. Initial classification must be T1 or T1.5.
2. During first 48 hours of development, T-no. cannot be lowered at night.
3. 24 hrs after initial T1, storm's T-no. must be <T2.5.
4. Final T-no. limits: <T4: change of 1/2 over 6 hrs. >T4: change of 1 over 6 hrs, T.5 over 12 hrs, 2 over 18 hrs, and 2.5 over 24 hrs.
5. Final T-no. must = MET ±1.

9. Current Intensity (CI) Number Rules:

1. Use CI = final T-no. except when final T-no. shows change to weakening trend, or when redevelopment is indicated.
2. For initial weakening, hold CI same for 12 hours, then hold CI ½ or 1 higher than T-no. as storm weakens.

10. 24-Hr Forecast:

Extrapolate past trend unless one of the five rules in the instructions applies.

EIR Analysis Diagram-1

1. START
Locate cloud system center.

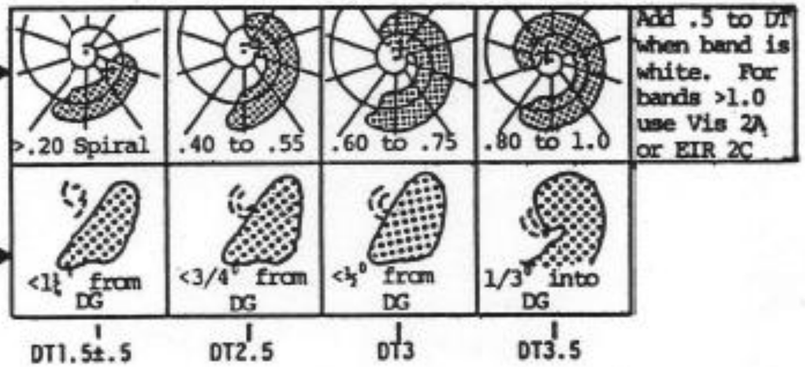
Locate the "CSC" at the focal point of all the curved cloud lines or bands. For initial development (T1), see Step 1A.

2. Analyze using pattern below when possible; then go to Step 3.

When your storm pattern does not fit the description of any of Steps 2A thru E, do Steps 3, 4, 5, and 6; then return to Step 2 if indicated.

2A "Curved Band" Pattern (Use spiral arc distance along 10° log spiral).

2B "Shear" Pattern
Use center definition and center's distance to dense overcast.



2C "Eye" Pattern

Was 24-hr old T-no. ≥T2?
YES →

Narrowest Width	≥.5	≥.5	≥.5	≥.4	≥.4	≥.3	≥.3
Surrounding Gray Shade	CMG	W	B	LG	MG	DG	OW
	E6.5	E6	E5.5	E5	E4.5	E4.5	E4

NO → Step 2A or 4

2E "Embedded Center" Pattern (Center within cold ⊕ by ≥0.4.)

Was 12-hr old T-no. ≥T3.5?
YES →

Embedded Distance	≥.6	≥.6	≥.5	≥.5	≥.4	≥.4
Surrounding Gray Shade	White or Colder	B	LG	MG	DG	OW
	CF5	CF5	CF4.5	CF4	CF4	CF3.5

NO → Step 2A or 4

GRAY SHADE CODE (BD CURVE)

- WMG (Warm Medium Gray), > +9°C
- OW (Off White), +9 to -30°C
- DG (Dark Gray), -31 to -41°C
- MG (Medium Gray), -42 to -53°C
- LG (Light Gray), -54 to -63°C
- B (Black) -64 to -69°C
- W (White) -70 to -75°C
- CMG (Cold Medium Gray), -76 to -80°
- CDG (Cold Dark Gray), ≤ -81°C

EYE TEMPERATURE

SURR. RING TEMP.	WMG	OW	DG	MG	LG	B	W
OW	0	-0.5					
DG	0	0	-0.5				
MG	0	0	-0.5	-0.5			
LG	+0.5	0	0	-0.5	-0.5		
B	+1.0	+0.5	0	0	-0.5	-0.5	
W	+1.0	+0.5	+0.5	0	0	-1.0	-1.0
CMG	+1.0	+0.5	+0.5	0	0	-0.5	-1.0

Eye Adjustment?
E-no. + Eye Adj = CF

Banding Feature (BF)?
CF + BF = DT

EIR Analysis Diagram-2

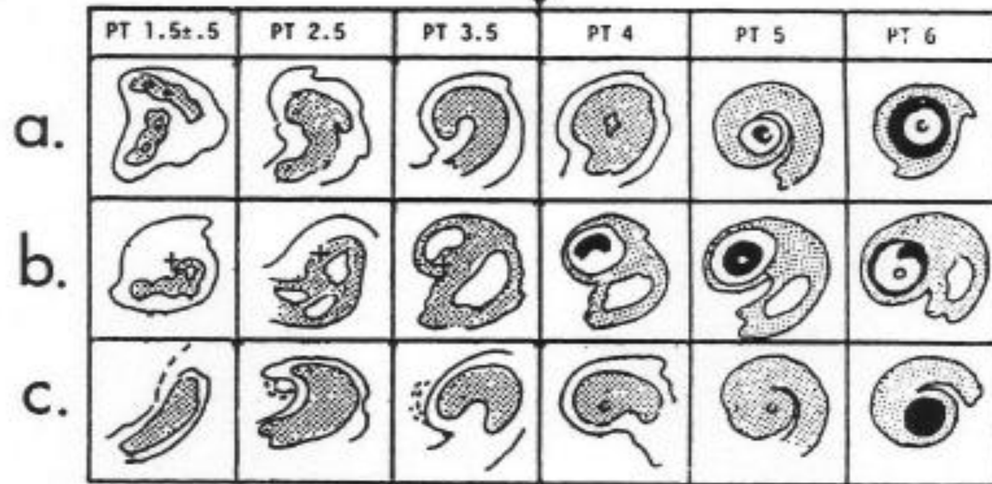
3. "Central Cold Cover" Pattern

Rules: When past T-no. ≤T3, maintain model trend for 12 hours; then hold same. When past T-no. ≥T3.5 hold T-no. same. Use as final T-no.; then go to Step 9.

4. Determine past 24-hour trend. Is Development, Weakening, or Same indicated in a change of:
(a) center or eye characteristics, or
(b) center's involvement with the cold overcast.

5. Determine Model Expected T-no. (MET).

6. Determine pattern T-no. Select pattern in diagram that best matches your storm picture within one column of the MET. Adjust MET ± .5 when indicated.



*When hatched part of these patterns is white or colder, add .5 to pattern number.

7. T-no. Determination:

1. Use data T-no. from Step 2 when cloud features are clear-cut.
2. Use Pattern T-no. when DT is not clear and adjustment to MET is made.
3. For all other cases, use the MET.

8. Final T-number Constraints:

1. Initial classification must be T1 or T1.5.
2. During first 48 hours of development, T-no. cannot be lowered at night.
3. 24 hrs after initial T1, storm's T-no. must be <T2.5.
4. Final T-no. limits: <T4: change of 1/2 over 6 hrs. >T4: change of 1 over 6 hrs, 1.5 over 12 hrs, 2 over 18 hrs, and 2.5 over 24 hrs.
5. Final T-no. must = MET ±1.

9. Current Intensity (CI) Number Rules:

1. Use CI = final T-no. except when final T-no. shows change to weakening trend, or when redevelopment is indicated.
2. For initial weakening, hold CI same for 12 hours, then hold CI ½ or 1 higher than T-no. as storm weakens.

10. 24-Hr Forecast:

Extrapolate past trend unless one of the five rules in the instructions applies.

Step No. 1:Tropical System Identification

- **Whenever we observe convective cloud clusters placed randomly over certain area having approximate dimension of 5ºx5º for 24hrs and does not disappear due to diurnal variation. Than we keep a close watch for the formation of vortex (low pressure system) over the area.**
- **The tropical disturbance reaches tropical storm intensity (T2.5) 36 hours after the first classification (T 1.0).**
- **Animation suggests that the cloud pattern does not evolve continuously from stage to stage but appear to form in surges. The center as defined by the cloud feature would appear well-defined and easy to interpret during a surge of pattern growth; but following the surge, the clouds features generally become poorly defined and difficult to understand.**

Cloud System Center (CSC) Identification

From Dvorak (1985):

"The cloud system center is defined as the focal point of all the curved lines or bands of the cloud system. It can also be thought of as the point toward which the curved lines merge or spiral."

and

"Centre not always obvious, especially at night."

- **Maintain track continuity.**
- **Use all available data – QuikSCAT, Microwave data, etc.**
- **Centre location can influence intensity measurement.**

Cloud system center (CSC) is also defined as the focal point of all curved lines or the bands of the cloud system or geometric center of eye, if present. When more than one well-defined CSC is apparent, we use the best one that fits the past track of the system.

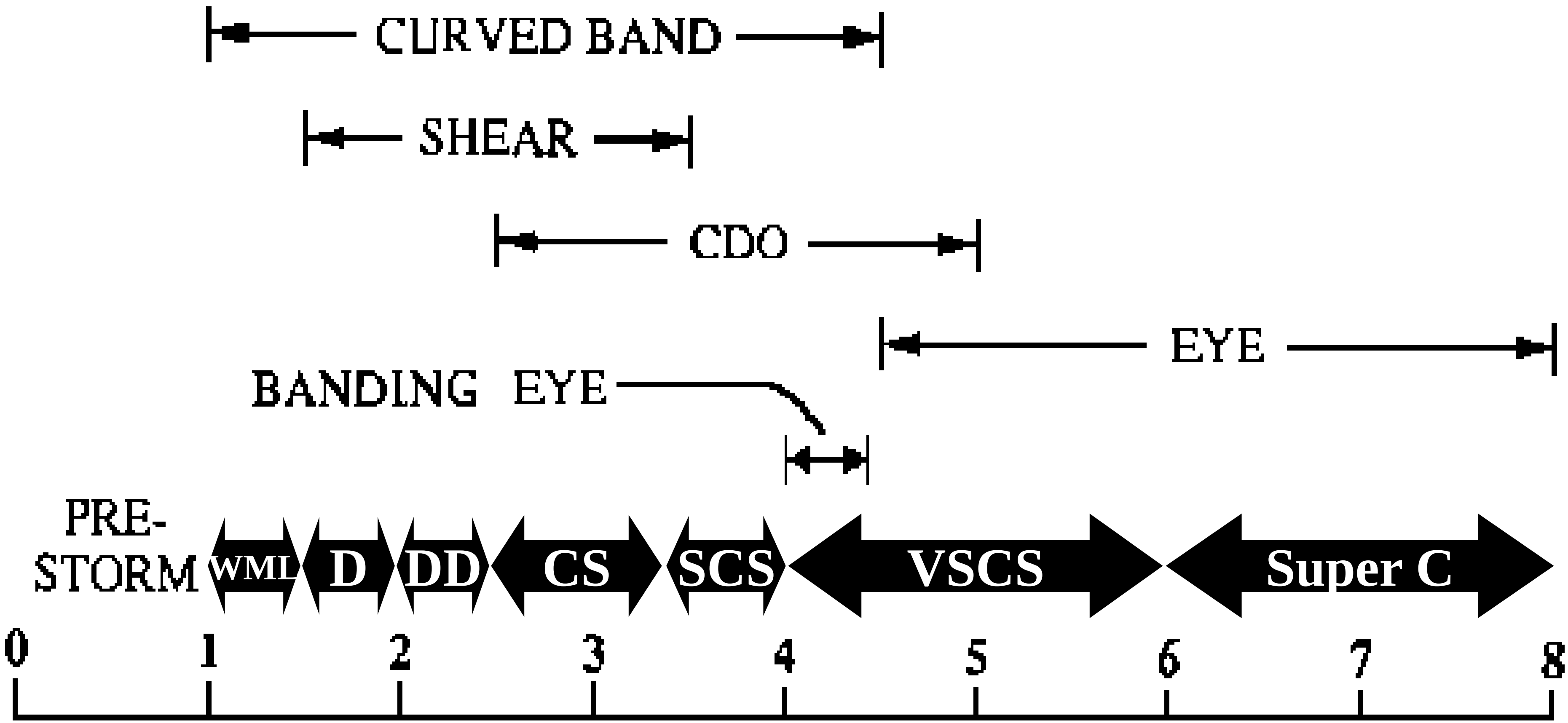
- CSC is generally well defined by the cumulus cloud lines in visible imagery.

- During night time- we are left with only Water vapour & IR imagery. Water vapour imagery filter the low clouds. In IR imagery there is not much contrast between clouds top temperature of low (cumulus) clouds and surrounding land surface. Therefore it is difficult to fix cloud system center during night time especially in shear pattern system.

- If convective cloud mass persists for 24 hrs and it has a CSC defined with an area having a diameter of 2.5º latitude or less and persist for 6 hrs, then we measure its feature to assign the intensity.

Step No. 2: Pattern Reorganizations:

FOUR PRIMARY PATTERNS AND TYPICAL T - NO.'s

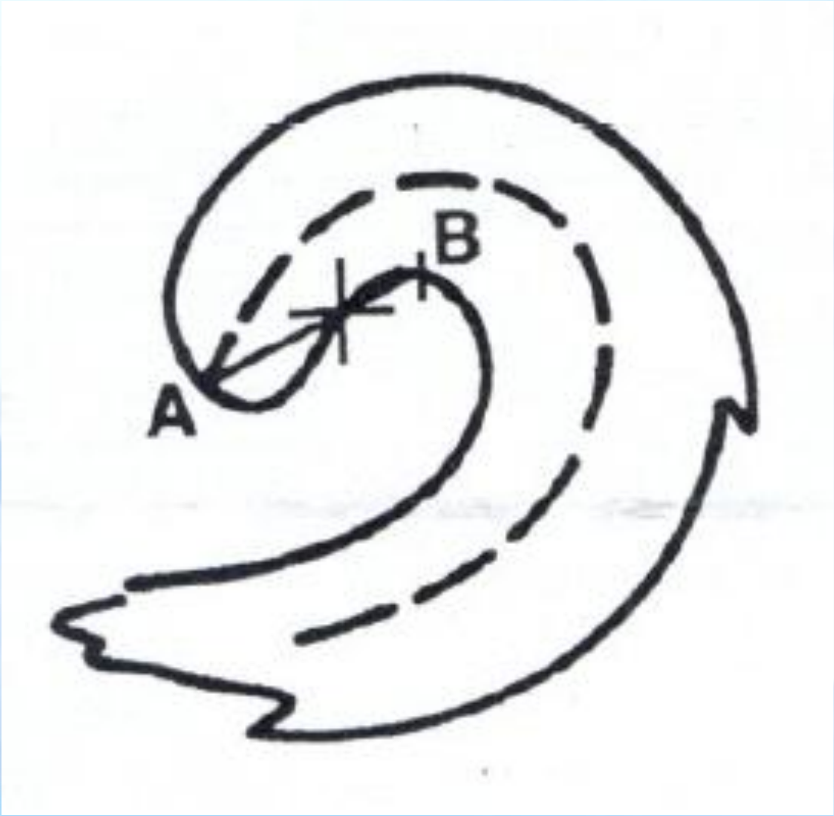


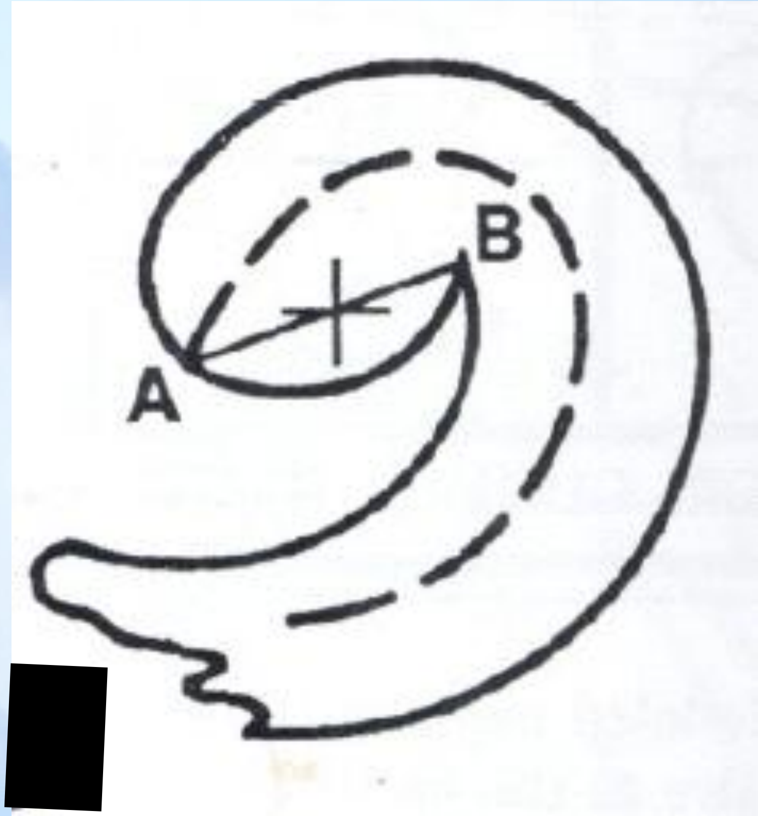
Curved Bands Pattern

Method: Measure the curvature of the band.

Physical principle: the "wrap-aroundness" of the convective bands indicates the vorticity associated with the system.

Technique for determining center for Curved band pattern



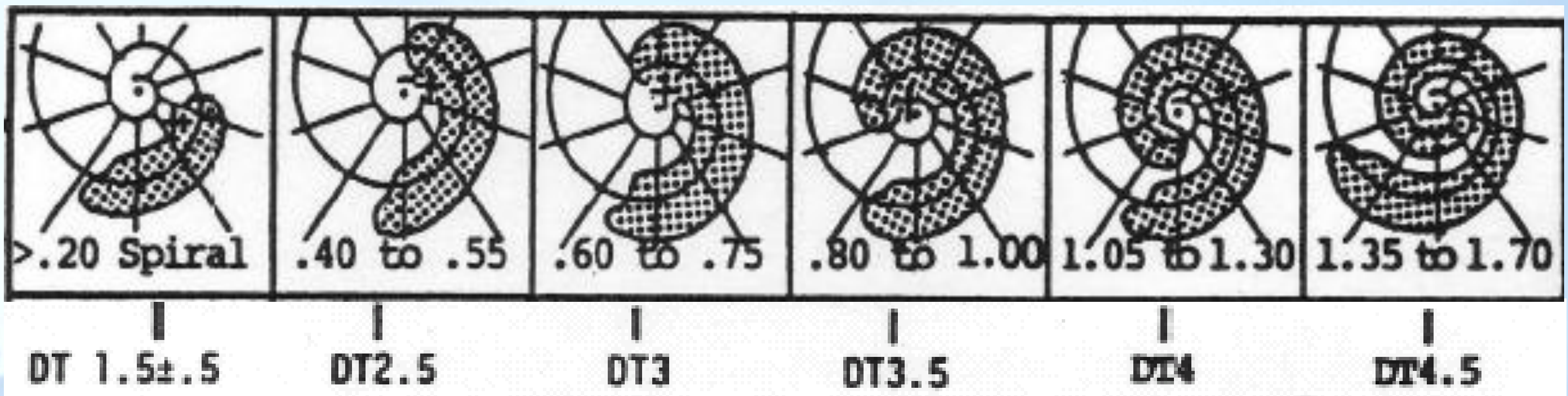


[redacted]

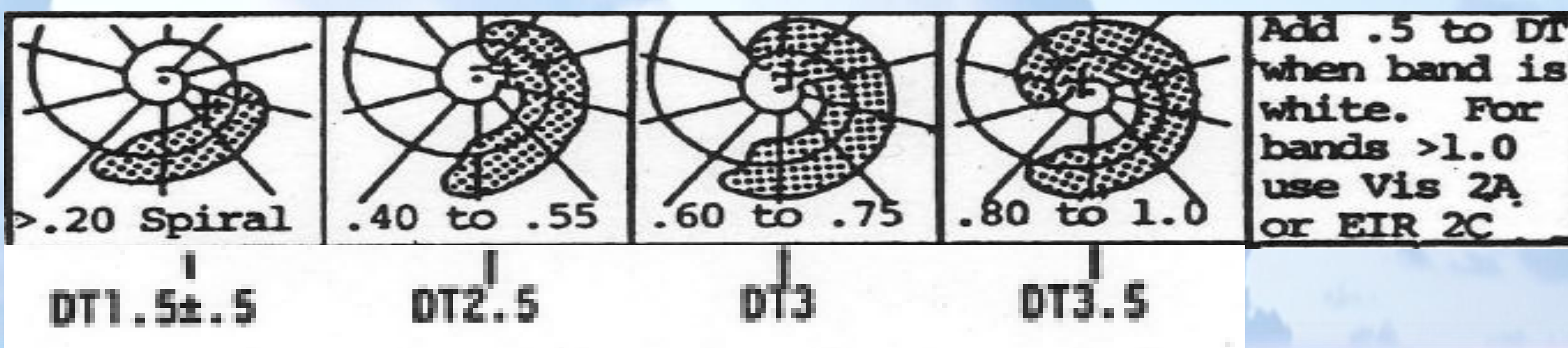
Curved Band

Rule 2A → Use spiral arc distance along 10^o log spiral

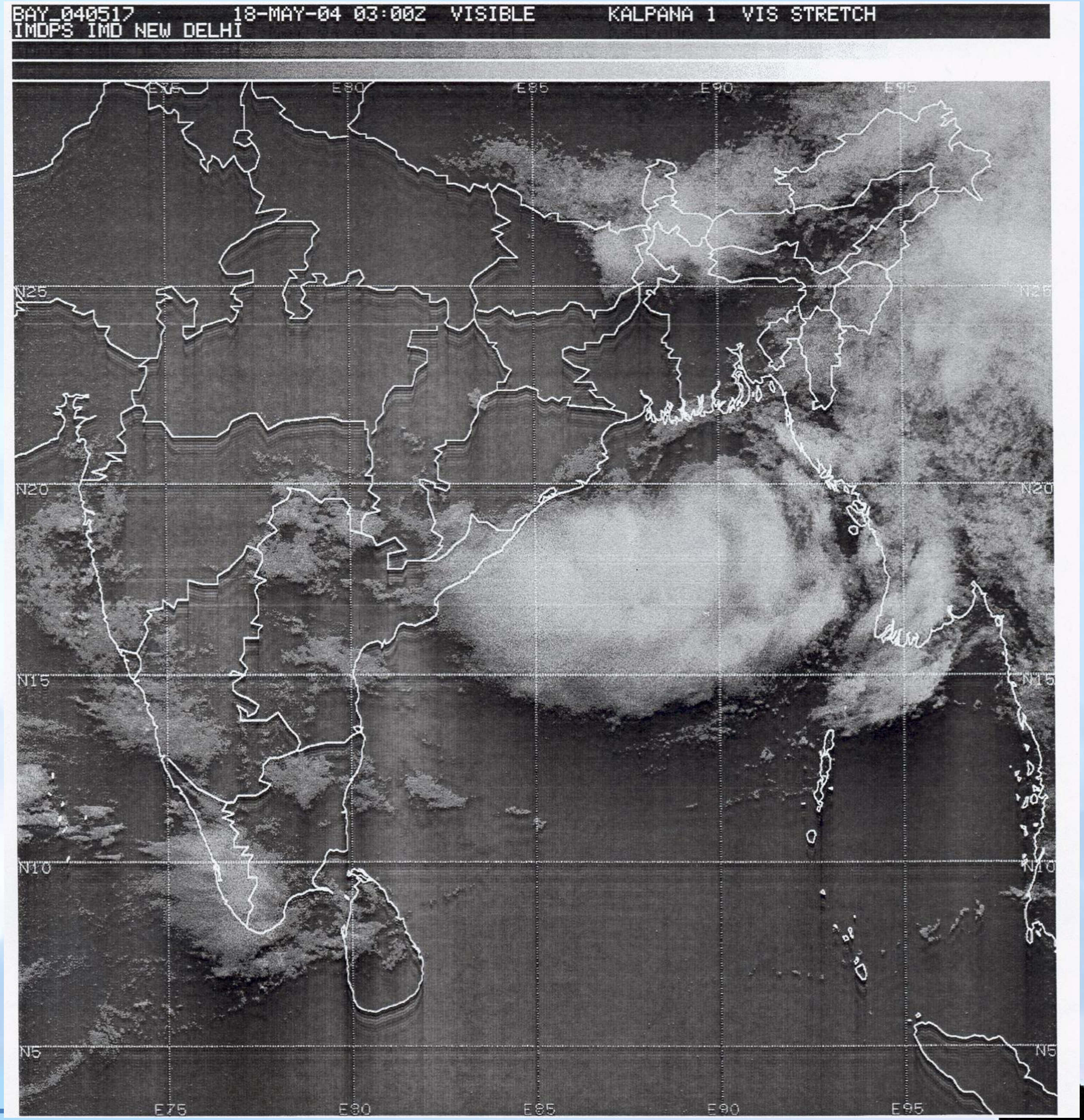
VIS→

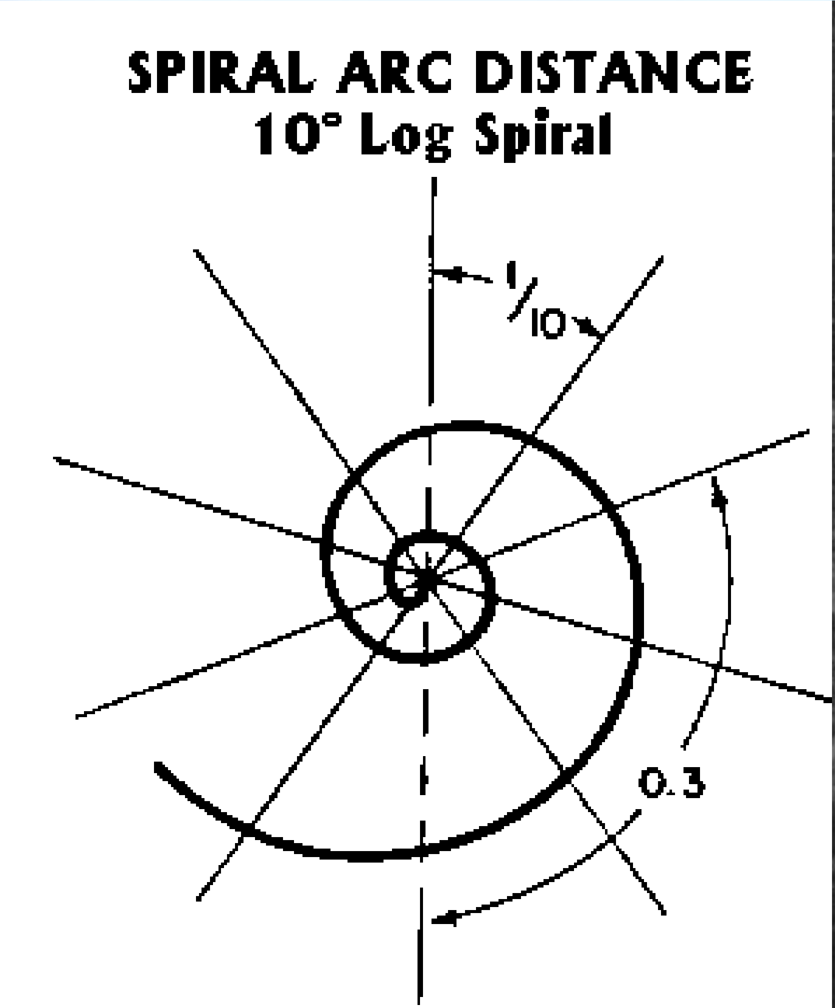


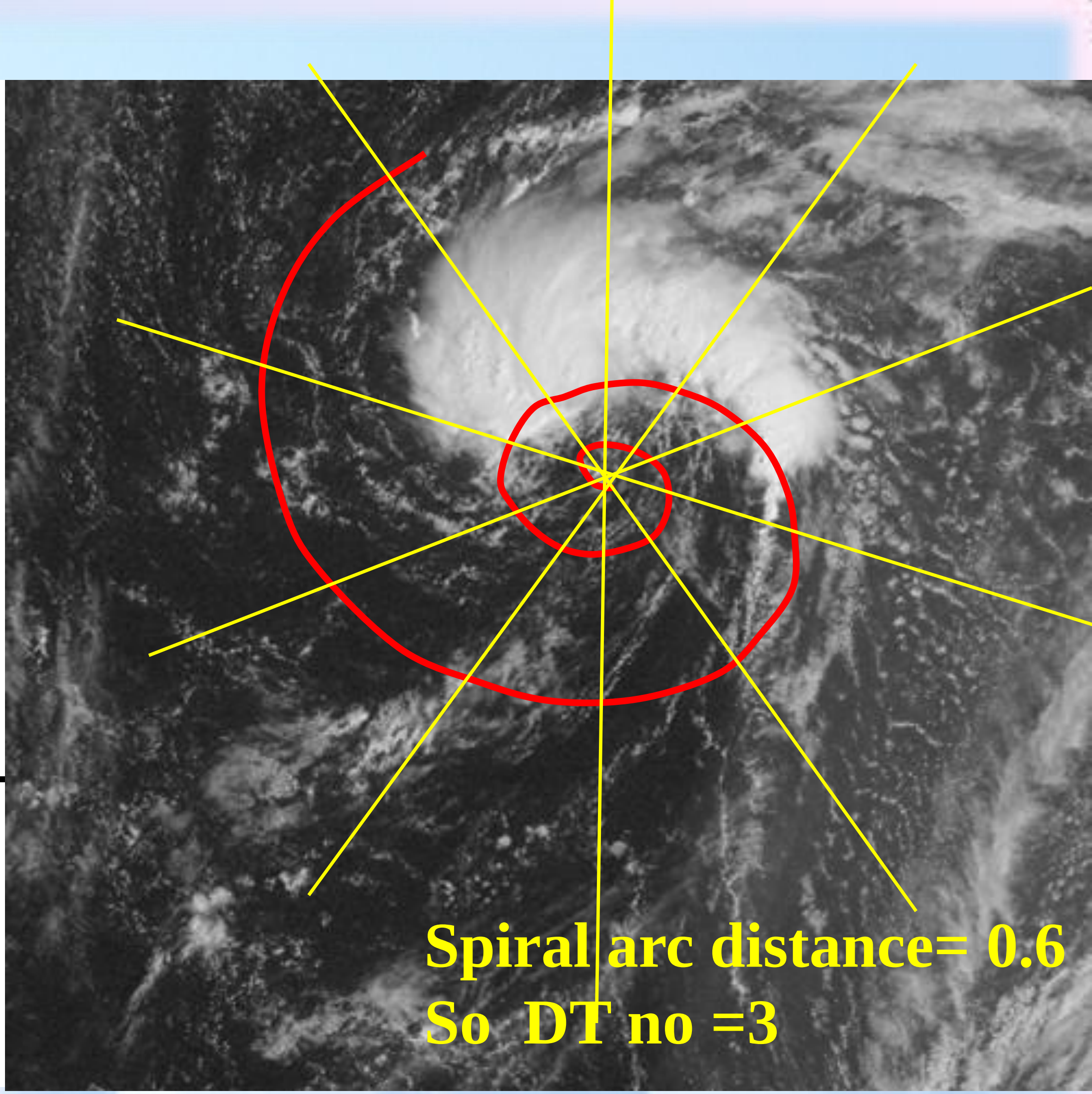
EIR→



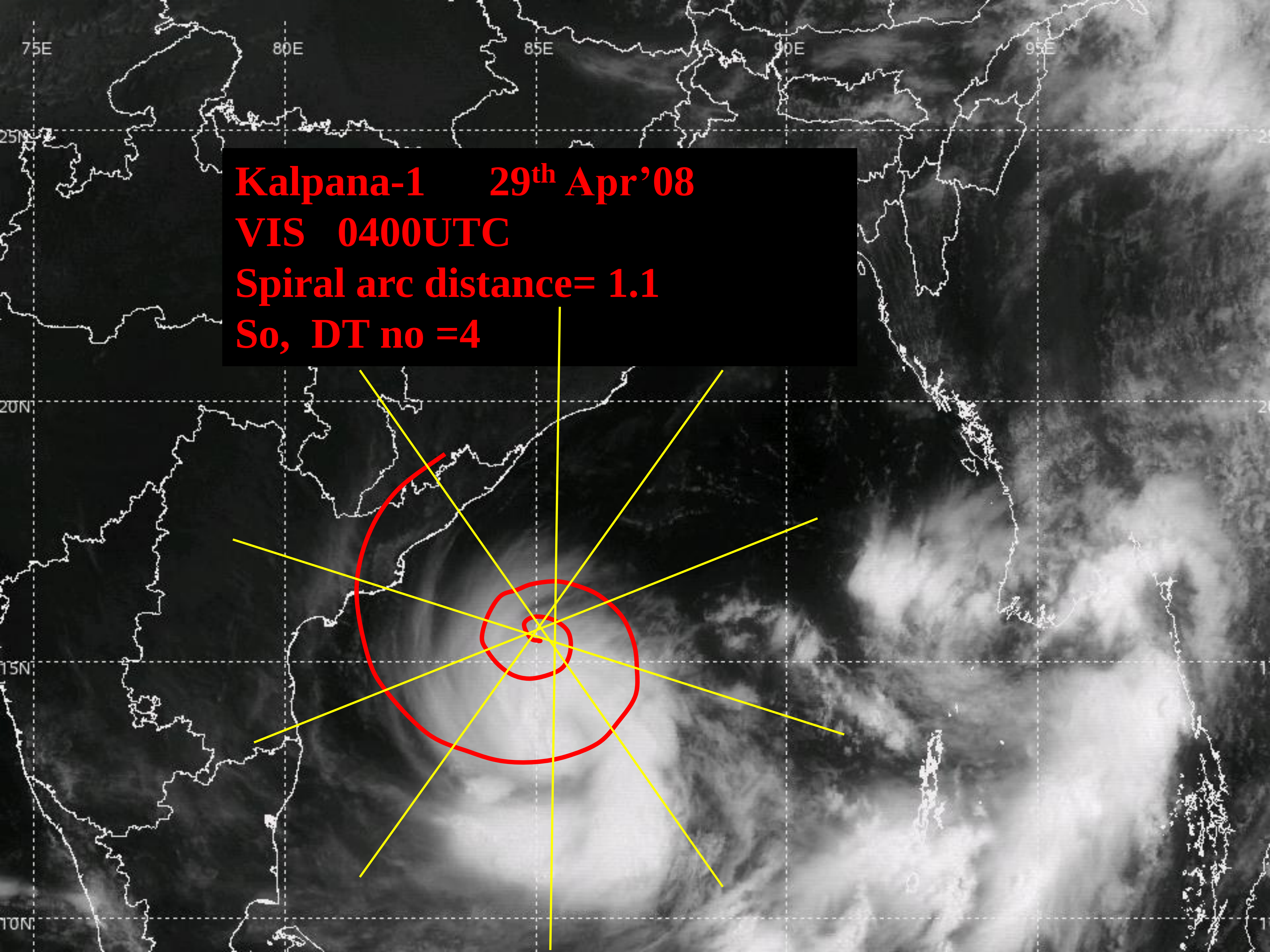
Band Pattern







DT number is determined by curvature of band around 10° log spiral


Kalpana-1 29th Apr'08
VIS 0400UTC
Spiral arc distance= 1.1
So, DT no =4
75E
80E
85E
90E
95E
25N
20N
15N
10N

SHEAR PATTERN

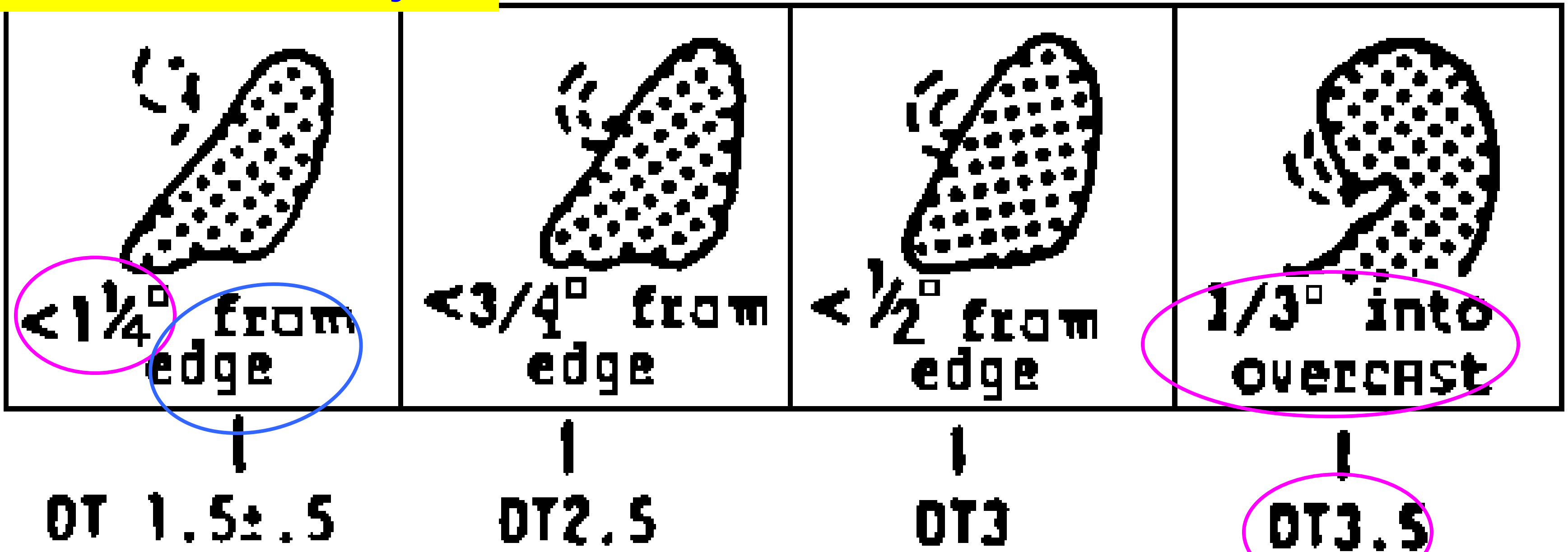
<u>Method</u>: Measure the distance form the low level centre to the edge of the “dense overcast”.

<u>Physical principle</u>: greater involvement of the low level centre with the deep convection indicates a stronger system.

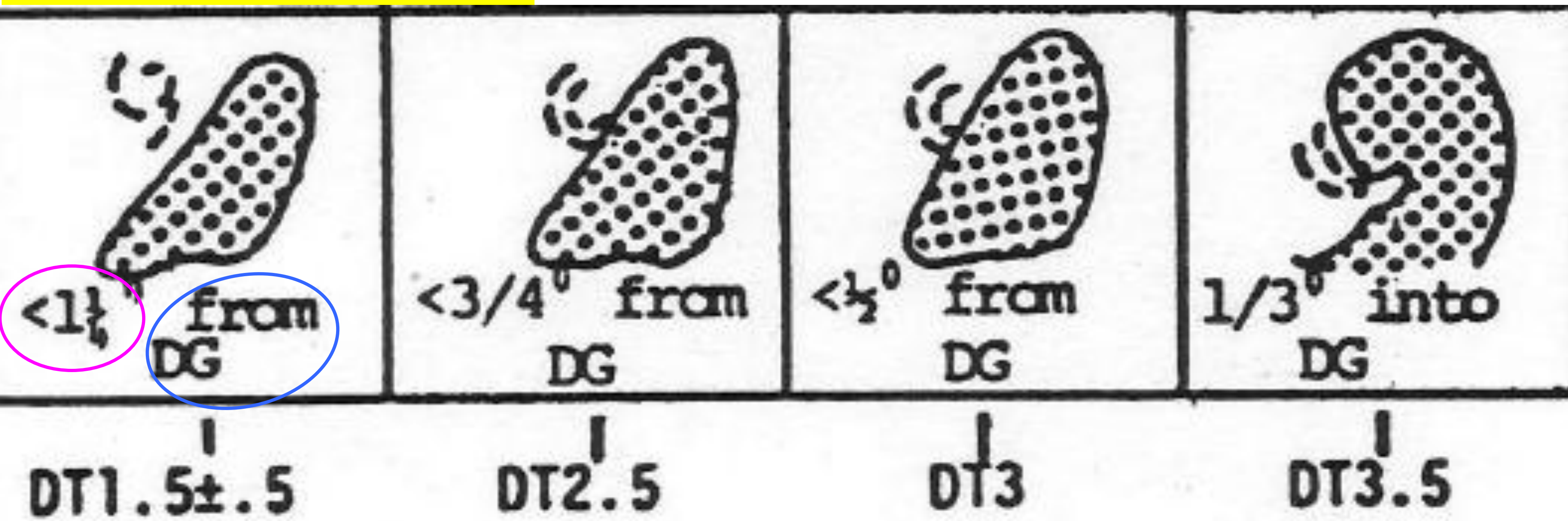
- **Due to strong vertical wind shear convective cloud mass associated with weak vortex are moved away from the CSC.**

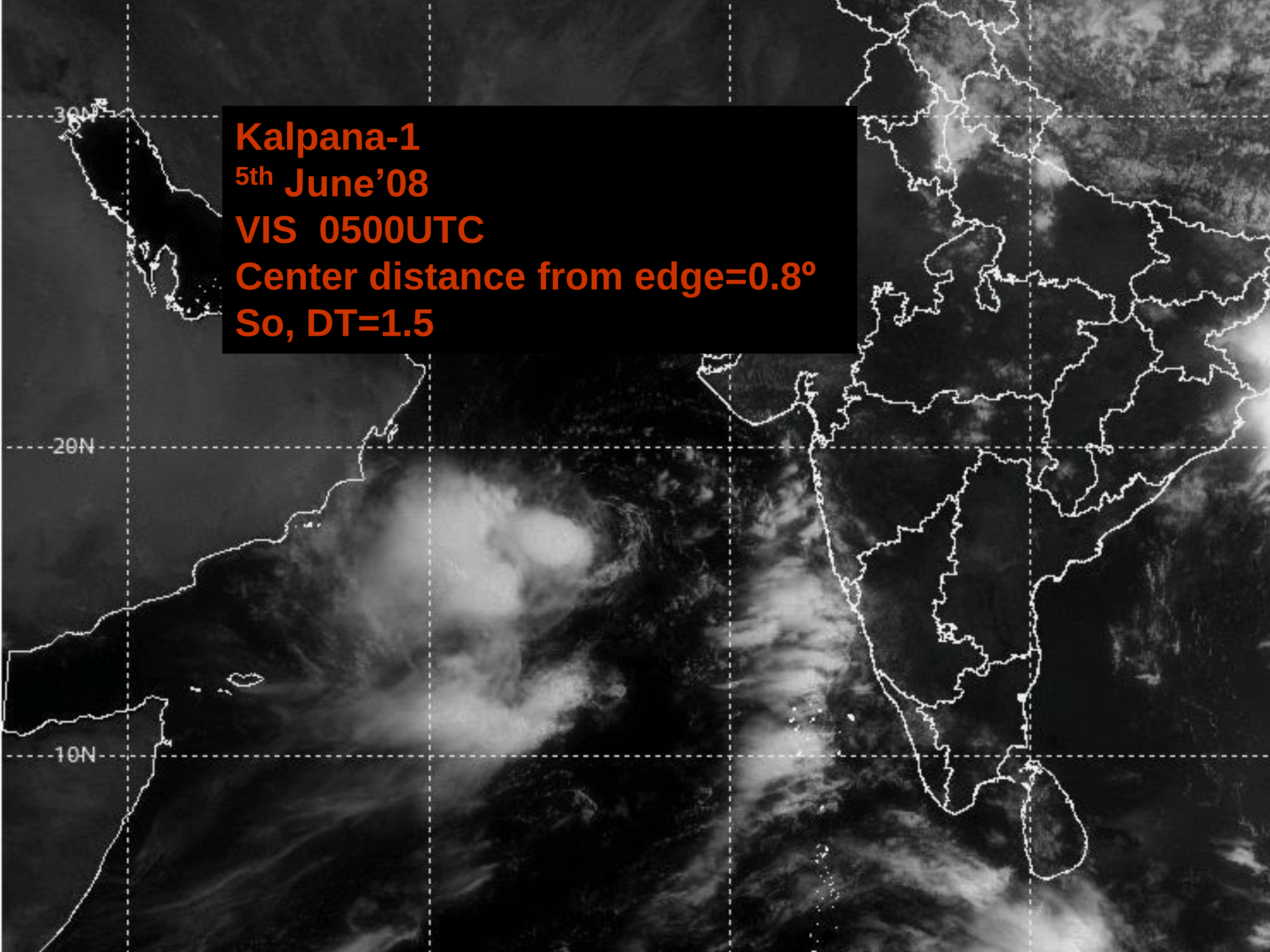
- **We measure the distance between convective cloud mass and CSC. This distance gives intensity of vortex directly.**

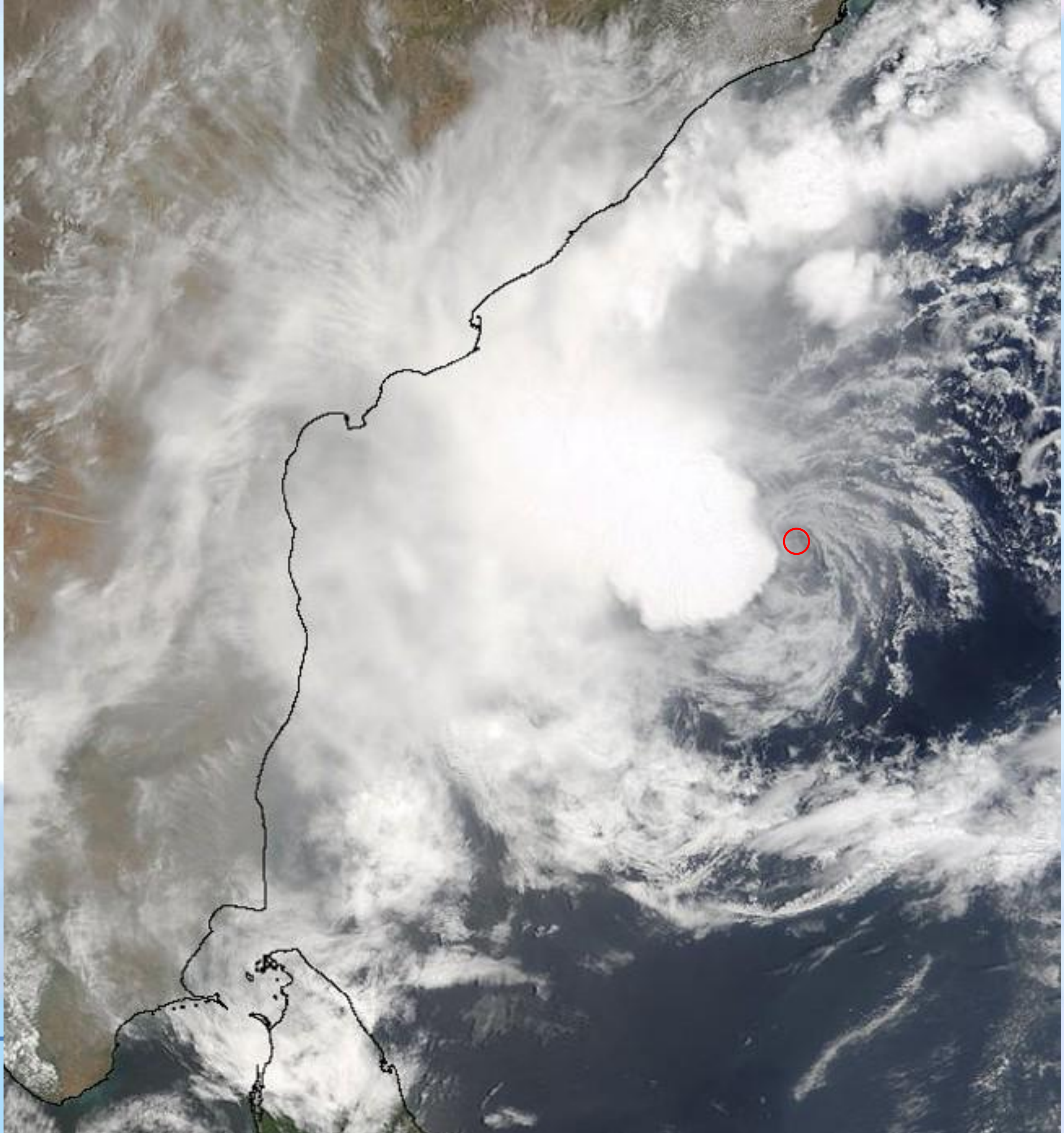
Rules for VIS analysis

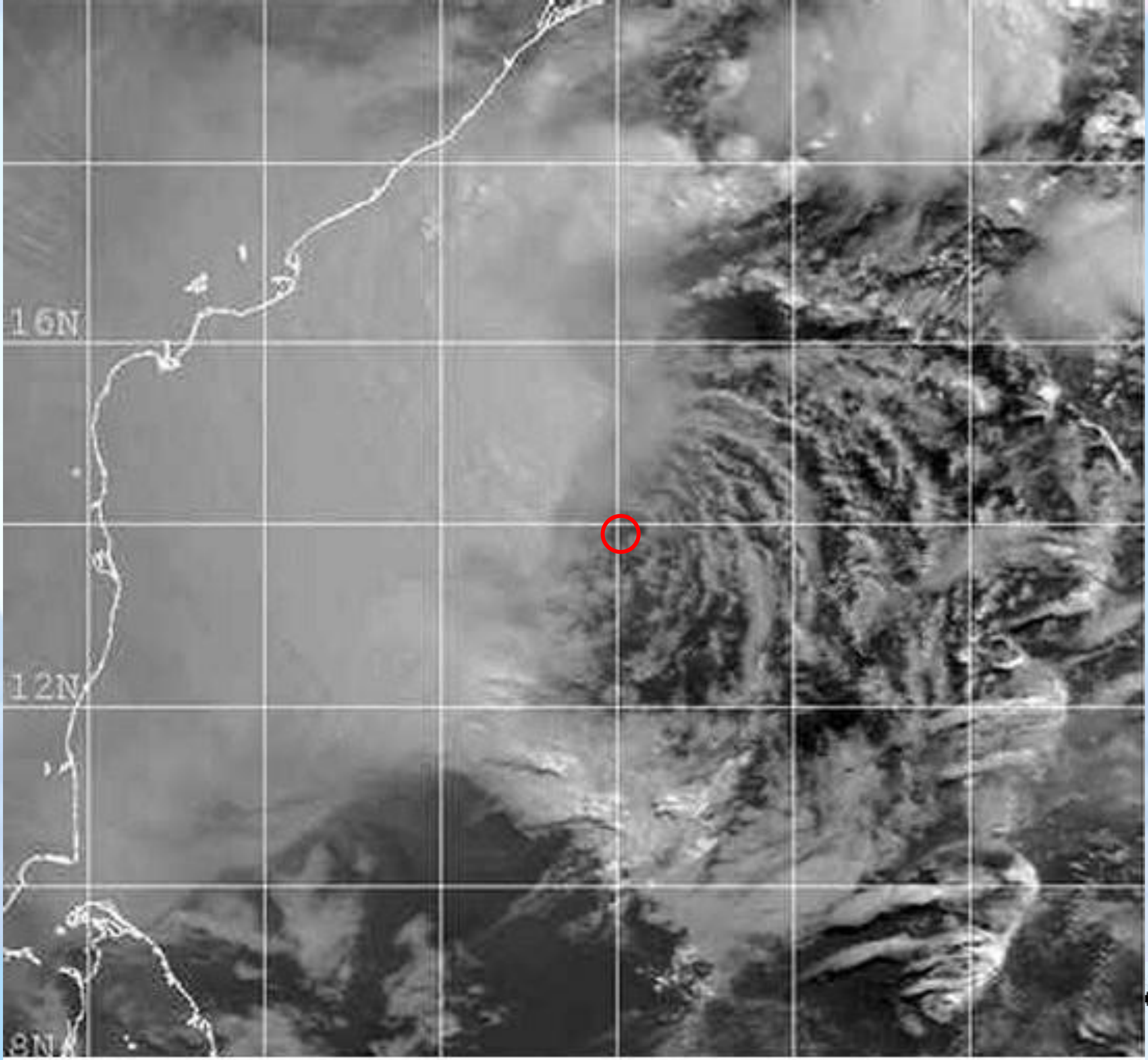


Rules for EIR analysis




Kalpana-1
5th June'08
VIS 0500UTC
Center distance from edge=0.8º
So, DT=1.5
30N
20N
10N




16N
12N
8N

Covered Centre Patterns

In VIS these patterns are called Central Dense Overcast (CDO)

In IR these patterns are called Embedded Centre (EC)

CDO PATTERN

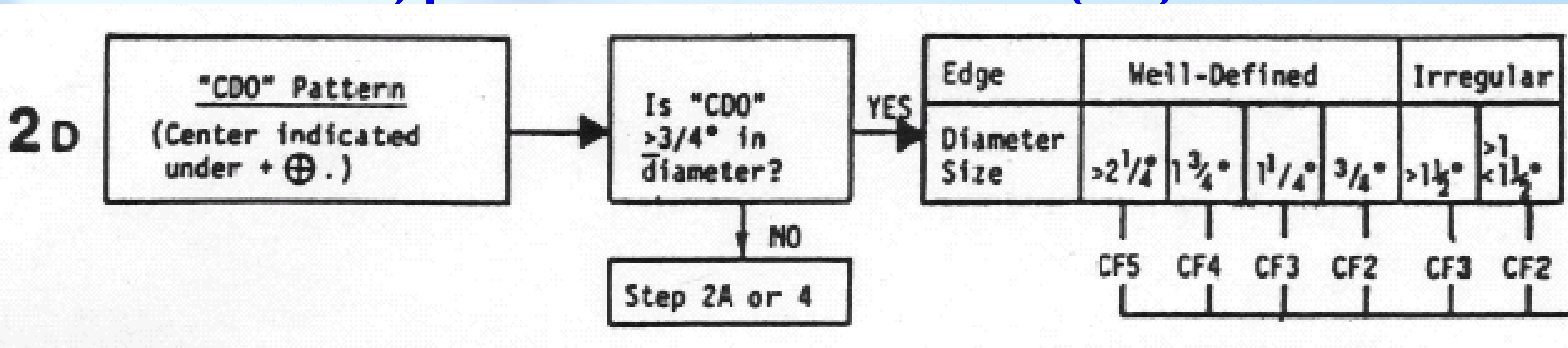
- **This type of pattern is analysed only with VIS imagery.**

- **The CDO is a dense overcast mass of clouds that appears within the curve of the curve band axis and covers the cloud system center.**

CDO PATTERN

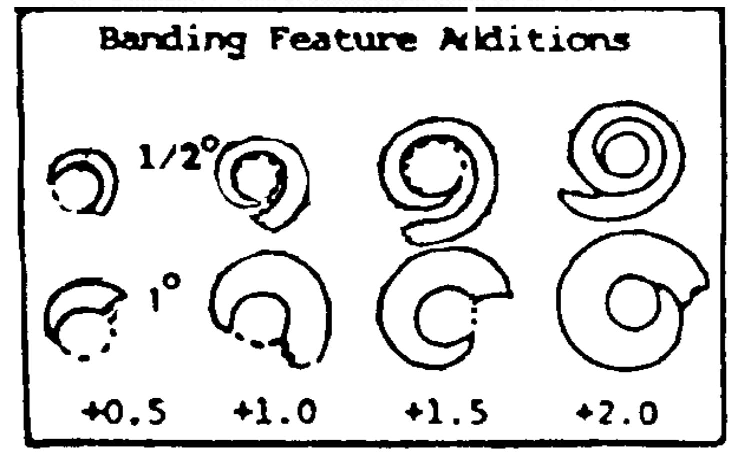
Rules for measurement of T no. :

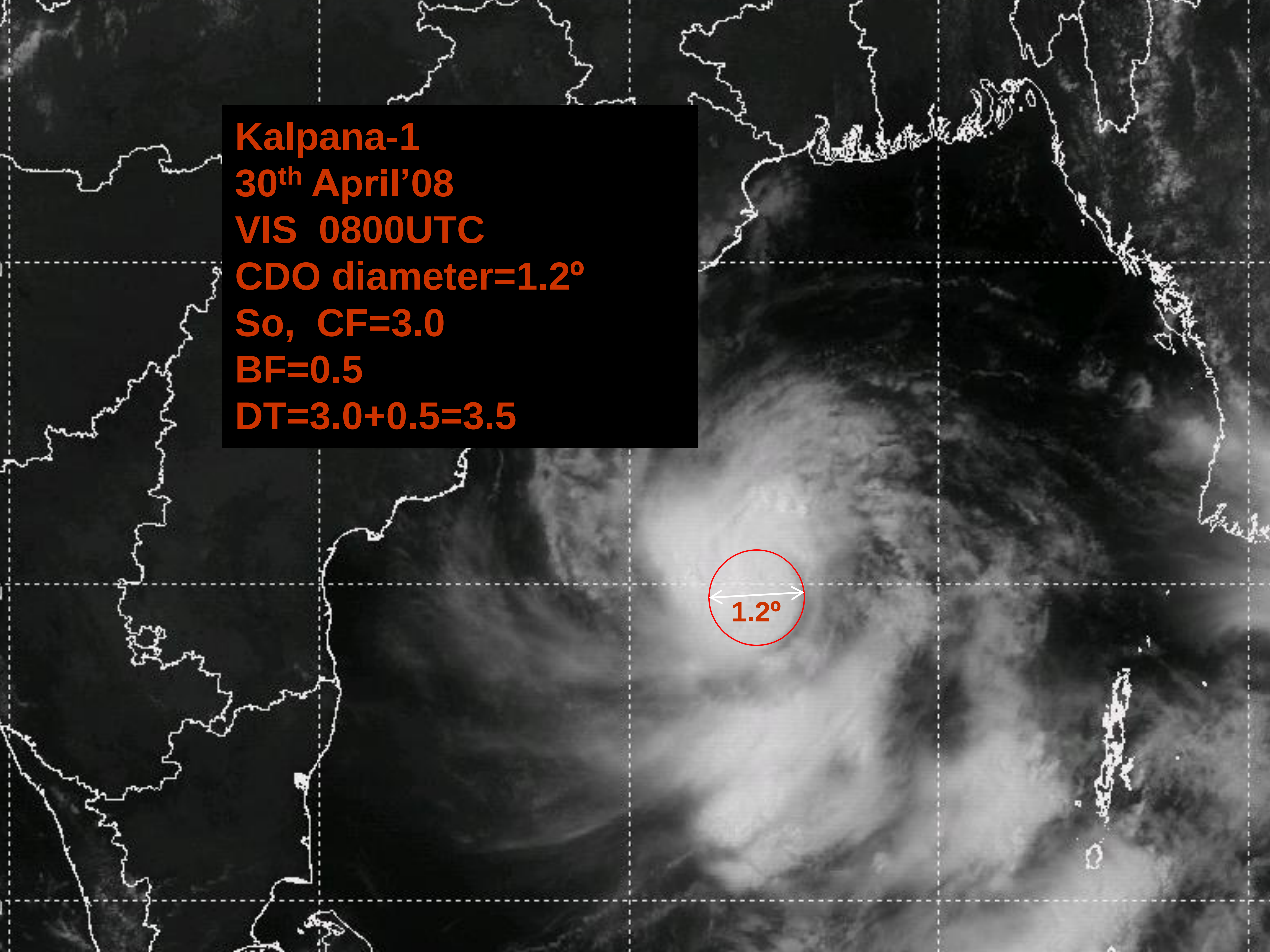
1.The boundary definition of the CDO and its size (diameter across narrowest width) provides the central feature (CF).



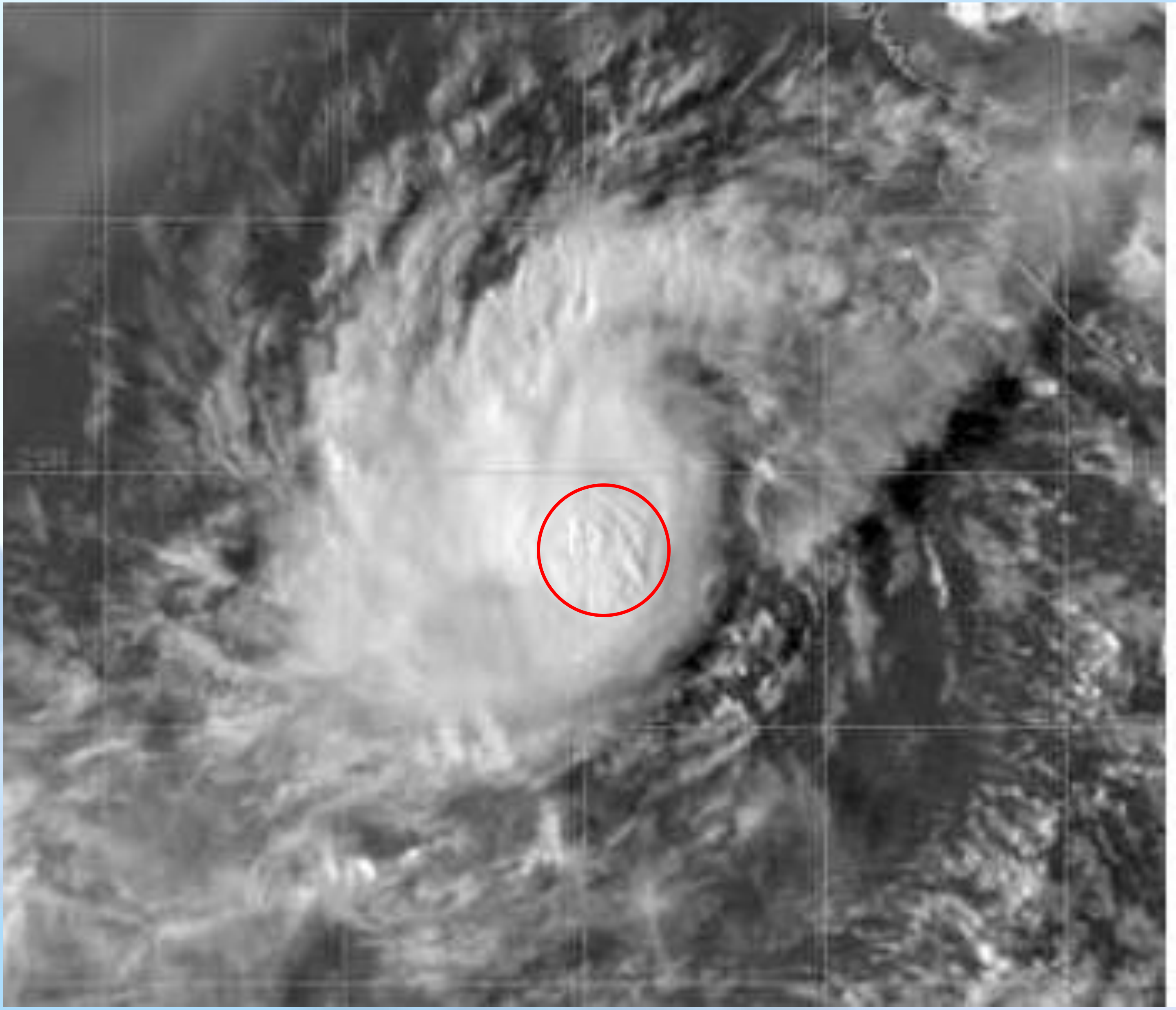
2. Banding feature (BF) is added according to the amount of banding observed around the CDO.

3. Data T-no. (DT) = CF + BF

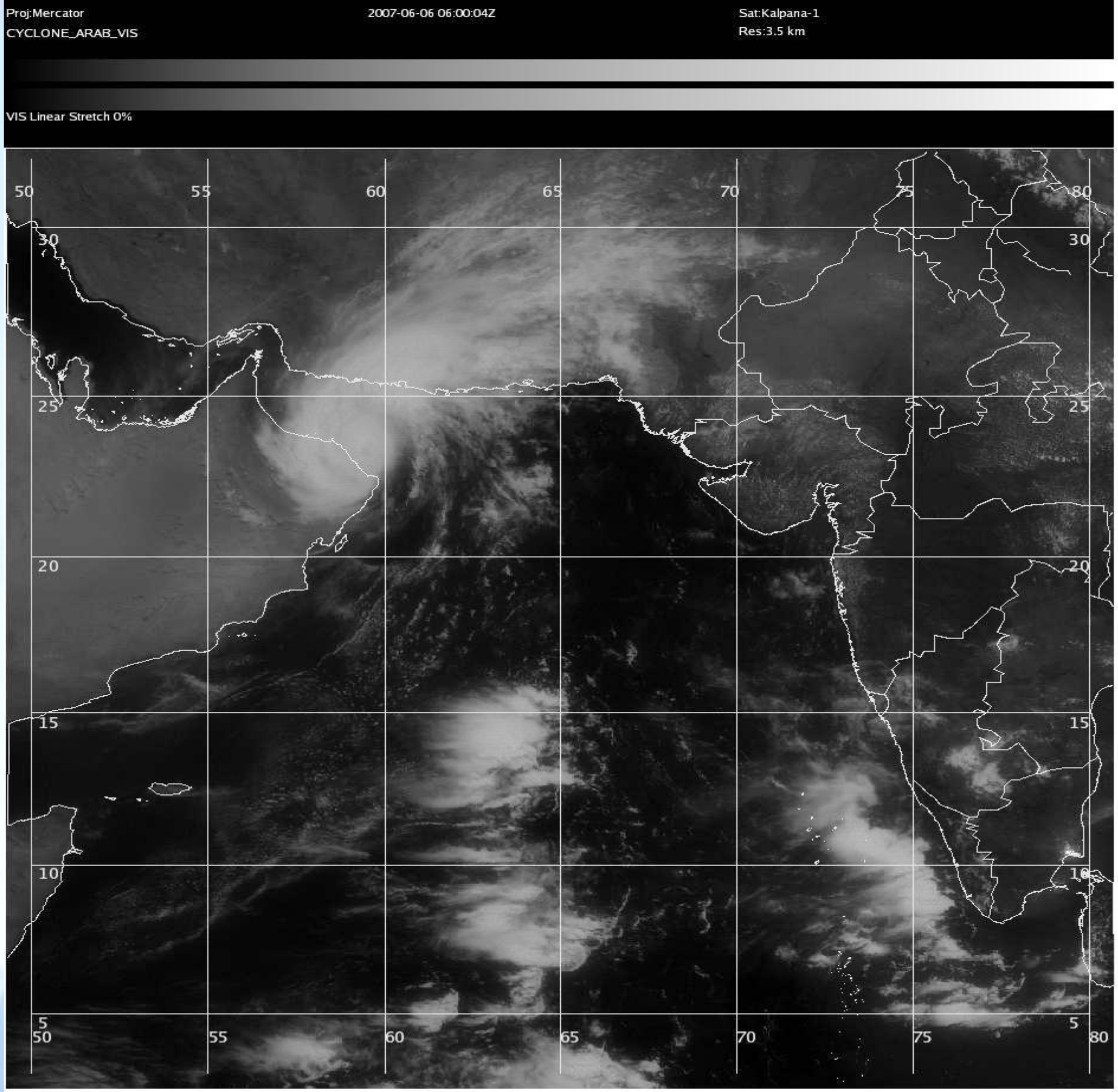



Kalpana-1
30th April'08
VIS 0800UTC
CDO diameter=1.2°
So, CF=3.0
BF=0.5
DT=3.0+0.5=3.5
1.2°

CDO PATTERN

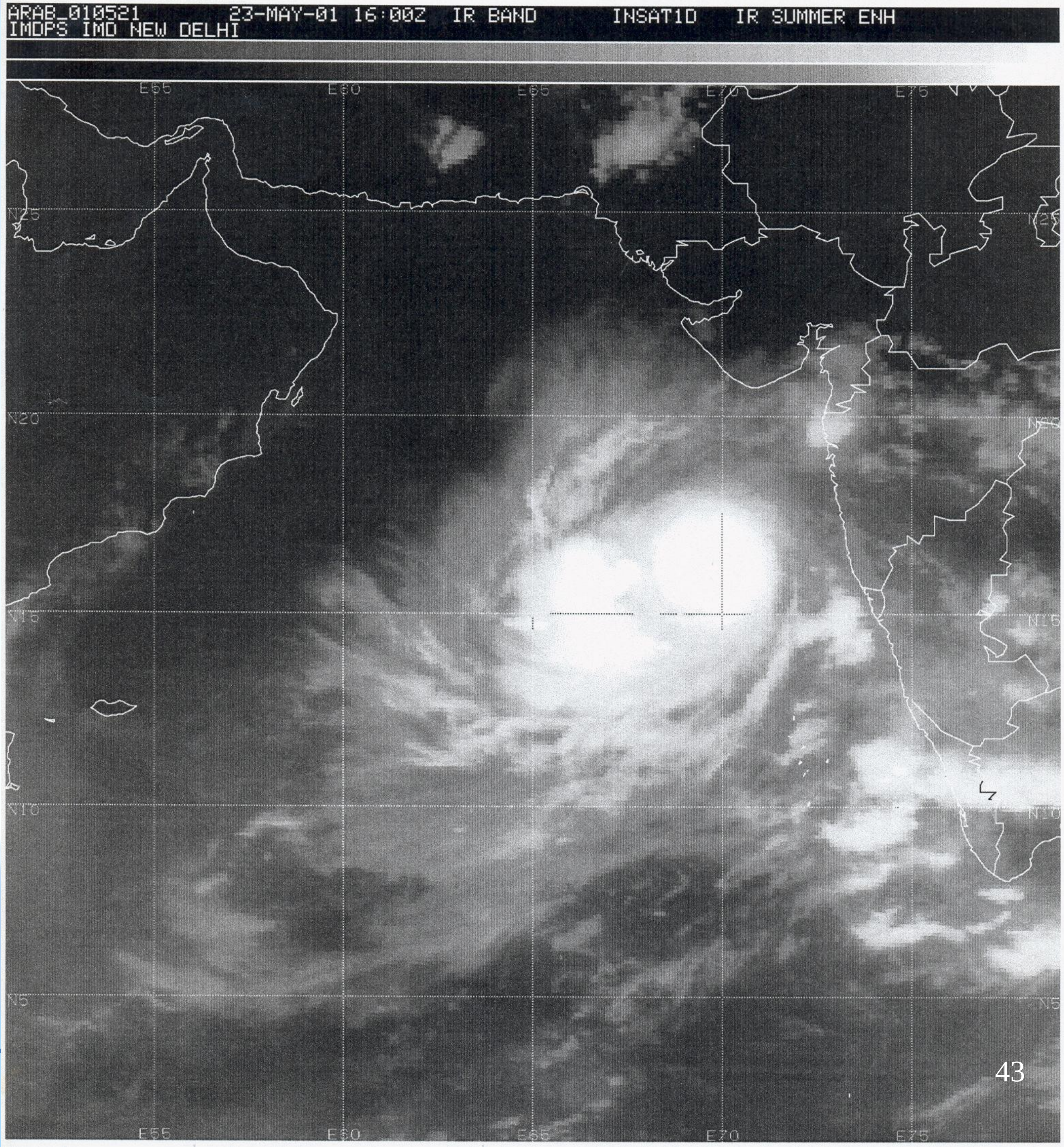


CDO Pattern



Proj:Mercator
CYCLONE_ARAB_VIS
2007-06-06 06:00:04Z
Sat:Kalpana-1
Res:3.5 km
VIS Linear Stretch 0%

CDO Pattern


ARAB_010521 23-MAY-01 16:00Z IR BAND INSAT1D IR SUMMER ENH
IMDPS IMD NEW DELHI

EMBEDDED CENTRE PATTERN

This pattern is only used with the EIR imagery when

(1) the cloud system center clearly falls within the central overcast of the pattern ; and also

(2) the 12-hrs-old Final T no. was ≥ 3.5.

EIR is used for measurements of covered center pattern to measure the CDO size and embedded distance measurements because in IR imageries thin Cirrus covers the boundaries of cloud features.

Rule 2E → **center within cold clouds by ≥0.4 deg**

↓

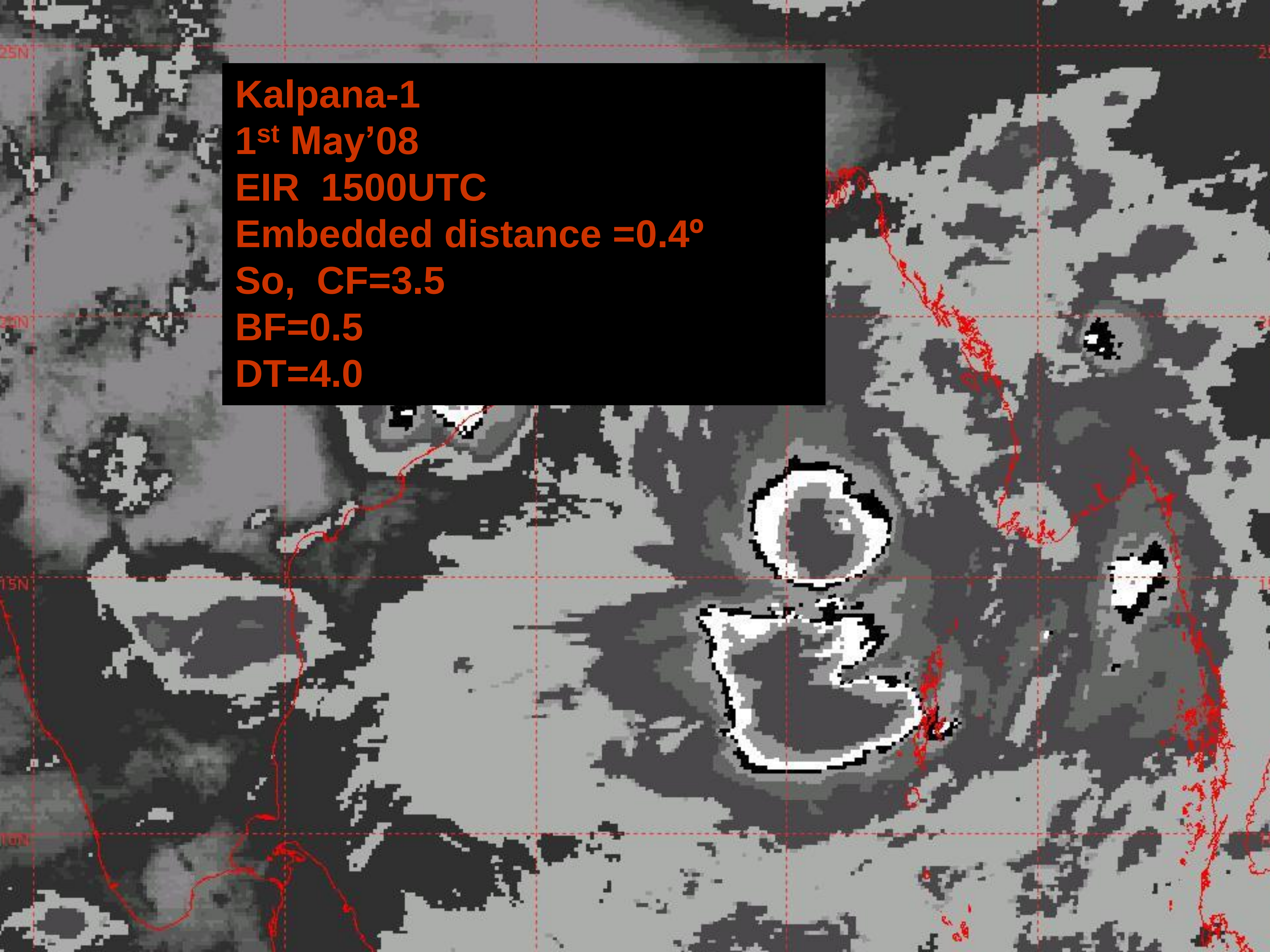
Was 12-hr old Final T no. ≥ T3.5 ??

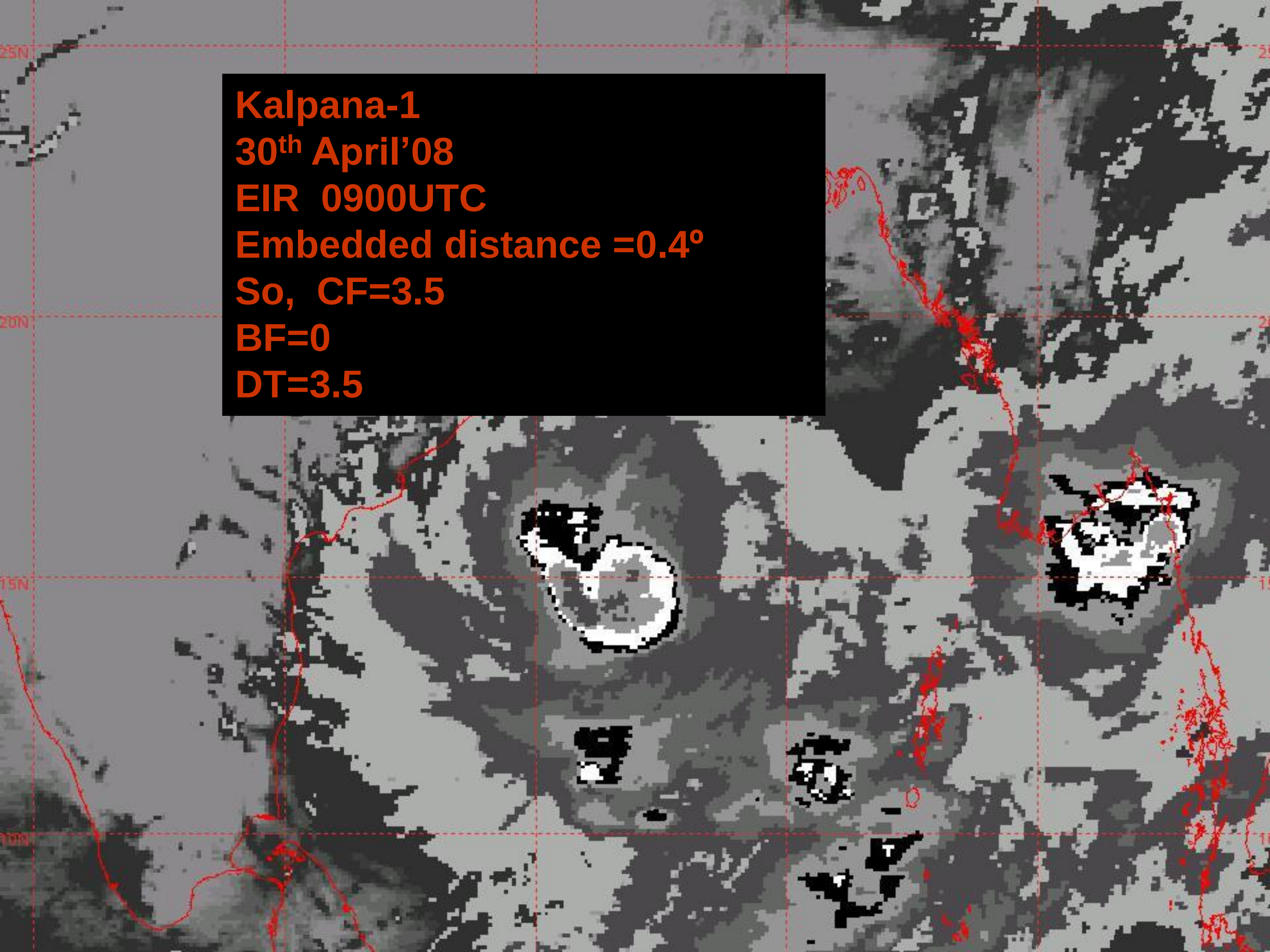
- **No** → **Step 2A or 4**
- **Yes** ↓

Embedded Distance	≥.6	≥.6	≥.5	≥.5	≥.4	≥.4
Surrounding Gray Shade	White or Colder	B	LG	MG	DG	OW
	CF5	CF5	CF4.5	CF4	CF4	CF3.5

a. Add 1/2 no.   b. Add 1/2 no.   c. Add 1 no.

→ **DT = CF + BF**


Kalpana-1
1st May'08
EIR 1500UTC
Embedded distance =0.4º
So, CF=3.5
BF=0.5
DT=4.0



Kalpana-1
30th April'08
EIR 0900UTC
Embedded distance =0.4º
So, CF=3.5
BF=0
DT=3.5
25N
20N
15N
10N

Eye Pattern

- This pattern is the most complex of the five pattern types.
- Eye pattern appears only when intensity is greater than T2.0.
- Intensity analysis for this pattern can be carried out by using both EIR and VIS imageries.

Eye Pattern Analysis by using VIS Imagery

For small eye (<0.6^{o} diameter): Embedded distance is measured from the center of the eye, otherwise from the inner wall of the eye.

EYE Pattern Analysis by using VIS Imagery

Rule 2C → **Was 12-hr old Final T no. ≥ T2 ??**

No → **Step 2A or 4**

Yes ↓

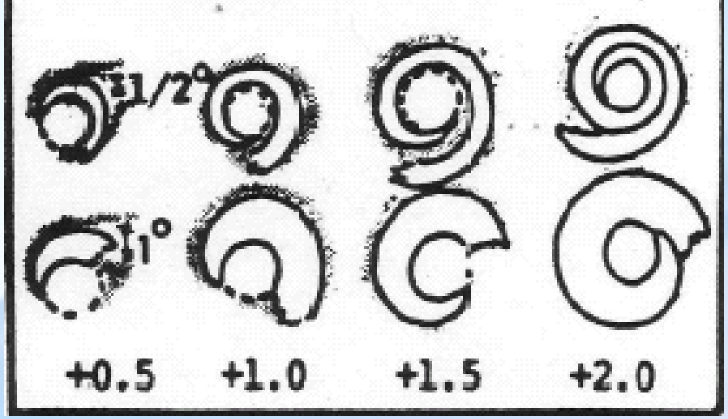
Embedded Distance	> 1°	≈ 1°	≈ 3/4°	≈ 1/2°	≈ 1/4°	Banding Eyes		
Average Band Width						1 1/4°	3/4°	1/4°
	E7	E6	E5	E4	E3	E5	E4	E3

Eye Adjustment Rules:

1. Poorly defined or ragged eyes: Subtract ½ for E ≤4.5 and 1 for E ≥5.
2. Large eyes: Limit T-no. to T6 for round, well-defined eyes, and to T5 for large ragged eyes.
3. For MET ≥6, .5 or 1 may be added to DT for well defined eye in smooth CDO when DT < MET.

→

Banding Feature Additions:

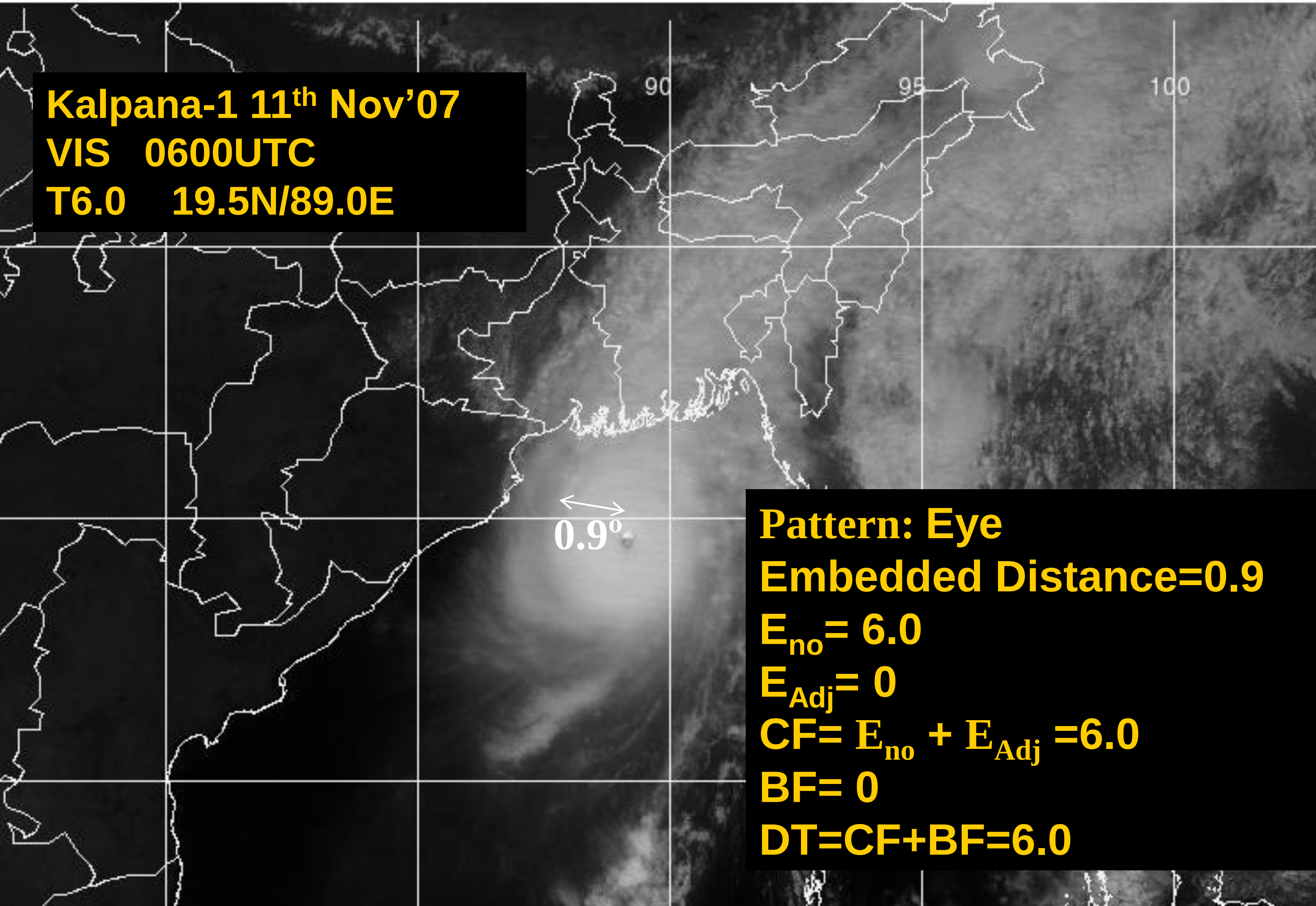


CF = E + E_{adj}

↑

DT = CF + BF

hancement



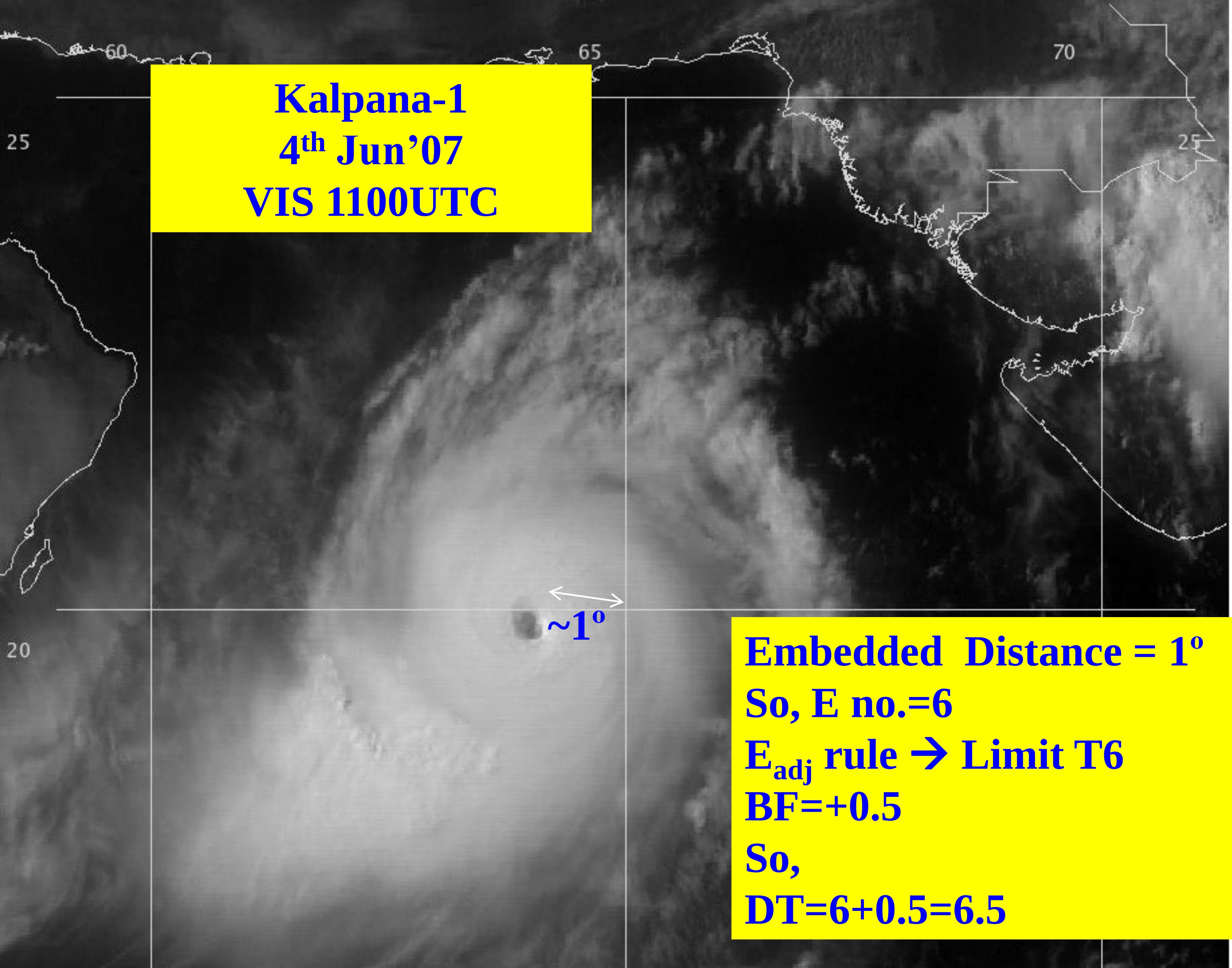
Kalpana-1 11th Nov'07
VIS 0600UTC
T6.0 19.5N/89.0E

Pattern: Eye
Embedded Distance=0.9
E_{no}= 6.0
E_{Adj}= 0
CF= E_{no} + E_{Adj} =6.0
BF= 0
DT=CF+BF=6.0

Kalpana-1

4^{th} Jun'07

VIS 1100UTC



Embedded Distance = 1°

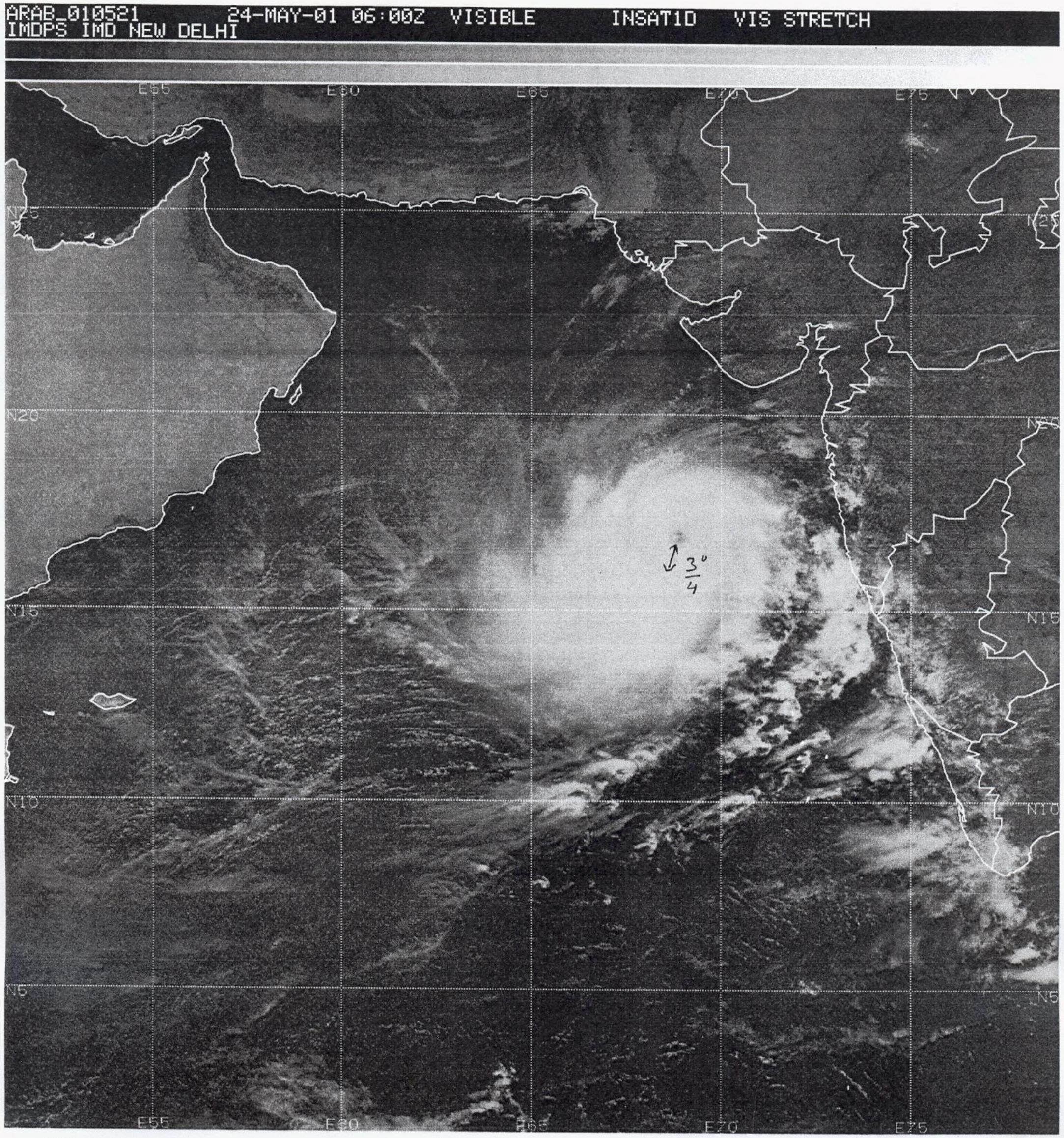
So, E no.=6

E_{adj} rule → Limit T6

BF=+0.5

So,

DT=6+0.5=6.5



It is an "eye pattern". Embedded distance is 3/4° and is least in SW sector. So E.No = 5. Eye Adj = $-\frac{1}{2}$. B.F = 1.0. Hence DT = $5 - \frac{1}{2} + 1 = 5.5$

EYE Pattern by EIR Analysis

- If 24 hrs old T number $\geq$ 2 then we use this EIR analysis.
- We measure the narrowest width of the surrounding gray shade (which surround the cloud system center).
- The gray shade which fulfill the minimum width criteria is considered to assign E Number.
- If surrounding gray shade doesn't fulfill the criteria of minimum width then we consider outer gray shades, which fulfill the criteria of minimum width.

EYE Pattern Analysis by using EIR Imagery

Rule 2C → **Was 12-hr old Final T no. ≥ T2 ??**

No → **Step 2A or 4**

Yes ↓

Narrowest Width	≥.5	≥.5	≥.5	≥.4	≥.4	≥.3	≥.3
Surrounding Gray Shade	CMG	W	B	LG	MG	DG	OW
	E6.5	E6	E5.5	E5	E4.5	E4.5	E4

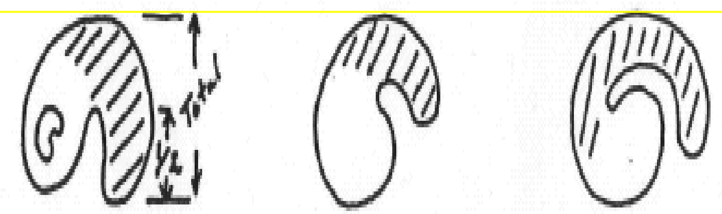
Banding Addition are only made when DT would be less than the MET.

GRAY SHADE CODE (BD CURVE)

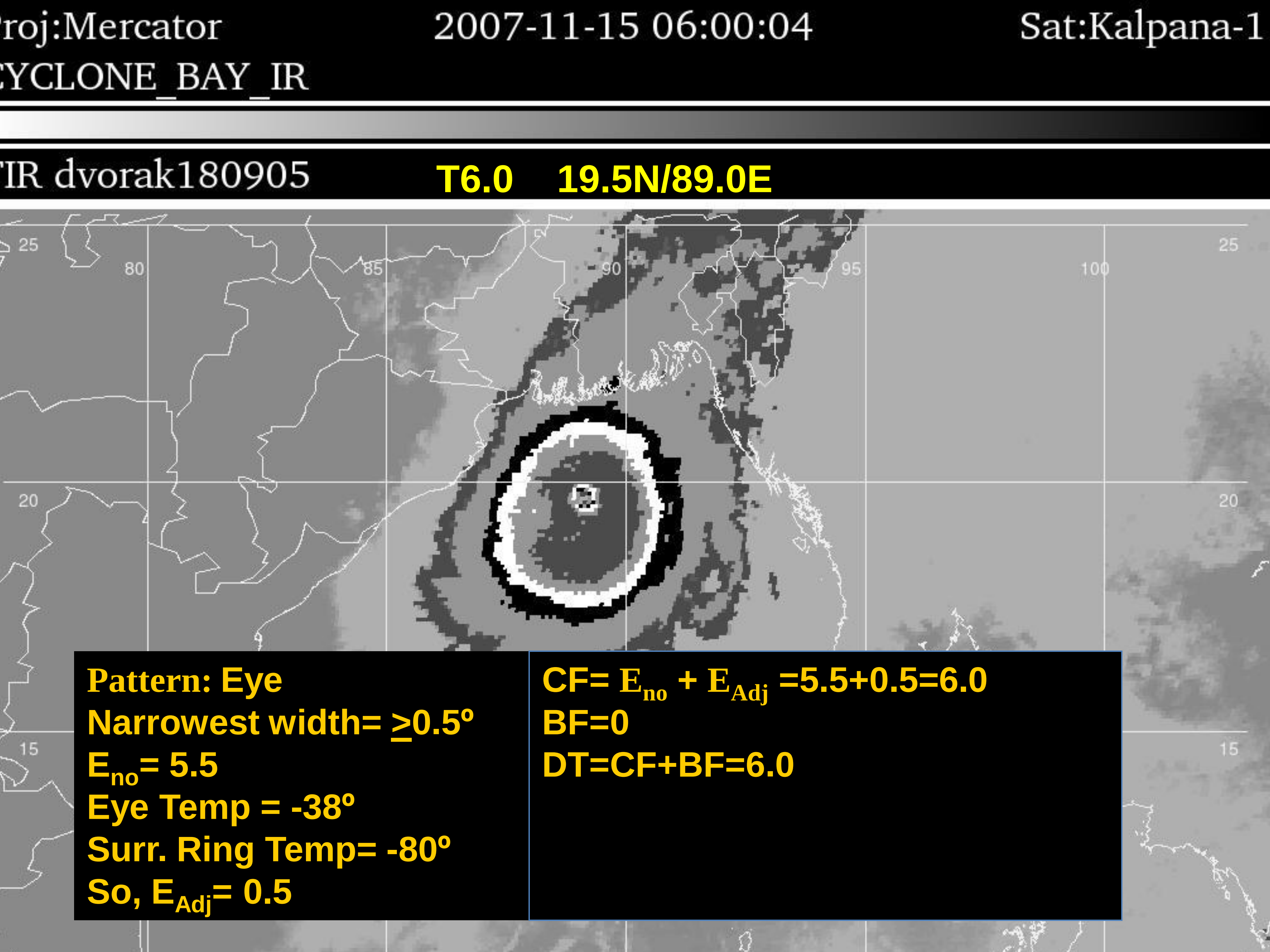
- WMG (Warm Medium Gray), > +9°C
- OW (Off White), +9 to -30°C
- DG (Dark Gray), -31 to -41°C
- MG (Medium Gray), -42 to -53°C
- LG (Light Gray), -54 to -63°C
- B (Black) -64 to -69°C
- W (White) -70 to -75°C
- CMG (Cold Medium Gray), -76 to -80
- CDG (Cold Dark Gray), ≤ -81°C

EYE TEMPERATURE

Banding Feature



→ $CF = E + E_{adj}$ → $DT = CF + BF$



Pattern: Eye

Narrowest width= $\geq$0.5º

E_{no}= 5.5

Eye Temp = -38º

Surr. Ring Temp= -80º

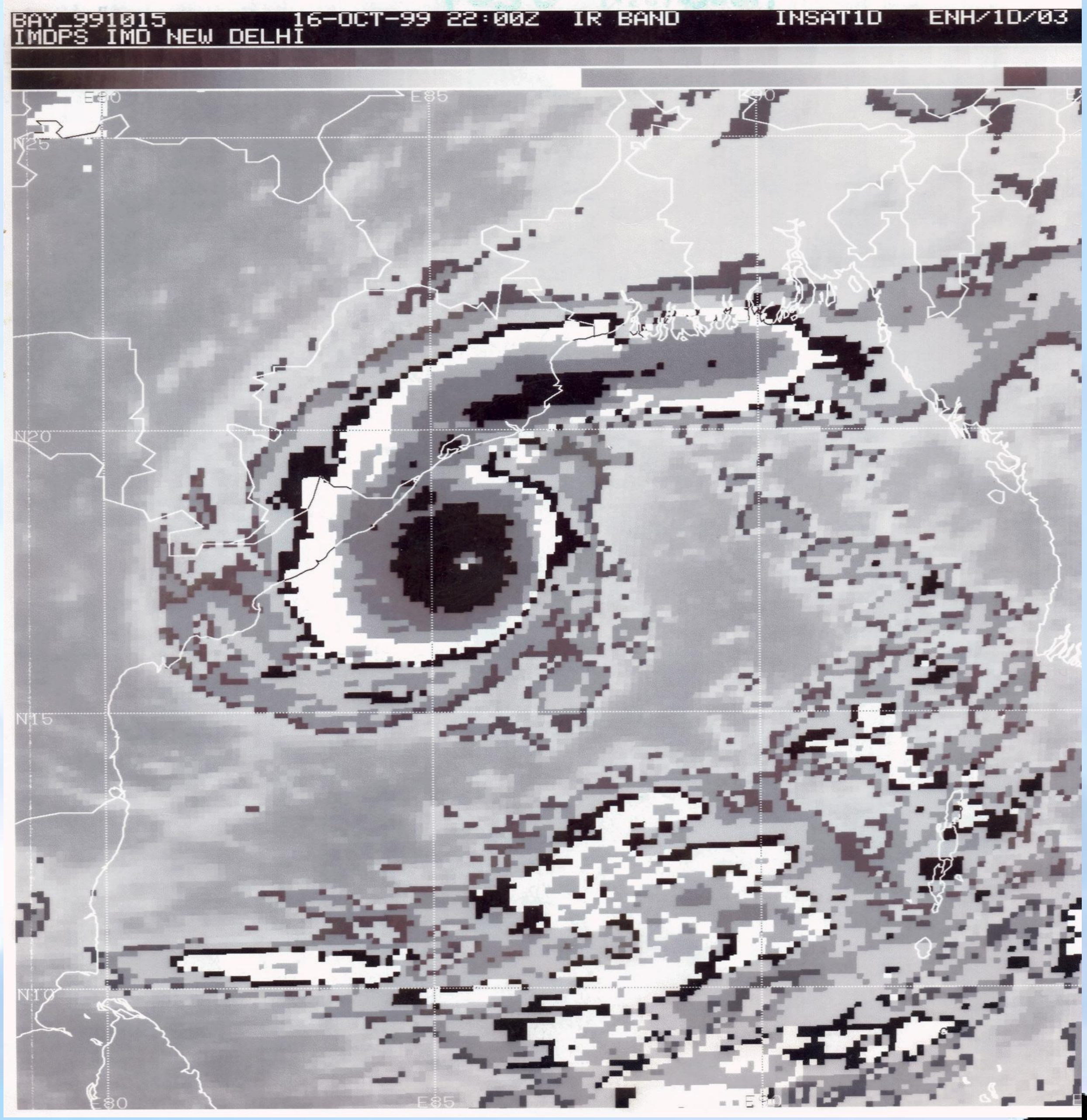
So, E_{Adj}= 0.5

CF= $E_{no} + E_{Adj}$ =5.5+0.5=6.0

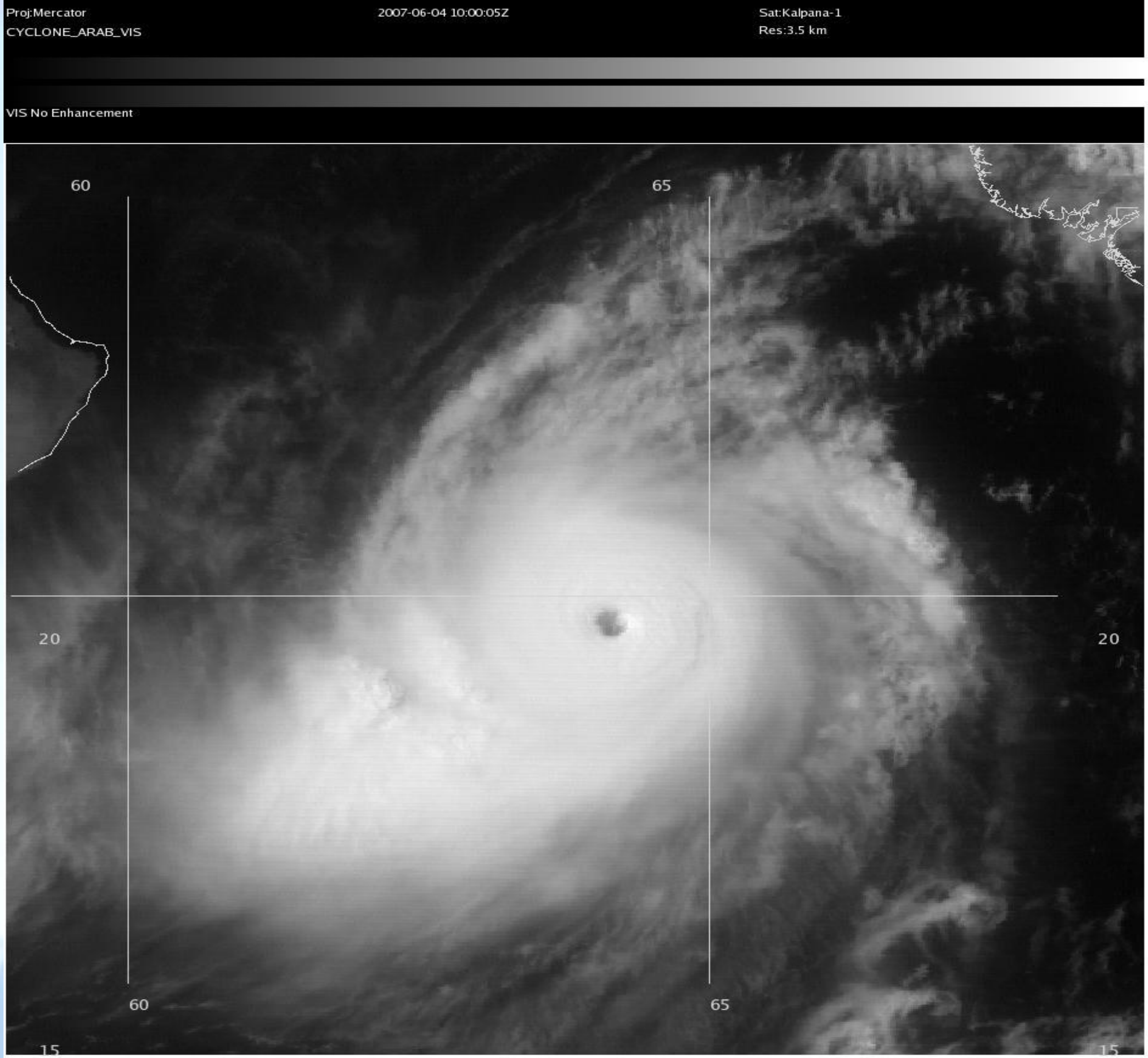
BF=0

DT=CF+BF=6.0

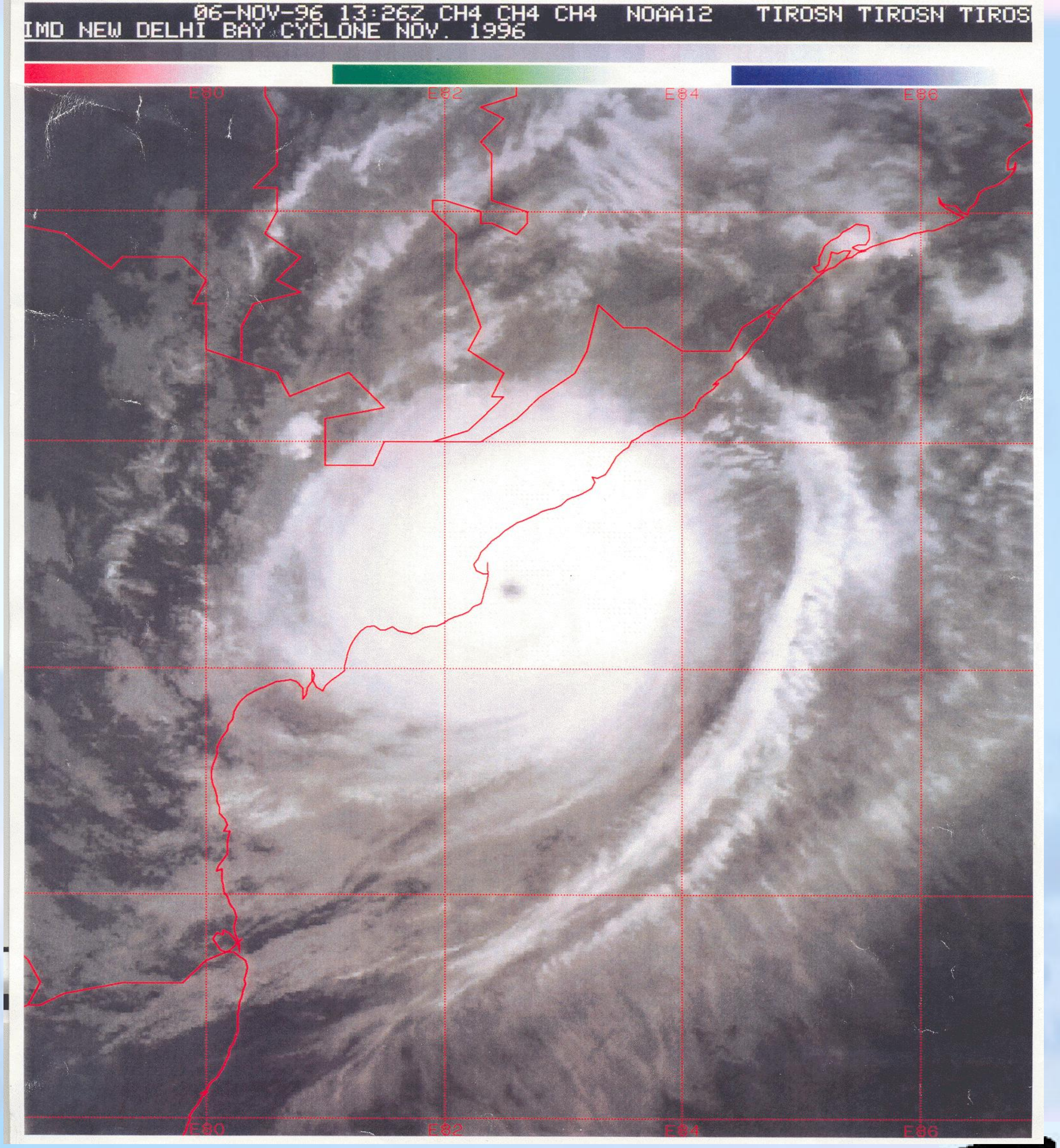
Eye Pattern
IR Enhancement



Eye Pattern


Proj:Mercator
CYCLONE_ARAB_VIS
2007-06-04 10:00:05Z
Sat:Kalpana-1
Res:3.5 km
VIS No Enhancement
60
65
20
20
60
65
15
15

Eye Pattern



06-NOV-96 13:26Z CH4 CH4 CH4 NOAA12 TIROSN TIROSN TIROS
IMD NEW DELHI BAY CYCLONE NOV. 1996
E80
E82
E84
E86

Step No. 3: Central Cold Cover (CCC) Pattern

Rule 3:

(1)When past T-no $\leq$3, maintained model trend for 12 hours; then hold same.
(2)When past T-no $\geq$3, hold T no. same and use as Final T no.

In this case all the cloud features related to its intensity are obscured by cirrus clouds. Also very little change in intensity occurs when this happens or we can say that this pattern is an indicates "arrested development" – and has immediate implications for the FT (DT can not be derived) and the ongoing rate of development.

Step No. 4: Past 24 hours trend (D, S, W)

Past 24 hours trend is determined by comparing the current and 24 hours past cloud features.

Development (D)

Development is generally associated with increased organization and better defined central features

a. **Curve band pattern:** curved band coils further around the CSC.
b. **CDO:** CDO becomes larger or an increasing in banding features.
c. **Shearing Pattern:** CSC become more tightly defined in curved cloud lines or appears closer to the dense overcast.
d. **Eye Pattern:** Eye is more embedded, more distinct (warmer) and less ragged or is surrounded by colder clouds or more banding features.
e. No significant (non-diurnal) warming of the cloud system is noted.

Weakening

When we observe features opposite to the development a. to e.

Steady State

a. A central cold cover (CCC) appears in T3.5 or greater tropical cyclones or has persisted for more than 12 hours in weaker systems.

b. CSC relationship to the cold clouds has not changed significantly.

c. There are conflicting indications of both development and weakening.

Step No. 5 & 6: Model expected T no. (MET) and the Pattern T no. (PAT)

- In step 5, 6, **second (MET)** and **third (PAT) estimates** of intensity are determined for all cloud patterns other than CCC pattern.

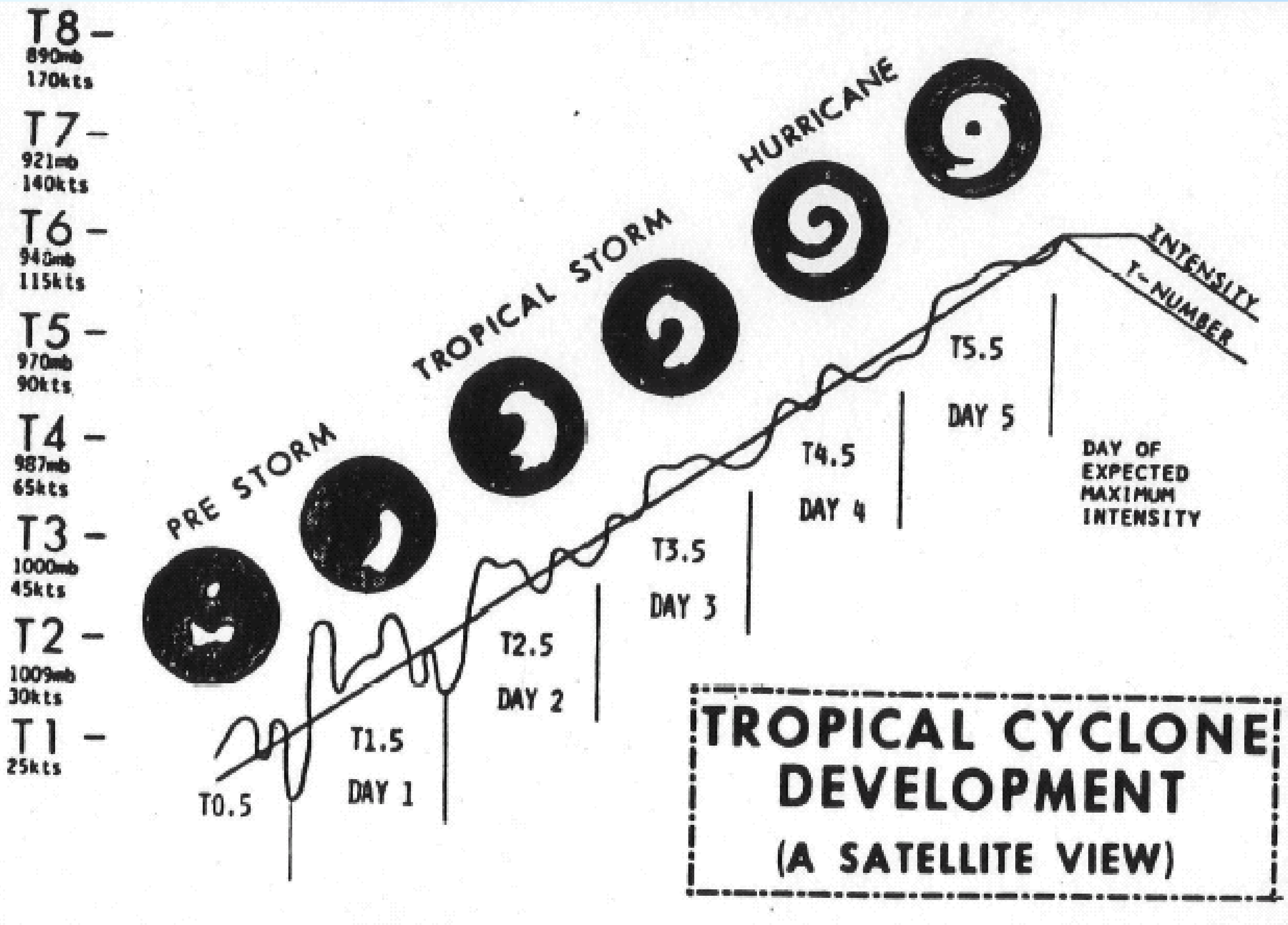
Step No. 5: Model Expected T number (MET)

- The MET is determined for practically all clouds patterns no matter how clear-cut or how poorly defined.

- The MET is reasonable “first guess” intensity estimate that provides guidance when indications are vague, non-existence, or not within the limits of climatology.

- MET determination:
  - 1st : compare today and yesterday (24 hour old) images apart and decide whether the storm has deepened(D), weakened(W) or remained steady(S).
  - 2nd : add or subtract between 0 and 1.5 from 24 hour old final T no.

Model of tropical cyclone development used in intensity analysis (curved band pattern type).



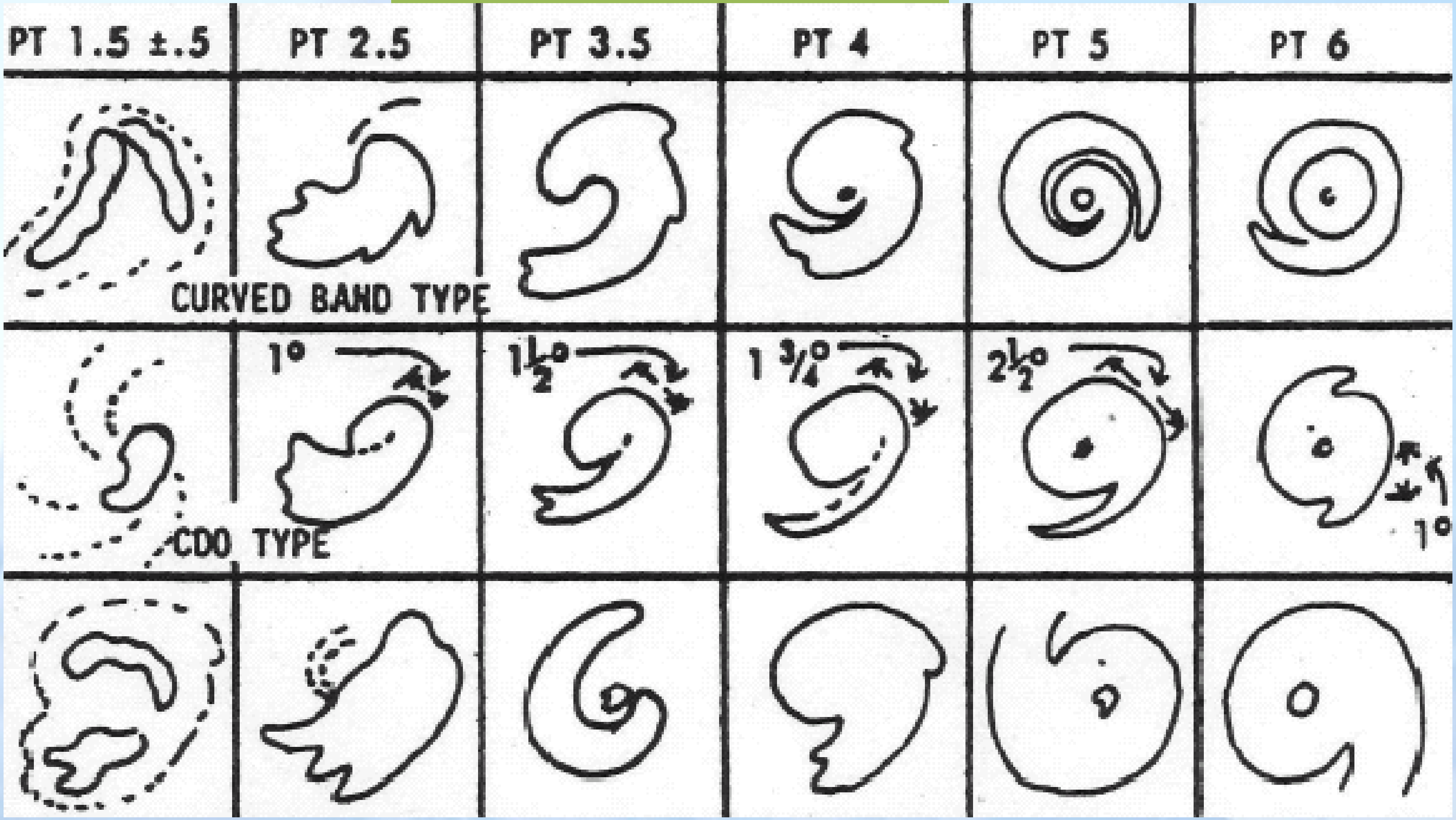
Step No. 6: Pattern T number (PT)

- The Pattern T-No (PT) is *not* independent of the MET – it is an *adjustment* to the MET.

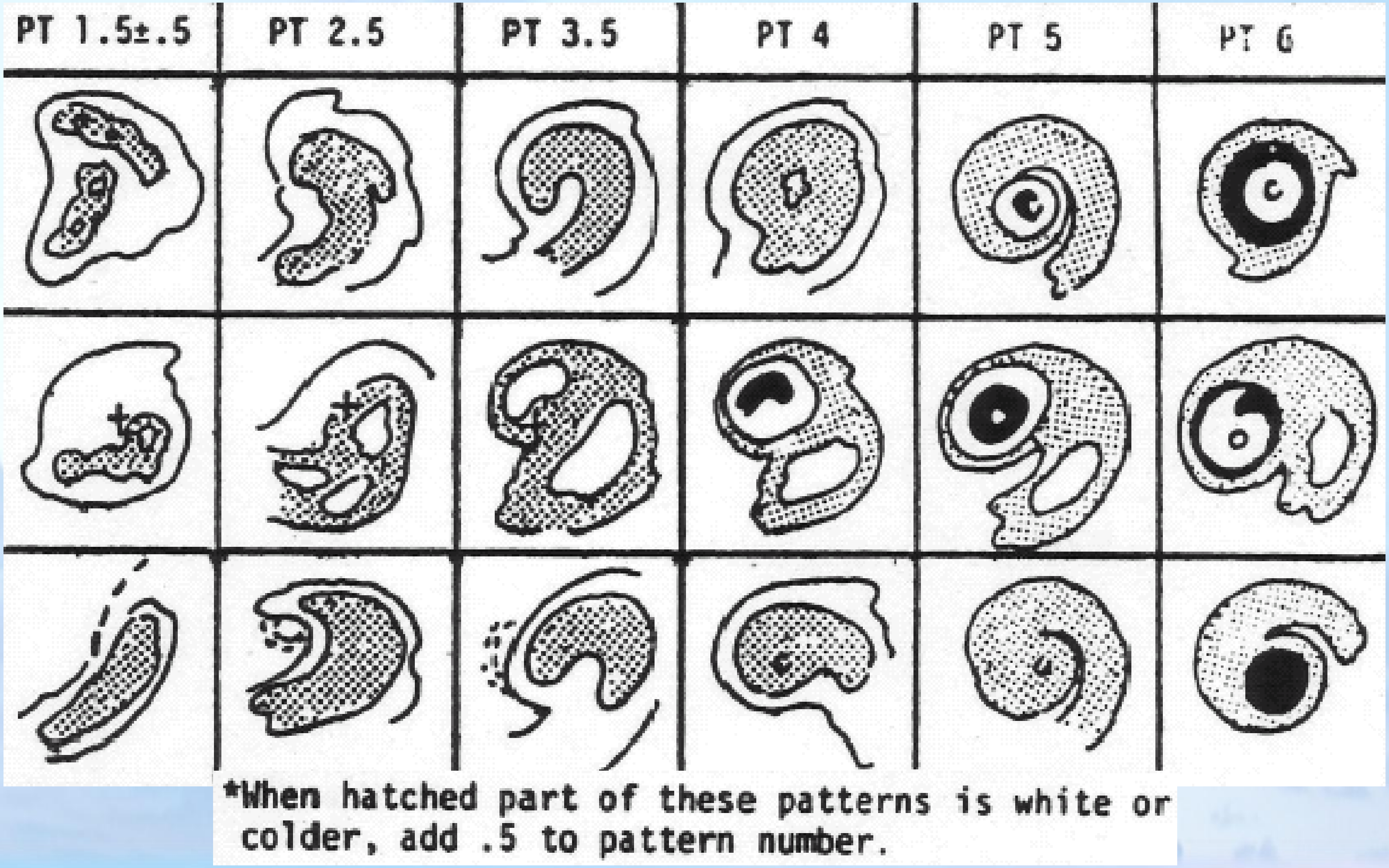
- The PT is determined by first establishing the MET, then determining whether the pattern in the current imagery looks "obviously stronger or weaker" than the corresponding pattern indicated at step 6 on the flow chart.

- The MET can then be adjusted by ±0.5 (no greater adjustment can be made) and the resulting T-No is called the PT (so we can call it the "*adjusted-MET*").

VIS analysis diagram



EIR analysis diagram



Step No. 7 and Step No 8:
Final T number Determination

Step No. 7 : Rules for choosing between the DT, PAT, and MET numbers

Step No. 8 : Rules which constrain the Final T-number under specific circumstances.

Step No. 7 and Step No 8:

- Use Data T-number (DT) from step 2 when cloud features are clear enough.
- Use pattern T number when DT is not clear and
- Use the MET for all other cases.

The above rules are subject to the following constraints:

- Initial classification must be T 1 or T 1.5.
- During first 48 hours of development T number cannot be lowered at night.
- 24 hours after initial T 1, storm T number must be less than T 2.5
- Final T number limits < T 4 change of ½ over 6 hours

  ≥ T 4 change of 1.0 over 6 hrs,

  1.5 over 12 hrs,

  2.0 over 18 hrs

  2.5 over 24 hrs.

Step No. 9: Rules to determine Current intensity (CI) number

Each analysis results in a Final T-number as well as a CI number.

Rules:

- **For developing cyclones: CI no is the same as final T no.**
- **For weakening cyclone: CI no. is higher than final T-no as storm continue to weaken.**
- **For redeveloping Cyclone: CI no remains same until the T-no rises to existing CI no.**

Step No. 10: The 24 hours intensity forecast and track forecast

- Winds at 200 mb can be used to forecast the direction in which the vortex is likely to move.
- If the vortex remained stationary, then it is an indication for further intensification or recurving.
- If the vortex is near to the COL region then system remain stationary.

Digital IR Technique

In this method only two values of temperatures are required.

- **Temperature of the eye (the warmest pixel)**
- **Coldest surrounding (wall clouds) temperature.**

Table 5.2.1

Hurricane Intensity from digital IR data (from Dvorak,1984)

--------------------Eye temperature °C--------------------

Surr Temp °C	T	17	14	11	8	5	0	-5	-10	-15	-20	-25	-30	-35	-40	-45
-0	3.9	0.3	0.1	0	-0.1	-0.2	-0.3									
-2	3.9	0.3	0.1													
-4	3.9	0.3	0.1													
-6	4.0	0.3	0.1													
-8	4.0	0.4	0.2	0.2	0.1	0										
-10	4.0	0.4	0.2													
-12	4.1	0.4	0.2													
-14	4.1	0.4	0.2				0	-0.1	-0.2	-0.3						
-16	4.1	0.5	0.3	0.2	0.2	0.1										
-18	4.2	0.5	0.3							-0.2						
-20	4.2	0.5	0.3					0								
-22	4.2	0.5	0.3													
-24	4.3	0.6	0.4	0.4	0.3	0.2	0.1	0.1	0	-0.1	-0.2	-0.3				
-26	4.3	0.6	0.4						0							
-28	4.3	0.6	0.4													
-30	4.4	0.6	0.4													
-32	4.4	0.7	0.5	0.5	0.4	0.3	0.2	0.2	0.1	0	-0.1	-0.2	-0.3			
-34	4.4	0.7	0.5													
-36	4.5	0.7	0.5													
-38	4.5	0.7	0.5								0					
-40	4.6	0.8	0.6	0.6	0.5	0.4	0.4	0.3	0.2	0.1	0	-0.1	-0.2	-0.3	-0.4	
-42	4.6	0.8	0.6													
-44	4.7	0.8	0.6													
-46	4.7	0.8	0.6													
-48	4.8	0.9	0.7	0.7	0.6	0.5	0.5	0.4	0.3	0.3	0.2	0.1	0	-0.1	-0.1	
-50	4.8	0.9	0.7													
-52	4.9	0.9	0.7													
-54	4.9	0.9	0.7													
-56	5.0	0.9	0.8	0.8	0.8	0.7	0.6	0.5	0.4	0.4	0.3	0.2	0.1	0		
-58	5.0	1.0	0.8											0		
-59	5.1	1.0	0.8													
-60	5.1	1.0	0.8													
-61	5.2	1.0	0.8													
-62	5.2	1.0	0.9	0.8	0.8	0.8	0.7	0.6	0.5	0.5	0.4	0,3	0.2	0.1	0	
-63	5.3	1.0	0.9	0.8												0
-64	5.3	1.0	0.9	0.9												
--65	5.4	1.0	0.9	0.9												
-66	5.4	1.0	1.0	0,9												
-67	5.5	1.0	1.0	0.9	0.9	0.8	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	
-68	5.6	1.0	1.1	1.0												
-69	5.7	1.0	1.1	1.0												
-70	[illegible]	1.0	1.1		1.0											
-71	5.9	1.1	1.1	1.1	1.0	0.9										
-72	[illegible]	1.1	1.1	1.1	1.1	[illegible]	0.8	0.8	0.7	0.6	0.5	0.4	0.3	0.2		
-73	[illegible]	1.1	1.2	1.1	1.1	1.0	0.9									
-74	6.2	1.1	1.2	1.2	1.1	1.0	0.9									
-75	6.3	1.2	1.2	1.2	1.1	1.1	0.9									
-76	6.4	1.2	1.2	1.2	1.1	1.1	0.9									
-77	6.5	1.2	1.2	1.2	1.2	1.1	1.0	0.9	0.8	0.8	0.7	0.6	0.5	0.4		
-78	6.6	1.2	1.2	1.2	1.2	1.1	1.0									
-79	6.7	1.2	1.2	1.2	1.2	1.1	1.0									
-80	6.8	1.2	1.2	1.2	1.3	1.1	1.0	0.9	0.8	0.8	0.7	0.6	0.5	0.4	0.3	

Suppose

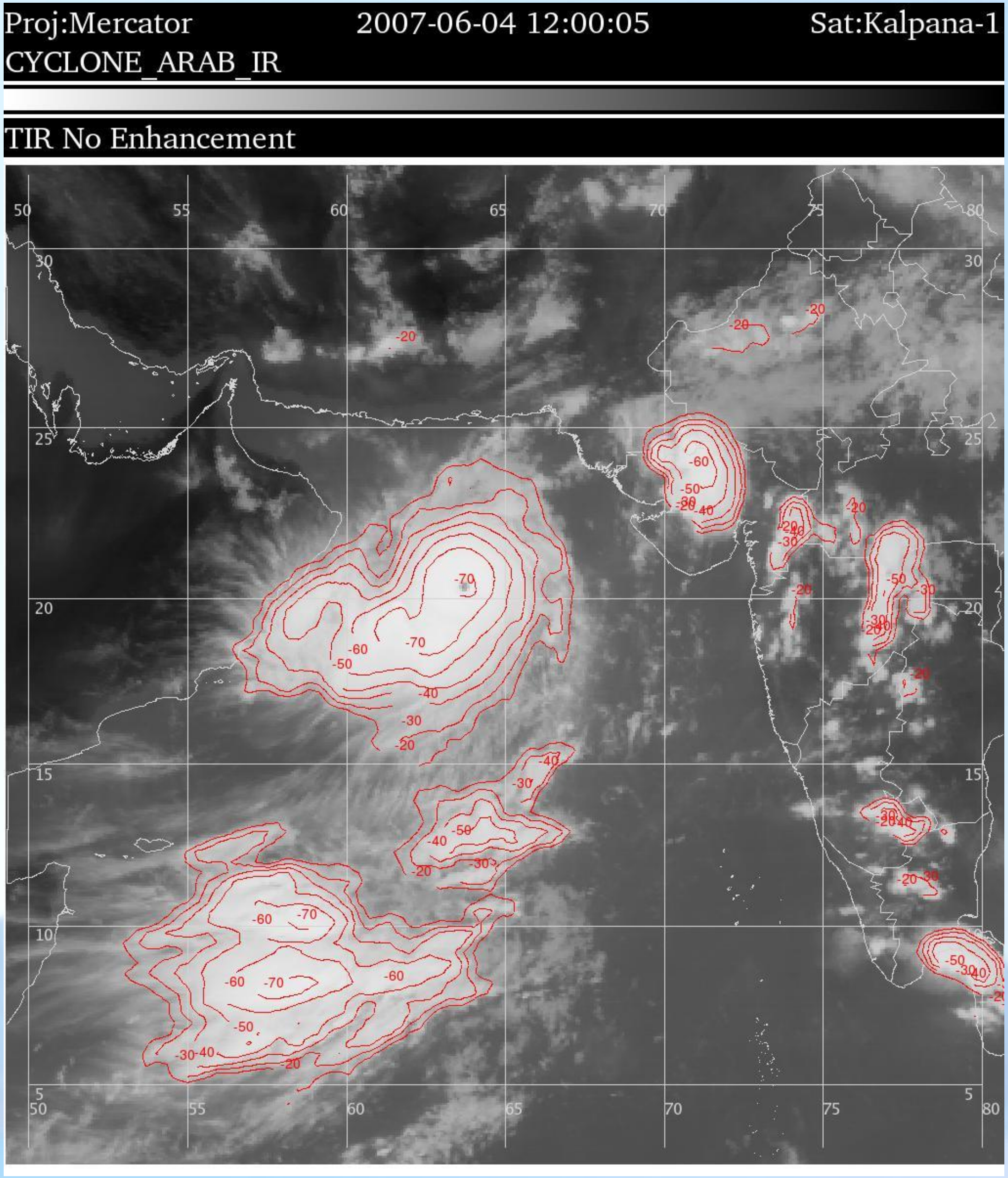
Eye temperature is + 5°C

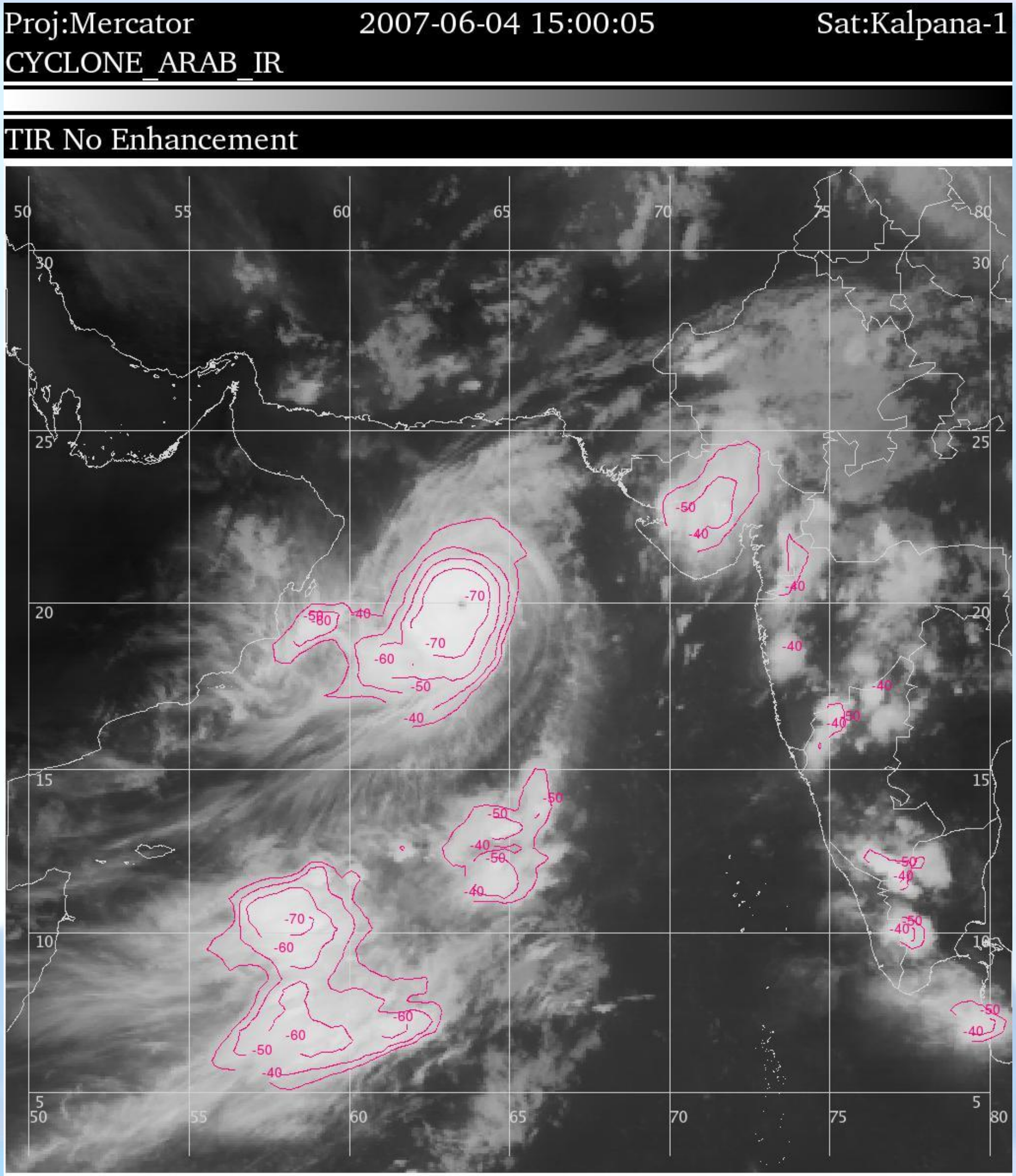
Wall cloud temperature is -71ºC

Wall cloud temperature contributes 5.9 while relatively warm eye adds 0.9 to the T number.

DT = 5.9 + 0.9 = 6.8

भाग
ARTMENT


Proj:Mercator
2007-06-04 12:00:05
Sat:Kalpana-1
CYCLONE_ARAB_IR
TIR No Enhancement



Proj:Mercator
2007-06-04 15:00:05
Sat:Kalpana-1
CYCLONE_ARAB_IR
TIR No Enhancement

Limitations of Dvorak Technique

1. **Dvorak Tech does not directly measure wind, pressure, or any other quantity associated with TC intensity.**

2. **The method is subject to analyst interpretation.**

3. **Dvorak has expressed his views that analysis of weak system (T<2.5) is more complex and more subjective.**

Limitations of Dvorak Technique

4. These weak systems are also more prone to diurnal and non-period oscillations in convection which have no relationship to the slowly varying circulation. Therefore we don’t lower the T number at night during first 24 hours of development.

5. The technique is physically restricted due to natural variability between the remotely sensed cloud patterns and the wind speed.

6. The most limiting factor of the technique is dependence on IR imagery during night in which cirrus can obscure TC organisation.

Automation of Dvorak Technique and Recent Developments

Intensity Measurement Algorithms

- ODT -- (Velden/Olander) 1995-2001
- AODT –(Olander/Velden) 2001-2004
- ADT–(Olander/Velden) 2004-present

ODT : Objective Dvorak Technique, CIMSS, Olander / Velden

Velden, C.S., T.L. Olander, and R.M. Zehr, 1998: Development of an objective scheme to estimate tropical cyclone intensity from digital geostationary satellite infrared imagery. *Wea. and Forecasting*, **13**, 172-186

- **Documented and validated objective algorithm and showed it to be competitive with the operational Dvorak technique.**
- **Applicable only for Intense System (Hurricane/Typhone Strength).**
- **Required manual selection of Storm Centre.**

AODT: Advanced Objective Dvorak Technique, CIMSS, Olander / Velden

Technique developed for tropical depression and storm stages.

- implemented several additional rules and methodologies.
- Incorporated an automated storm center determination methodology.

ADT: Advanced Dvorak Technique, CIMSS, Olander / Velden

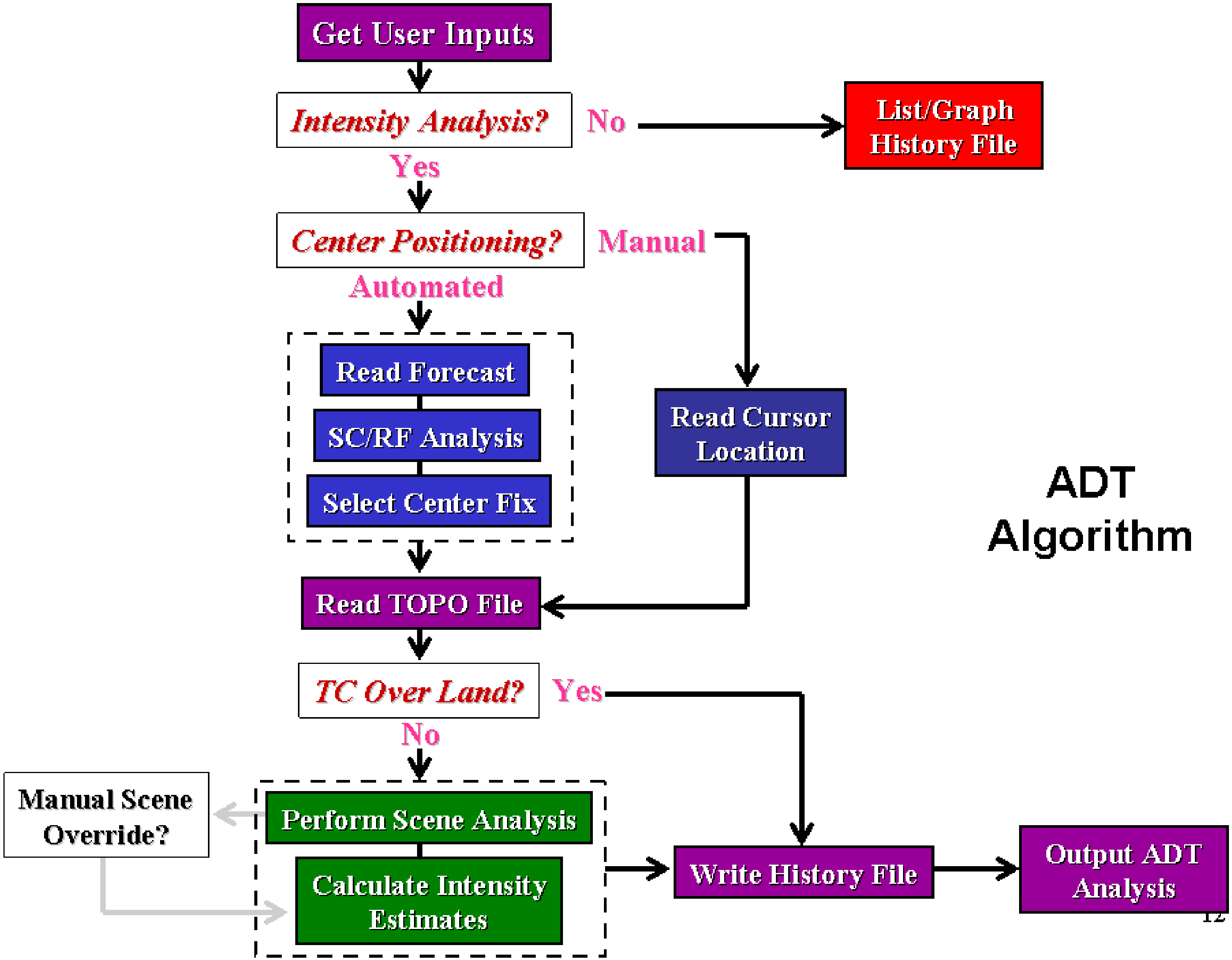
Velden, C.S., and T.L.Olander, 2006: The Advanced Dvorak Technique (ADT) – continued development of an objective scheme to estimate tropical cyclone intensity using geostationary infrared satellite imagery. Submitted, *Wea. and Forecasting*

- Implemented operationally at:

  1. TPC / NHC

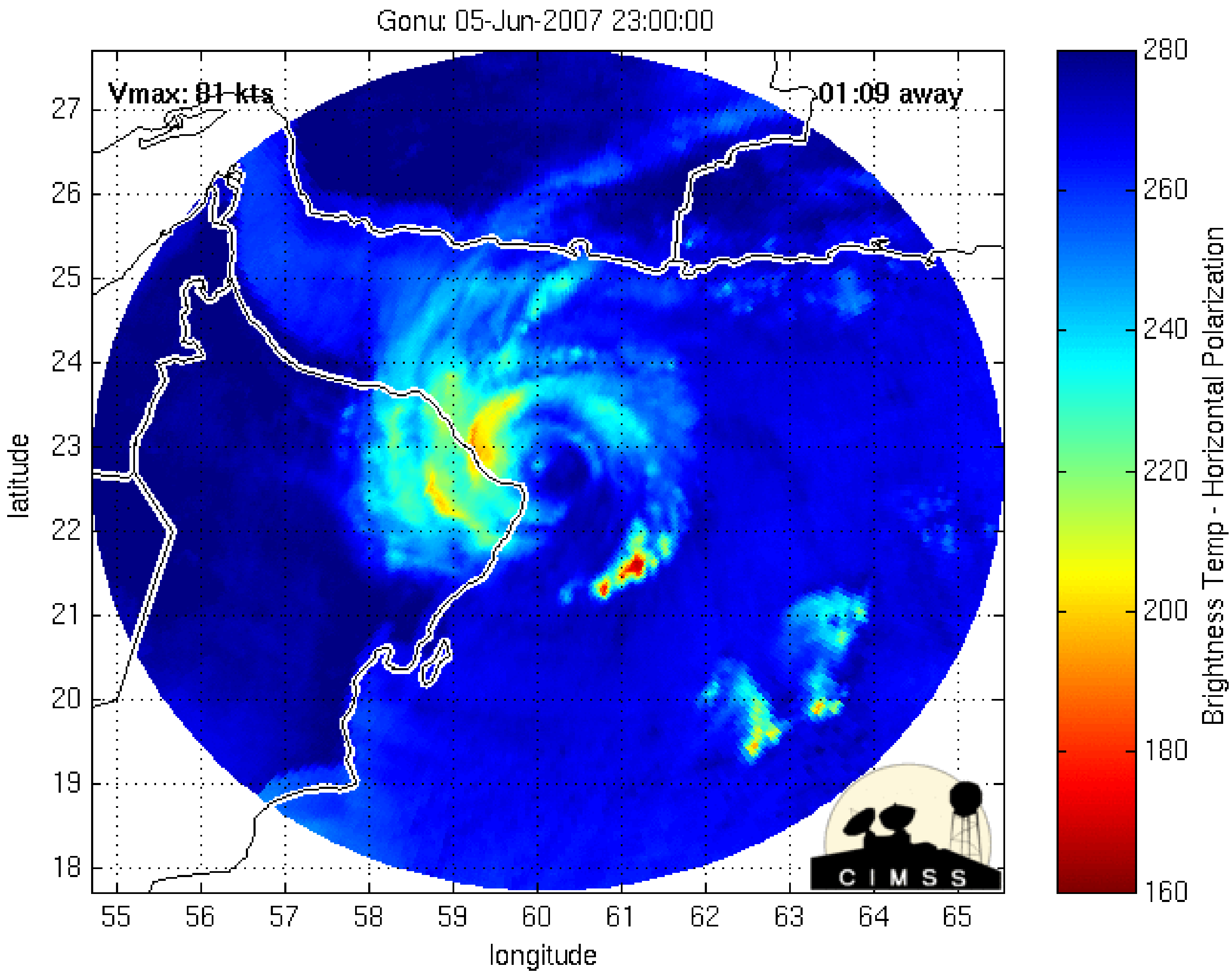
  2. JTWC

ADT Algorithm

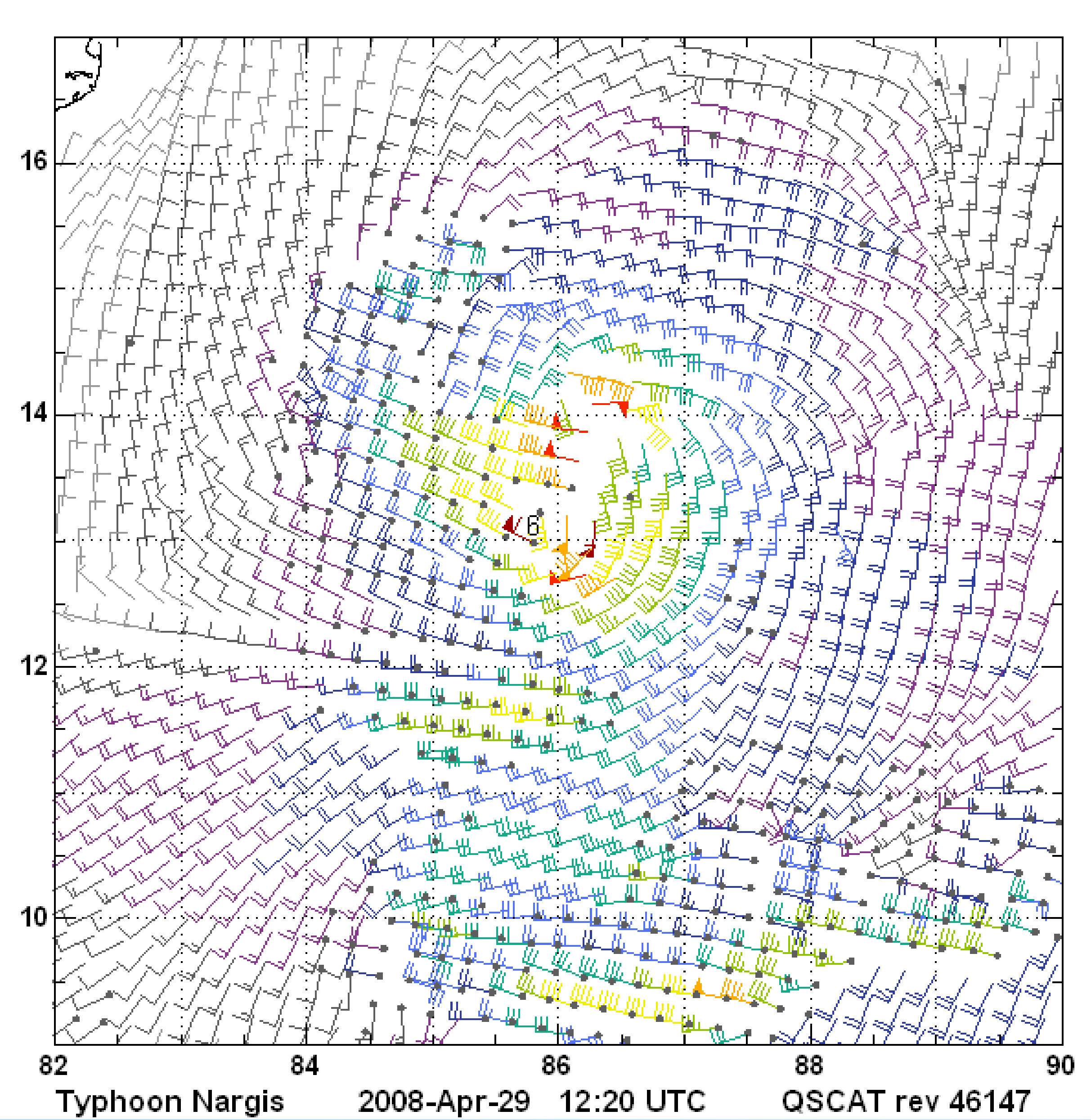


Use of advance Satellite Products in TC analysis

- QSCAT
- ASCAT
- WVW
- SSMI
- TMI
- AMSU
- Morphed integrated microwave imageries



Gonu: 05-Jun-2007 23:00:00
Vmax: 81 kts
01:09 away
latitude
longitude
Brightness Temp - Horizontal Polarization
27
26
25
24
23
22
21
20
19
18
55
56
57
58
59
60
61
62
63
64
65
280
260
240
220
200
180
160
CIMSS


16
14
12
10
6
82
84
86
88
90
Typhoon Nargis
2008-Apr-29
12:20 UTC
QSCAT rev 46147

General Comments

1. When available use VIS-IR pairs. Perform at least two VIS analysis per day to check agreement between VIS and IR analysis.
2. When an image can be analysed using more than one pattern perform both analysis and compare the results (Dvorak 1984).
3. Always try to analyse more than one image leading up to the analysis time, then average the resulting DT numbers (Dvorak 1984,1995). This is particularly applicable to shear patterns that often go through a cyclic pattern of convection blow-up near the low-level centre followed by increasing separation of the overcast from the low-level centre. This can lead to rapidly varying DT numbers over several hours.

General Comments

4. It is good practice to perform a reanalysis of earlier imagery whenever a TC reaches a stage of well-defined intensity (for example when an eye first appears). The dependency of the Dvorak technique on the MET can lead to situations where it appears that model constraints have to be broken, when in fact a reanalysis of previous day's data shows that earlier FTs could have been higher and the analyst(s) has (have) 'got behind the power curve'.

General Comments

5. Recognise the limitations of the Dvorak technique – it was not designed for monsoon depressions, subtropical systems or systems undergoing extratropical transition (Dvorak 1995). A separate technique exists for the classification of subtropical systems (Herbert and Poteat 1975).
6. The Dvorak technique does not adjust for the effects of system translation on surface winds. It was initially derived using a set of cyclones with an average speed of around 3-12 knots (Brown and Franklin 2004). For systems with close to average translation speeds the error from this will generally be much less than that inherent in the technique itself. For systems with rapid translation speeds the error may be significant, however the effect of translation on surface wind speeds is complex and non-linear and there is no systematic way of incorporating these effects into warning policy.

General Comments

7. There can be times in a TC's life cycle when no DT can be determined – do not force a DT when no pattern can be applied – use the MET or other observations (e.g. scatterometer data) to help estimate intensity in these circumstances.
8. The winds experienced at the surface vary depending on the presence of deep convection. Thus a weak system that is going through a diurnal maximum in convection will generally have larger areas of more damaging winds than a weak system that is going through a diurnal minimum in convection. This can make the difference between a Category 2 (Australian scale) impact and a Category 1 or weaker impact.
9. Midget cyclones (gale radius < 60 nm) present problems for analysis. Although Dvorak states 'It is the pattern formed by the clouds of a tropical cyclone that is related to the cyclone's intensity and not the amount of clouds in the pattern'(Dvorak 1984), several parts of the technique rely on measurements of size (most noticeably in the CDO pattern, but also when determining BFs). Midget storms tend to intensify and decay more rapidly than larger storms.

General Comments

10. Whenever Dvorak talks about the ‘model’ he is referring to the Dvorak model of TC development wherein a cyclone intensifies by one T-number per day.
11. It is a common mistake amongst inexperienced analysts to assume that the MET is the same as the ‘Forecast Intensity Number’ from 24 hours ago. The first step in determining the MET is to qualitatively compare images 24 hours apart (remove diurnal influences) and decide whether the storm has deepened (D), weakened (W) or remained steady (S). The second step is to add or subtract between 0 and 1.5 from the 24-hour-old FT (not the DT or CI) based on the D, S, W determination (Dvorak 1984, 1995).
12. The pattern T-number (PT) is not independent of the MET – it is an adjustment to the MET (Dvorak 1984). The PT is determined by first establishing the MET, then determining whether the pattern in the current imagery looks ‘obviously stronger or weaker’ (Dvorak 1984) than the corresponding pattern indicated at step six on the flow chart. The MET can then be adjusted by ±0.5 (no greater adjustment can be made (Dvorak 1995)) and the resulting T-number is called the PT (we could have called it the ‘adjusted-MET’).

General Comments

15. Recent comparisons of reconnaissance-based best-track data (Atlantic basin) with Dvorak intensity estimates found that Dvorak intensity estimates of weakening storms showed an overestimation bias. This bias could be virtually removed by using a six-hour rule for holding the CI number during initial weakening rather than the existing 12-hour rule (Brown and Franklin 2004).

General Comments

16. The same study (Brown and Franklin 2004) found that:
    - (a) Dvorak intensity estimates had an RMS error of 11.0 knots;
    - (b) 50 per cent of Dvorak intensity estimates were within 5 knots;
    - (c) 75 per cent of Dvorak intensity estimates were within 12 knots;
    - (d) 90 per cent of Dvorak intensity estimates were within 18 knots;
    - (e) for storms moving faster than 12 knots there was a slight underestimation bias.
17. The advent of frequent passive microwave imagery has given tropical cyclone forecasters greater insight into structural and intensity changes in tropical cyclones than can be obtained through IR and VIS imagery alone. The Dvorak technique cannot be validly applied to microwave imagery, however forecasters should use microwave imagery to assist in determining the centre position. Trends in intensity that are evident in sequences of microwave imagery can also inform the analysis process.

Thank you